MANUFACTURING INSECURITY

AMERICA'S MANUFACTURING CRISIS AND THE EROSION OF THE U.S. DEFENSE INDUSTRIAL BASE

A Report Prepared for the

Industrial Union Council • AFL-CIO

by

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About this paper

The unions of the AFL-CIO Industrial Union Council represent millions of manufacturing workers. The Council commissioned this research because our unions and their members believe that a vibrant manufacturing sector is vital to the nation's economic and national security of the nation. For additional information please also contact the IUC Executive Director, Bob Baugh, at bbaugh@aflcio.org or call 202-637-3966. Also see the IUC Manufacturing web page at http://www.aflcio.org/issues/jobseconomy/manufacturing/.

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HIGH ROAD STRATEGIES

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I. Introduction

During the Bush Administration's first term, even as America's armed forces were fighting wars in both Afghanistan and Iraq, the Pentagon embraced policies to globalize the American defense industrial base.[1] Rather than relying on its traditional U.S. suppliers, the Pentagon increased both its openness to shopping overseas for weapons systems, and its tolerance for foreign purchases of U.S. defense businesses. Pentagon officials argued that the foreign sourcing of products, components, and materials would actually be a good thing for all but the most defense-critical technologies, even claiming that this would lead to faster innovation while cutting costs.

Defense industry officials have echoed this position, arguing that the Department of Defense (DOD) should not be restricted to domestic suppliers for its products. For example, in opposition to proposals to include "Buy American" provisions in defense authorization legislation, the Aerospace Industries Association (AIA) warned that restricting foreign imports would drive up the cost of defense products and prevent access to the most advanced electronics and information technologies from the commercial marketplace. The AIA notes, for example, that aerospace platforms use information technologies and electronics systems, such as flat panel displays, which are no longer made in the United States.[2]

Alarmed about the growing dependence of the U.S. defense systems on foreign suppliers for critical products and technologies, industry and labor leaders, as well as Congress members, have warned that the Pentagon's policy of increasing this dependency will contribute to the erosion of the nation's defense industrial capacity, and consequently, undermine national security. The Pentagon and defense industry responses to these critics, and to those who support Buy American requirements, are not only contradictory, but, ironically, highlight the fundamental challenge the nation confronts in maintaining a strong defense industrial base—the continuing decline in U.S. manufacturing.

Pentagon officials have acknowledged that there are areas of advanced technology critical to military systems—armor plate steel, defense-specific integrated circuits, night vision goggles—in which domestic capacity is insufficient.[3] But beyond this short list, they have claimed that foreign sourcing has no impact on America's long-term defense readiness—that is, the U.S. military relies little on foreign suppliers for critical technologies, components, and systems, and the U.S. industrial base is sufficiently robust to supply most of its needs. Yet, almost in the same breath, they seem to admit that the United States lacks the necessary industrial capacity to supply many important goods that the military needs.

Indeed, Pentagon officials have opposed efforts to require preference for domestic suppliers over foreign sourcing in defense procurement, on the basis that many foreign products are superior in reliability and performance, while costing less than those made domestically. For example, aside from the lack of U.S. capacity in flat panel displays and information technologies noted above, which has required the DOD to search for foreign suppliers for these critical products, DOD and aerospace industry officials have raised concerns about the viability of the U.S. machine tool industry to supply the ultra-high precision tools needed to replace existing tools and meet future demand for these products.[4]

In short, there is a tacit acceptance, despite all the Pentagon and defense industry rhetoric in support of globalizing defense procurement, *that the United States lacks a sufficiently robust commercial industrial base to supply many vital products needed for maintaining a strong defense industrial base.* The problem is not just in a handful of very specialized items designed to meet narrow defense requirements (or milspecs), but the "eradication of U.S. industry capability," according to Col. Michael Cole, deputy chief of the Joint Enabling Command of the U.S. Joint Forces Command. Cole also warns in a recent paper that current strategies to deal with an industrial base that is increasingly unable to supply the military with manufactured parts and electronic components are not working.[5]

Cole's is a welcome voice emanating from the Pentagon, which is now under different management from the one that first promulgated the globalization policy. Over the past few years, Cole's view has been echoed—or at least given added credence—by a growing number of analysts from industry, labor, government, academia, and think tanks.[6] But the underlying premise is not new. As historian Paul Kennedy wrote in his 1989 classic, *The Rise and Fall of the Great Powers*: "To be a Great Power—by definition, a state capable of holding its own against any other nation—demands a flourishing economic base,"[7] which in turn, cannot be sustained without a strong, flourishing manufacturing sector. That is, the health of the overall manufacturing base is fundamental for assuring the health of the defense industrial base. Conversely, the Pentagon's support for globalizing defense procurement not only reflects the growing inability of our industrial base to meet national security needs, but in itself contributes to the ongoing unraveling of the nation's overall industrial capacity.

The purpose of this report, conducted by High Road Strategies, LLC (HRS) of Arlington, VA is to examine the extent of this unraveling, and the resulting weakening of America's defense industrial capacity in the coming decades. The approach taken here, however, is different than other efforts to assess the defense industrial base and its reliance on foreign sources of supply for critical items. Most of these efforts, especially the periodic assessments of defense preparedness that the Pentagon itself regularly undertakes, tend to focus very narrowly on a relatively limited group of technological products and the industries—or segments in those industries—that supply those parts, that the DOD deems vital for meeting defense needs.

Instead, the study reported on here analyzes a large body of evidence—drawn from industry and government sources, the professional literature, and many other sources—in an effort to examine the extent that the deterioration of the overall U.S. manufacturing base is contributing to the erosion of the nation's defense industrial base. That is, its focus is on assessing the health and competitiveness of the nation's *civilian* industrial base upon which a strong *defense* industrial base—including the ability to produce specialized defense-critical products—ultimately rests. Specifically, the study:

- Analyzes key domestic and international trends—which taken together show that the foundations of U.S. manufacturing have been deteriorating across the board, especially over the past decade.
- Describes the linkages between manufacturing and the defense industrial base, and how erosion in a wide range of American manufacturing industries is hurting the domestic capacity to supply critical products for national security, which has been forcing the Pentagon to depend on less secure foreign sources.
- Explores how a diminishing domestic manufacturing base also contributes to a decline in American technological leadership and innovation capacity, which is widely recognized to be vital for maintaining U.S. defense capabilities.

Although the U.S. domestic manufacturing base remains the world's largest, most productive and technologically advanced, its economic and technological lead in many important sectors vanished years ago, and many of the remaining areas of superiority and strength face powerful challenges in the coming years. The signs of industrial decline reflected by major domestic and global economic indicators, the threat to innovation and the loss of America's technology edge, and the shrinking skilled workforce and loss of science, engineering and manufacturing know-how, that this study shows are particularly worrisome. These trends are troubling enough for America's economic future, and for working families and communities around the United States—especially in light of the financial and economic crisis of 2008-2009, which has led to one of the highest levels of unemployment in U.S. history since the Great Depression. The danger to our national security—at home and abroad—that these trends also signify, should elevate the revitalization of American manufacturing to a very high priority among policy makers.

II. Indicators of Industrial Decline

No single indicator can by itself represent economy-wide manufacturing capabilities or trends. But several key indicators of domestic economic performance and global competitiveness, when taken together, do provide strong evidence that America's manufacturing base has been greatly weakened over the last decade.

Economic indicators such as *value-added output*, *industrial capacity and capacity utilization*, *employment* and *number of establishments* are measures of domestic industrial capability, activity, and strength, and together reflect an economy's ability to maintain and increase output growth over the long haul. Global competitiveness indicators such as the *balance of trade in goods* and *import penetration rate* reflect the extent to which U.S. manufacturers are able to compete in the U.S.'s own markets against foreign producers. (See Box A for definitions.) While the domestic indicators point to a sustained diminishment of U.S. manufacturing economic performance, production capacity and capability, the global indicators reflect a corresponding loss of domestic markets by American manufacturers to foreign competitors. The principal historical trends for these indicators are presented below.

BOX A—ECONOMIC INDICATORS

Domestic Indicators

- *Value-added* is defined by the U.S. Bureau of Economic Analysis (BEA) as an industry's gross output (sales or receipts and other operating income, commodity taxes, and inventory change) minus its intermediate inputs (energy, raw materials, semi-finished goods, and purchased services). It also measures an industry's contribution to the Gross Domestic Product (GDP). Its components include the returns to labor (compensation of employees), returns to capital (gross operating surplus) and returns to government (taxes on production and imports less subsidies).[8]
- *Industrial capacity* is defined by the Federal Reserve Board (the Fed) as the greatest level of output that an industry's factories can practicably sustain. *Capacity utilization,* also monitored by the Fed, is the share of that capacity actually being utilized to generate an output.[9]
- The *number of establishments* for each industry sector is reported in the U.S. Bureau of Labor Statistics' (BLS) Quarterly Census of Employment and Wages (QCEW), which includes data on establishments, employment, and wages by size of establishment for the first quarter of each year. Establishment sizes are divided into nine categories based on number of employees working at an establishment (from under 5 employees to over 1,000 employees).[10] The number of establishments should be distinguished from the number of American manufacturing firms that may own

multiple manufacturing plants in different locations. That is, the establishment figures refer to the actual number of separate locations where manufacturing activity occurs, regardless of ownership.

- *Manufacturing employment* data from the BLS's Current Employment Statistics (CES) survey covers total payroll employment for all industries classified as manufacturing according to the 2007 North American Industry Classification System (NAICS 31-33).

Global Competitiveness Indicators

- The *international trade balance in goods* is measured by subtracting the total amount of goods (merchandise supplies, raw materials, and products) imported into the United States from the total exported. A trade deficit occurs when imports exceed exports; a trade surplus occurs when exports exceed imports. This figure is the most widely cited trade-related measure of American manufacturing's health.[11]

- The *import penetration rate* (IPR) measures the extent to which imports substitute for domestically produced goods in the domestic consumption of these goods. Large IPRs imply that a large share of U.S. consumption of a good is being met by foreign sources. Increases in IPRs over a given period imply that foreign imports have replaced goods produced domestically at the beginning of that period. IPR data are not kept by the U.S. government but can be calculated from the import, export, and domestic output figures compiled by the U.S. Census Bureau.[12] The U.S. Business Industry Council (USBIC) Education Foundation has calculated IPRs for 115 six-digit NAICS-based high-tech, capital-intensive industries, including every manufacturing sector judged to be a major contributor to the nation's economic health, as well as to its security.[13]

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a. Indicators of Domestic Economic Performance

America's manufacturing sector is still the largest and most productive in the world, but there are serious signs of weakening in its foundation. Although America's industrial competitiveness problems first appeared in the 1970s and 1980s, the erosion in America's manufacturing capabilities began to deepen in the first half of the 2000s decade. There were indications of a modest recovery in manufacturing performance between 2004-2007. However, in 2008 the U.S. economy was plunged into one of the worst recessions in its history, dragging U.S. manufacturing output and employment down to new lows.

The impact of the recession has been felt throughout the manufacturing sector, including in many industries important to the national security base. There is a great deal of uncertainty about the extent to which U.S. manufacturing will recover as the economy pulls out of the recession. The long-term trends, however, suggest that the erosion of U.S. manufacturing capacity and competitiveness is likely to continue.

Decline and weak growth of value-added output. Although growth in U.S. manufacturing real value-added has historically been positive, recent value-added trends strongly suggest erosion in manufacturing's economic strength over the past decade. Value-added is a key measure of an industry's domestic economic performance. It reflects the amount of an industry's total output value that can be attributed to the labor and capital inputs that an industry directly employs. It also shows an industry's contribution to the nation's GDP. Since 2000, the manufacturing value-added share of U.S. GDP has been declining at a much faster rate, its annual contribution to the percent change in real GDP has been much smaller, and its real annual growth rate has been substantially slower, compared to earlier periods.

Manufacturing value-added (in current-year dollars) as a share of GDP has been falling for decades. Although from 1947 to 1968 this share never dropped below 25 percent, it fell steadily after 1968, down to 14.5 percent in 2000. Manufacturing's shrinking GDP share does not necessarily indicate weakening capacity. This trend also reflects the relatively faster growth of large service and information sectors, which, at least in part, was spurred by innovations and products generated by the manufacturing sector.

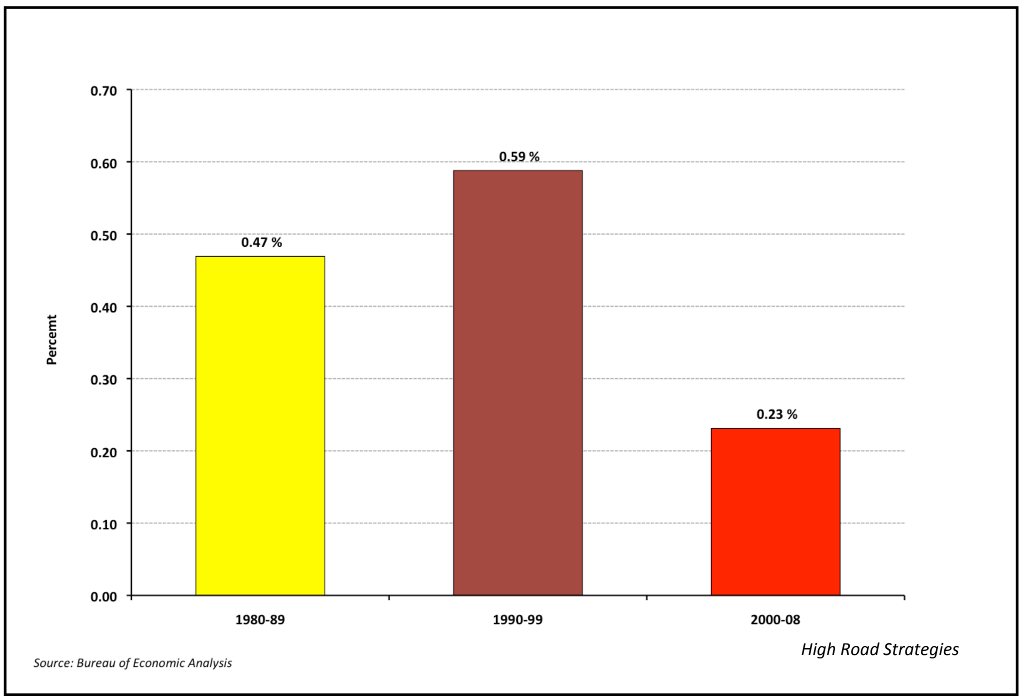
However, since 2000 manufacturing's GDP share has fallen at almost *twice* the average annual rate of the previous fifteen-year period—down to 11.5 percent in 2008. Similarly, as figure 1 shows, over the 1980s, manufacturing's average annual contribution to the real GDP growth rate was more than twice its contribution than during the 2000-2008 period—and over the 1990s it was 2½ times greater.[14]

Correspondingly, although U.S. manufacturing's real value-added annual growth has generally been positive, tracking GDP growth, its annual rate of growth since 2000 has been substantially lower than in prior decades. Figure 2 shows that manufacturing's average real annual growth rate was only 1.3 percent between 2000-2008, substantially lower than the average growth rate over any prior decade; for example, it was less than a third of the previous decade's average real annual rate of growth.

These trends are reflected at the disaggregated industrial level. The durable goods manufacturing sector's annual real value-added growth rate from 2000 to the present has only been about 40 percent of its growth during the 1990s, and the nondurable goods manufacturing rate turned from positive to negative. As table I illustrates, nine major manufacturing industrial sectors experienced negative average real annual growth rates in their value-added since 2000. All but one had positive growth rates in the decade before. Five other industries still maintained positive average growth rates from 2000 to 2008, but lower than the prior decade's average rate—in a few instances, substantially lower.

These two sets of industries, durable and nondurable goods, which had weakening or negative rates of real-value-added growth after 2000, include several industries important to the defense base. This includes non-metallic mineral products, primary metals, fabricated metal products, electrical equipment, appliances, and components, motor vehicles, bodies and trailers, and parts, plastics and rubber products, and most significantly, computer and electronic products. The computer and electronic parts industry, whose real annual growth rate is significantly higher than any other, still had only half the average real annual growth rate from 2000-2007, than it experienced through the 1990s.

Figure 1
Manufacturing's Value-Added Average Annual
Contribution to GDP Growth Rate

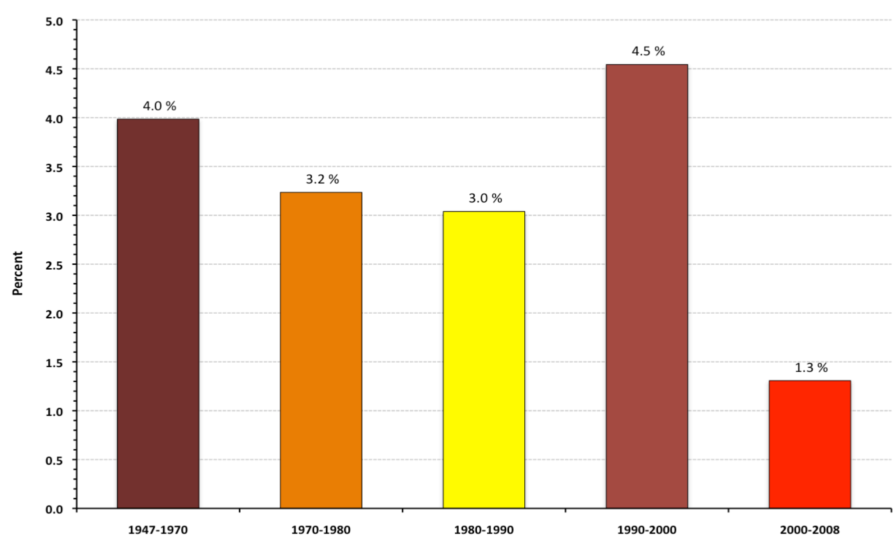


The relatively high, real value-added growth of the computer and electronics parts industry's (NAICS 334) reflects the way the federal government calculates this particular measure—i.e., using a quality-adjusted (a.k.a. hedonic) price index incorporated into the price deflator. The quality-adjustment is based on the assessment that units of production in this sector (especially, microchips) are much more powerful, and therefore create greater value in the economy, at the same or lower prices than in preceding years—a reflection of "Moore's Law" which states that microprocessors double in processing speed and power every 18-24 months. However, the average annual growth rate for *current year* value-added, which does not take into account this quality adjustment, was substantially lower than the real growth rate for this industry between 1990-2000—6.8 percent per year versus 28.1

percent—and was actually negative—a -2.7 percent average growth rate—between 2000 and 2007.[15]

Important outliers to this trend include the transportation equipment (which includes aerospace and shipbuilding), chemical products, and machinery industries, which experienced higher real value-added growth after 2000 compared to the earlier decade. That said, it is likely that value-added growth for all industries has deteriorated since 2007, and perhaps suffered more significant declines as the recession and financial crisis deepened in 2008 and 2009. This was reflected in manufacturing's 2.7 percent decline in real value-added in 2008, and comparable declines in durable and nondurable manufacturing (-1.3 percent and -4.6 percent, respectively).

Figure 2
Manufacturing Value-Added Real Average Annual Growth Rate



Source: Bureau of Economic Analysis

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Weak industrial capacity growth and declining capacity utilization. Growth in *manufacturing industrial capacity* has been tepid since 2000 compared to previous periods, back to 1972.[16] As figure 3 shows, the industrial capacity index for manufacturing (NAICS 31-33) grew at a modest rate of 1.8 points per year from 1972-1994, accelerated to 6.8 per year during the expansion after the recession of the early 1990s, and slowed to only 1.3 per year from 2000 on. If high-tech production industries—computer and electronic products (NAICS 334)—are excluded, manufacturing capacity growth slowed markedly from 1994 through 2000 (to 3.5 points per year), and was very slow (0.3 per year) after 2000.

These differences reflect the rapid growth in high-tech capacity in the 1990s and into the early 2000s, relative to all other manufacturing sectors, though this growth also slowed after 2000. The high-tech industrial capacity values are calculated using hedonic or quality-adjusted price indices, which were also applied in calculating real value-added (see above). As a result, industrial capacity for this sector appeared to grow steadily, even as other industries' capacities slowed or declined. Hence, the industrial capacity indices for manufacturing and durable goods are somewhat inflated by inclusion of this sector.

Table I
Average Annual Percent Change in Real Value-Added Output by Industry Sector, 1990-2000 and 2000-2007(8)*

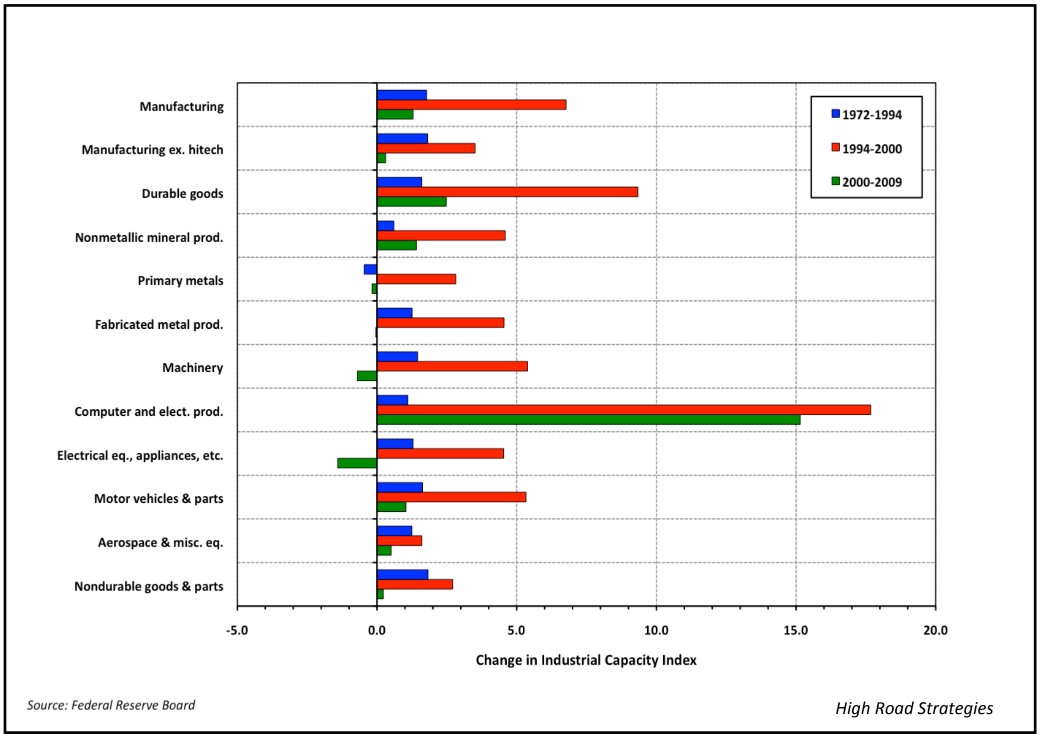
Industry Sector	Ave. Annual Percent Change [Chained (2000) Dollars]	
	1990-2000	2000-2007(8)*
Manufacturing*	*4.5*	*1.3*
*Durable goods**	*6.6*	*2.7*
Wood products	*-0.6*	*0.2*
Nonmetallic mineral products	*3.6*	*-0.4*
Primary metals	*2.7*	*-1.9*
Fabricated metal products	*3.0*	*0.4*
Machinery	*0.6*	*1.7*
Computer and electronic products	*28.1*	*14.1*
Electrical equipment, appliances, and components	*1.9*	*0.5*
Motor vehicles, bodies and trailers, and parts	*5.3*	*4.6*
Other transportation equipment	*-2.7*	*3.0*
Furniture and related products	*3.0*	*-0.2*
Miscellaneous manufacturing	*3.6*	*3.1*
*Nondurable goods**	*1.6*	*-0.4*
Food and beverage and tobacco products	*1.2*	*1.1*
Textile mills and textile product mills	*1.5*	*-3.7*
Apparel and leather and allied products	*-1.9*	*-5.6*
Paper products	*0.5*	*-0.9*
Printing and related support activities	*0.1*	*-0.5*
Petroleum and coal products	*6.4*	*-0.5*
Chemical products	*1.8*	*3.5*
Plastics and rubber products	*5.5*	*-1.1*

* Later period data are for manufacturing, durable goods and nondurable goods is for 2000-2008.

Source: Bureau of Economic Analysis *High Road Strategies*

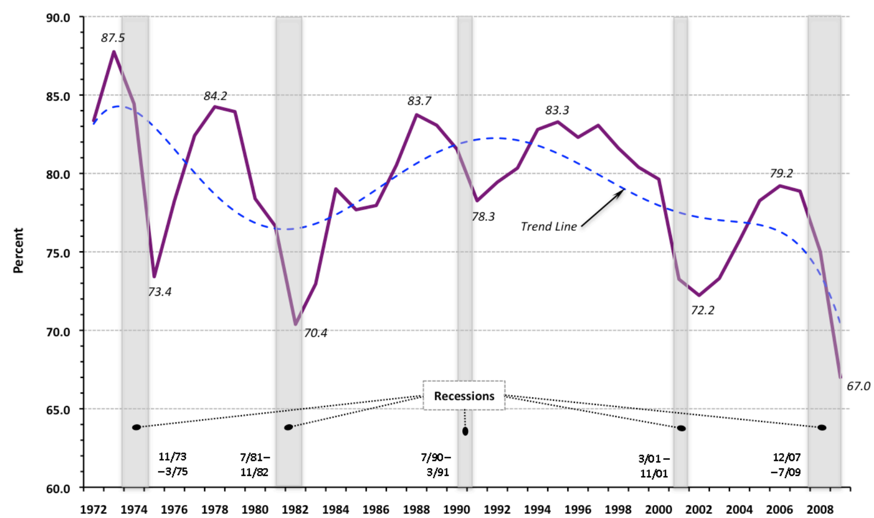
Nevertheless, the industrial capacity indices for both manufacturing and for manufacturing excluding high tech industries actually *declined* in the early 2000s,[17] and again in 2009, when the industrial capacity index for manufacturing excluding high-tech fell by nearly 1 percent—the first decline in the nearly 70 years during which this data has been available. Durable goods and nondurable goods capacity growth followed a similar pattern, as did that for nonmetallic mineral products, primary metals, fabricated metal products, machinery, electrical equipment and appliances, motor vehicles and parts, and aerospace and miscellaneous equipment—all industries important to the defense industrial base.

Figure 3
Change in Industrial Capacity for Manufacturing
for Selected Industry Sectors



Along with the weak manufacturing capacity growth rate since 2000, recovery in the *utilization* of that capacity was slow after a sharp drop during the recession in 2001. Manufacturing capacity utilization's peaks and valleys corresponds to expansions and contractions in the economy. As figure 4 shows, the peaks have progressively fallen since 1972. The lowest peak in annual capacity utilization was 79.2 percent in 2006, which was slightly lower than the average utilization rate throughout the 1972-2008 period. Capacity utilization then fell precipitously to 67 percent in 2009, which is the lowest level for at least the past four decades.

Figure 4
Manufacturing Capacity Utilization, 1972-2008



Source: Federal Reserve Board

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A comparison of annual utilization rates for key industrial sectors averaged over 1972-1999 and 2000-2009 is shown in figure 5. Utilization was substantially higher for almost all the industries in the earlier period compared to the later period, though the latter numbers reflect the sharp decline associated with the extreme recessionary contraction experienced since late 2007.[18]

Sharp decline in the number of manufacturing establishments. After steadily growing in the 1990s, the *number of manufacturing establishments* declined sharply after 1999. The total number of manufacturing establishments of all sizes grew by 25,967 or nearly 6.6 percent, from 1990-1998, but shrank by over 51,000 or 12.5 percent, between 1998-2008 (see figure 6). An additional 5,730 establishments disappeared in 2009, bringing the total net decline of the number of manufacturing establishments to over 57,000 since 1998.

Manufacturing establishments with less than 500 employees account for 99 percent of the total number of such establishments.[19] Nevertheless, the trend for the total number of establishments of all sizes (figure 6) is replicated for nearly every size category—i.e., establishments with under 100 employees, with 100-499 employees, with 500-999 employees, and over 1,000 employees (figure 7). While about 85 percent of closures occurred among establishments of less than 100 employees, the number of large establishments having more than 500 employees fell by nearly 1,600, or by a third, after 1998—a loss of one in three plants of that size. Large numbers of intermediate-sized plants (100-500 employees)—over 6,000—also closed their doors.

Figure 5
Average Annual Capacity Utilization, Key Industries

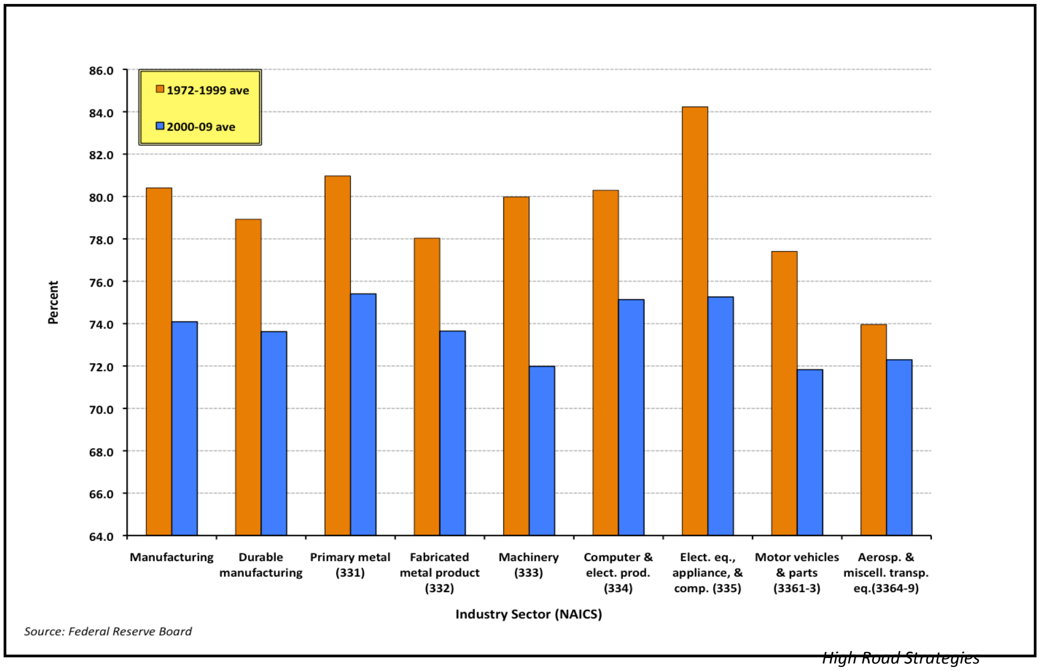
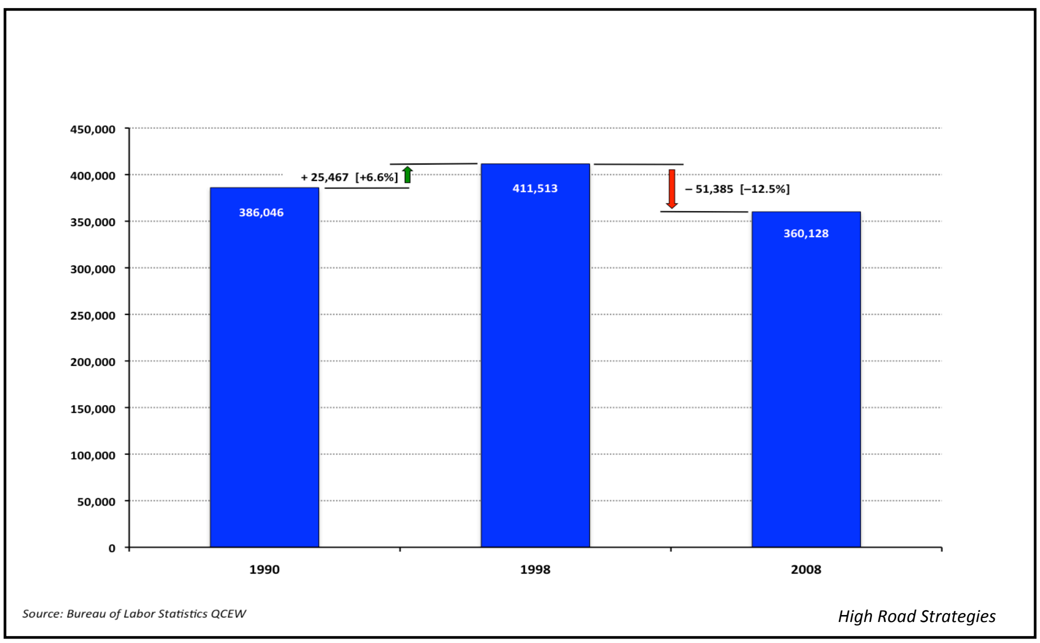


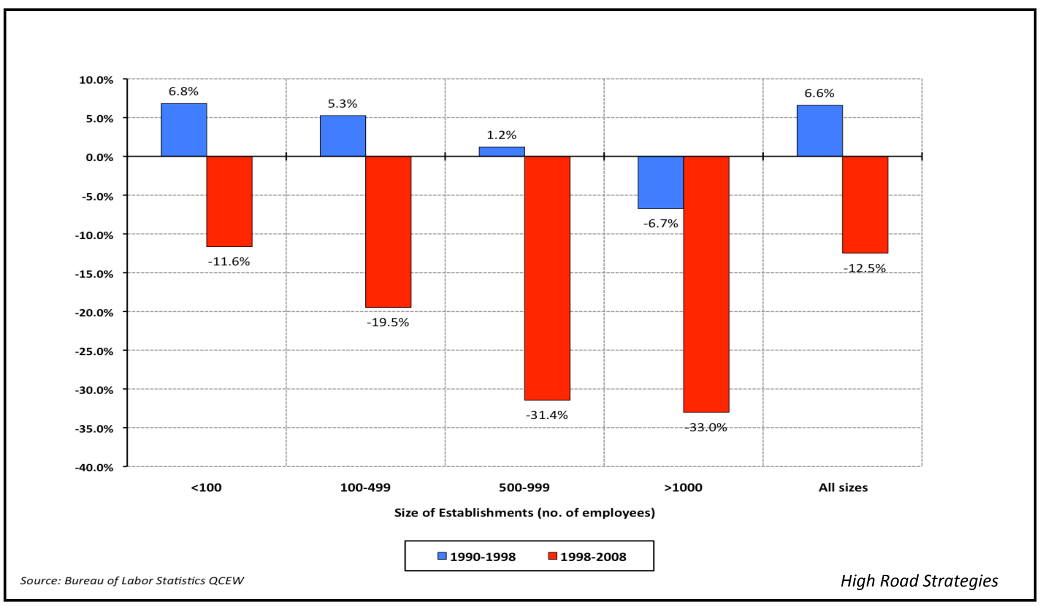
Figure 6
Number of Manufacturing Establishments



The trends in establishment numbers are very similar for almost every manufacturing sector (figure 8). Most major sectors (3-digit NAICS)—machinery, computer and electronic products, plastics and rubber products, wood products, paper manufacturing, electrical equipment and appliances, fabricated metal products, primary metals, and transportation equipment—added establishments of all sizes between 1990-1998, but shed establishments after 1999, sometimes in large numbers. A couple of sectors, chemical manufacturing and nonmetallic mineral products, gained establishments in both periods—but at a lower rate after 1998 than before—while two others, apparel and textiles, suffered significant losses throughout the 1990-2008 timeframe.[20]

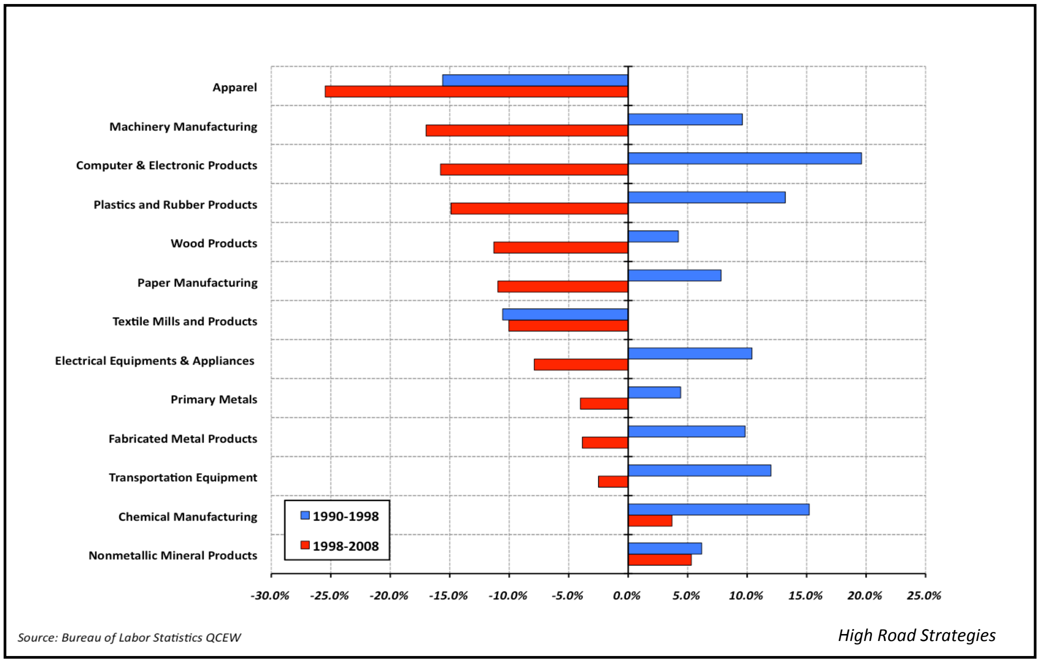
Every major manufacturing sector experienced a net loss of large establishments with 500 or more workers in this period. These trends are especially notable because of the large numbers of workers affected, as well as the disproportionate economic impacts on communities, when these large manufacturing facilities close. The data show that every single major manufacturing sector experienced a loss of such large establishments after 1998.

Figure 7
Change in Number of Manufacturing Establishments
by Size (number of employees)



In the durable goods sector, the machinery, electrical equipment and appliances, primary metals, fabricated metal products, computer and electronic products and wood products industries each lost from about 30 percent to 40 percent or more, and nonmetallic mineral products saw a decline of over half, of their large facilities. In the nondurable sector, textile mills and products and apparel lost well over 60 percent, paper manufacturing and plastics and rubber lost over 30 percent, and chemical manufacturing lost over a quarter, of plants with over 500 workers.[21]

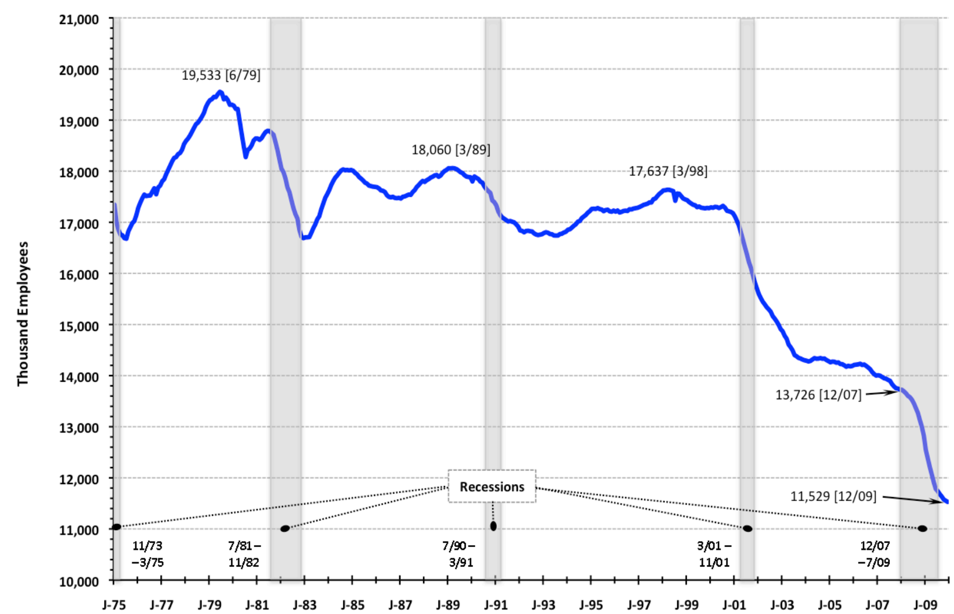
Figure 8
Change in Number of Establishments by Industry Sector



Dramatic loss of manufacturing jobs. As evidenced in figure 9, manufacturing employment has fluctuated with the business cycle, but steadily declined after its historic high of 19.5 million jobs in 1979. There have been recoveries after sharp losses in earlier recessionary periods, but the peaks have been progressively lower in a pattern similar to the fluctuation in capacity utilization discussed above. The latest peak was in 1998—17.6 million jobs—a product of the Internet and IT-driven boom of the mid-late 1990s.

The 2 million net jobs lost over the twenty-year period between the two peaks, though not insignificant, does not compare to the dramatic loss in manufacturing employment that followed in the decade from 1998-2009. Even before the recession and financial crisis starting in late 2007, the manufacturing workforce was shrinking at an alarming rate. Between August 2000 and February 2004 manufacturing jobs were lost for a stunning 43 consecutive months—the longest such stretch since the Great Depression. Manufacturing employment continued to fall well after the end of the 2001 recession, and by December 2007, over 3.9 million manufacturing jobs had been lost since the March 1998 employment peak. The losses have deepened significantly in the current recession, with another 2.2 million manufacturing jobs lost by the end of 2009. This brings the total number of manufacturing workers who have lost their jobs over the last decade to *6.1 million*![22]

Figure 9
Manufacturing Employment, 1977-2009



Source: BLS *High Road Strategies*

In total, manufacturing (NAICS 31-33) and its main divisions, durable and nondurable goods manufacturing, lost one-third of its workforce since 1998. As table II shows, no major sector (NAICS 3-digit) within these larger categories was spared.[23]

In most of the industries especially important to the defense base—computer and electronic products, electrical equipment and appliances, machinery, primary metals, transportation equipment, and fabricated metal products—job losses as a percent of total employment have risen to startling levels. In the durable goods industries, the losses have ranged from one-fifth to nearly half of 1998 employment levels. In nondurable goods manufacturing, the losses have ranged from only 6 percent (food manufacturing) to nearly three-quarters (textiles, apparel) of their original workforces between March 1998 and December 2009.

There are several factors contributing to manufacturing employment decline, though the recent sharp decline is attributable to the deep recession that began in December 2007. The extent to which productivity gains and trade-related factors (imports, global outsourcing) have contributed to the manufacturing job decline since the late 1970s—and the rapid decline between 1998 and 2008—is the subject of intense debate, as will be discussed below. Regardless of the cause, the correlation between manufacturing job losses and the net loss of manufacturing establishments over the same periods, especially since the late 1990s, is unmistakable.

Table II
Change in Manufacturing Employment by Sector, 3/98-12/09

NAICS	Industry	Change in Employment	
		No. of Jobs	Percent
31-33	**Manufacturing**	**-6,108,000**	**-34.6**
	Durable goods	*-3,912,000*	*-35.7*
321	Wood products	-258,200	-42.5
327	Nonmetallic mineral products	-148,400	-27.9
331	Primary metals	-295,400	-45.7
332	Fabricated metal products	-476,000	-27.3
333	Machinery	-551,300	-36.2
334	Computer and electronic products	-757,800	-40.9
335	Electrical equipment and appliances	-230,600	-39.0
336	Transportation equipment	-766,500	-36.8
337	Furniture and related products	-274,600	-43.1
339	Miscellaneous manufacturing	-152,600	-21.0
	Nondurable goods	*-2,196,000*	*-32.8*
311	Food manufacturing	-97,900	-6.3
312	Beverages and tobacco products	-24,900	-11.9
313	Textile mills	-308,900	-71.5
315	Apparel	-477,000	-74.1
316	Leather and allied products	-56,900	-66.5
322	Paper and paper products	-231,500	-36.8
323	Printing and related support activities	-328,200	-39.6
324	Petroleum and coal products	-23,700	-17.5
325	Chemicals	-200,800	-20.2
326	Plastics and rubber products	-332,100	-35.0

Data Source: BLS *High Road Strategies*

Figure 10 illustrates the close linkage between manufacturing establishment and employment trends. For all establishment sizes, the change in number of establishments and number of jobs seems to track closely. Figure 11 shows that this pattern, with some exceptions, is repeated for the major industry sectors (3-digit NAICS), as well.

It is notable that although small establishments with 100 or fewer workers accounted for over 90 percent of all manufacturing establishments, they employed only one-third of the total number of manufacturing workers in 2008. In contrast, even though plants with 500 or more employees accounted for only 1 percent of establishments, they employed 28 percent of the manufacturing workforce.

Figure 10
Changes in Numbers of Manufacturing Establishments and Employment, by Establishment Size (percent of size category)

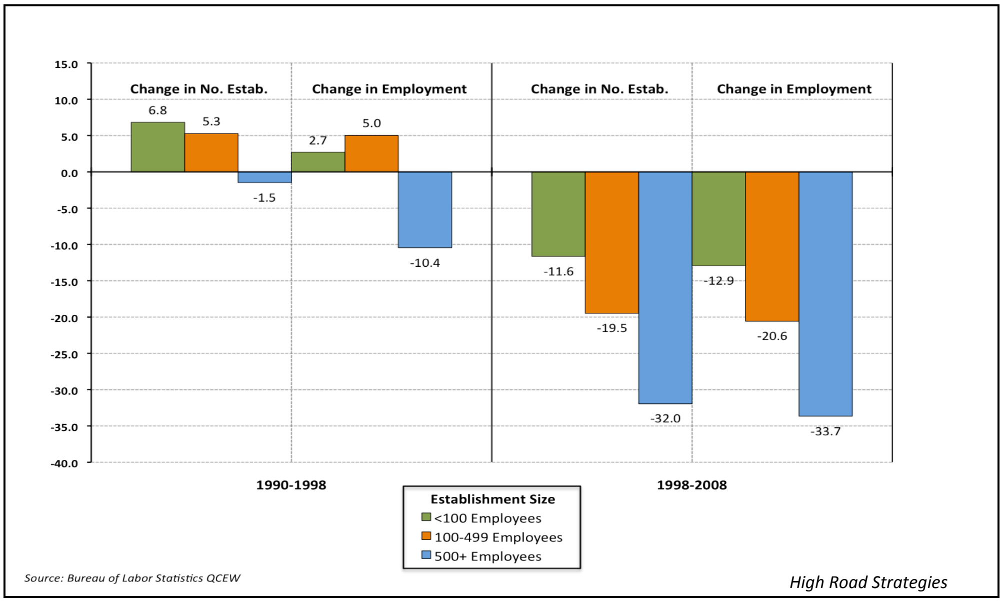
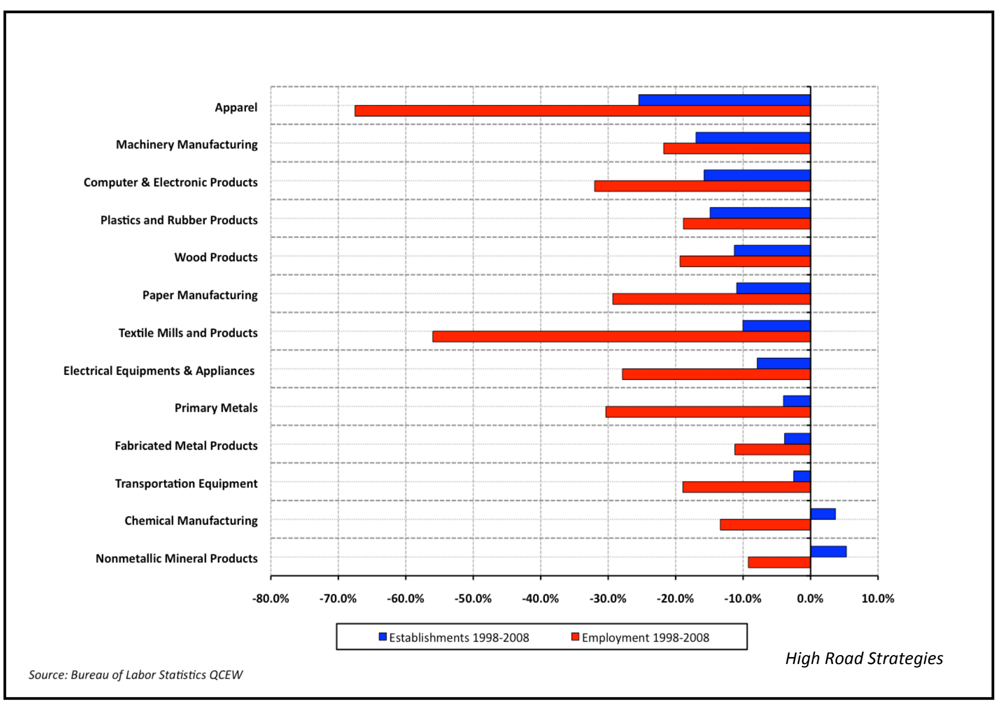


Figure 11
Changes in Number of Manufacturing Establishments and Employment, by Industry Sector, 1998-2008



Mid-sized plants (100-499 employees) accounted for the remaining 7 percent of establishments and 37 percent of the workers. Correspondingly, the shedding of large and mid-sized establishments was associated with the lion's share of manufacturing jobs lost between 1998-2008; large plants accounted for only 3 percent of establishment losses but nearly *half* of the reduction in manufacturing jobs, and mid-sized plants accounted for 12 percent of establishment losses and one-third of the jobs shed in manufacturing over the last decade.[24]

b. Indicators of Global Competitiveness

Paralleling the trends of internal weakening of America's manufacturing capabilities described above, are clear signs of America's declining competitiveness in global markets. These are indicated by growing trade deficits in goods, including in advanced technology products, and the penetration of foreign imports into U.S. markets across the spectrum of manufacturing industries.

Starting in the 1970s, U.S. manufacturers have been facing challenges from international competitors—starting with the Japanese and Europeans in the 1980s. But over the past decade, China has begun to emerge as America's leading economic competitor, especially in manufacturing. As the trends below show, the United States has suffered from a massive, and steadily growing, international trade deficit in goods, especially with China, and a rapid expansion of foreign competitors capturing U.S. markets in numerous industries, including many which are critically important for supplying the U.S. defense industrial base.

Growing trade deficits. As figure 12 shows, the *U.S. trade deficit in goods* has been growing since 1976, and at an especially rapid rate since 1998, rising to a record 828 billion USD in 2006. It remained above 800 billion USD for the next two years—hitting 816 billion USD in 2008. That is, the United States imported more goods than it exported at a rate of 2.2 billion USD a day. In real terms, the deficit in goods in 2008 was 18 times larger than it was in 1980, and equal to nearly 6 percent of U.S. GDP.[25]

In addition, as figure 13 illustrates, the United States has been running large, chronic trade deficits in nearly every major U.S. manufacturing sector. Most of the traditional manufacturing sectors—apparel, primary metals, electrical equipment, appliances and components, fabricated metal products, textile mill products—have significant trade deficits. Some of the largest deficits, however, occur in transportation equipment (despite large U.S. aerospace surpluses) and computers and electronics products, which are especially critical to the defense industrial base.[26]

Figure 12
U.S. Trade Deficit in Goods, 1976-2008 [Census Basis]

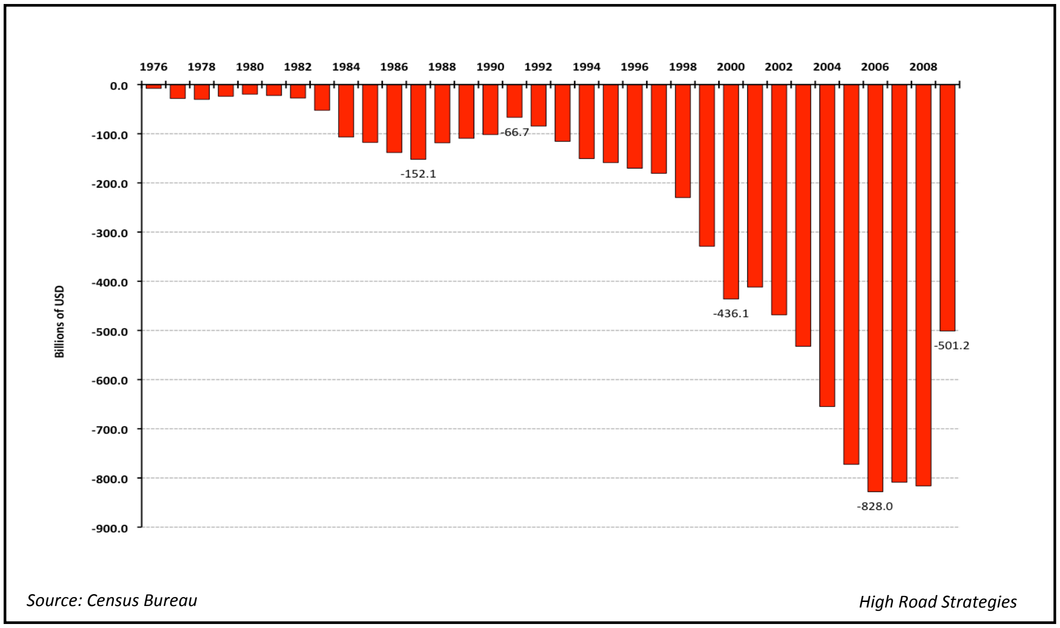
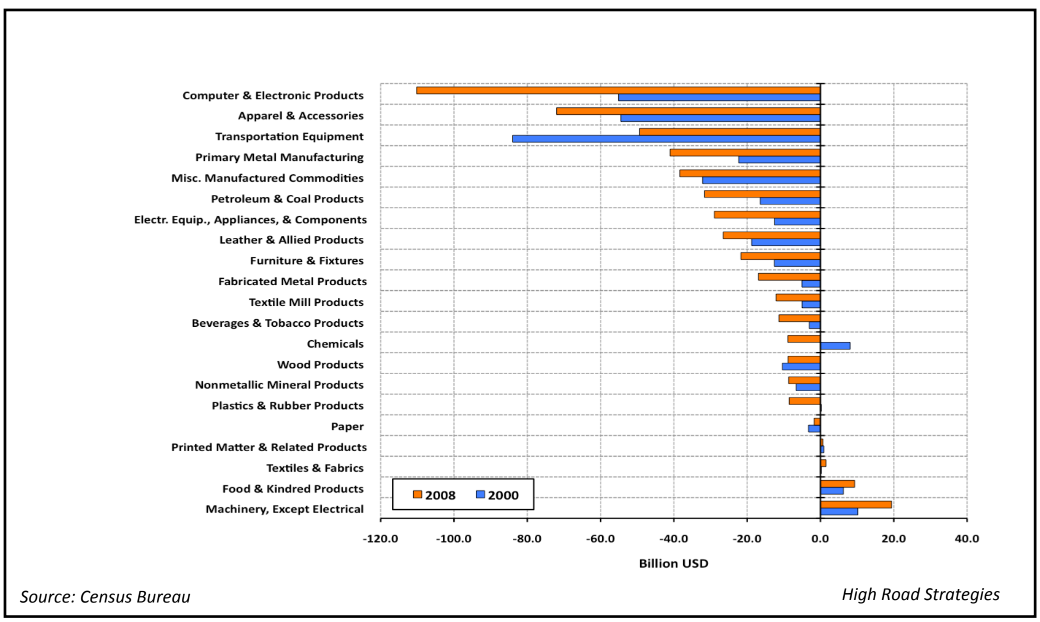


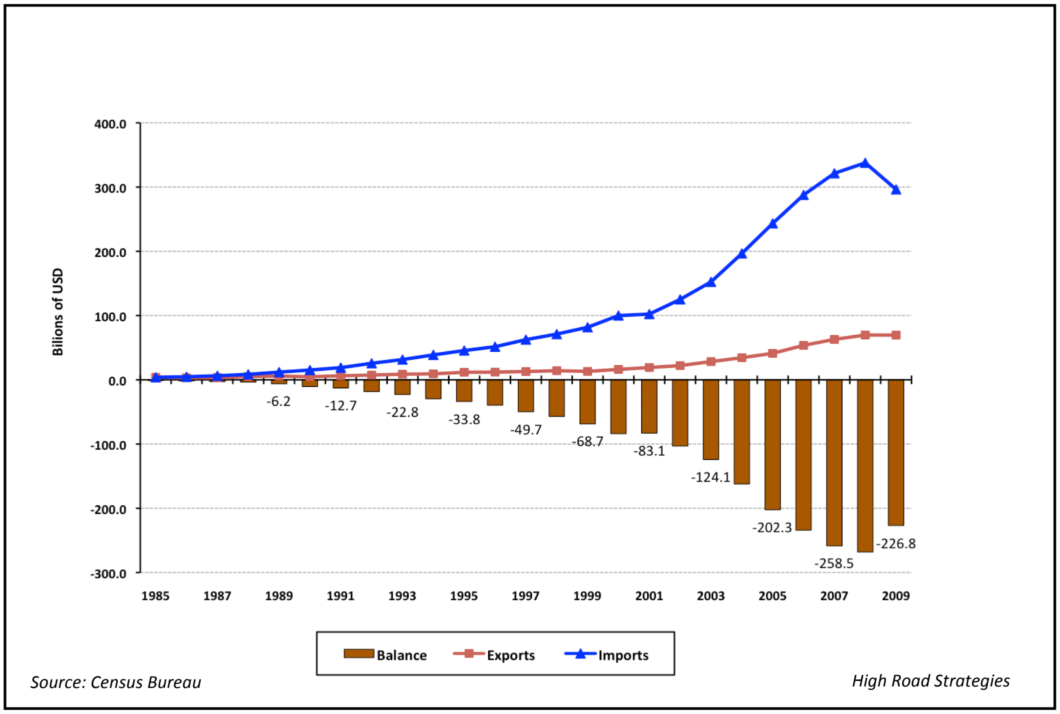
Figure 13
U.S. Trade Balance by Manufacturing Sector, 2000 & 2008



The United States also has run large, chronic goods trade deficits with almost every major trading country and region in the world.[27] After Canada, China is America's second largest trading partner, followed closely by Mexico, Japan and Germany. The United States has long had a goods deficit with each of these countries, but the U.S.

trade deficit with China by far exceeds its goods deficit with any of its other trading partners. This gap has grown exponentially since 1985 (see figure 14). By 2008, the dollar amount of this imbalance had more than tripled—reaching a record 268 billion USD—since 2001, the year Congress granted China permanent normal trade relations and China joined the World Trade Organization. Although the deficit in goods with China dipped by about 15 percent to 227 billion USD in 2009 due to the recession, it already showed signs of growing again in 2010.

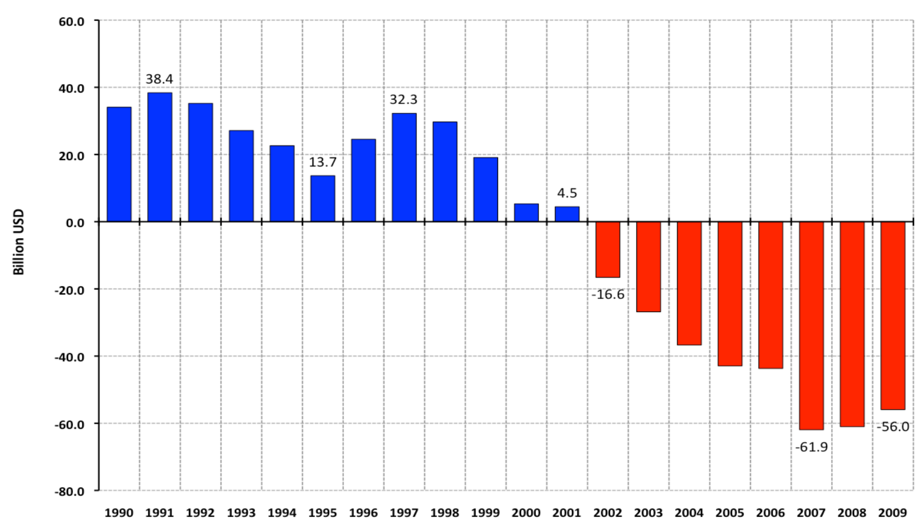
Figure 14
U.S. Imports, Exports and Trade Balance With China, 1985-2009



Advanced Technology Products. Especially troubling from a national security standpoint is the shift in the U.S. trade balance in advanced technology products (ATP)[28] from a surplus to a deficit, as illustrated in figure 15. ATP has traditionally been a source of American comparative advantage in international trade. Yet since 1997, the ATP trade balance has declined at a rapid rate, recording deficits since 2001. By 2004, the ATP deficit grew to an all time high of 62 billion USD, though it fell back in 2008 and especially in 2009, again, a result of the recession.

As figure 16 shows, although half of the sectors that comprise ATP—especially electronics and aerospace—continue to enjoy trade surpluses, the other half show significant and growing trade deficits. The information and communications products sector in particular has large, escalating deficits. The deficits for life sciences and optoelectronics are relatively smaller, but also have been growing. Much smaller still, but still consistently experiencing negative trade balances, are the nuclear technology and advanced materials sectors. In any event, the existence of large, chronic U.S. trade deficits across the board and even in many of the most capital- and knowledge-intensive sectors indicates that, whatever the fortunes of its multinational companies and their global production networks, the United States is losing competitiveness as a site for manufacturing.

Figure 15
U.S. Trade Balance in Advanced Technology Products, 1990-2009



Source: Census Bureau *High Road Strategies*

Import penetration. Another critical indicator of U.S. manufacturing competitiveness, *the import penetration rate (IPR)* (see Box A*)*—the share of the U.S. market held by imports for a good or industry—has also been declining. Thus, IPRs can be seen as indicators of the extent to which trade factors are eroding domestic manufacturing production and jobs. In many respects, IPRs are better indicators of the competitiveness of manufacturing located in the United States than the trade balance figures.

The figures on this head-to-head competition between U.S. and foreign-based producers in the same U.S. market reveal that U.S. producers have lost significant ground. The data show an across-the-board, aggregate increase for 114 high-tech and capital-intensive sectors of 61 percent—from 21.4 percent of domestic consumption to 34.3 percent—between 1997 and 2007. That is, imports grew from one-fifth to over one-third of the total value of this large, diverse group of products consumed domestically in just one decade.

Figure 16
U.S. Trade Balance in Advanced Technology Products,
By Sector, 2002, 2005, and 2008

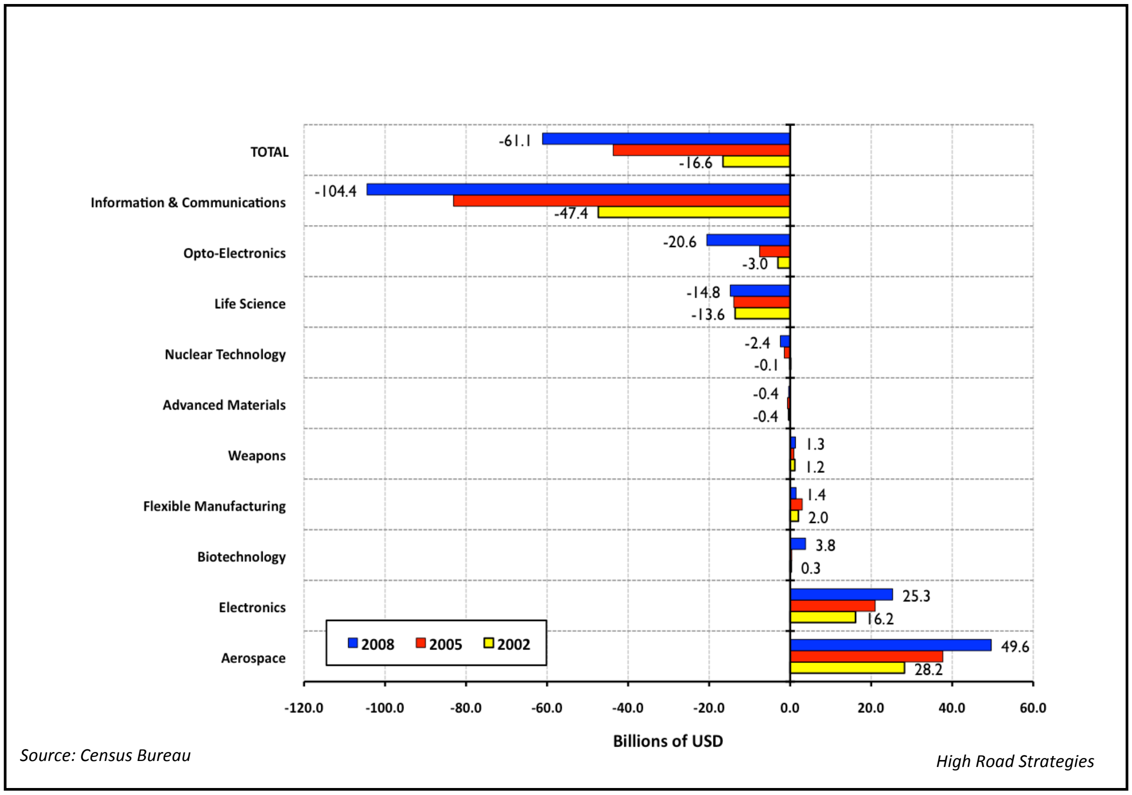


Table III lists the 25 items with the largest IPRs in 2007, ranging from 52.5 percent (relays and industrial controls) to 93.5 percent (electric capacitors and parts). Except for three of these items, the IPRs increased in every case between 1997 and 2007 by a range of 2 percent (computer storage devices) to 70 percent (household furnishings). The average IPR increase across all the items in the group was 26 percent to 68 percent, rising from an average IPR of 42 percent—an increase of nearly two-thirds—over that time period.[29] Moreover, although the NAICS industrial classification system was introduced in 1997, converting its categories to the corresponding codes for older systems shows that the increase in IPRs dates from at least 1992.[30]

c. The Eroding Base

As already noted, no single indicator is necessarily evidence of a decline in manufacturing capabilities. But when the indicators are lined up alongside each other and linkages between them clarified, a pattern emerges that strongly suggests that manufacturing in the United States has been losing significant capacity and strength for well over a decade, with roots going back much earlier. The U.S.

manufacturing base remains large and robust, and recovery is still possible—indeed, is essential for the long-term health of the overall economy—but the signs of erosion are clear and troubling.

Table III
Top 25 Products with Largest IPRs in 2007

Industry Code	Description	2007	1997	% Change 1997- 2007
314129	Household furnishings	**93.5**	**23.2**	***303.3***
322110	Pulp mill products	**92.7**	**45.2**	***105.0***
322122	Newsprint mill products	**90.6**	**54.3**	***66.8***
325411	Medicinals and botanicals	**85.8**	**49.5**	***73.3***
332911	Industrial Valve Manufacturing	**78.2**	**34.4**	***127.3***
333220	Plastics and rubber industrial machinery	**77.3**	**43.4**	***78.2***
333512	Metal-cutting machine tools	**76.9**	**58.6**	***31.3***
333513	Metal-forming machine tools	**76.6**	**62.7**	***22.1***
333611	Turbines and turbine generator sets	**71.1**	**25.4**	***179.8***
333612	Speed changers, high speed drives, and gears	**70.7**	**38.5**	***83.6***
334111	Electric computers	**65.5**	**13.9**	***370.3***
334112	Computer storage devices	**64.9**	**66.7**	***-2.7***
334210	Telephone switch apparatus	**64.5**	**17.7**	***265.3***
334220	Radio and TV broadcasting and wireless equipment	**63.0**	**16.1**	***291.0***
334414	Electric capacitors and parts	**62.1**	**69.1**	***-10.0***
334415	Electronic resister manufacturing	**61.8**	**47.5**	***30.0***
334419	Other electric components	**58.2**	**56.9**	***2.2***
334513	Industrial process control instruments	**58.1**	**45.7**	***27.1***
334613	Magnetic and optical recording media	**57.1**	**38.6**	***47.8***
335312	Motors and generators	**56.7**	**28.4**	***99.9***
335314	Relays and industrial controls	**56.3**	**24.1**	***134.1***
336111	Autos	**56.0**	**50.4**	***11.0***
336120	Heavy duty trucks and chassis	**55.8**	**62.5**	***-10.8***
336399	Motor vehicle parts	**53.7**	**38.3**	***40.3***
336412	Aircraft engine and engine parts manufacturing	**52.4**	**40.0**	***31.0***
Average Top 25 IPRs		**68.0**	**42.0**	***61.7***

Source: USBIC

High Road Strategies

Quality adjustments, high-tech, and manufacturing decline. The erosion is apparent in the concurrent trends of weakening manufacturing value-added output, acceleration in manufacturing's steady decline as a share of U.S. GDP, stagnant and even negative growth—the first time in seven decades—in industrial capacity, and the substantial drop and long-term average yearly decline in utilization since 2000. It isn't coincidental that the peak levels in both manufacturing capacity utilization and manufacturing employment during business cycle expansions (see figures 4 and 9) have fallen successively from the 1970s. As industrial capacity stagnated and fell, both manufacturing employment and establishment numbers declined sharply from late 1999 to the present, with no increase at all during the weak expansion of 2002-2007.

ICT quality adjustments. These trends hold in spite of the quality (hedonic) price adjustments the federal government uses in calculating real value-added and industrial capacity—which mostly applies to the computer and electronic products industry (NAICS 334). As noted, quality adjustments in the value-added and industrial capacity indices are designed to account for the fact that for certain products, value contributions to the economy may be somewhat larger than reflected in their current prices. This is particularly true for the high-tech industries—computer and electronic products, publishing industries (including software), information and data processing services, and computer systems design and related services—which the BEA calls the information-communications-technology-producing (ICT) industries. The quality adjustment assumes that an ICT product or service produced today is in effect worth exponentially more than the same product or service produced in prior years, even at comparable prices.

With this adjustment applied, the ICT sector appears to have been a major driver of *real* GDP growth since the early 1990s, although its annual share of current year GDP has remained around 4-5 percent. For example, the ICT industries accounted for a little less than 4 percent of U.S. GDP, but contributed to over 20 percent for real GDP growth in 2007—and 30 percent in 2008.

Computer and electronic products is the only manufacturing industry in the ICT sector. Its share of ICT value-added has slid since the late 1990s, from over 40 percent to a little under 30 percent in 2008, as information products and services industries have expanded their output. Nevertheless, it has been the largest driver of manufacturing real value-added, even as most other manufacturing industries have suffered declines during the past decade. Although ICT's share of GDP value-added (current dollars) has ranged from 1 to 2 percent, its contribution to annual real GDP growth averaged 9 percent between 1998-2007 (it was 10 percent in 2007) and accounted for the largest share of the manufacturing sector's contribution to real GDP growth by far.

A misleading indicator. In short, though the quality adjustments to computer and electronic products value-added and the consequent increases in manufacturing real value-added are a genuine reflection of real growth in economic value, it can be a misleading indicator of the actual health and competitiveness of the U.S. manufacturing sector. The significant growth in computer and electronic products real value-added over the past decades was still not sufficient to prevent weak performance in overall manufacturing value-added, industrial capacity and capacity utilization over the past decade, nor to offset the dramatic losses in manufacturing establishments and manufacturing employment over this period. For example:

- In current dollar terms, the computer and electronic products industry's value-added *declined* at an average annual rate of nearly 3 percent between 2000-2007, even though non-deflated manufacturing value-added *grew*.
- The industry lost 5 percent of its workforce between January 1990 and March 1998, and 41 percent between March 1998 and December 2009 (see table II). In absolute terms, it lost the second largest number of jobs out of 21 industry sectors (3-digit NAICS)—second only to transportation equipment—in manufacturing,
- The industry lost a net of 16 percent of its establishments between 1998-2008 (figure 8), including nearly 40 percent of establishments with over 500 employees and one-quarter of establishments with between 100 and 500 employees. In contrast, it gained a net of 20 percent of its establishments from 1990-1998.
- It had the second largest trade deficit of any manufacturing industry in 2000 (-55 billion USD) and by far the largest deficit in 2008 (-110 billion USD) (figure 13).
- Information and communications products also accounted for the largest, and progressively increasing, share of the trade deficits in advanced technology products (figure 16).

Trade deficits and employment losses. Manufacturing's erosion becomes even more evident when we examine the domestic economic trends in light of the steady growth in trade deficits and import penetration. Generally speaking, increasing trade deficits in goods are a result of U.S. consumers becoming dependent on foreign-produced manufactured goods at the expense of domestically produced goods. That is, foreign producers captured greater and greater shares of domestic markets as U.S. manufacturers cut capacity and/or moved their operations offshore to lower-cost foreign locations. As seen below, many analysts link the large scale, steady losses in manufacturing employment and establishments, especially those since 1998, to these trade-related factors—though this correlation is disputed.

Trade, productivity and job displacement. Simply stated, while increasing exports can create new jobs, expanding imports can eliminate jobs, especially if foreign-made items replace domestically produced goods in domestic markets. Therefore, if imports exceed exports—especially if this differential is large, as it is in the United States—there will be a net loss of jobs, potentially in significant numbers. Traditional economists, however, typically have argued that productivity gains and declining demand (i.e., as occurs during recessions) have played a far more important role in declining manufacturing employment, and some have claimed that trade has played little or no role in these losses. In contrast to this view, several excellent empirical studies from the Washington, DC think-tank, the Economic Policy Institute (EPI), show that demand factors and productivity alone cannot explain the large-scale displacements shown in the data. Moreover, they have estimated that millions of U.S. jobs that have been displaced or job gains foregone as a result of international trade, including the losses associated with specific trade agreements (e.g.., the North American Free Trade Act (NAFTA)).[31] This work supports the argument that a large share of the employment and establishment losses in U.S. manufacturing—over the past decade in particular—are linked to consolidations and plant closures arising from the pressures of international competition for domestic and foreign goods markets, and the offshoring of operations by large OEMs and their suppliers in almost every major manufacturing sector.

That is to say, manufacturing employment losses, and the very large number of manufacturing establishments that have closed their doors since 1998, are more plausibly indicators of systemic erosion in the U.S. manufacturing base, than the result of productivity improvements or declining domestic demand. First, although economic recessions clearly have been correlated with job losses, and expansions with job recoveries (see figure 9, for example), there have been many instances of employment declines even as domestic demand (during expansions) has increased. Most notably, even after the relatively shallow recession in 2001, manufacturing jobs declined sharply after the recession was technically over, and stagnated or fell during the past decade, even as U.S. GDP increased. Of course, manufacturing employment and establishment numbers have both fallen sharply since 2008 due to the extreme recession and financial crisis, exacerbating the downward trends that already started during the late 1990s.

On the other hand, productivity gains over a period of decades have contributed to the long-term decline in manufacturing employment, even during peak periods. Historically, productivity and technological change (which helps drive the former) have played a major role in reducing the labor *cost* component in manufacturing, yet the generated gains, until recently, have often been accompanied by new job creation in both manufacturing and services, and increased income for workers. In principle, productivity gains have been a good thing, as they help generate economic growth and more available income for workers.

As Economic Policy Institute (EPI) economist Josh Bivens acknowledges, although productivity growth has played an important role in manufacturing job loss, "this growth is to be welcomed over the long-run, as productivity provides the ceiling on how quickly living standards can rise."[32] Nevertheless, Bivens's work shows that domestic factors, including productivity and demand, cannot explain a major share of the jobs displaced in manufacturing, especially over the last decade. For example, he estimates that trade deficits explain 59 percent of the decline in manufacturing employment between 1998-2003, and at least a third of manufacturing job loss between 2000-2004.[33] Moreover, he noted that these estimates are a "conservative measure of the involuntary job displacement," and concludes that they are indicators of "how trade has affected the composition of jobs in the U.S. labor market," often resulting "in large income losses and even permanent damage to workers' earning power."[34]

Similarly, EPI's Robert Scott has produced several studies estimating the number of jobs that have been displaced due to U.S. trade deficits. For example, he has consistently argued against other economists' predictions that NAFTA would generate rising trade surpluses that support the creation of domestic jobs. He noted that the United States had a 1.7 billion USD trade surplus with Mexico in 1993, which soon transformed into a rapidly growing trade deficit that reached 74.8 billion USD in 2007.[35] Scott estimated that by 2006, trade deficits with Mexico and Canada displaced production that had supported 1,015,290 American jobs, mostly in manufacturing, since NAFTA took effect in 1994. This includes 560,000 job losses due to growing deficits with Mexico and 456,000 jobs lost due to the deficit with Canada.[36]

China trade and job losses. Scott has also examined the impacts of the growing U.S. trade deficit with China, which he argues in a 2007 report "has displaced huge numbers of jobs in the United States, and been a prime contributor to the crisis in manufacturing employment over the past six years."[37] Like many other trade analysts, Scott attributes China's large and expanding trade surplus with the United States to currency manipulation, low labor costs (associated with suppression of labor rights), lax environmental regulations, and export production subsidies.

The U.S. trade deficit with China has mushroomed since the latter's entry into the World Trade Organization (WTO) in 2001—rising from 84.1 billion USD in 2001 to 262.1 billion USD in 2007. Scott has calculated that between 2001-2007, 2.3 million U.S. jobs were lost or displaced, including 366,000 in 2007 alone, due to the increased deficit with China, with more than two-thirds of the job losses in manufacturing. Since China's entry into the WTO, an average of 382,500 jobs per year were lost or displaced compared to 101,000 lost or displaced jobs per year from 1997-2001. Moreover, the rising trade deficit in manufacturing goods with China has reduced demand for goods produced in every region of the United States, resulting in job displacements in all 50 states and the District of Columbia.[38]

China also plays a prominent role in the shrinking U.S. high-tech trade balance and the growing advanced technology deficit. China's exports to the United States of electronics, computers, and communications equipment, as well as other products that use highly-skilled labor and advanced technologies, are growing much faster than its exports of low-value, labor-intensive products, such as apparel, shoes and plastic products. For example, Scott reported that the 68 billion USD deficit in advanced technology products with China in 2007 is responsible for more than 25 percent of total U.S.-China trade deficit. Almost half of the 178 billion USD increase in the U.S. trade deficit with China between 2001-2007 was accounted for by rapidly growing imports of computers and electronic parts, which displaced 561,000 U.S. jobs over this period. China has also rapidly gained advantage in other advanced industries such as autos and aerospace.[39]

Empirical studies. Studies by Cornell researchers and the AFL-CIO Industrial Union Council's (IUC) Job Export Database Project (JEDP) provide further evidence of a link between imports and offshoring with plant closures and mass layoffs in U.S. manufacturing across the nation. First, two studies by the Cornell School of Industrial and Labor Relations, led by professor Kate Bronfenbrenner for the U.S.-China Economic and Security Review Commission (USCC) present strong empirical evidence about the shift of production out of the United States to Mexico, China, India, and other Asian countries.[40] In one study, Bronfrenbrenner and Stephanie Luce report that from January-March 2004 there "were 69 announced or confirmed production shifts to Mexico, … 58 shifts to China, 31 to India, 39 to other Asian countries, 35 to other Latin American and Caribbean countries, 23 shifts to other countries including Eastern and Western Europe and Canada."[41] They estimated that in 2004 as many as 406,000 US jobs would be shifted to other countries compared to 204,000 jobs in 2001.

The AFL-CIO IUC project produced a series of job export studies for several states, which also provided hard data that international trade, including offshore production shifts, has played a larger causal role in the loss of manufacturing jobs. Using common data sources and a methodology similar to the one employed by Bronfenbrenner et al., the IUC reports examine manufacturing mass layoffs in four states—Ohio, Wisconsin, Pennsylvania, and Washington.[42] The findings of the reports are summarized in table IV.

The IUC reports found that from 52 to 88 percent of layoffs examined for the reports had trade related causes. The IUC and Bronfenbrenner studies are highly complementary, and both emphasized that their findings account for only a *minimum* number of trade-related job losses. The studies show only the tip of a much larger iceberg of global trade pressures pervading the U.S. economy and influencing employers' location and employment decisions across manufacturing supply chains.

Productivity's explanatory limits. There is some evidence that productivity is a problematic indicator that has been incorrectly interpreted as an explanatory factor in manufacturing employment decline over the past decade. Decisions about new technology investments are frequently—if not most often—made in response to global competitive pressures. That is, technological change is not an independent, exogenous causal factor in the loss of manufacturing jobs. In fact, productivity enhancing technology investments both accompany firms' decisions to shed domestic suppliers and go offshore for cheaper suppliers or move their operations overseas, and enable this process.

Although productivity is traditionally associated with job growth and increased wages over the long term, the internationalization of production enabled by technology may have changed this equation, as productivity gains now reflect global efficiencies that do not show up as domestic economic gains in the form of jobs and wage growth.

Table IV
Summary of Findings, IUC State Job Loss Reports
January 2001- May 2004

Manufacturing Share of GSP	Manuf. Jobs Lost (BLS)	Job Loss Impacts	WARN-Related Layoffs	Trade-Related Layoffs *(WARN-based)*	Trade-Related % of Total. Layoffs *(WARN-based)*	New Jobs' Wages Compared to Lost Jobs
Ohio						
23.4% 2000 GSP	170,000	1 in 6 manuf. jobs lost	38,830	20, 124	52%	$11,355 less
Wisconsin						
25.0% 2000 GSP	67,500	1 in 9 manuf. jobs lost	26,243	15,912	61%	$9,312 less
Pennsylvania						
18.4% 2000 GSP	161,200	1 in 5 manuf. jobs lost	40,733	28,259	70%	$12,456 less
Washington						
12.3% 2000 GSP	66,700	1 in 5 manuf. jobs lost	30,991	27,196	88%	$18,400 less

Source: Jobs Exports Database Project, Industrial Union Council, AFL-CIO *High Road Strategies*

Many of the productivity gains that some industries have seen over the past decade or more, have enabled global trade flows on a larger scale than ever before, due to the introduction of advanced information and telecommunications (Internet-enabled business-to-consumer and business-to-business electronic commerce) and transportation and logistical advances,. These advances have made it easier for firms to coordinate distributed operations and supply chains on a global basis, and have reduced the transactions costs of doing such.[43] That is, these technology advances have contributed to productivity gains accompanied by increased international trade and offshoring—and subsequently mass layoffs and increased displacement of jobs.

Susan Houseman of the Upjohn Institute for Employment Research has raised additional questions about the biases in the productivity measure in the face of large-scale outsourcing and offshoring of suppliers. Her studies argue that U.S. productivity data may not sufficiently account for the lower-cost labor inputs embedded in intermediate materials inputs (components and parts) produced by foreign suppliers or U.S. producers' offshored operations and then shipped back into the United States for assembly into final products. That is, high productivity numbers could be inflated, since the value of U.S. products seemingly made with smaller amounts of domestic labor does not include the labor content of foreign-made components and parts. For example, for 1997-2007, the offshoring of intermediate inputs may explain 16-26 percent of multifactor productivity growth for all manufacturing and 22-37 percent of growth for manufacturing less the computer sector.[44]

III. Eroding Industrial Sectors

The broad domestic and global economic trends examined above provide strong evidence that the U.S. manufacturing base is experiencing a sustained and potentially dangerous erosion across nearly all manufacturing industries. Because a wide range of manufacturing industries include subsectors that supply products, components and technologies that the Pentagon considers important to defense, the significant declines in plant capacity and jobs raise serious concerns about U.S. manufacturing's longer-term ability to remain sufficiently innovative and robust to meet military supply needs, especially in times of international crises.

This sector examines the structure and composition of the defense industrial base, and how the erosion in key U.S. manufacturing industries weakens the capability of this base to supply goods and services important to national security. The section that follows extends this examination to the loss of innovation capabilities resulting from the erosion of manufacturing, which threatens to undermine America's technological leadership. It also focuses on the loss of the skills and know-how embodied in the manufacturing workforce vital to maintaining the innovative edge so critical to the nation's economic health and national security.

a. The Defense Industrial Base

A National Research Council (NRC) study of the long-term directions of defense manufacturing notes that the DOD makes a distinction between what it calls *defense-unique* and *defense-critical* products or processes.[45] A defense-unique product or process is used only for defense purposes and has no commercial application. A defense-critical product or process is used for defense purposes, but is more likely to be commercially made and have commercial applications. For example, many commercially produced microprocessors and other electronic technologies indispensable to many defense products are defense-critical. Microchips designed solely for a defense application with very stringent environmental and performance criteria, may be considered defense-unique.

A broad domestic industrial base. In reality, there is no bright line between the production systems that design, develop and manufacture defense-unique items with those that produce defense-critical products and processes. As the NRC study points out, the boundaries between the defense industrial base—the set of industrial and military facilities devoted partially or entirely to the production of defense-related products—and commercial industry have become increasingly blurred.[46] Many of the most militarily valuable products used by the Defense Department are versions of commercially produced commodities modified for unique military functions.

Pentagon evaluations of defense industrial capabilities fail to address longer-term trends in the domestic industrial base in the face of global market forces, particularly in commercial markets, that reflect a weakening ability to supply the much larger number of other critical technologies and products on which the military depends.

University of Texas at Austin engineering professor Michael Webber defines the U.S. defense industrial base as "the end-to-end capability within the United States to design and produce advanced military systems." The manufacturing base to support this capability from "materials to finished product," he states, "is comprised of making, bending or shaping materials; producing components; applying treatments; or providing manufacturing-related services such as rapid prototyping."[47]

What we call the defense industrial base, those industrial capabilities required to serve national security needs, both rest upon, and are embedded in, the larger domestic manufacturing base of the nation. Defense systems do not solely depend on a handful of defense-unique, cutting-edge or emerging technologies. They draw upon a vast array of technologies, materials, components, parts, and subsystems from across the industrial spectrum. These range from advanced special purpose microchips used in missiles and smart munitions, to advanced machine tools and advanced composite materials, to mundane but critical items such as fasteners, ball bearings, uniforms and specialized protective clothing and footwear, and polymeric tray containers for packaged combat field rations.

Correspondingly, the industrial base to supply these items is very diverse and multilayered. At the top of the defense industrial supply chain are the prime defense contractors who now primarily serve as systems integrators, assembling components, parts, subsystems and systems into large weapons platforms. Although most have some commercial operations, and in some instances, such as Boeing, these operations are very large—the "primes" largely depend on the Pentagon for a major portion of their business. A larger number of second and third tier contractors are suppliers to the primes, though some contract directly with the Pentagon to provide specialized, defense-unique technologies, components and equipment. A myriad number of lower tier suppliers serve the upper tiers, providing a variety of more mundane products and commodities directly to the military services.

Many of the second and third tier, and most of the lower tier suppliers, are primarily or exclusively commercial enterprises. Although many of the lower-tiered suppliers may have specialized divisions serving defense markets, most ultimately depend on maintaining competitiveness in commercial markets in order to stay in business.

The broad intent of the Defense Production Act of 1950 (DPA), as amended, is to ensure the health of the nation's domestic sources of goods and services needed to meet national defense requirements. The DPA defines the "domestic defense industrial base" as those "domestic sources which are providing, or which would be reasonably expected to provide, materials or services to meet national defense requirements during peacetime, graduated mobilization, national emergency, or war."[48] The central question examined in this report is whether the domestic "manufacturing support base," as Webber calls it, is capable of supplying the large range of items needed to meet these requirements now and into the future, or whether the U.S. national security system become increasingly reliant on foreign sources for critical products and services?

Increasing foreign dependency. Despite the stated intent of the DPA and the findings of the studies described above, the Pentagon has adopted policies and procedures that no longer appear to follow the intent of the DPA. Instead it has pursued a strategy that weakens the ability of "domestic sources" to meet future defense supplying needs, and increases the dependence of our defense industrial system on foreign sources, with potential adverse implications for our national *and* economic security. As the 2005 annual report of the USCC observed:

> The Department of Defense transformed its acquisition model to reflect the globalized nature of the defense industrial base. While the new model analyzes the availability of key technologies to maintain a strong defense, it may not adequately consider the long-term effects on the defense industrial base of the offshoring of industries that, while not classified as critical technologies, nonetheless may impact defense and homeland security operations.[49]

There are numerous examples of defense critical technologies where domestic sourcing is endangered:

- The DOD reports that domestic suppliers of propellant chemicals, space qualified electronics, space power sources (batteries and photovoltaics), and specialty metals used in military applications have "consolidated to where there are only one or two qualified sources in each area," and frequently "are finding it difficult to justify the business to continue production."[50]
- There is strong foreign competition for five different types of batteries (nickel metal hydride, lithium ion, silver zinc, zinc air, thermal), photovoltaics, and fuel cells that the Air Force has interest in for power source applications.[51] An Air Force report notes that many small domestic niche manufacturers supporting the U.S. military in these areas are in "moderate or high risk due to declining sales, foreign competition, and limited investment in both R&D and infrastructure."[52]
- Hard disk drives and flat panel displays are considered defense critical technologies, but little or no production remains in the United States and government programs attempting to sustain domestic production of these products have failed.[53]
- The United States no longer has a significant commercial liquid crystal display (LCD) manufacturing industry, and its very limited military LCD industry depends on foreign sources for LCD technologies, which may not satisfy future

military display panel requirements.[54]

Many small and medium-sized suppliers mainly serve commercial domestic and global markets, while tailoring a small part of their business to provide specialized versions of their products to military or military industrial customers. These firms face increasing foreign competition domestically, and in global markets are under pressure to relocate or outsource some or all of their operations overseas in order to stay in business.

Consolidations by suppliers in the face of this competition have also contributed to the decrease in the available number of qualified domestic sources for defense critical items, with small, lower-tier manufacturers especially at risk. The failure of these lower-tier firms could mean a further loss of important domestic industrial capabilities to supply specialized products to meet defense needs. Suppliers that provide commercial-off-the-shelf (COTS) items for military industrial customers also may find that the only way to stay in business is to move part or all of their production offshore to low-wage locations.

b. Critical Industries

The examples above are only the tip of a large iceberg. To illustrate the full extent of the erosion of industrial capabilities and its impact on defense, and the growing dependency on foreign goods to fill this gap, a fuller, more systematic examination of a range of key industrial sectors is warranted. Webber has conducted one such study, in which he evaluates the economic health of sixteen industrial sectors "within the manufacturing support base" of the U.S. defense industrial system, "that have a direct bearing on innovation and production of novel mechanical products and systems," and whose output "is used directly in the design process of other industries." These include the electrochemical, thermochemical and optomechanical sectors, as well as machine tool industries, which Webber deemed relevant to the innovation of mechanical systems.[55]

Webber's study looks at the period between 1998-2008, and uses three indicators to evaluate whether an industry appeared to be eroding: employment, economic activity (contributions to GDP by shipments) and the number of establishments. His results are summarized in table V. Of the sixteen industries he examined, thirteen showed significant signs of erosion--especially since 2001, two (navigational, measurement, electromedical, and control instruments, machine shops) were healthy, and one (semiconductor machinery) was holding steady or showed signs of recovery. The study only looks at the trends through September 2008, after which time, "demand for products in virtually every consumer and industrial category fell off a cliff."[56]

The profiles below provide a broader cross-section of the defense industrial base, to illustrate the full scope of the impact of declining manufacturing capacity on the defense industrial base. They overlap several of Webber's sectors (semiconductors, printed circuit boards, machine tools), but include one sector not in his group, which he acknowledged is important to the nation's innovation system (advanced materials), other, smaller industries such as bearings manufacturing and optoelectronics, and the largest systems integrator industry (aerospace). As in Webber's study, there are signs that some segments remain relatively healthy and globally competitive. However, the overall prognosis is one of a serious weakening—occurring even before the recent recession and financial crisis—of a wide-range of key domestic manufacturing industries, that could undermine their ability to support critical defense requirements, and increase the dependency on foreign sources to supply vital defense materials, components, parts, and systems.

i. Semiconductors

Semiconductor manufacturing plays a prominent role in the U.S. economy as a source of high value-added production, high-wage jobs, productivity gains, and wage growth.[57] Semiconductors also are critical to today's information-based, "network-centric" warfighting capabilities.[58] As noted by William J. Spencer, chairman emeritus of International Sematech, a consortium of semiconductor firms created with federal assistance in the late 1980s to promote the industry's competitiveness: "The military significance of microelectronics as the decisive advantage for the U.S. warfighter has increased exponentially since the 1980s."[59] The Defense Science Board (DSB) has called semiconductor technology and manufacturing leadership "a national priority that must be maintained if the U.S. military is to continue to lead in the application of electronics to support the warfighter."[60] Preserving a world-class domestic semiconductor industry is therefore vital to national security.

Declining capacity and leadership. However, while the United States remains one of the world's largest manufacturers of semiconductors, it has been losing capacity and its leadership position in the industry for a number of years. Spencer summarized industry and government leaders' concerns about this troubling trend:

A combination of market forces and foreign policies is creating powerful incentives to shift new chip production offshore. If this trend continues, the U.S. lead in chip manufacturing, equipment, and design may well erode, with important and unpleasant consequences for U.S. productivity growth and, ultimately, the country's economic and military security.[61]

These warnings were echoed in reports by the National Security Agency, as well as by many high-level government advisory groups, including the DSB and the Pentagon's Advisory Group on Electron Devices (AGED),[62] independent bodies such as the National Academies of Sciences[63] and the USCC,[64] industry associations such as the Semiconductor Industry Association,[65] and Congressional leaders.[66]

Table V
Results of Michael Webber's Study
Erosion of Selected Defense Industrial Support Base Sectors

NAICS	Industry	Employment	Economic Activity	Establishments	Overall Status
3315	Foundries	●	⊘	●	*Eroded*
33211	Forging & Stamping	●	●	●	*Eroded*
33271	Machine Shops	○	⊘	⊘	*Healthy*
332811	Metal Heat Treating	⊘	●	●	*Eroded*
332997	Industrial Pattern Manufacturing	●	●	●	*Eroded*
333295	Semiconductor Machinery	⊘	⊘	⊘	*Holding Steady*
333314	Optical Instrument and Lens	⊘	●	●	*Eroded*
333511	Industrial Mold Manufacturing	●	●	●	*Eroded*
333512	Machine Tools (Metal Cutting)	●	●	●	*Eroded*
333513	Machine Tools (Metal Forming)	●	●	●	*Eroded*
333514	Special Die & Tool, Die Set, Jig	●	●	●	*Eroded*
334412	Bare Printed Circuit Boards	●	●	●	*Eroded*
334413	Semiconductor & Related Devices	●	●	⊘	*Eroded*
334418	Printed Circuit Assemblies	●	●	○	*Eroded*
3345	Nav. Meas. & Control Instruments	●	○	⊘	*Healthy*
33591	Battery Manufacturing	●	●	●	*Eroded*

● Indicator eroded; ○ Indicator expanded; ⊘ Indicator held steady or showed signs of recovery

Source: Michael Webber, "Erosion of the U.S. Defense Industrial Support Base." In Richard McCormack (ed.), *Manufacturing A Better Future For America,* Washington, DC: Alliance for American Manufacturing (2009), 245-280: 274, Figure 3.

The erosion predicted in the middle of the 2000s has become increasingly apparent:

- Webber identified semiconductor and related device manufacturing (NAICS 334413)—semiconductors, integrated circuits, memory chips, microprocessors, diodes, transistors, solar cells, optoelectronic devices, and other solid-state devices—as an eroding industry in his defense industrial support base study.
- The semiconductor and other electronic component manufacturing sector (NAICS 3344), comprised of establishments primarily engaged in manufacturing

semiconductors and other components for electronic applications (capacitors, resisters, microprocessors, printed circuit boards, electron tubes, electronic connectors, and computer modems), lost a net of nearly 1,200 plants of all sizes between 1998 and 2008, a drop of 17 percent, including 83 large establishments with over 500 employees (a 37 percent drop) and 58 mid-sized establishments of between 100-500 employees (a 41 percent loss).

- By 2008, employment levels, number of establishments, and GDP for the industry had fallen below its 2001 levels.[67]
- According to the USBIC, imports account for nearly one-half the U.S. market for semiconductor and related devices—an import penetration rate of 44.5 percent in 2007.[68]
- According to the DSB, the U.S. semiconductor industry's share of total world capital expenditures fell from a high of 42 percent in 2001 to a projected 33 percent in 2004.[69]
- Of worldwide capital investment in *leading edge* semiconductor manufacturing capacity—300-mm wafer fabrication plants—the U.S. share fell to 20 percent in 2004, from 35 percent in 1999. Never before had less than 25 percent of the world's advanced fabrication capacity been located in the United States.[70]
- The U.S. share of global semiconductor capacity has continued its descent, dropping to 17 percent in 2007, and 14 percent in 2009, falling to fourth place in the world. Japan was the largest (with 25 percent of world capacity), followed by Taiwan (with 18 percent, up from 11 percent in 2001), and Korea (17 percent, up from 11 percent in 2001).[71]
- *Manufacturing & Technology News* reported that in 2009, out of 16 semiconductor fabrication facilities ("fabs") under construction throughout the world, only one was being built in the United States. It noted that 7 fabs under construction elsewhere in the world will produce light-emitting diodes, one of the most promising energy-saving technologies developed in the past 50 years.[72]
- The United States leads the world in fab closures. Out of 27 fabs closed worldwide in 2009, 15 are in the United States, 4 each in Europe and Japan, 2 in China, and one each in Korea and Southeast Asia. The United States led the world in closures (4 out of 15) in the prior year, as well.[73]

In December 2009, the Bureau of Labor Statistics forecasted that the U.S. semiconductor manufacturing sector will lose 146,000 jobs, a decline of 34 percent, over the coming decade.[74]

Offshoring and globalization. Driving these losses has been the growing migration (i.e., offshoring) of critical microelectronic manufacturing capabilities to low-cost foreign locations, a practice which many observers warn will result in a loss of "trusted" and "assured" supplies of high-performance microchips used in critical military and infrastructure applications. The primary beneficiaries of these movements are Taiwan, Singapore, China, Korea, and Japan, which have been increasingly challenging U.S. technological leadership.

First, U.S. semiconductor manufacturers moved their assembly, testing and packaging operations to Asia in the 1960s to the 1980s. Then, in the 1980s and 1990s, U.S. companies shifted fabrication abroad, contracting with offshore fabrication plants in Taiwan, China, Malaysia, and the Philippines to produce semiconductor wafers from designs created in the United States.[75] The DSB links the decline in investment in U.S. semiconductor manufacturing to the accelerating evolution toward vertical disaggregation in the semiconductor business, accompanied by firms outsourcing virtually all manufacturing operations, including chip fabrication, assembly, testing, and process development. That is, U.S. firms developed global supply chains for sourcing different parts of the semiconductor production process over multiple locations around the world. As a result, critical semiconductor manufacturing operations have been removed from U.S. national control.[76]

The rapidly rising cost of building semiconductor fabrication factories—now 3-5 billion USD per facility, with some even costing upwards of 8 billion USD,[77] for a full-scale, 300 mm wafer, 65 nm process chip fabrication plant—and the pressures of economies of scale spurred the formation of huge, specialized wafer processing facilities or foundries that accept business from all qualified customers in the broad industry base. Foundries have been especially important for the new fabless chip companies that lack in-house manufacturing capacity. Faced with the successful growth of the fabless/foundry model of semiconductor production, the traditional chip firms are steadily being forced to follow suit to become "fab-light."[78] The result is the rise of "fabless" integrated circuit production that grew to 16 percent of the overall industry by 2005, a proportion that is expected to rise over the next 10 years.[79]

Semiconductor firms from the United States and other developed nations have continued their control of design, while contracting out to overseas foundries to perform the capital-intensive wafer fabrication. Consequently, Asian countries, especially Taiwan and China, have increased their share of overall production, expanding their roles as major suppliers of fabrication services. In recent years, however, some U.S. firms—in part to maintain close contact with Asian customers in order to meet their specific needs—have been offshoring complex semiconductor fabrication and design services, essentially moving up the value chain, as Taiwan and other foreign fabricators have become more adept at producing more complex semiconductors.[80]

Industry and government officials are increasingly concerned about similar trends in industries that support integrated circuit fabrication, such as photomask production. Photomasks are a fundamental building block of semiconductor manufacturing.[81] The domestic photomask industry is reportedly being threatened by the rising complexity and cost of developing the next generation of microchips, and the relentless efforts by foreign governments, especially Japan, to establish their own capacity in this field.[82]

A U.S. Government Accountability Office (GAO) report noted two consequences of the shift in production and trade flows towards Asia. First, because "final production increasingly takes place in Asia, the United States is importing an increasing share of electronics and telecommunications products (that use semiconductors)." This is reflected in the growing U.S. trade deficit with Asia, and China in particular, including advanced technology products. Second, "as electronics and telecommunications production chains increasingly locate in Asia, there are benefits to U.S. producers of semiconductors to locate abroad near their customers and take advantage of the production clusters developing there." As a result, there is a further incentive for U.S. firms to offshore their activities.[83]

China's emergence in semiconductors. Although Taiwan has traditionally dominated global foundry production, China, a relatively new entrant in global semiconductor fabrication, has rapidly increased its market share. China still lags behind the United States and other Asian and European nations in semiconductor manufacturing capacity, but industry and defense officials have become increasingly concerned about China's rapid development in this area because of its military-industrial potential.[84] China emerged as an important new source of fabrication services in the late 1990s. It has since been especially energetic in making semiconductor manufacturing a national priority and is particularly effective in attracting the latest generation of semiconductor fabrication plants. through preferential tax treatment, use of technology standards to favor domestic firms, and government support for R&D.[85]

Although China entered the global semiconductor industry at the low end of the foundry business, Chinese foundries have made rapid progress.[86] Spencer reported that in September 2002, only four or five wafer foundries were proposed or underway in the United States. In contrast, four fabs were operating in mainland China, one was under construction, and ten others were planned. By 2006, China reportedly accounted for 70 percent of the semiconductor designing market in the Asia-Pacific region.[87] In 2009, China led the world in new semiconductor factory construction with six fabs, followed by Taiwan with five, and Korea, Japan, the European Union, and Southeast Asia, with one apiece.[88]

National security concerns. The semiconductor industry exemplifies the problems for meeting critical U.S. national security needs created by the globalization of a key industrial sector, even though defense applications account for only a small fraction of that industry's business.

- The capacity of U.S. foundries to meet the DOD's integrated circuits needs is limited and diminishing. Most of the 16 U.S. foundries are special-purpose, devoted to memory or microprocessor production, and not suitable to meet government ASIC[89] needs. In 2005, only one, and no more than three, of the U.S. fabs were accessible to the DOD to produce "trusted" microelectronics.[90]

- Dependence on off-shore or foreign-owned semiconductor components can threaten the United States with loss of its access to state-of-the-art microelectronics in times of war, when quick response and surge capacity are necessary. This vulnerability results specifically from the concentration of the foundry industry into a few Far Eastern countries, one of which, China, could become a military adversary.
- Natural disasters pose another potential threat to U.S. supply. The devastating earthquake that hit Taiwan in 1999 shut down all factories in Hsinchu, the national wafer fabrication center. Although these plants restarted in a matter of weeks, the DSB warned that "a temblor that seriously damaged Taiwan's wafer capacity would have started a worldwide run on commercial wafer capacity that would have taken years to rectify. During such a time, DOD and its contractors would have little leverage to obtain needed fabrication services."[91]
- A potential threat to the security of classified information embedded in chip designs can arise from the shift from U.S. to foreign IC manufacturing. This shift increases the possibility that "Trojan horses" and other unauthorized design inclusions, such as viruses and worms, may appear in unclassified ICs used in military applications.[92]
- The DSB is worried about the broad loss of national technology leadership that would accompany the migration of semiconductor fabrication offshore, while foreign technology capabilities begin to catch up to, if not leap-frog, U.S. capabilities in this sector. Lags in U.S. firms accessing leading-edge technology (as happened in the 1980s with Japanese advanced lithography tools) slow the time to market for U.S. advanced technologies. "Loss of leadership in critical advanced microelectronics technologies," the DSB stated, "would slow the entire commercial and defense product development process."[93]

ii. Printed Circuit Boards

Outside of semiconductors, the printed circuit boards (PCBs) industry may be the most important domestic electronics sector experiencing serious erosion. PCBs connect a variety of active components (microchips and transistors) and passive components (capacitors and fuses) into electronic assemblies that control systems. They and other printed circuitry are critical elements of commercial and defense systems. Indeed, they represent many of the most important aspects of the design of electronics products and assemblies.

A 2005 National Research Council (NRC) report has noted that the effectiveness of defense systems depends on the underlying PCB technology. Because the military is increasingly reliant on networked operations, "these applications will expand for the foreseeable future, and the use of and requirements for PCBs will continue to grow." However, while commercial components can meet many of these requirements, "significant defense needs will be met only by the production of specialized, defense-specific PCBs that are unavailable from commercial manufacturers."[94] At the same time, the report observed, companies that serve U.S. military requirements will need a direct connection to the technology advancements of the global PCB industry to maintain their performance over the long run. Unfortunately, DOD purchases from military suppliers will not be sufficiently large to create that linkage. As a result, the report concluded, "the loss of this industry in the United States may adversely affect the remaining companies to supply future military needs."[95]

Declining capacity. The U.S. PCB industry has seen dramatic erosion in its domestic production capacity and position in global PCB markets over the last decade. As the NRC study concluded, "by a number of measures, the PCB industry is in a steep decline," and the remaining "U.S. companies may not be able to stay competitive in this high-technology area." Moreover, without outside support, it warned, PCB suppliers "will not be able to meet the requirements of U.S.-manufactured [PCBs] for government and military applications."[96]

In 2004, there were only about 400 PCB manufacturers left in the United States of which only 20 were capable of making military boards, and the industry continued to deteriorate over the remainder of the decade. By 2009, there were only 300 U.S.-based PCB shops. The industry's revenues have also fallen dramatically, from 11 billion USD in 2000 to 4 USD billion in 2008.[97] According to one source, the U.S. PCB industry has shrunk 74 percent since 2000.[98]

Webber's study concluded that the two main divisions in the PCB industry, *bare printed circuit board* manufacturing (NAICS 334412) and the *printed circuit assembly* industry (NAICS 334418) are eroding industries. The bare printed circuit board industry includes companies that primarily manufacture rigid and flexible printed circuit boards without mounted electronic components. Webber reported that all three indicators examined in his study showed signs of severe erosion in this industry with little indication of recovery. For example:

- Employment dropped more than two-thirds from 150,000 in 2001 to less than 50,000 in August 2008;
- Share of GDP decreased by 50 percent between 2000-2006; and
- The number of establishments of all sizes fell more than 40 percent between 2001 and 2008,[99] including, according to BLS data, a sizable share of mid-sized plants (50-499 employees) and large plants (500 or more employees).[100]

The printed circuit assembly industry includes firms that load components onto printed circuit boards, producing printed circuit assemblies, electronic assemblies and modules. Webber noted that his indicators show a confusing mixture of results, though a closer look suggests more consistency than apparent on the surface. Both employment and industry GDP fell:

- Employment dropped nearly 20 percent between 2001 and August 2008—from 67,000 to about 54,000, just above employment levels at the end of the 1991 recession;
- GDP dropped approximately 50 percent from 16 billion USD in 2000, to about 7 billion USD in 2006;
- Although the number of establishments steadily grew by 270 from 2001 to 2008.

However, drawing on BLS establishment data, it is likely this gain was mostly due to growth in the number of small shops of under 50 employees, while medium- and large-sized plants probably followed the same pattern of loss as during the first half of the decade. For example, the PCB assembly industry lost 23, or 10 percent of mid-sized plants, along with 5,400 jobs, and 8, or nearly half of large plants with 500 or more employees each, along with a total net loss of nearly 10,300 workers. A net total of nearly 12,800 jobs, one-fifth the sector's workforce, were lost in this period, entirely due to the shuttering of mid- and large-sized plants.[101]

This trend tracks with the large-scale closure or movement offshore of large PCB plants in both industry segments, in the United States over the last decade. As an industry insider laments, what remains are mostly "shops," which are "owner operated and employ themselves. They are small. They barely survive. They cannot invest. Most offer only small lot, quick-turn delivery. There is very little R&D if any at all. They can't afford equipment. They are stale."[102]

Globalization and offshoring. The primary causes of this sector's malaise are the offshore movement of not only PCB production, but also of PCB-consuming industries. The NRC report attributed the movement of interconnection technology (PCB) manufacturing capacity overseas to globalization of the electronics industry. "The intense competition in the face of this increasing globalization," the report argued, "currently challenges U.S. manufacturers and leaves many U.S. firms unable to raise prices to keep pace with rising production costs." In addition, lacking a technology innovation base in this sector, these firms will be unable to increase their productivity. The report observed that PCBs are intermediate products, not end products. Consequently, the location of their customers matters. Not only are U.S. PCB manufacturers losing domestic markets, they must find global markets, which could be difficult to compete in because they are insular with respect to U.S. producers. It concluded, that for PCB companies to be successful, they "must follow their markets offshore, which eventually could leave a base too small to support U.S. defense needs."[103]

Analysts agree that exactly how much of this industry has been lost remains conjecture. But most also agree that by 2005, between forty and fifty percent of

North America's PCB orders have migrated offshore.[104] At the same time, between 1997 and 2007, imports' share of the U.S. domestic consumption of the bare printed circuit board and printed board assembly industries have grown steadily. The import penetration rate for the printed circuit boards industry increased by nearly half, from 24 percent to 35 percent, between 1997 to 2007. Printed circuit board assembly imports rose from 37 percent to 47 percent, an increase of more than a quarter, over the same period.[105]

Parts and materials suppliers to the PCB industry are suffering similar problems. For example, by 2004, industry leaders were already concerned that the U.S. laminates industry, which forms the basic underpinnings of all electronics, will soon be lost. Doug Bartlett, chairman of Bartlett Manufacturing Co., Cary, IL (the nation's oldest PCB company until it closed in 2009), noted in 2004, that ten years earlier there were ten major U.S. producers of rigid laminate used by the PCB industry, and U.S. firms dominated the market. By the end of 2004, he predicted, virtually all rigid laminate will be imported from Asia.[106] Similarly, the industry relies on foreign sources for drill bits, imaging materials, specialty chemicals, film and capital equipment, whose production has largely disappeared from U.S. shores.[107]

Loss of global leadership. Once dominating global PCB production, the United States has lost its leadership, especially to Asian nations:

- The U.S. share of global PCB revenues fell from 42 percent in 1984, to only about 30 percent in 1998, to less than 8 percent in 2008.
- Although in 2000 the United States was still second only to Japan in PCB production—the latter had 28 percent of world output, the former 26 percent[108] —by 2009, Asia's share had grown to 80 percent, up from 33 percent a decade ago.[109]
- By 2003, while Japan's top ten PCB producers continued to dominate the market, with 29 percent of the global market share, the United States had fallen behind China—the latter's top 10 controlled 17 percent of the global market while the U.S. top ten had only 15 percent.[110]
- By 2007, China/Hong Kong had moved to the top, accounting for 28 percent of worldwide PCB output, followed by Japan, Taiwan and Korea—the United States was a distant fifth.[111]

According to the Chinese Printed Circuit Association, by 2005, it had become the world's second largest PCB producer, after Japan, and was a dominant player on the world stage. Asia's growth as a whole in PCB manufacturing was explosive, with China alone accounting for almost a quarter of the global production of rigid and flexible circuits.[112] According to one source, in 2005, China was already home to about 1,000 PCB companies that produced a combined annual revenue of 8 billion USD in rigid board production, half of which is exported.[113] Lamenting his own firm's loss of over half its annual sales between 2000 and 2003, Bartlett has claimed that Chinese companies were able to produce comparable products for half the price. Blaming Chinese government subsidies and predatory trade practices, he argued that Chinese-subsidized rigid laminate suppliers were similarly undercutting the competitiveness of U.S. producers such as Westinghouse, GE, and Norplex."[114]

National security concerns. The loss of the domestic PCB industry to foreign producers presents concerns similar to those posed by the threatened loss of U.S. microelectronics capacity. The NRC report concluded that "the continued dissipation of downstream electronic systems components manufactured in the United States inevitably means that the Department of Defense will have less access to and availability of leading-edge electronic subsystem technology including PrCBs, microchips, and displays."[115]

As the underpinning of nearly all electronics systems, PCBs are critical technologies for numerous military applications. For example, U.S. companies making PCBs used in sonabuoys employed to detect submarines are going out of business.[116] The Trojan Horse threat presented by foreign microprocessor manufacturing could emerge, too, as overseas companies could sabotage military electronics by clandestinely placing hard-to-detect defects in circuit boards.[117] Bartlett argues that it "does not make sense to have Chinese build productions that go into the products of our national defense. The implications for national defense and homeland security should be obvious."[118] He also predicted that within five years, the domestic PCB industry "would not be able to meet the advancing needs of the military in a volume sufficient for national defense and homeland security."[119]

By 2006, the Pentagon appeared to awaken to the problems of assuring a secure supply of electronics products, including printed circuit boards (and printed circuit board mounted components) that meet its specialized, defense-unique requirements, when most of the nation's electronics manufacturing capacity has moved offshore. A task force comprised of representatives from 10 military agencies, the National Security Agency, and the State Department, agreed with the NRC report, calling for a program aimed at creating a "trusted" supply of printed circuit boards. In a report to Congress in July 2006, it recommended that PCBs be included in the "Defense Trusted Integrated Circuit Strategy," a program set up to deal with the shift of high-tech production overseas. It noted that while "[e]nsuring a supply of trusted integrated circuits is necessary," it would not be "sufficient to remove risks and vulnerabilities associated with populated printed circuit assemblies." Therefore, including PCBs into the Trusted Strategy program "could mitigate the risks posed by tampering and counterfeiting . . .While the DOD has not experienced specific disruptions to date, the globalization trend beginning in the 1990s has increased this vulnerability."[120]

Today, few, if any, defense-specific components that meet increasingly sophisticated DOD requirements can be provided by domestic high-volume, low-cost, commercial PCB suppliers of components used in commercial durable goods (such as automobiles, appliances, heavy equipment).[121] However, even some analysts in the defense electronics community are skeptical that the DOD's "trusted" approach will be sufficient. They view it as a stop-gap—"putting a Band-Aid on a bullet hole," as described by some. But, as Gary Powell, Deputy Undersecretary of Defense for Industrial Policy in the Bush Administration, acknowledged a defense unique solution to the electronics supply chain problem would be insufficient to address this problem. "We have to figure out what's really important from a system level," he argued, "and make sure those [things] have an adequate level of protection and for less importance systems, we have to rely more extensively on commercial best practices."[122]

iii. Machine Tools

Machine tools are the principal devices used to cut and form metal. A part of machinery manufacturing (NAICS 333) and the metalworking machinery manufacturing subsector (NAICS 33351), machine tools manufacturing includes two industries: metal-cutting machine tool manufacturing (NAICS 333512) and metal-forming machine tool manufacturing (NAICS 333514). The former comprises establishments engaged in manufacturing metal cutting machine tools, including lathes, mills and CNC machines. The latter includes establishments engaged in producing metal forming machine tools, such as punching, sheering, bending, forming, pressing, forging, and die-casting machines.

Machine tools are employed in nearly all manufacturing involving metals, from automobiles to airplanes to ball bearings. Because of their importance in producing weapons systems and other military products, the United States imposes export controls on machine tools and supporting systems. Indeed, efforts to control the exports and imports of machine tools reflect the perception that manufacturing technology may often be more important than the products of that technology.[123]

Because each subsector provides a fundamental capability in the innovation process—the creation of prototypes and finished products—Webber considers them, along with industrial molds and semiconductor machinery, among the most critical industries in the defense industrial support base. Metal cutting machine tools, he observes, "have a profound impact on the ability to create more sophisticated components out of a wider range of materials," and allow "for the manufacture of different designs," thereby "enhancing greater innovation up the supply chain." Similarly, metal forming machinery (such as metal presses) has allowed the creation of "more sophisticated components over a wider range of sizes and from more diverse materials."[124]

Declining capacity. By most measures, the U.S. machine tool industry has been in a steep decline for over a decade. In Webber's study, the metal-cutting and metal-forming machine tool industries showed clear signs of erosion. Employment and establishment numbers fell sharply in both cases, and industry GDP fell from

1998 until 2002 for both industries, though the metal cutting subsector showed modest signs of recovery through 2007. Two related industries, industrial mold manufacturing (NAICS 333511) and special die and tool, die set, jig, and fixture manufacturing (NAICS 333514), that Webber examines, showed even more severe signs of erosion.[125] Drawing on BLS employment and establishment data, the machine tool industry's downward trajectory is clearly apparent:

- The metal cutting machine tool industry shed 16 percent of its establishments, and lost over 8,000 jobs, or 22 percent of its workforce, between 2001 and 2008; as the recession took off, it lost another 5,000 jobs in the first 6 months of 2009 alone, for a total employment loss of 40 percent over the decade;
- The metal forming machine tool industry lost 17 percent of its establishments and over 2,200 jobs, or 14 percent of its workforce, between 2001 and 2008; another 2,700 jobs were lost the first six months of June 2009, a total decline in the industry's workforce of 31 percent from its 2001 level.[126]

In terms of U.S. consumption and production, the machine tool industry suffered a steep five-year decline starting in 1998, and then showed signs of a very modest rebound starting in the mid-2000s up through 2008—though it never attained the high levels it enjoyed over the previous decade (see figures 17a and 17b):[127]

- Reflecting the recession at the beginning of the decade, the U.S. market for machine tools shrank by more than half between 1998 and 2002, from a record 8.7 billion USD down to 3.8 billion USD.
- U.S. machine tool shipments were also cut by more than half, from 4.4 billion USD in 1999 to a low of 2.2 billion USD in 2003. In constant dollars, this represented the lowest level of machine tool shipments since industry data tracking began in the 1920s.[128]
- By 2008, U.S. machine tool consumption was still close to 40 percent below its 1998 level (in constant dollars), and U.S. machine tool production was over 30 percent lower than in 1999.
- Even worse, in 2009, as the recession hit, the domestic machine tool industry went into a freefall. April 2009 machine tool sales were 78 percent lower than the same month the year before, and year-to-date consumption was down 71 percent compared to 2008.[129]

International comparisons. As shown by figures 17a and 17b, and the following trends, the U.S. machine tool industry increasingly lags in both consumption and production behind foreign competitors, notably China, Japan and Germany:

- Once the world leader in machine tool consumption,[130] the United States had fallen to fourth (behind China, Japan, and Germany) by 2004, where it current remains—though Italy is not far behind;

- China surged into the top spot in machine tool consumption in 2002, reflecting the robust expansion of its advanced manufacturing sector; although China's economy is only about one-tenth the size of the United States'. In 2004, the Chinese machine tool market set a new world record with purchases of 9.26 billion USD, nearly twice that of the United States, and one-and-a-half times that of Japan;[131]
- By 2008, even though U.S. consumption had rebounded, it was almost 20 percent smaller than that of Japan, and one-third that of China;
- In 2000, the United States was the world's third largest producer of machine tools (behind Japan and Germany), but by 2004 it had fallen to sixth place (behind Japan, Germany, China, Italy, and Taiwan) and by 2008, it was seventh (after Korea);
- In 2008, Japan (15.85 billion USD) and Germany (15.66 billion USD) each produced an estimated four times, and China (13.97 billion USD), 3½ times, the worth of machine tools made in the United States (3.79 billion USD).[132]

Although the top five consumer nations' share of world consumption and world production remained the same between 2000 and 2008, at around 71 percent, and 61 percent, respectively, the United States had lost ground in both categories in that time period (see figures 17a and 17b):

- In 2000, it led with 19 percent of global machine tool purchases—followed by Germany (15 percent) and China (10 percent)—but by 2008, it had fallen behind China (24 percent), Germany (12 percent), and Japan (10 percent, with only 8 percent of global consumption;
- Similarly, in 2000, the United States accounted for the third largest share of world machine tool production (11 percent), behind Japan (24 percent) and Germany (20 percent)—but ahead of China (6 percent); by 2008, its share of world output was only 6 percent, compared to 19 percent each for Japan and Germany, and 17 percent for China.[133]

Globalization and import penetration. The same countries as listed above are eating away at the U.S. share of its own domestic machine tool market. The United States has long been the leading importer of machine tools in the world, but in past decades that reflected robust growth in manufacturing overseas. In the 2000s, the U.S. remained one of the world's top two importers of machine tools—it was surpassed by China early in the decade, but the import share of domestic consumption grew steadily, even as its consumption and production declined.

In 1996, the United States was the number one importer, and sixth largest exporter in the world, and imports accounted for 53 percent of the value of machine tools consumed. By 2000, the import share of U.S. machine tool consumption had grown to 61 percent and it continued to grow throughout the decade, rising to 72 percent in 2008. That is, only one in four machine tools purchased in the United States was domestically made. Similarly, according to the USBIC, from 1997 to 2007, the import penetration rate for metal-forming machine tools increased by 44 percent, from 62.7 percent to 90.6 percent, and that for metal-cutting machine tools increased by 11 percent, from 58.6 percent to 64.9 percent.[134]

In testimony to the USCC in 2005, Dr. Paul Freedenberg, Vice President of the Association for Manufacturing Technology, observed that the decline of the domestic machine tool industry directly reflects decline in the broader U.S. manufacturing sector. Machine tool companies' industrial customers were disappearing, either closing down or moving to other countries—often China. Further, he claimed, many companies are "unwilling to make new investments in sophisticated and productive equipment that is necessary to remain competitive in today's manufacturing marketplace, because of the uncertainty concerning the future of manufacturing in the United States." [135]

According to Freedenberg, foreign penetration of the U.S. machine tool market had risen from about 30 percent in 1983 to more than 70 percent in 2004. Between 1998 and 2002 alone, import penetration increased by 15 percent, which Freedenberg attributed to the "diminished market abroad [at that time] and fierce competition for one of the last open machine tool markets in the world."[136]

China's emergence. China has made both major quantitative and qualitative progress in machine tool production. Companies in China and Taiwan have caught up to U.S. firms in technical capabilities, and foreign rivals have been purchasing U.S. firms. Until recently, China could produce only relatively simple machines, and purchased largely unsophisticated equipment. Japanese and Western suppliers were the sources for most of their sophisticated equipment needs.[137] Today, however, China is buying state-of-the-art, computer-controlled machine tools with greater precision and durability, and its domestic factories are producing increasingly sophisticated equipment.[138] In his USCC testimony, Freedenberg, predicted that "within five years the Chinese will be ready to compete in world markets" for cutting-edge machine tools.

In fact, China has been successful in building up its capacity in advanced machine tools, including in the production and use of five-axis machines (see Box B). It makes 24 distinct models. China is supplying most of its demand for the five-axis models, including those used by its military, and depends on only 10 percent from import.[139] It also has 28 companies capable of making over 1000 CNC machine tools per year, and over 130 companies with an annual capacity of more than 100 machine tools. In the first eleven months of 2009, China made 139,000 CNC machine tools including 125,000 for metal cutting and 9,628 for metal forming—a number that was expected to rise to 150,000 by the end of the year.[140]

Figure 17a
Machine Tool Consumption—U.S., Japan, Germany and China

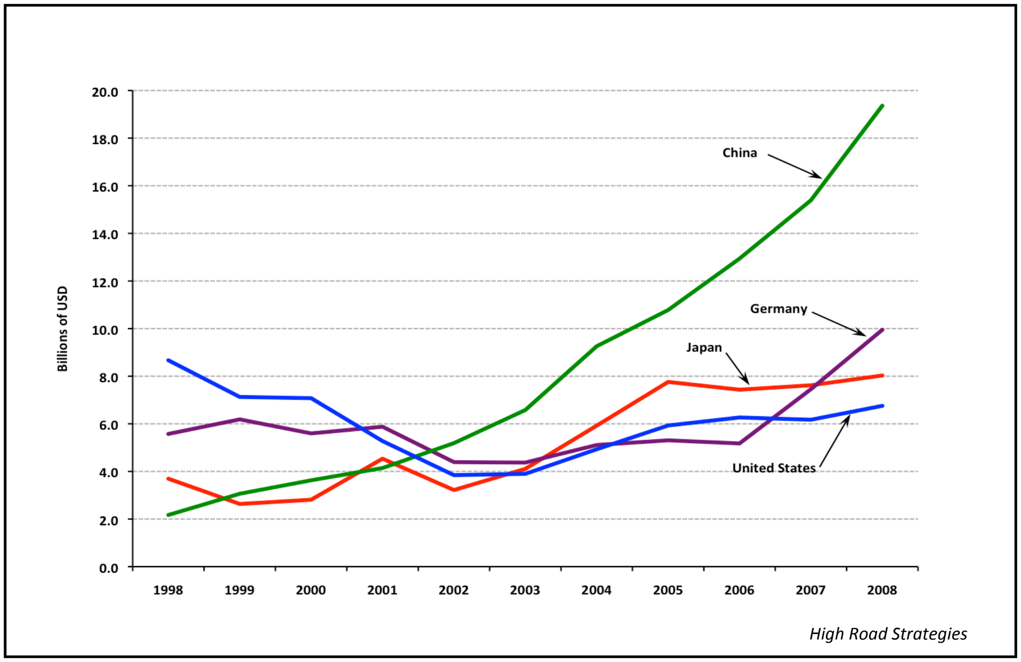
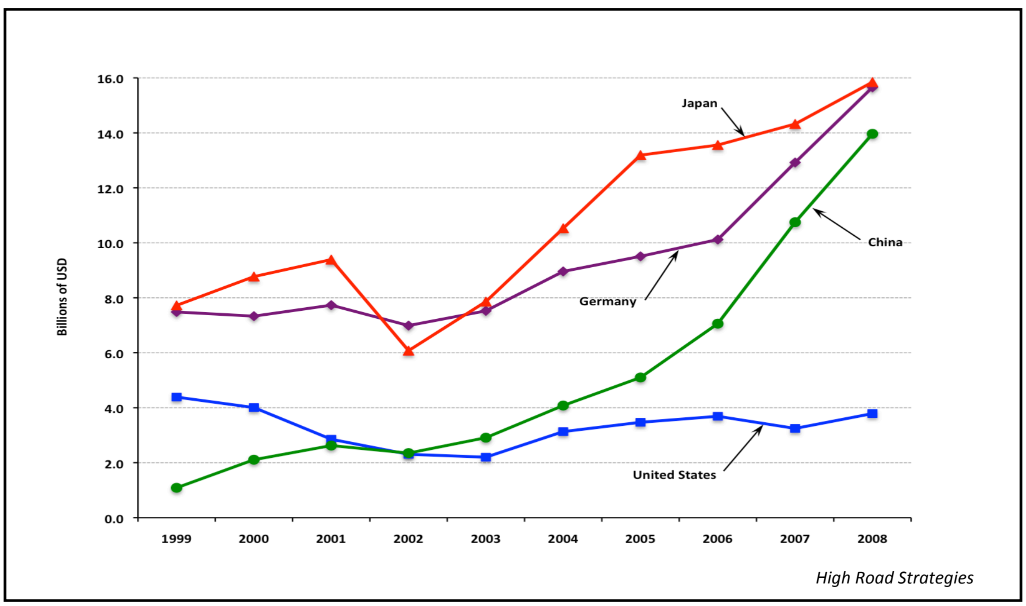


Figure 17b
Machine Tool Production—U.S., Japan, Germany and China



National security concerns. The critical importance of machine tools to maintaining defense industrial capabilities is widely recognized. The significant erosion of the U.S. machine tool industry, however, could seriously damage the domestic manufacturing base that supports the U.S. defense industry. In times of emergency, the manufacturing capacity to build weapons systems will have to be squeezed out of existing capacity, imported, or produced off-shore. Freedenberg observed that DOD's warfighting plan "does not seem to anticipate the threat of disrupted supply lines, a concern that existed during the Reagan Administration and was an integral part of all previous administrations' war planning."[141]

BOX B—FIVE-AXIS MACHINE TOOLS

The U.S. loss of competitiveness in the five-axis machine tool market exemplifies the serious deterioration in this sector. Five-axis machine tools are some of the most technologically advanced machine tools. They are used in the production of precision components in aerospace, gas and diesel engines, and automobile parts, and are used throughout the medical, textile, oil, glass, heavy industrial equipment and tool industries. About half of all commercial five-axis machines in the United States are purchased for government contracts, and the majority of these purchases are used solely for government work.

According to a study by the Department of Commerce's Bureau of Industry and Security (BIS), U.S. producers' sales of five-axis machine tools fell by 11 percent, from 284 million USD to 253 million USD between 2005 and 2008, before the financial and economic meltdown in 2009, when domestic consumption tumbled by 60.4 percent. Sales to domestic customers dropped by 19 percent from 2005 to 2008, corresponding with a precipitous decline of 20 percent in domestic sales among U.S. manufacturers over the same period.[142]

According to BIS, there are only six remaining U.S. companies dedicated to five-axis machines, compared to at least 20 in China and 22 in Taiwan. The remaining machine tool firms have either shifted their production to other machine tool lines, or have moved offshore. Between 2005 and 2008, 80 percent of all five-axis machines sold in the United States were imported, the majority from Japan and Germany.[143]

Ironically, efforts to argue against requiring U.S. content in defense goods further illustrate the deterioration in the ability of the domestic machine tool industry to meet defense needs. For example, the White House argued in 2003 that a bill introduced by U.S. Representative Duncan Hunter (R-CA), requiring that the U.S. content in defense goods rise from 50 percent to 60 percent, and that four years after enactment, all machine tools in U.S. defense programs be 100 percent American made, had "the potential to degrade U.S. military capabilities" and more specifically would "unnecessarily restrict the Department of Defense's ability to access non-U.S. state-of-the-art technologies and industrial capabilities."[144]

Similarly, aerospace industry representatives have argued that, "Plant floors across the industry would need to be retrofitted at huge cost," in order to meet U.S. military needs. The Aerospace Industries Association (AIA) further estimated that "foreign machine tools and components represent at least 30 percent to 40 percent of the value of defense industry machine tools" and endorsed Boeing Corp.'s judgment that the market-share gains made by foreign tools was owed to "greater accuracy, higher technology, and better reliability of foreign equipment." In all, according to the AIA:

> DOD's assessment of the capacity of the machine tool industrial base finds that it would take well into the next decade to produce the required replacement tools There are many cases where American tools do not currently exist and new production lines would have to be built to produce them. U.S. machine tool builders currently have neither the ability nor capacity to meet an increased demand . . . It will take at least ten years to make the American machine tool industry viable again, especially in the ultra-precision market in which America does not participate.[145]

iv. Advanced Materials

Advanced materials are included in the U.S. Census Bureau's Advanced Technology Products (ATP) trade statistics. The advanced materials industry "[e]ncompasses recent advances in the development of materials that allow for further development and application of other advanced technologies. Examples are semiconductor materials, optical fiber cable and video discs."[146] A 2005 National Research Council study, which examined the globalization of materials R&D, similarly identified a range of materials science and engineering subfields as the most important to advanced manufacturing, and thereby to national security.[147] These include biomaterials; ceramics; composites; magnetic materials; metals; electronic and optical-photonic materials; superconducting materials; polymers; catalysts; and nanomaterials. In almost every one of these subsectors, there are important and often critical national security applications and products. Webber did not include materials manufacturing in his study of the defense industrial support base, though he appreciated that "materials provide the foundation of the modern manufacturing and defense industrial base," and suggested that a separate study of the materials industries would be warranted.[148]

Because materials industries are so technology intensive, keeping at the cutting-edge in materials R&D is critical to the U.S. remaining globally competitive in manufacturing. In turn, the importance of materials competitiveness to national security should be self-evident. In fact, military needs have long driven the development and application of new materials. The Defense Department has unique demands for certain high-performance metals, ceramics, polymers, and composites. As the NRC study noted, "[m]eeting the defense needs of the country in the 21st century will rely on R&D in materials and processes to improve existing materials and achieve breakthroughs in new materials and combinations." The NRC identified several specific materials applications important to warfighting capabilities: new lightweight materials with greater strength and functionality, materials that enhance protection and survivability, stealth materials, electronic and photonic materials for high-speed communications, sensor and actuator materials, high-energy density materials, and materials that improve propulsion technology.[149]

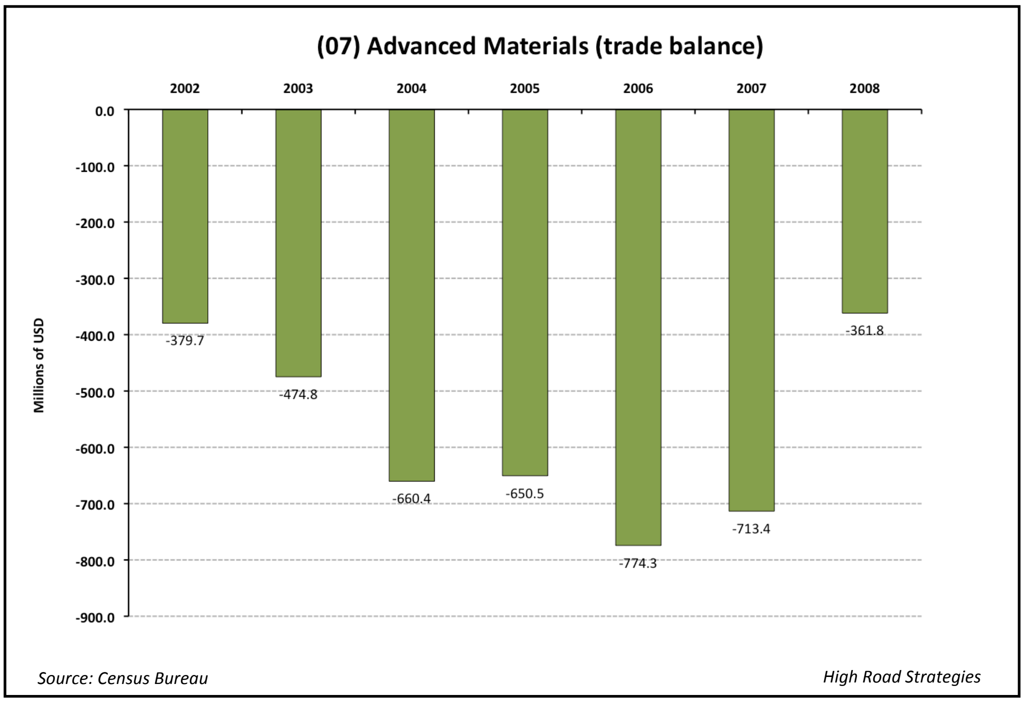
Weakening global leadership. The United States has long been—and remains—the world leader in most materials-related technologies, but during the first half of the 2000s decade the NRC warned that this leadership was eroding. A review of the subfields identified by the NRC reveals that several are characterized by globalized manufacturing and R&D. Moreover, the study added, "[w]hile the strength of these trends varies from one subfield to another, the trends themselves are clear and point to a loss in national capability in materials subfields of national importance."[150] Among the NRC report's main findings:

- *Domestic materials production is disappearing and moving offshore.* Due to financial difficulties and foreign competition, businesses have consolidated in many, if not most, materials subsectors since 2000. Plant capacity and employment have declined, and for a number of critical materials (specialty steels, advanced ceramics, and magnesium) production capabilities have been moving offshore.
- *Materials R&D and innovation is following production offshore.* The large-scale migration of materials producers and users has harmed domestic advanced materials R&D by inducing many U.S. companies to shift some of their materials science and engineering R&D overseas. Many U.S. materials firms that have offshored R&D are also drawn to the growing availability of foreign intellectual resources, often available at lower costs, and by "the increasing availability of unique technologies not found in the United States."[151]
- *The margin of U.S. leadership in advanced materials R&D is eroding and increasingly challenged by other nations.* As U.S. companies cut back their R&D or move it offshore, other countries—in particular Japan, Germany, and other Asian states, including China, Korea and India—are actively supporting their own technological capabilities in materials fields important to commercial competitiveness and military needs. These countries are investing heavily in their science and technology infrastructure, in science and engineering education, and in a variety of specific R&D initiatives.[152]

According to ATP trade data, advanced materials is a relatively small sector compared to the other ATP categories, with total combined exports and imports of 4.4 billion USD in 2008, compared to 2.6 billion USD in 2002 (current year). The sector has suffered consistent trade deficits throughout the decade, reflecting inroads made by foreign competitors into U.S. markets. The U.S. advanced materials industry has amassed a global trade deficit that jumped from 380 million USD to 774 million USD, essentially doubling, between 2002 and 2006 (see figure 18), before falling back to a little below the 2002 level in 2008 due to the recession. Despite the shift in the trade balance for advanced materials, both exports and imports also grew substantially, 74 percent and 54 percent, respectively.[153]

By far, the largest U.S. advanced materials trade deficit was with Japan, whose imports into the United States grew steadily over the decade, more than doubling between 2002 and 2008, from 417 million USD to 948 million USD. The United States also ran substantial, if somewhat smaller, advanced materials trade deficits with Mexico, Germany, France, and Finland throughout the decade, and until 2008, with China, and South Korea. In contrast, the United States has enjoyed sizable advanced materials trade surpluses with Canada, Hong Kong, Taiwan and Singapore, Ireland, and the United Kingdom.[154]

Figure 18
U.S. Trade Balance in Advanced Materials



The growth in exports to China, which until 2008 outpaced imports, most likely reflects China's increasing appetite for advanced materials products that the nation currently lacks sufficient internal capacity to meet. Indeed, a new report predicts that China's market for advanced materials is expected to grow by 60.5 billion USD by 2012, a compound average annual growth rate of 14.7 percent. This includes applications of advanced non-metal materials, advanced metals and alloys, energy materials and nano-materials. At the same time, China is aggressively seeking to develop its own technological and production capabilities in this area making the development of advanced materials an important part of its national sustainable development strategy, with the goal of fostering competitiveness and furthering the state of the art for China's industrial base. A recent study shows that the Chinese government has placed advanced materials high on its development agenda for the next decade, and listed it as among the key high-tech industry sectors that should be given high-priority for development.[155]

Offshoring of materials R&D. The NAS report reaffirmed the link between the offshoring of materials production and the offshoring of materials R&D. The relationship between the two was vividly illuminated in testimony by Dr. Jack W. Schilling, Chairman of the Specialty Steel Industry of North America (SSINA) and Chief Technical officer of Allegheny Technologies Inc. to the USCC:

> It is very important to understand that technology development travels with the manufacturing process. Our plants in the specialty metals industry are our laboratories. It is thus naïve to think that manufacturing of these materials could be transferred to China while technology development is kept here in the U.S."[156]

Section IV presents a number of examples demonstrating the manufacturing-R&D linkage in multiple industrial sectors, included advanced materials. The following are additional examples of major materials technologies illustrating how the migration of R&D to follow manufacturing offshore has weakened U.S. capabilities vital to national security.

Night-vision systems. Night vision systems enable soldiers and airman to see, identify and track targets at night, in low-visibility weather conditions and through fog and mist – "to own the night."[157] They give the United States a major military advantage in sea, air and ground environments. In Congressional testimony in 2003, Siva Sivananthan, inventor of mercury cadmium telluride (MCT) semiconductors used in night vision devices, maintained that the U.S. military was almost entirely dependent on foreign sources of materials, components and production of night-vision infrared devices. He also claimed that outsourcing was primarily responsible for the complete absence of U.S. suppliers of substrates for molecular-beam epitaxy-grown MCT devices. [158]

At that time, he asserted that a company in Japan is the world's only source of these crucial materials. Only three small companies are involved in the infrared material field and four small firms make components, he said. Most U.S. suppliers to the military have gone out of business. In addition, night vision research has disappeared almost entirely from the United States. In 1988, eight universities performed research in this area. In 2008, only the University of Illinois-Chicago remained active. Meanwhile, China, India, France, Israel, Germany and the United Kingdom have invested heavily in developing new night vision systems and technologies, and in developing markets outside the United States.[159]

■ *Rare-earth magnets.* Lanthanides, or rare-earth elements, boast functional properties essential for permanent magnets, sensors, telecommunications, electronics, and many other key defense applications. For example, neodymium-ion-born magnets are used in servomechanisms for guided missiles and smart bombs. Magnetic materials research had become important to the field over first half of the 2000s decade for a wide range of commercial, medical and defense applications. Permanent magnets are available from only a few sources in the United States. By offering lower priced materials, and improved quality, however, Chinese firms have replaced U.S. suppliers (see Box C).[160] This reflects the Chinese government's strategy for cornering the market for rare-earth elements, the raw material for this industry, as described in the USCC's 2005 Annual Report.[161]

BOX C—THE MAGNAQUENCH STORY

In 1995, two Chinese firms, San Huan New Materials and China Non-ferrous Materials Corporation, partnered with U.S. investors, purchased Indiana-based Magnaquench from parent company General Motors, one of the few remaining U.S. rare earth magnet producers. Magnaquench had produced rare earth magnets and magnet powders used in hard drives, consumer electronics and guidance systems. Concerned about the military uses of the magnets, the Committee on Foreign Investment in the United States (CFIUS) reviewed the case. It approved the acquisition based on a commitment that the company's Indiana plant would remain in the United States. However, the investors backed out of that promise and the whole facility was eventually moved to China.[162]

At that time, Magnaquench was the only U.S. manufacturer of rare-earth "neo" magnets, critical components in military smart bomb guidance systems. Because of the decision to shut down Magnaquench's U.S. production, the U.S. military has to buy "neo" magnets from China. Deals such as these around the world, the USCC notes, have enabled China to control the markets in rare-earth products.[163] In 2008 U.S. Senator Evan Bayh (D-IN) protested the government's decision to shut down the Indiana Magnaquench plant. He complained that, "Not only did we compromise our national security interests, but we also lost more than 225 good-paying Hoosier jobs."[164]

In response to the loss of U.S. capacity in the rare-earth magnets sector, U.S. Senator Evan Bayh (D-IN) supported language in the 2008 Department of Defense authorization bill to preserve and enhance the "specialty metals clause" that requires the U.S. military to purchase specialty metals used in defense systems solely from U.S. producers. For example, it called for the military to purchase domestically produced "alnico" and other high performance magnets, so long as there are U.S. manufacturers who make them. Bayh promoted this provision to ensure the survival of companies such as high-performance magnet producer Thomas & Skinner of Indianapolis, IN. Thomas & Skinner is one of only five producers left in the United States that makes "alnico" magnets, which are used in numerous defense and aerospace applications, including missiles, military fighters and other aircraft, ground transport vehicles and radar systems.[165]

The 2009 USCC report to Congress warned that China now appeared to be tightening its control over the supply of rare-earth elements, through limits on the amount that can be exported in the last three years. China already supplies the vast majority—93 percent—of the world's production of rare earth minerals. The tighter export limits place foreign manufacturers (including American producers) at a disadvantage compared to domestic Chinese manufacturers.[166]

■ *Specialty metals.* Specialty metals feature unique chemistries and high tech processes. They include stainless steels, superalloys and other nickel alloys, tinanium and titanium alloys, zirconium, and niobium alloys, and are used in a wide variety of industrial markets, including defense. In a statement to the USCC, Jack Schilling of the SSINA touted the importance of specialty metals to virtually every U.S. military platform. "Simply put," he wrote, "weapons systems can neither be built nor operated without these materials," including missiles, jet aircraft, submarines, helicopters, Humvees, and munitions. Schilling added that most of these materials have been invented and developed by domestic specialty metals firms. Leading-edge defense applications represent only less than 10 percent of overall sales of specialty metals companies, but the same equipment and same engineers working in the civilian side of these businesses are employed for these defense products as well. The health of U.S. specialty metals companies, therefore, "is very important to the defense related industrial base of the nation," Schilling argued, as their commercial profits support their defense work.[167]

BOX D—CHINA'S STAINLESS STEEL STRATEGY

SSINA's Schilling noted that Beijing has embarked on a "highly coordinated, systematic, strategic initiative" to acquire western technology, "which, left unchallenged, will result in the transfer of specialty metals technology in China."[168] According to a SSINA analysis in 2007, China's industrial strategies, such as providing "massive" subsidies, tax rebates, low-or no-interest loans or grants, and various import restrictions, to greatly boost the production outputs of key industries—beyond what can be consumed domestically—have been applied to the metallurgical sector which includes stainless steel.[169]

As a result, China has grown to be the world's largest producer of stainless steel—its output in 2006 grew by more than 60 percent (3 million tons). It added 8 million tons of capacity over the previous two years alone, and has the capacity to make up to 12 million tons of stainless steel. To put this in perspective, the U.S. consumption in 2006 was only 2.6 million tons.

The SSINA report noted that China was ramping up its capability to be a major exporter of stainless steel. China's stainless steel exports increased by 137 percent in 2006, to 852,000 tons, and the government continues to approve new plants while foreign firms invest in new capacity in the country. China has 20 new stainless steel and steel production plants that were expected to begin production in 2007 alone. As a result, the SSINA report concluded, "The growth of the Chinese stainless steel to the point of excess capacity has been at the expense of its international competitors."[170]

Schilling, however, reported that although the domestic industry is currently profitable and remains the global leader in technology, North American suppliers face major new competitors in China, India and Russia. The United States could lose its specialty metals industry, he warned, if companies reduce their domestic investment in manufacturing and technology and then move these activities offshore to improve their profitability (see Box D). He noted that today there are "fewer companies producing specialty steels in North America than at any time in the last fifty years." He goes on to say that the playing field has become "increasingly tilted in favor of moving production and technology offshore."[171]

v. Aerospace

Aerospace (NAICS 33641) is a core industrial sector fundamental to America's economic and national security, and many consider it the technological backbone of the U.S. manufacturing base.[172] Unlike the other industries examined above, national security and space agencies constitute a major, if not the largest, portion of the customer base for the aerospace sector. Aerospace represents the largest downstream sector in the defense industrial base, encompassing the big systems integrator companies that oversee the design, construction and assembly of major systems and weapons platforms used for the nation's defense (others include shipbuilding and automotive transport). It includes a cluster of related but somewhat distinct industries, including aircraft, engines and parts, guided missiles, and space vehicles. This profile will primarily focus on the largest segment in the sector by far—accounting for nearly 90 percent of total aerospace shipments[173]—the aircraft, engines and parts industries (NAICS 336411-3), which produce commercial jets, military aircraft, regional jets, and general aviation aircraft

In addition, the aerospace sector depends on an extensive network of purchasers, subcontractors, suppliers and partners (the second, third, fourth tier contractors and beyond) comprising the sector's supply chain, which provide parts and components to U.S. and overseas manufacturers.[174] The AIA estimates that there are over 30,000 aerospace suppliers in the United States.[175] These include many firms in the semiconductor and electronic products, printed circuit boards, machine tools, advanced materials, and bearings industries examined in this report.

During the early 1990s, after the end of the Cold War, consolidation of the aerospace industry that had begun in the 1980s accelerated dramatically. Over twenty-two years ago, the primary aerospace firms included 75 separate companies. Today, only a handful of prime contractors remain—Lockheed Martin, Boeing, Raytheon, Northrop Grumman, and General Dynamics—to serve the federal national security and space agencies. Yet these firms also own holdings that lie outside of aerospace, including defense and commercial electronics and shipbuilding. Several of these firms (Boeing, Northrop Grumman) and others (United Technologies, Gulfstream Aerospace, Textron, among others) are also major firms in the commercial aerospace sector.[176]

Economic trends. Aerospace is a major source of high-skilled, high-wage jobs in the U.S. economy. It employs 500,000 workers, accounting for 4 percent of the nation's manufacturing workforce. About 61 percent of these jobs are concentrated in six states--Washington, California, Texas, Kansas, Connecticut, and Arizona. Trends over the past decade, however, show substantial shrinkage of this workforce over the past two decades due to a variety of factors affecting both the commercial and defense business sides of the sector.[177]

Business cycles. By nature, the aerospace industry is cyclical, with industry-specific cycles occurring approximately every 10 years, resulting from changing international conditions and market forces. The commercial aircraft industry's sales are tied to the health of the airline industry, which in turn depends on several factors that can influence demand for air travel, such as swings in economic activity, regional conflicts, terrorism, and disease outbreaks. The defense segment is largely reliant on the U.S. government (DOD and NASA, in particular), and federal budget decisions for most of its sales. Often a downward cycle in commercial aircraft sales is offset by large government contracts that sustain the defense aircraft side.

The defense industry's massive downsizing following the end of the Cold War drove a wave of aerospace and defense industry consolidation and restructuring. The large "primes" emerged as full-fledged multinational corporations whose interests now transcended the domestic industrial base. In order to grow and maintain healthy profit margins, these firms have become more and more reliant on foreign sales. At the same time, as in most other major industrial sectors, the drive to lower costs in the face of increasingly fierce foreign competition, including offsets and other foreign trade practices, has led them to offshore large portions of their own production operations, and to rely on an increasingly global supplier base.

After the drop off in aerospace business during the recession and defense cutbacks of the early 1990s, growth resumed in the mid-1990s, peaking in 1999 with 139 billion USD worth of shipments. From 1999 through 2003, the industry, like most other manufacturing sectors, fell into a pronounced slump—exacerbated by the 9/11-induced troubles of the worldwide commercial airlines industry. Total aerospace shipments plunged 11 percent below the 1999 peak, to 124.1 billion USD. Shipments by the aircraft and parts and the guided missile and space vehicle and parts subsectors each dropped by comparable amounts in these years.[178]

The aerospace industry showed signs of recovery beginning in 2004. Shipments, capacity growth and utilization, and employment all exhibited positive growth, as the industry experienced a lucrative period with a strong market upturn. In 2008, aerospace manufacturing sales were 204.2 billion USD, up from 200.3 billion USD the year before (current US dollars), according to an AIA review, accounting for 1.4 percent of U.S. GDP. This was still down from 1.5 percent in 2000 and 1.7 percent in the late 1990s, however.[179]

Employment and establishment trends. These trends paralleled a much larger shift in both employment levels and the number of establishments, especially in the aircraft and parts subsectors. Changes in the number of establishments and jobs by establishment sizes also displayed the same patterns.

- Overall, between 1990 and 1995, aerospace employment fell nearly 40 percent, to 514,200, then bounced back over the next few years to a new peak of 578,600 in 1999, before sharply declining again, with the greatest losses occurring in 2002 and 2003.
- In the aerospace products and parts sector (NAICS 3364), a net 47 plants of all sizes disappeared between 1999-2004—with mid-sized facilities suffering the greatest losses, though 83 percent of all job losses were recorded in the large plants that dominated employment in the industry.
- Between 1999-2004, the aircraft, engines and parts industries (NAICS 336411-13) were responsible for all the establishment losses and 90 percent of the job destruction in the aerospace sector.[180]
- The aerospace sector's decline seemed to reverse itself in the 2000s decade, as the number of establishments increased by 6 percent between 1998-2008, though it lost two large establishments of over 1,000 employees, which in part accounted for the loss of 75,000 jobs, or a 13 percent drop, over this period.[181]
- Employment in the aircraft manufacturing (336411) and aircraft engine and engine parts manufacturing (336412) industries fell by 15 percent each between 1998-2008, mostly in large plants with 500 or more employees.[182]
- The aircraft engines sector also saw a sizable loss in mid-sized establishments of 100-499 employees (a 9 percent decline) and large facilities with 500-999 employees (a 28 percent decline) between 1998-2008.[183]

Import penetration. Another sign of potential weakness in the American aerospace industry is the expanded penetration of imports into domestic aerospace markets. Import penetration in the aircraft, aircraft engine and engine parts, and other aircraft part and auxiliary equipment manufacturing industries (NAICS codes

336411, 336412, 336413) rose by 117 percent, 34 percent and 45 percent respectively, between 1997 and 2007. In 2002, foreign manufacturers captured 15 percent of the domestic aircraft manufacturing market, 40 percent of the aircraft and engine parts market, and 31 percent of the other aircraft part/auxiliary equipment market. By 2007, these shares grew to 33 percent, 14 percent and 45 percent respectively.[184]

In 2009, however, the worldwide recession greatly weakened all U.S. manufacturing, including aerospace. In 2008, commercial aircraft and parts shipments totaled 96.6 billion USD, 63 percent of total aerospace shipments, but orders for new civil aircraft and parts fell for the first time since 2003.

The loss on the commercial side was offset by strong military aircraft expenditures. Defense aircraft and parts equaled 56.4 billion USD in 2008, up 40 percent from 2007. Analysts predict, though, that there could be tough times ahead for military aircraft.[185] For example, a *New York Times* article reported that problems in the building of Boeing's new 787 Dreamliner aircraft were exacerbated by the recession, which curtailed orders for planes. The company may not be able to depend on its large military business, which had buffered the company from a similar collapse of aviation after the 9/11 terrorist attacks in 2001, because of cuts in Pentagon spending on large weapons systems.[186]

International trade and offsets. Aerospace products are one of the most important American exports, and they make up a major share of Advanced Technology Products trade (figure 16). The industry has long enjoyed a positive trade balance, led by commercial aircraft and sales of military products to foreign governments (often subsidized by the U.S. government), and in recent years, has been one of the sole bright spots in the otherwise dismal U.S. trade picture. After 2000's substantial drop to 26.5 billion USD, 35 percent below the peak of 1998, the aerospace trade surplus grew only sluggishly until 2004, when it rose to 30 billion USD, though in nominal terms, it was still only three-quarters its 1998 level. However, the aerospace trade surplus continued to grow through the remainder of the decade, rising to 54 billion USD in 2009.[187]

The large positive trade surpluses enjoyed by the aerospace sector reflect the heavy dependence of U.S. aerospace manufacturers on international markets for sales. In 2008, it sold more than 95 billion USD in aerospace vehicles and equipment (including defense and space products) to foreign customers in Japan, France, Germany, and United Kingdom, among others. With imports of over 37 billion USD, its total trade balance grew to 57.8 billion USD in 2008.[188]

The apparent strong performance of the aerospace industry in terms of sales and trade needs to be tempered by the understanding that some divisions within that sector, not to mention the large second- and third-tier supplier chain that provides subsystems, parts, components, and materials to the prime aerospace contractors (i.e., the systems integrators), have been weakening. The profiles of the other industries examined here, and the evidence of Webber's findings, strongly suggest that the erosion of the capacity of the industries that supply vital products and technologies for inclusion in defense systems—a trend substantially linked to offshoring trends in each industry—can ultimately weaken the competitiveness of the "primes" that build and assemble the large-scale end-product defense systems. As Webber concludes: "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."[189]

Offset agreements. A key strategy of aerospace companies is to secure new foreign sales through *offset* agreements. Offsets agreements and transactions require a domestic exporter of articles and services to foreign customers (government or commercial enterprises) to produce parts of the exported items in the foreign location or agree to the purchase of goods and services unrelated to the exported goods. For example, the Indian government has made mandatory an offset clause for aerospace firms abroad that must be at least 30 percent of the total value of a deal.[190] Most offsets have involved the export of defense items, though major commercial deals, such as Boeing's foreign sales of its aircraft, also involve offset arrangements. For example, transportation equipment, comprised mostly of aerospace products, accounted for nearly two-thirds of the total value of direct offsets, between 1993 and 2003.[191]

American defense firms have entered into offset arrangements with foreign governments for decades (see Box E). These arrangements, however, have grown increasingly prevalent, and recently, foreign governments have been requiring U.S. arms producers to provide offsets greater than the value of actual sales. Indeed, foreign governments recently have been requiring U.S. arms producers selling their weapons overseas to provide offsets equal to a major share of the value of the actual sales (see figure 19). According to the BIS, in 2003, the total value of offsets for the first time exceeded the value of the defense contracts to which they were linked—offsets equaled 122 percent of sales—for the first time; a substantial increase over 2002 levels.[192] Although the offsets/contract ratio fell in subsequent years, it was still well above 50 percent by 2008. Offset arrangements totaled 68.93 billion USD and averaged 71.0 percent of the related defense contracts.[193]

Foreign beneficiaries. European nations have been the largest beneficiaries, receiving offsets in 2003 equal to an average of 148.8 percent of the value of total export agreements.[194] However, the data show—and Box E illustrates—that more countries outside of Europe also are demanding higher offset percentages, such as the Indian government requires that major foreign sales to India include offsets equal to 30 percent of the contract. According to the BIS, as a result of a growing buyers' market for defense goods, "almost all purchasers of U.S. defense systems require offset agreements as a condition of the sale."[195]

BOX E—AEROSPACE OFFSETS

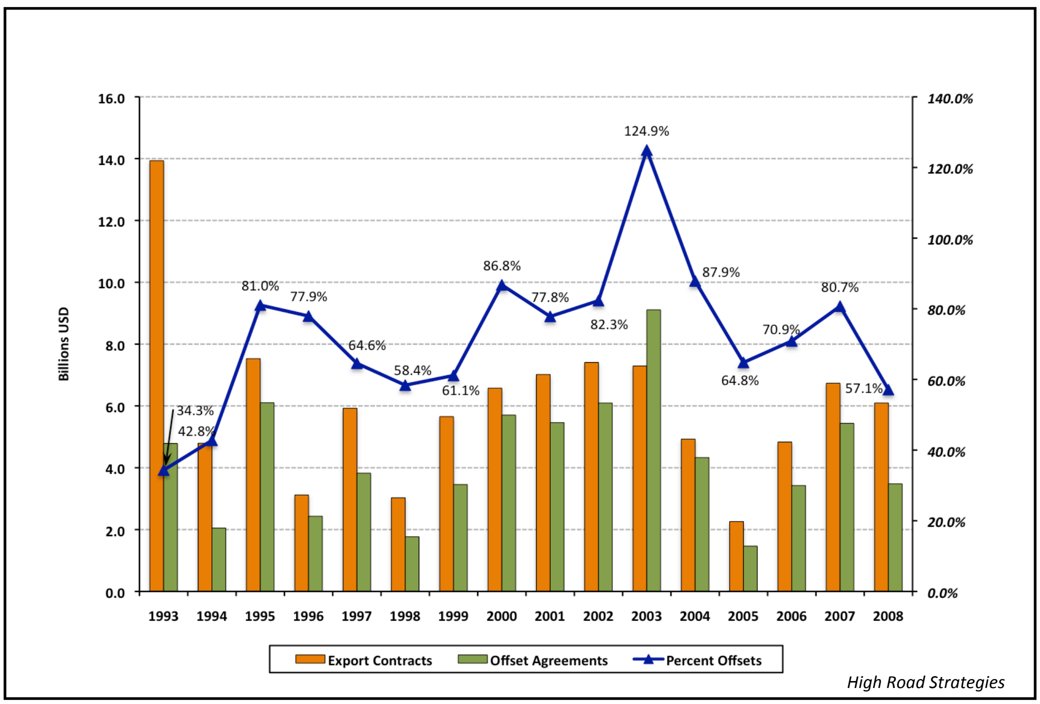
Offsets refer to agreements and transactions in which an exporter of articles and services to foreign customers (government or commercial enterprise) is required to produce parts of the exported items in the foreign location or agrees to the purchase of goods and services unrelated to the goods being exported. Direct offsets are transactions directly related to the items or services exported by the domestic firm and usually take the form of co-production, subcontracting, technology transfer, training, production, licensed production, or financing activities.[196] Indirect offsets involve transactions of goods and services not directly related to the items or services being exported. They may include purchases, investment, training, financial activities, market and exporting assistance, and technology transfer.[197]

Most offset arrangements are associated with the export of defense items, though major commercial deals, such as Boeing's foreign sales of its aircraft, also involve offset arrangements.[198] A few examples:

- In 2004, Lockheed Martin sold 48 F-16 fighters to the Polish Government, a contract worth 3.5 billion USD. The estimated value of corresponding offsets was 9.7 billion USD, or 2.6 times the value of selling the F-16s themselves. Direct offsets in the deal include Pratt & Whitney purchasing a Polish factory, modernizing it, and establishing a manufacturing line to produce lower complexity F-100 engine components for the Polish F-16s, which are shipped back to the United States for assembly into the engine. Indirect offsets include the purchase of Roll-on Roll-off Ships from Polish shipyards; tooling for Cessna and Lycoming from Polish sources; components for land moving equipment, and other technologies.[199]
- In a 3.3 billion USD agreement for the sale of 40 F-15K Strike Eagle jets to South Korea, Boeing is required to give South Korea avionic, software and design technology valued at 1.5 billion USD. Boeing will do the assembly of the completed jets in St. Louis, but the wings and front fuselages will be made in Korea.[200]
- In one of more than 300 offset agreements entered into over the last two decades, Lockheed was required to use Rolls-Royce engines, instead of ones made in the United States by General Electric, to power Apache attack aircraft sold in Europe.[201]
- Since the 1960s, foreign content from offset agreements in Boeing's commercial aircraft has grown from only 2 percent to as high as 70 percent for its 787 Dreamliner. The offsets include the subcontracting of design and production of wings to Japanese firms—the first time Boeing has ever farmed out this vital, technologically sophisticated part of its aircraft manufacturing operations.[202]

- In 2008, Boeing has sold 25 billion USD worth of civilian aircraft, ranging from Air America airliners to private business jets. In return, Boeing has been investing in broadening India's capability, including a 100 million USD maintenance center in Nagpur, the emerging intermodal transport hub for the country, and helping Air India set up a 75 million USD engineer and pilot training facility in Mumbai. In high-level manufacturing, meanwhile, Boeing has been encouraging Indian firms to become part of its supply chain. For example, it has a 500 million USD deal with Tata Steel to provide titanium floor beams for the Dreamliner.[203]
- Indian defense officials announced in January 2009 an agreement to purchase eight of Boeing's P-8 Poseidon sub hunters, a militarized version of the 737 jetliner. The 2.1 billion USD contract is India's largest military airplane deal with the United States. Boeing agreed to offset commitments equal to 30 percent of the contract, as mandated by the Indian government. In 2008, India agreed to buy six C-130J transports from Lockheed Martin for 1 billion USD, including the requisite offset agreement.[204]

Figure 19
Export Contracts and Offset Agreements, 1993-2008



Source: BIS, Offsets in Defense Trade, Fourteenth Study, December 2009

In addition, foreign governments' growing desire to sustain or create new indigenous defense capabilities has boosted demands for offsets, which can mollify internal political objections to large public outlays for foreign-made weapon systems, and foster domestic economic development. The BIS notes that developed countries with established defense industries use offsets to channel work or technology to their own defense companies. Newly industrializing countries, such as China, employ offsets as a way of fostering the transfer of technology and know-how to build up both their commercial and military capabilities.

Most U.S. defense contractors have viewed these practices with mixed emotions. On the one hand, offsets deprive them of revenues and force them to make procurement decisions for political, rather than sound business reasons. On the other hand, the priority that these contractors place on systems integration, as opposed to manufacturing, has reduced the perceived stakes in keeping components production in house, much less in country. Moreover, these contractors believe that accepting offsets is usually the only way to keep expanding foreign sales and maintain production lines, increase the exports of both U.S. defense and commercial products, and improve interoperability.[205]

On the other hand, offsets also open up more opportunities for contractors to expand their investment and presence in foreign markets, which may not necessarily be to the benefit of U.S. workers and communities. The 2009 BIS report notes that offset agreements can negate some of the economic and industrial base benefits obtained through the sale of defense items to foreign entities. The report observes, for example, that "offset transactions that require a high proportion of subcontracting, co-production, license production or purchases transactions can displace U.S. defense subcontractors and suppliers, and in some cases, portions of the prime contractor's business."[206]

Competitiveness and security concerns. Despite the industry's robust growth in exports and trade surpluses, industry experts have expressed concern that the growth of offsets as part of foreign sales transactions could adversely affect the health of the American aerospace industrial base. The impacts of offsets arrangement on the aerospace industry are manifold:

- *Offsets have increased the pressure on U.S. firms to offshore more of their operations, leading to the loss of domestic manufacturing capacity and jobs*, a trend that the USCC warned could "undermine U.S. global leadership in aircraft manufacturing."[207] Offsets can directly cost jobs in some companies who, under these agreements, transfer to foreign producers work and manufacturing capacity that otherwise would remain in domestic facilities. The increase in aerospace-related offsets could also lead to a rapid increase of imports of aerospace production, which would adversely affect U.S. jobs.[208]
- *The growth of offsets and outsourcing by large U.S. contractors could hurt small and medium-sized defense contractors*. Offset agreements that include subcontract or licensed production offsets could displace U.S. subcontractors and suppliers.[209] Previous experience has shown, the BIS notes, that U.S. contractors "sometimes develop long-term supplier relationships with overseas

subcontractors based on short-term requirements," which can reduce future business opportunities for U.S. subcontractors.[210] Not only are suppliers squeezed by their customers' requirements to be leaner, their foreign competitors can benefit from offset agreements made with their customers. This creates greater demand on U.S. suppliers, and possibly hurts industries that supply critical components to the U.S. aerospace industry.[211]

- *The growing demand for offset agreements by foreign countries is making U.S. aerospace firms more reliant on foreign firms*. As the U.S. supplier base erodes, especially in the second and third-tiers, defense contractors become increasingly dependent on foreign suppliers for critical products.[212] University of Buffalo geographers David Pritchard and Alan MacPherson note, "Boeing has become increasingly dependent upon outside suppliers for technologically complex and/or critical airframe components such as wings, fuselage assemblies, center wing boxes, and tail sections."[213] The outsourcing of the design and construction of wing and fuselage sections are at the root of Boeing's recent production and delivery problems with its 787 Dreamliner.[214] Offsets also add to the financial pressures on U.S. firms who are increasingly reliant on foreign partners for financial support.[215]
- *Offsets transfer technological and production capabilities to foreign governments and companies, helping to enhance or create current and future foreign competitors*.[216] Not only do direct offsets send aerospace work overseas, they are helping other nations move up the value chain in aerospace production. This represents the conscious efforts of other nations to build up the capabilities of their own industries, which then compete directly with U.S. companies, including hard hit suppliers.[217] Offsets also can lead to the transfer of sensitive technology and production to foreign defense industries, raising national security issues.[218]

As Charles Wessner of the NRC's Board on Science, Technology, and Economic Policy has noted, "Offsets are a symptom of a broader challenge mounted by foreign governments determined to support their aerospace industries—both their commercial and defense components—by whatever means possible in a strategic sense, they are one tool from a tool kit of foreign industrial policies focused on the aerospace industry and its high-tech manufacturing."[219] Boeing's expansive offset agreements exemplify this situation. They include technology transfer arrangements that jeopardize Boeing's competitiveness in global aircraft markets by helping Japan, China and others build planes on their own.

China's Commercial Aircraft Company and Japan's Kasaki Heavy Industries, along with Russian and Canadian regional jet manufacturers, have plans to make planes large enough to compete with Boeing and Airbus.[220] Pritchard and MacPherson noted that as Japan "incrementally acquired production for a wide range of airframe components via years of industrial offsets from Boeing, the transfer of wing manufacturing and assembly expertise to Japanese companies" will now effectively give Japan "'total production competence' with regard to commercial airframes."[221]

Similarly, as the USCC observed, "China nurtures its domestic aviation and aerospace industry by exploiting the international competition already present in the industry."[222] Other nations are also utilizing U.S. offsets and outsourcing arrangements to build up their aerospace capacity. For example Boeing's F-15 K Strike Eagle deal with South Korea is expected to result in the transfer of jobs and skills that will enable South Korea to produce its own fighter jet by 2015.[223]

vi. Other Sectors

A number of other representative sectors that provide critical materials, technologies, products and systems to the defense industrial base could also be examined. These range from the relatively "low-tech" ball and roller bearings industry to cutting edge technology products such as optoelectronics, both with applications important to defense applications as well as commercially. The erosion of U.S. capabilities in these industries at opposite ends of the technological spectrum follows similar patterns as the other industries profiled in the report, illustrating again how the endemic erosion of the U.S. manufacturing base contributes to a corresponding weakening of U.S. defense industrial capability.

Bearings manufacturing. Ball and roller bearings (NAICS 332991) represent critical components used ubiquitously in defense products (as well as in numerous civilian products). Bearings are carefully engineered, precision-made components that enable machinery to move at extremely high speeds and carry great loads with ease and efficiency. Bearings are found in a very wide range of applications from automobiles, airplanes, computers, construction equipment, machine tools, DVD players, refrigerators and ceiling fans. The Pentagon considers them to be "critical components to weapon systems."[224]

While bearings do not meet Webber's criteria of directly contributing to the innovation capabilities of the defense industrial base, they nevertheless require advanced production processes to achieve the very high levels of precision needed to serve their function in defense systems. In order to do their primary job—reduce friction—manufacturers are constantly in search of new materials, lubrications, and coatings to improve bearing life and their ability to hold up in harsh environments.[225]

The bearings industry has suffered significant losses in employment and establishment numbers over the 2000s decade. It also has been suffering from growing trade deficits and import penetration. For example:

- Employment fell by 31 percent, from 39,500 to around 27,250, between 2001 and June 2009;
- The industry lost a total of 13 percent of its establishments of all sizes, from 251 to 219, over the same period;[226]

- The import penetration rate for ball and roller bearing manufacturing grew by nearly one-fifth over the 1997-2007 decade, from 22.6 percent to 27.1 percent;[227] BIS data suggest that the ball bearing segment in the industry might be suffering from even worse IPRs.[228]

As early as 2000, an Army-sponsored study warned of the continued attempt by foreign concerns to dominate the U.S. industrial base for ball bearings, noting that only two out of the world's top ten ball bearing manufacturers were U.S. companies at that time. Although the Army expected the domestic super precision bearing market to remain vibrant due to the industry's high labor costs, the U.S. bearings industry was described as a prime candidate for offshoring production. Meanwhile, foreign firms were willing to subsidize production to gain U.S. market share while trade barriers limited U.S. exports.[229]

In 2002 the Department of Commerce and the International Trade Commission slapped a dumping duty on Chinese bearings imports, in response to a petition by the American Bearings Manufacturing Association (ABMA) (but rescinded it 6 months later). The ABMA claimed that the 2 billion USD U.S. market was being overrun with unfairly-priced ball bearings from China, which threatens the survival of the domestic industry, and complained that Chinese ball bearings and parts imports into the United States had reached record levels each of the four previous years.[230]

The pressure on U.S. bearings manufacturers to offshore their production has continued throughout the decade. The market for bearings is still very strong in the United States, Europe and Japan, because of the advanced industrial and technological nature of their economies as well as the large number of bearing-containing equipment.[231] Sales for bearings in the developing economies, however, are expected to outpace sales in the advanced developed regions through 2013.[232] Most bearing manufacturing is now being done in low-cost countries,[233] and as foreign suppliers improve the quality of their goods, U.S.-based bearing companies are being forced to invest increasingly in overseas manufacturing plants, limiting advances in domestic industrial production.[234]

Optoelectronics. As the 2010 USCC report notes, optoelectronics is another "advanced technology industry that might have stayed in the United States but is now almost completely relocated overseas."[235] Optoelectronics is used in emitting diodes, and solar technology, among other advanced technologies. This includes photovoltaic panels, solid-state lighting systems that reduce electricity consumption by a factor of five in new generation televisions and telecommunications, and sensors that will be deployed in numerous mechanical and industrial systems, roadways, electrical grids and manufacturing production.[236]

Optoelectronics was considered a strategic critical technology for national defense in the late 1980s and early 1990s. According to Michael Lebby, president and CEO of the Optoelectronics Industry Development Association (OIDA) in Washington, DC, other than for parts built to military spec, "most manufacturing and assembly has moved outside the United States or is in the process of doing so."[237] The Defense Advanced Research Projects Agency was concerned enough about maintaining the U.S. capability in optoelectronics that it helped to create OIDA in order to champion domestic efforts to preserve this capacity.

The U.S. loss of optoelectronics manufacturing is reflected in the rapid growth in the U.S. trade deficit, which rose from only 3 billion USD in 2002 to 21 billion USD in 2008 in the Advanced Technology Products account.[238] Most of the manufacturing capacity being installed offshore, and the infrastructure for all of the subcomponents is now in Asia. As a result, Lebby contended, even if labor costs were equalized, "you would still have to be there. . . You can't just bring back the assembly and manufacturing of components. You have to get the subcomponents back as well." A major additional worry is that R&D and technical know-how will follow the shift in optoelectronics manufacturing capacity. Although innovation hasn't shifted away from the United States yet, Lebby said that we "are beginning to see China, Taiwan, and Korea come up with really creative solutions," and over the next decade "they will be climbing the design and innovation ladder."[239]

The Chinese government, for example, which supported the shift of some manufacturing of optoelectronics to China, is now trying to attract research and design work, the highest value-added portion of the industry. It has created five national laboratories and is sponsoring academic-industry collaborations around the country with the hope of leapfrogging the United States and Europe. The focus of these efforts includes liquid crystal displays, plasma screens, light-emitting diodes and solar technology, among others."[240]

IV. Eroding Technology Leadership

The industries profiled above encompass widely varied products and processes. They operate in different markets and maintain different relationships with the Pentagon and the military industrial base, though each provides products and technologies critical to national security. Nevertheless, they have important characteristics in common. They all show signs of erosion in their physical, human, and technological capabilities over the past decade, and some for considerably longer periods of time. At the same time, all have been greatly affected by the intense competitive pressures of global markets, and, to varying degrees, each sector has experienced migration of production and jobs overseas.

These trends parallel the aggregate statistical patterns for the entire industrial base, described in section II, that, taken together, demonstrate a broad-based, cross-cutting weakening and erosion of the nation's manufacturing base that could worsen over time if corrective actions are not taken. There are a range of other industry sectors and their subdivisions—shipbuilding, fabricated metals manufacturing, primary metals, nonmetallic mineral products, apparel and textile products—which, while they still may be economically important and are not necessarily "critical" to the defense base, supply specific products and technologies critical to national security. Most of these industries exhibit similar patterns of domestic erosion and global dispersion, which could undermine their long-term ability to produce these defense critical products domestically.

A key premise of this report is that if the underlying civilian manufacturing base continues to unravel, even with direct interventions by the Pentagon to preserve specific defense-unique technological and production capabilities (e.g., the DOD's "trusted" production strategy), defense agencies and contractors would become increasingly forced to rely on foreign sources for vital goods. As has been noted, this is a controversial point, and not all Pentagon planners or industry officials (i.e., from the large systems integrator companies) believe that this is a problem. On the other hand, other experts from government, industry, labor and academia, argue that ultimately this trend is damaging to national security readiness.

Support for the latter view, in particular, comes from evidence that the erosion in the U.S. manufacturing base is directly contributing to an apparent erosion of the nation's innovation capabilities and undermining America's global technological leadership. As Webber warned:

> 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.[241]

Of special concern is the tight, overlapping relationship between the design, development *and* production of both commercial and defense-specific technologies and products. Two key aspects of this relationship are examined below:

- The linkage between R&D and innovation with manufacturing activity, and how erosion in the latter is undermining the nation's innovation capacity;
- The related link between manufacturing and maintaining a base of scientific, technological and industrial know-how embodied in a highly educated and trained, skilled workforce.

a. Offshoring innovation.

The impacts of an eroding domestic manufacturing base on national security largely stem from the military's growing reliance on commercial cutting-edge technology since the 1980s. There are reasonable doubts that military technology still lags commercial technologies in all areas, as it generally did during the 1980s and 1990s. Starting in those years, and continuing into the present, defense procurement policy has put an emphasis on promoting greater civilian-military integration, and encouraging agencies and their contractors to purchase commercial-off-the-shelf (COTS) and "dual-use" technology products. The rationale is that drawing on the often more innovative civilian sector not only would yield more up-to-date products but also big cost savings.

Many, if not most, "dual-use" contractors and suppliers try to separate their defense and commercial businesses, in large part to avoid the bureaucratic drag of defense procurement requirements on their commercial work. Nevertheless, the ability of a firm to design, innovate, and improve on defense-critical technologies or devices that it produces for defense markets, increasingly depends on its ability to preserve and draw upon the technological edge it has obtained in its commercial business.

As military products become more reliant on commercial advanced technologies, technology transfer from commercial technologies into defense-critical products requires a close relationship between the Pentagon or defense contractor customer and the suppliers of these technologies. However, as the commercial base upon which the defense sector relies for most of its components and subsystems globalizes, integrating commercial technology into defense systems becomes more difficult to achieve. That is, the loss of production facilities can lead to the loss of innovation capabilities, which would dangerously undermine the nation's ability to maintain a strong defense base.

Specifically, the migration of manufacturing offshore is associated with the following trends:

- Weakening innovation capabilities of domestic industrial sectors;
- The transfer—deliberate and unwitting—of cutting-edge technologies and know-how to economic rivals and potential military adversaries; and

- A decline in the United States' overall technological leadership in the world.

Laboratories of production. The close link between manufacturing and technology development and innovation is apparent in each of the industries profiled above. Jack Schilling's observation that "technology development travels with the manufacturing process," and that "[o]ur plants in the specialty metal industry are our laboratories,"[242] holds as much for traditional manufacturing industries such as machine tools and ball bearings as it does for advanced high-tech sectors such as microelectronics, printed circuit boards, or systems integrator-dominated industries such as aerospace. Many experts agree not only that manufacturing and technology development are intimately linked, but also that manufacturing's migration is contributing to the erosion of U.S. innovation and R&D capacity itself.

For example, a 2002 report of the Defense Advisory Group on Electronic Devices (AGED) warned of "global economic, political and technological trends that threaten the ability of the U.S. to be a world leader in technology." It was especially concerned that the "off-shore movement of intellectual capital and industrial capability, particularly in microelectronics, has impacted the ability of the U.S. to research and produce the best technologies and products for the nation and the warfighter." The report concludes that over the previous decade, these "profound changes in the R&D base are adversely affecting cutting edge electronics for warfighter superiority and may potentially slow the engine for economic growth."[243]

As AGED's chairman, Thomas Hartwick explained in testimony before Congress, without actual production remaining onshore, even America's most knowledge-intensive sectors could become hollowed out. He expressed worry that the "structure of the U.S. high-tech industry is coming unglued with innovation and design losing their tie to prototype fabrication and manufacturing." Inventions, he claimed, would be left "on the cutting room floor because they cannot be manufactured." As a result, there may not be a U.S. manufacturing base capable of creating "mega-billion industries like micro-electromechanical systems or nanotechnologies."[244] This danger is apparent in the industries examined in this report.

- *Semiconductor R&D*. Over the last decade, industry leaders have warned that as semiconductor production moves offshore to places such as Taiwan and China, more and more research activities will be drawn along with it. Some experts have noted that as the manufacturing process become more complex, developing close relationships among design and manufacturing becomes increasingly important to enable feedback discussions between the two types of activities.[245] This concern was raised, for example, with respect to the design and production of photomasks, a crucial component in semiconductor manufacturing. As integrated circuits increase their densities, masks become more and more complex, forcing the costs of mask sets to soar, prompting some government officials to worry about a growing disconnect between the conceptual design of new chips and the ability to manufacturer them.[246]

In its 2005 report, the Defense Science Board (DSB) asserted that "[s]emiconductor technology and manufacturing leadership is a national priority that must be maintained if the U.S. military is to continue to lead in applying electronics to support the warfighter." Key to maintaining this leadership, moreover, is preserving the "close coupling of manufacturing with the development of advanced technology and the design of leading-edge integrated circuits." This is best achieved, the report contends, "if development and manufacturing are co-located."[247] The report further observes that leading-edge R&D has historically tended to migrate along with production leaders, consequently attracting the most talented process scientists and engineers toward advanced production. But, if this production has gone offshore, "[t]he close collaboration between process engineers and designers required for lead-edge chip development could be rendered ineffective for the U.S. defense industry.[248]

According to industry leader William J. Spencer, "semiconductor manufacturing is a learning-by-doing industry." U.S. chip fabrication plants historically have anchored the specialized industrial clusters including R&D labs and the facilities of semiconductor equipment and materials makers, which in turn work closely with device manufacturers on technology development. The close proximity of fabrication facilities to R&D facilities therefore "is important for researchers and manufacturers alike."[249] But if U.S. chip manufacturing moves offshore, the link with chip design and innovation is weakened, and these clusters begin to unravel. Spencer predicted that "although U.S. clients of Asian foundries believe they can retain in-house chip design expertise in the absence of manufacturing, their negotiating position may shift as capacity tightens," a problem that could be exacerbated with the need to maintain effective intellectual property protections, which is difficult at best in China.[250]

■ *Printed circuit board R&D*. Industry leaders have also warned of the obstacles to reestablishing a printed circuit board industry if production capacity leaves the United States, because R&D and critical design know-how would leave with it.[251] This concern was raised by the National Research Council's report on manufacturing trends in the PCB industry, which traced the loss of R&D in that industry to the loss and migration of manufacturing. In 1980, the report notes, original equipment manufacturers (OEMs) and their captive factories manufactured 52 percent of the PCBs made in the United States. These OEMs traditionally spent about 10 percent of the sales values of these in-house-produced products on R&D efforts aimed at improving manufacturing, quality, and yields. By 2001, however, the estimated percentage of PCB production by domestic OEMs had dropped to 1 percent, and by 2004, only a few OEM facilities remained. Their capacity (primarily for dedicated military products) was less than 0.1 percent of the total U.S. output. As a result of this shift, the NRC states, "the traditional sources of R&D funding dropped by two orders of magnitude. In reality, the critical mass of R&D in this industry disappeared, reducing the investment in new technology to near zero."[252]

A similar trend was evident in the PCB supply base, which was another big source of R&D resources. Funding for technical activities from these manufacturers was once estimated at 10 percent of all U.S.-generated supplier sales dollars in the 1990s. By 2001, both the levels of sales and the share spent on R&D were declining. In 2003, it was estimated that less than 3 percent of sales income was spent on technical activities to support PCB manufacturing. "The effect of this loss of R&D spending" the NRC predicted, "is expected to have long-term effects. In 1999, U.S.-based PCB suppliers spent an estimated 50 million USD on technical activities and new-process and -product R&D. In 2005, this sector will spend less than 10 million USD for such R&D."[253]

■ *Advanced materials R&D*. Comparable findings have been presented for the advanced materials sector. The NRC's report on the globalization of materials R&D concluded that as U.S. materials manufacturing disappears and moves offshore, domestic materials R&D capacity has diminished. Meanwhile, many U.S. companies, attracted to the growing availability of often lower cost foreign intellectual resources, have shifted their materials science and engineering R&D activities to follow their manufacturing operations overseas.[254] The net result has been an erosion of U.S. leadership in advanced materials R&D. The NRC reported several instances that illustrate this trend:

- Research into the production, processing, and development of metallic materials in the United States has been declining since 1998. Metal producers do very little alloy development anymore, and companies in metal consuming industries have also decreased their efforts. Evidence suggests that the United States is losing its leadership role in metals R&D. There are no signs that this trend will be reversed any time soon.[255]
- Superalloy R&D has declined significantly for over a decade, as U.S. firms confront slower demand and higher costs, and many face financial difficulty. Attracted by lower costs, superalloy manufacturers are increasingly locating their production offshore. The NRC predicted that U.S. companies that move overseas will remain competitive and survive "only to the extent that they are privy to future developments at non-U.S. laboratories and plants."[256]
- Composites are a critical technology used in major defense systems such as the F-22 fighter jet, ballistic missiles and orbital satellites. Once unchallenged, U.S. leadership in composites has been supplanted by other countries. Europe now leads in composites manufacturing and modeling, and there are fewer U.S. commercial carbon-carbon composite manufacturers and far fewer companies providing oxidation coatings than 10 years ago. U.S. defense and commercial programs—the Joint Strike Fighter and Boeing's 787 Dreamliner—have outsourced production and supporting R&D in composites overseas. The NRC concluded that without long-term investments in composite research, the United

States risks losing the ability "to exploit the promise of composites because of the significant and continuing decline of its leadership in the subfield." Moreover, U.S. industry could "stagnate and eventually become uncompetitive with foreign companies that have maintained active research programs."[257]

- Electronic and opto-photonic materials are critical technologies for maintaining leadership in semiconductors, and as noted above, this industry and its material supply chain are moving toward a global processing and manufacturing infrastructure that is taking some of its R&D capacity with it. Many large electronic materials suppliers have globalized their manufacturing base and support laboratories.[258]
- The ceramics[259] and catalysis[260] industries have been following similar trajectories. As manufacturing in these sectors confronts growing foreign competition—especially from China and other Asian nations—and globalizes their production, their R&D activities are also globalizing, and U.S. leadership in these critical technologies has declined.

■ *Aerospace R&D*. Aerospace is another critical industry witnessing a migration in manufacturing accompanied by diminished R&D capacity at home. For example, Boeing has transferred a wide-range of critical technologies to foreign partners in offset arrangements for its new 787 line. Industry specialists Pritchard and MacPherson reported on Boeing's lack of R&D investment for its commercial product lines, noting that Boeing trailed Airbus with regard to R&D and capital spending for many years. For example, in 2003 Airbus allocated 9.5 percent of its total revenues towards R&D, while Boeing spent only 3.5 percent.[261] In testimony to the USCC, Heidi Wood of Morgan Stanley stated that "Boeing has been . . . possibly insufficiently innovative," as its commercial R&D-to-sales ratio was projected to be 4.8 percent in 2005, compared to Airbus projected at 8.5-9 percent. Overall, the USCC warns that "[t]he ability of the U.S. aerospace industry to attract investment and sustain a base for high-technology development is . . . reportedly at risk and may deteriorate further as more aerospace technologies migrate offshore."[262]

Measuring the extent to which U.S industrial R&D—especially that performed by industries that constitute the defense industrial base—has eroded over the decade or more warrants additional research. National Science Foundation statistics on total U.S. industrial R&D funding and performance indicate that both declined over the first half of the 2000s decade,[263] though this trend then reversed itself, rising steadily from 2003 to 2007. U.S. industry continues to be a major supporter of R&D domestically and internationally.

For purposes of the current analysis, however, the most important trends are at the disaggregated industrial sector level (i.e., at the NAICS 6-digit level). As the examples above suggest, at this level, considerable evidence shows that U.S. innovation capacity in critical industrial sectors has been eroding—and may continue to deteriorate as production in these sectors continues to move away.

This finding is consistent with the findings of authoritative investigations of U.S. industrial and technological competitiveness. For example, the 2005 report of the National Academy of Sciences Committee on Prospering in the Global Economy of the 21st Century, *Rising Above the Gathering Storm*, states that: "Having reviewed the trends in the United States and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength."[264]

Similarly, the USCC's 2005 report to Congress recognized that this trend presented potential problems for U.S. defense capabilities. It observes that as the DOD becomes more reliant on private sector technology developments, "the private sector is moving offshore much of its industrial and technology production and some of its technology design and research and development."[265] Noting that maintaining leadership in technological innovation is critical for national security, and that commercial technologies increasingly set the direction for military technologies, the report warns that "a lack of innovation in the private sector could have serious detrimental effects on the capability to produce innovative military technology."[266]

Migrating R&D. The offshore migration of U.S. innovation capabilities has also been a contributing factor in the buildup of other countries' R&D capacities. Moreover, the more factories that are built overseas, the more powerful the attraction of offshoring R&D becomes, as multinational companies want their facilities to be located in the closest proximity possible. As noted above, for example, aerospace offset arrangements are an important means of technology transfer between U.S. commercial and defense aerospace firms and foreign companies, which is leading to a build up of aerospace manufacturing and R&D capacity in countries such as Japan, China and South Korea.

Similarly, the NRC study of advanced materials R&D globalization identified several subfields—composites, ceramics, electronics and opto-photonic materials, catalysis, and magnetic materials, among others—where large commercial and defense firms are moving R&D and customer support functions overseas to be close to new manufacturing bases they have created.[267]

A *BusinessWeek* article, "Outsourcing Innovation," identified two types of design and R&D offshoring, both of which have increased in recent years. One refers to corporate outsourcing of R&D or product design to other, foreign firms, as in the practice of companies such as Dell, Motorola, and Philips buying complete designs of digital devices from Asian developers, modifying them to their own specifications, and selling them under their own brand names.[268] Although the electronics sector has the greatest experience in this area, "the search for offshore help with innovation is spreading to nearly every corner of the economy." Other examples include Boeing working with India's HCL Technologies to co-develop software for navigation systems, landing gear, cockpit controls and other systems for the its 787

Dreamliner aircraft, pharmaceutical giant Eli Lilly teaming with Asian biotech research firms to develop new drugs, and Proctor & Gamble seeking to generate half of its new product ideas offshore by 2010, compared to 20 percent now. [269]

Although Taiwan may be one of the principal locations for contract design outfits, China and India have become leading sites for foreign direct investment (FDI) by large multinational corporations (MNCs) for establishing R&D centers, either their own or, frequently, with local partners. As Box F illustrates, the numbers and quality of U.S. MNC investments in R&D centers in China and India in particular have accelerated over the past decade. MNC's are especially attracted to these nation's abundant pools of highly-educated engineers and high-tech workers capable of taking on increasingly sophisticated high-tech work, while being willing to work for wages far below U.S. and European levels.

Some U.S. firms prefer to hold onto their critical design and development work rather than farm it out to foreign contract design and manufacturing firms. Others have increased their R&D and design capacity and employment at their labs in India, China, and Eastern Europe, while downsizing their U.S. labs. For example, Lucent Bell Labs in Murray Hill, NJ, which once employed well over 6,000 workers, is now a shadow of its former self following Lucent's merger with French telecom equipment and services giant Alcatel (forming Alcatel-Lucent) in December 2006. Meanwhile employment at its Chinese and India R&D centers has expanded.[270]

Box F
U.S. Corporate R&D Investments and Technology Transfer in China and India

Rochester Institute of Technology public policy professor Ron Hira noted in his study of R&D globalization that there is no comprehensive list of R&D investments in China by U.S. MNCs.[271] However, an ongoing Cambridge University study shows that emerging economies like India and China are fast becoming favored destinations for global R&D with top MNCs, such as GM, IBM, Cisco, Motorola and GE. According to this 2009 survey—covering 500 of the largest MNCs operating in 21 major world economies—China ranked fifth and India seventh in housing R&D activities; the United States, Germany, Japan, and the UK ranked first through fourth and France ranked sixth. India has 63 such centers while China has 98. Among countries attracting more R&D centers, China and India ranked fourth and fifth, respectively.[272]

R&D Investments in China

China has been attracting the largest number of foreign MNC's to set up R&D centers and form joint ventures. Yale School of Management dean Jeffrey E. Garten recounts in *BusinessWeek* that in 2005 General Electric had 27 laboratories in China working on projects ranging from composite-materials design to molecular molding, and Microsoft had nearly 200 researchers in China, with "Cisco, DaimlerChrysler, IBM, Intel and many others" following suit.[273] According to MBG Information Services' Charles McMillion, over 400 of the largest companies in the world had invested in China by June 2002, including Microsoft, General Electric, Sony, Exxon-Mobile, Royal Dutch Shell, General Motors, Toyota, Volkswagen, Boeing, Matsushita, Siemens, Toshiba, Intel, Kodak, Hewlett-Packard and IBM.[274] According to an estimate by China's Ministry of Commerce, by 2008, foreign MNCs had established 1,160 research institutions in China. This compares to only 30 such institutions in 1999, about 200 in 2001 and 700 by 2005.[275]

- General Motors' technology transfers to China in the 1990s took the form of joint research and development projects, and training of Chinese workers and managers.[276] In 1997, it entered into a 50-50 joint venture with Shanghai Automotive Industry for establishing a research center, which now employs 1,300 workers.[277] By 1999, both GM and Ford had established several research institutes in China devoted to developing technology.[278] In 2008, GM started construction of a new wholly-owned advanced R&D center in Shanghai to develop hybrid technology and other advanced designs, resulting in a total investment of 250 million USD. The center is expected to house 2,500 employees, of which 300 would be engaged in R&D. This was the first stage in GM's planned move of its Asia-Pacific headquarters along with other operations in China to the new center.[279]
- Lucent Technologies entered China in 1985. By 2005 its investment in China totaled 2.9 billion USD, with 8 regional offices, two Bell Labs branches, five R&D facilities and several joint ventures and wholly owned enterprises. Lucent China produces an array of telecom network equipment and solutions shipped and installed worldwide. In 2005, it employed 4,000 employees.[280] Bell Labs, which had been in China since 1997, with development labs in Beijing and Shanghai, has since built a basic research center in China, its first such facility outside the United States, to broaden and deepen its research in China, and integrate research done in the United States.[281] In 2010, Alcaltel-Lucent was chosen by China Telecom to deploy advanced network technologies in Shanghai and Shangdong province, to leverage its strong and localized R&D capacity to build a next-generation telecom infrastructure.[282]
- Most of Motorola's hardware is assembled and partly designed in China.[283] The company established its first R&D lab in China in 1993. By 2006 it had 17 R&D centers and labs in Beijing, Tianjin, Shanghai, Nanjing, Chengdu and Hangzhou provinces, employing 3,000 workers,[284] with investments of over 100 million USD annually,[285] and totaling US 1 billion USD by 2008, with plans to increase spending in product innovation and technology upgrades.[286] The centers provide Chinese operators with local access to Motorola's network technologies, including extensive R&D services for next-generation technologies and developing local talent.[287] In 2006, Motorola estimated that 10 percent of its 3,000 patents in China were obtained by local R&D center.[288] In 2007, Motorola announced the inauguration of a new R&D complex in Wangling, Beijing, which is expected to employ 3,000, including 2,000 engineers.[289]

- Intel is building a 2.5 billion USD 300mm semiconductor facility in Dalian, China, its first fab in Asia. In April 2008, the company announced a 500 million USD Intel Capital China Technology Fund for investments in wireless broadband, technology, media, telecommunications and "clean" technology.[290]
- Cummins, which in 1995 opened a diesel-engine plant in China, celebrated in 2005 its 20-year strategic partnership with China's Dongfeng Group by opening the East Asia R&D center in Wuhan Economic and Technological Development Zone. This is China's first joint-equity R&D center specializing in engine study, and represents a move from a collaboration in product development and manufacturing to joint R&D.[291]

R&D Investments in India

In 2006, India was reportedly drawing 25 percent of new global investments in R&D centers set up by MNCs, and these centers are currently among the MNCs' largest outside the U.S. or Europe. Over 200 global companies across information technology, biotechnology, chemicals, automobiles, consumer goods and pharmaceuticals have set up their R&D hubs in India. These include Oracle, Intel, Adobe, STMicroelectronics, IBM, Texas Instruments, Delphi, HP, Microsoft, GE, Philips, Motorola, Google, Cisco, Eli Lily, Bayer, Siemens and LG Electronics have all been tapping Indian talent for conducting cutting-edge research.[292]

- GM has eight research labs in India, including the India Science Lab established in Bangalore in 2003, with more than 70 percent of its researchers holding Ph.Ds. GM has also established collaborative research laboratories with Indian universities. India hosts two out of three such labs that GM has outside of the United States—out of a total of nine such labs.[293]
- Intel began its presence in India with a sales office in 1988 and established an R&D center in 1998. By 2007, it was employing 2,500 R&D workers in India and had invested 1.7 billion USD in its Indian operations. Notably, Intel's Bangalore Development center contributed to about half the work towards its "teraflop research chip," and in 2008, Intel unveiled its first microprocessor designed entirely in India—the first 45-nanometer technology designed outside of the United States.[294]
- Motorola opened its first R&D facility in India in 1991. In 2005, the company invested 85 million USD in technology and R&D, up from 50 million USD in 2002, and R&D spending was expected to grow by 10-20 percent per year. In 2005, the company also officially opened Motorola Labs India to augment its existing R&D infrastructure of more than 1,700 software engineers. The new lab engages in applied research in the areas of converged networks, enterprise applications and embedded systems, and physical sciences.[295] In 2006, Motorola launched another R&D center in Hyderabad, its second largest R&D facility in India, housing over 1,000 engineers engaged in pioneering development of new telecom switching technologies and products for a new class of computer.[296]

- Cummins, the world's leading engine producer, had manufactured engines in Pune, India for over forty years, when it opened a research & technology (R&T) center there in 2003. Much of the sophisticated software embedded in engines is designed in Cummins' Columbus, Indiana plant, but code is being written by KPIT Cummins Infosystems Ltd., in Pune. At Cummins' new R&T center, 100 Indian engineers specializing in 3-D computer modeling and simulated testing of engines and components use powerful workstations to analyze engine designs for defects and performance. Cummins' decision to open up the new research center was motivated by the desire to cut costs and gain access to India's highly educated, low-cost engineers.[297]

China, in particular, has greatly benefited from foreign corporate investment in R&D and technology transfer. The USCC's 2010 report noted that foreign direct investment (FDI) in China had grown from a mere trickle of a few billion dollars in the 1980s to more than 80 billion USD annually by 2008; it bypassed the United States as the destination for the largest amount of FDI in the world in 2003. Of this, U.S. firms accounted for 15 billion USD in 2008 alone.[298] FDI has been used not only to drive domestic economic growth through exports but also to gain access to foreign technology. For many years, U.S. firms have participated in a variety of business arrangements in China that represent one or another form of technology transfer.[299] Companies typically have agreed to donate equipment or sponsor scholarships for training Chinese workers in order to gain approval to set up facilities or enter into joint-venture manufacturing partnerships with Chinese enterprises.

As Charles McMillion has observed, "from Microsoft and Intel to General Electric and General Motors, there are few global technology firms that do not have at least one R&D center in China working jointly with Chinese state controlled firms and universities."[300] At the same time, these arrangements with foreign enterprises have been a primary source of exports out of China of high-tech goods. For example, the USCC 2010 report cites data that shows that two-thirds of the growth in Chinese exports of electronic information products in 2007 originated from foreign-owned companies, and one-sixth from joint ventures.[301]

But, as the USCC has observed, China's ultimate aim is not to promote joint ventures and foreign investment, or even just generate exports, but to create a "large and/or globally dominant state-owned-and-controlled sector."[302] That is, through all the different arrangements it has forged with foreign corporations, from offsets to joint ventures and R&D centers that facilitate the transfer of industrial technologies, China's goal is to enhance its own internal capacity for producing globally competitive, world-class technologies and products. U.S. policymakers are worried, however, not just that the migration of U.S. and other advanced industrial nation's R&D and design capabilities is helping China in its drive to become a major global economic power, but that it is boosting technology capabilities critical to improving the military-industrial prowess of a country that the Defense Department worries could become a formidable military opponent.[303]

New world leaders? Although the offshore migration of American R&D resources may provide short-run competitive advantages to the U.S. companies that engage in it, this practice has taken a toll on the nation's overall technological leadership in the world. Several studies provide strong evidence that the United States has been losing its traditional world leadership in technology and innovation, not only relative to its traditional trading partners—Europe and Japan—but also to major emerging economies, namely India and China.

- In 2005, the Task Force on the Future of American Innovation, comprised of the nation's largest high-tech and manufacturing industry trade associations and major high-tech corporations, produced a benchmark study of innovation in the United States. The study reports troubling trends in science and engineering (S&E) education, workforce, trade, knowledge creation, and R&D investment. According to this study, the United States appeared to be losing ground in every area relative to other developed and major developing countries (i.e., China), such as the share of S&E papers published worldwide[304] and R&D investment. For example, the world's fastest growing economies appear to be on track to catch up to U.S. R&D investment. Between 1995 and 2001, China, South Korea, and Taiwan together increased their gross R&D investments by 140 percent, while over this same period, U.S. investment increased only by 34 percent.[305]

- A 2009 report of the Information Technology and Innovation Foundation, *The Atlantic Century, Benchmarking EU and U.S. Innovation and Competitiveness,* reaches similar conclusions: the United States, while still *a* major leader in innovation and competitiveness, is no longer the "runaway leader in global competitiveness that some believe it to be," although it still leads Europe. The study ranks 40 countries/regions based on 16 indicators for assessing global competitiveness, which fall into six broad categories: human capital, innovation capacity, entrepreneurship, IT infrastructure, economic policy, and economic performance.[306] The United States ranked sixth in this listing, behind Singapore, Sweden, Luxembourg, Denmark, and South Korea. More significantly, the it ranked 40th in the amount of improvement in the ITIF competitiveness score between 1999-2009. By contrast, China and India were 1st and 14th respectively in the amount of improvement they made over the decade.

- In 2009, the Boston Consultant Group ranked the United States 8th among 110 nations, and second, behind South Korea, among the 20 largest countries (measured by GDP), on its International Innovation Index. The study concluded that, "Although still a top-tier player, it has fallen behind such countries as Singapore, South Korea, and Switzerland as an innovator." In addition, this report notes that the "United States is disadvantaged in several key areas, including workforce quality, and economic, immigration, and infrastructure policies." Finally, it reports that, based on its interviews with top executives, "the United States is losing its distinction as an innovation leader and may be underinvesting in its future."[307]

- The 2007 Georgia Institute of Technology's bi-annual Hi-Tech Indicators (HTI), which measures the technology-based competitiveness of 33 nations, found that China had surpassed the United States in the rankings based on the indicators in this study. According to the study, China improved its score from 22.5 in 1996 to 82.8 in 2007, improving by 9 points between 2005 and 2007 alone. The United States, which peaked at 95.4 in 1999 fell to 76.1 in 2007, dropping 6.8 points in the 2005-2007 period alone. The Georgia Tech center has been measuring high-tech competitiveness across nations for over 20 years. The model it employs assumes that technology-based competitiveness depends on the conjunction of national orientation to compete, socio-economic infrastructure, technological infrastructure, and productive capacity. Technological standing is tracked with one output factor addressing high technology export activity.[308]

Regardless of the competitiveness indexes used, even those that have consistently placed the United States at the top of competitiveness/innovation rankings, a few conclusions stand out. First, the United States remains a world leader, if not always *the* world leader, in technology competitiveness and innovation. However, there are indications that U.S. leadership has been slipping over the past decade, and this alone has raised alarm bells for many industry and political leaders. Most significantly, even though U.S. technological capabilities remain strong, other nations—most notably China, but also other Asian nations, including South Korea, Singapore, Taiwan, Malaysia and India—have been rapidly gaining ground relative to the United States and the other major economic powers, i.e., Japan and Europe.

As the Georgia Tech researchers observe, "China is rapidly heading to rival the United States as the principal driver of the world's economy—a position the USA has held since the end of World War II."[309] However, noting the impressive gains of other Asian nations, the Georgia Tech report concludes, "The expanded message is that global high tech competition will likely see not just China, but Asian economies more broadly, supplant Western leadership."[310]

Eroding leadership in emerging technologies. The U.S. ability to assert or maintain leadership in emerging technology areas is also jeopardized. Examples where the United States has begun to lag internationally are given above, including advanced materials and semiconductors R&D. As noted in Box F, Intel's "teraflop research chip" and 45-nanometer technology are being developed in Intel-funded labs in India, indicating a transfer of advanced microprocessor design capacity. Another emerging technology area where the United States has been losing ground is nanotechnology.

Additionally, U.S. entrepreneurial activity in nanomaterials is very fast-paced, but Europe has greater investment in fundamental R&D, while Asian nations, especially China, Japan and Korea, have adopted and integrated nanotechnology research into large commercial enterprises, which may ultimately lead to profitable manufacturing of nanostructured materials.[311] As a consequence, the NRS concluded, the "globalization of MSE [materials science and engineering] is narrowing the technology lead of the United States."[312] The USCC further noted that some advanced technologies that originally migrated from the United States to Taiwan are now relocating to the mainland.[313]

In many areas of advanced technology, the United States remains the leader or part of a collective leadership, most often including Japan and Germany, but also with other developed nations in Europe and Asia in selected areas. China, in particular, is not just playing catch-up with the United States and the other developed nations regarding basic manufacturing production and advanced technology areas. As the USCC 2005 report notes, China is developing and producing technology that "is increasing in sophistication at an unexpectedly fast pace."[314]

China has been able to leap frog in its technology development using technology and know-how obtained from foreign enterprises in ways that other developing nations have not been able to replicate."[315] China is rapidly becoming a source of innovative technology, and its technology research and development activities are steadily and substantially expanding. Since it has become central to the global supply for technology goods of increasing sophistication, China has gained increased leverage in global systems of production.[316]

China's increasing technological prowess gained through its policies of developing advanced technologies important to its economy also contributes to the development of advanced technologies important to China's military. At the same time, the USCC warned, China's becoming a major player at the center of the global technology supply chain raises "the prospect of future U.S. dependency on China for certain items critical to the U.S. defense industry as well as vital to continued economic leadership."[317]

b. Offshoring Critical Skills and Know-How

As the United States loses its technological edge through movements of R&D offshore, underinvestment in R&D by U.S. industry, and lack of attention by the U.S. government, which has also caused the loss of millions of skilled workers, the know-how, embodied in those displaced workers, and needed for maintaining and advancing the U.S. technology leadership vital for national security is being eroded. The dramatic loss of manufacturing jobs since 1998 afflicting almost every industrial sector was illustrated in section IIa (table II and figure 9). These losses also were accompanied by comparable losses in the number of manufacturing facilities in almost every sector, and for establishments of every size.

Along with the economic hardship suffered by U.S. workers, their families and communities wrought by this movement of jobs overseas, the nation is paying a long-term price in the deterioration of U.S. industrial and technology leadership:

- The large-scale reduction in the American high-skilled production and science and engineering workforces as manufacturing migrates offshore is leading to the loss of critical technological know-how needed to maintain U.S. leadership in technology areas critical to economic and national security;
- The deterioration in the nation's manufacturing base and technology leadership has created significant barriers to meeting the nation's near- and long-term needs for sustaining a high-skilled, high-tech workforce.

A Shrinking Skill and Knowledge Base. In the technology transfer community, the process of technology transfer has been called a "contact sport", meaning person-to-person interactions are an essential component in the exchange of knowledge, ideas, information and technical data that can enable a technology to go from the laboratory to the market place. Although the Internet and advanced telecommunications have facilitated the exchange of information between individuals across great distances, personal, face-to-face contact and exchange between people is still crucial. For example, Annalee Saxenian, regional economist, and Dean of the School of Information Management and Systems at U.C. Berkeley, has shown how California's Silicon Valley's rich culture of social networks and interactions among its high-tech professional workforce was crucial to the flourishing of innovation and the proliferation of successful high-tech firms in that region during the 1980s and 1990s.[318]

Harvard Business School professor Michael Porter has written extensively on the importance of industry clusters, such as that in Silicon Valley, to regional economies. Industrial clusters confer competitive advantages to related industries through their geographical proximity to product producers, service providers, suppliers of specialized inputs and infrastructure, supporting institutions (universities, community colleges, trade associations, unions, venture capital, and government agencies) and pools of skilled, experienced workers. These clusters foster technological innovation and are key drivers of regional economic growth. Although some drivers of innovation may be national in scope, many, if not most, are regional in nature and are tied to specific regional industrial clusters. Technological spillovers are magnified by the proximity of interdependent firms and related industries.[319]

But as U.S. firms move their manufacturing operations and plants offshore, and reduce or cease their investment at home, the advantages of regional industrial clustering fade, and R&D and technology innovation resources move away as well. Most notably, this loss includes the skilled workforces, both production and professional, which embody the know-how and skills essential for maintaining the nation's technological edge.

S&E and high-skilled employment. Although some economists and proponents of globalization have argued that the loss of manufacturing jobs has largely fallen on low-skilled production workers, a very large portion, if not most, of manufacturing workers are actually high-skilled and well-trained. In fact, they tend to be more skilled than workers in most other sectors of the economy. The manufacturing workforce includes large numbers of engineers and scientists, as well as machinists, technicians, high-skilled assemblers, machine tool operators, mechanics, process control operators, computer systems operators and inspectors, and many others types of production workers. These workers embody an enormous range of tacit knowledge and know-how that may be irretrievably lost to the American economy as manufacturing plants shut down and move overseas.

Moreover, the offshoring of R&D and design work and U.S. establishment of offshore R&D centers is displacing highly educated engineers, scientists and technical professionals. While companies such as Alcatel-Lucent, Motorola, GE, and Boeing, among many other major high-tech firms, have been cutting back on science and engineering (S&E) workers in their U.S. R&D facilities, they have been hiring at their R&D centers in China and elsewhere around the world. As high-tech semiconductor and computer makers offshore the design and manufacturing of their products to contract manufacturers and design outfits, work that was once done onshore by U.S. workers, this capacity is no longer readily available in the United States. Similarly, as aerospace companies, such as Boeing and Lockheed, make offset arrangements that shift work to foreign companies that used be done by U.S. workers—including technology development and design work—critical technological, engineering and production know-how is diminished, if not entirely lost.

As the following examples illustrate, similar trends are seen in diverse sectors that also supply critical products, technologies and systems to the defense base.

■ ***Aerospace.*** The aerospace industry's long-term employment trend has been downward since the 1980s. Total aerospace and parts (NAICS 3363) employment fell over 40 percent since 1990, dropping from nearly 900,000 to under 490,000 in 2010. Since the last employment peak in 1998, about 15 percent of jobs in this sector have been lost, probably permanently. The aerospace nonproduction and supervisory workforce, which is inclusive of the S&E workforce has suffered even greater losses, fell by more than half since 1990 and nearly 30 percent since the 1998 peak.[320]

Stanley Sorscher, legislative director of the Society of Professional Engineering Employees in Aerospace[321] (the union representing over 20,000 engineers, scientists, technical and professional employees in the aerospace industry), testified before the U.S. House Armed Services Committee about the long-term decline in aerospace S&E employment. He stated that between 1986 and 2001, the number of

U.S. aerospace S&Es fell by 83 percent, from 145,000 to 21,000, and by another 5,000 by 2005, paralleling the 18,000 machinists jobs lost over this same period at Boeing.[322] "This decline," he asserted, "dismantles our technical and manufacturing communities from within, eroding the network of relationships, expertise and authority developed over decades." Sorscher partly attributes the losses in his workforce and in U.S. technological capacity, to offset agreements, which enable foreign firms to "acquire the knowledge, skills and experience embodied in the work packages sent to their domestic firms." These firms also "will inherit the competitive advantage of future learning curve benefits. They will learn certain institutional lessons while our body of retained knowledge erodes," he warned.[323]

■ *Printed Circuit Boards.* A more troubling situation exists in the printed circuit board industry. As described above (see Section IIIb). both the PCB assembly and bare PCB industries have lost significant numbers of jobs and establishments, especially over the last decade. As the National Research Council report on the industry notes, most of these lost jobs were high-tech well paying manufacturing jobs. The NRC further notes that these cuts were made across all jobs descriptions as plants closed because of bankruptcy or relocation to Asia. Since no major technological change was introduced into the industry over the same period, productivity increases had little to do with the losses, "so the decrease can be almost wholly attributable to production moved from U.S. to overseas locations," the report contends.[324]

The NRC report also tracks the almost total loss of the technical service and engineering workforce at what it calls "Tier I" suppliers to the electronic interconnection industry in the United States. As in most U.S. manufacturing, secondary, or "Tier II," suppliers have, "with few exceptions, passed direct sales and technical support of PCB products to Tier II distributors, who have little technical background and have difficulty troubleshooting products in any depth." Thus the downsizing of this industry's workforce, which entails first and foremost the loss of skilled workers, leads to "the loss of capacity for innovation and the ability to compete for state-of-the-art contracts," followed by continued erosion of technical competency over time. "These resources," the report concludes, "most likely will not be replenished in the current environment."[325]

■ *Semiconductors.* The loss of skilled high-tech workers is taking a similar toll in the semiconductor industry. After a booming decade in the 1990s, the industry has shed over 100,000 jobs, well over one-third of its workforce, since 2000, and modest job losses continued in 2010. According to industry leader William Spencer, the production of state-of-the-art integrated circuits requires a wide variety of interdependent skills, which need to be honed constantly in order to stay on the cutting edge.[326] But, he warned that,

> . . . as the number of first-line fabs decreases and as competition grows for scarce top-level human resources, risks to the health and vibrancy of U.S. clusters grow as well. The redirection or dissolution of semiconductor production clusters in the

> United States would likely result in the loss of on-the-job training and shifts in career choices for engineers while reducing activity in associated industries, which are also high-value-added and R&D intensive. This, in turn could lead to the loss of learning skills needed for promising new sectors such as solid-state lighting and nanotechnologies, while at the same time calling into question the country's ability to retain the current level of R&D capabilities.[327]

■ *Materials.* The close linkage between manufacturing migration and the loss of technological know-how is also apparent in the metallurgical sectors. The NRC study on globalization of materials R&D associated with the continuing loss of trained researchers in metallurgy with a concomitant loss of corporate expertise in producing, refining, processing, and applying the metals that constitute the basic engineered material of industry.[328]

An aging skilled workforce. The growing loss of technical skills and erosion of the knowledge base is exacerbated in many manufacturing sectors by the aging of the skilled workforce, a large part of which will start retiring over the next couple of decades. It is not clear how new generations of workers with the right skills will be recruited to replace older workers as they retire. This concern cuts across occupational lines, from production to S&E workforces. The National Science Foundation (NSF) has predicted that the rate of growth in the number of S&E-trained persons in the workforce will be slowed as more S&E workers reach the traditional retirement age. The NSF notes that, across all S&E degree levels, by age 61 about half of S&E workers no longer work full time, and for doctorate holders, half no longer work full time by age 66. Finally, the NSF reports that a larger portion of doctorate degree holders than those with bachelors and masters degrees are approaching retirement.[329]

Sorsher noted Boeing's aging technical workforce and the "total elimination" of younger workers at the company as it has downsized. Thus, "lacking young people in the workplace, no one is present to capture and retain the body of knowledge accumulated from decades of experience. The next generation of supervisors, managers and system integrators cannot be cultivated if they are not present." As a result, "a 15-year period of experience has been forgone and cannot be recovered."[330]

Similarly, Amy Praeger of the American Shipbuilding Association testified before the USCC that since 1991, 24,000 engineers and production jobs were lost in the U.S. shipbuilding industry, with many skilled workers leaving because the sector does not have consistent and stable contracts with the military, a major and important customer for this sector. She added that replacing this skilled workforce could take 15 years in order to replicate the lost skill level.[331] Along the same lines, the majority of the current approximately 30,000 workers in the printed circuit board industry will reach retirement in the 2015 to 2020 time frame. According to the NRC, current industry trends "will make it difficult for corporate leadership to attract a future talent pool to continue to serve the industry's requirements."[332]

Losing the edge. Ever since the early 2000s, industry, government, academic and political leaders have been raising the alarm that the United States has begun to lose its scientific and technological leadership in the world. For example, the 2005 NRC report, *Rising Above the Gathering Storm,* acknowledges that while the United States remained the undisputed leader in basic and applied research, and an international leader in applying research and innovation to the improvement of economic performance,[333] it was "deeply concerned that the scientific and technological building blocks critical to our economic leadership are eroding at a time when many other nations are gathering strength."[334]

Several of the most important trends that suggest the U.S. S&T leadership is eroding are summarized in Box G. Drawing on National Science Foundation and Organization for Economic Co-operation and Development (OECD) data, these trends include U.S. and international comparisons of R&D performance and spending, ratios of R&D spending and GDP, numbers of S&E publications (article output), numbers of researchers, numbers of first university natural sciences and engineering (NS&E) degrees (bachelors degree in the United States) and the ratio of this number to the college-age population, and the number of NS&E doctoral degrees awarded. These indicators allow useful comparative assessments of the size, scope and strength of national S&T institutions and capabilities.

By any measure, the United States was unquestionably the leader in science and technology for the last half of the 20th century, from the 1950s through 2000. Beginning in 2000, although in absolute terms America has continued to spend more on R&D, it has more scientists and engineers in its workforce, and with notable exceptions continues to turn out more S&E graduates than any other nation, the trends in these areas slowed or even reversed. Although some of the trends showed some sign of recovery from 2004 on, it remains to be seen if the upward movement of prior decades will be restored, or whether the U.S. R&D and S&E workforce patterns—especially relative to China and other economic competitors—will settle into a generally slower rate of growth, if not decline.

What direction these trends take, of course, will depend on economic factors and government policies, neither of which can be known *ex ante*. The impacts on these trends on the recent economic crisis and financial system meltdown are also uncertain, though it is possible, if not likely, that these events have put a damper on these trends. One trend remains clear and unchanged, however: China—and to a lesser extent, other emerging economies—has rapidly been gaining ground in all areas of science and technology, relative to the United States, as well as to the other major advanced industrial nations.

The implication of these, and the many related trends described in this report, is that the U.S. industrial skill and knowledge central to maintaining on the cutting edge in technology development and innovation in areas ultimately vital to maintaining the nation's national security industrial base, has been deteriorating, both absolutely and relatively. Other nations are challenging American technological leadership, which ultimately rests on having access to a broad, robust foundation of manufacturing and technological skills and knowledge.

Box G
U.S. and International Comparisons of R&D and S&E Trends

R&D Performance and Spending

- Private industry accounts for the largest share of U.S. R&D performance and expenditures. Its share of U.S. R&D performance increased from 66 percent in the early 1970s to a high of 75 percent in 2000, and then dipped to 69 percent in 2002, following the 2001-02 recession, when firms curtailed R&D growth. Similarly, private industry funding for R&D as a share of the U.S. total rose from about 40 percent in the early 1970s to a peak of 70 percent in 2000, before dipping to 64 percent in 2004. In constant dollar terms, the drops in industrial R&D performance and funding after 2000 were the largest in the post-WWII period. Private industry R&D performance and funding then grew again, to 67 percent in 2008.[335]
- Over the past two decades, R&D performance and funding were dominated by the 30 developed member nations of the Organization for Economic Co-operation and Development (OECD). For more than a decade, however, selected economies in Asia, Latin America, and elsewhere have been rising rapidly. The National Science Foundation reports that the average annual real R&D growth rate of nine non-OECD nations (Argentina, China, Israel, Romania, Russian Federation, Singapore, Slovenia, South Africa, and Taiwan) was 15.5 percent from 1995 to 2005, compared with an OECD average of 5.8 percent.[336] The combined share of the United States and Japan, the two largest R&D-performing countries, declined from 56% of the world R&D total in 1995 to 47% in 2007.[337]
- The expansion of China's R&D spending and performance has been the most rapid and sustained. According to OECD data, China's R&D expenditures in 2000 (45 billion USD) was the fourth largest in the world, and increased in 2007 to an estimated 102 billion USD, pushing it to third place, behind Japan.[338] As the NSF reports, China's "nearly decade-long, steep ramp-up of R&D expenditures and R&D is unprecedented in the recent past."[339] Its real average annual growth rate between 1997 and 2007 was exceptionally high at just above 19 percent—compared to the U.S. rate of 3.3 percent.[340] Other less-developed countries on the way to becoming large R&D performers include Brazil (14 billion USD in 2004) and India (21 billion USD in 2000).[341]
- The United States ranked eighth in the world in terms of reported R&D/GDP ratios (2.7 percent in 2007) in the most recent year for which data was available, falling behind Israel, Sweden, South Korea, Finland, Japan, Switzerland, and Iceland. The

U.S. ratio in 2007 was still somewhat lower than its 2000-01 levels. Despite its quickly rising investment in R&D, China reported a ratio of only 1.5 percent in 2007, but this still represents a dramatic rise from 0.6 in 1995, and it must be kept in mind that China's GDP has been marked by sustained, record growth.[342]

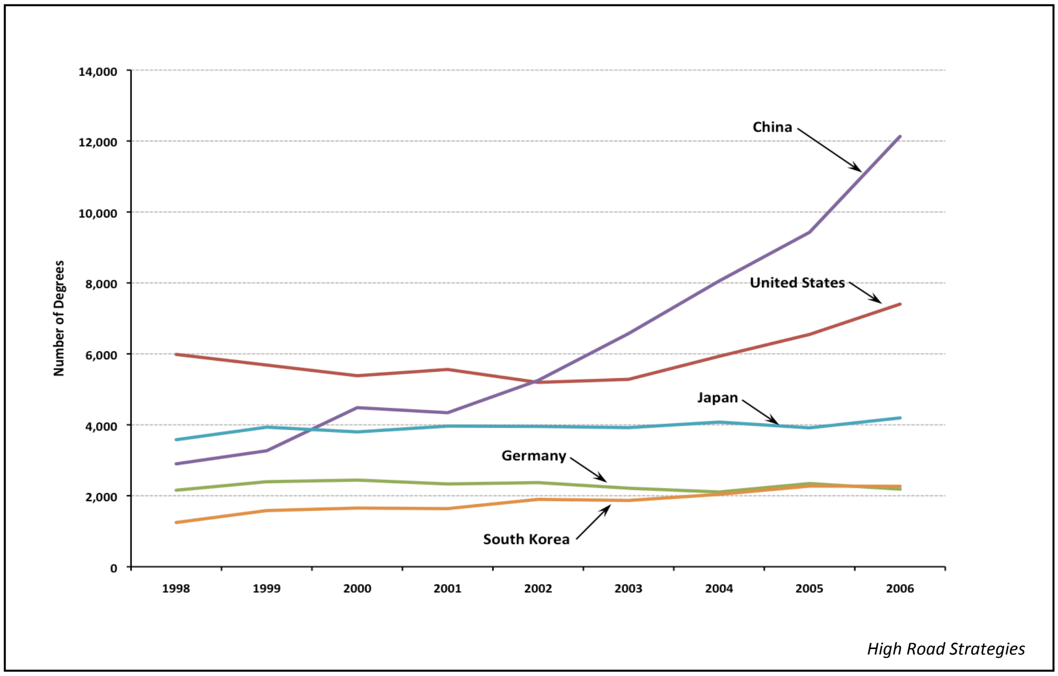
- The United States accounts for the largest share of world S&E article output by far, though it lost ground between 1995 and 2007, as other nations' outputs have grown. The U.S. output grew at an average annual rate of 0.7 percent, less than most other major developed nations' (Japan, Germany, Canada, Italy, Finland) and many large developing nations' (China, India, Brazil) output, falling from 34.2 percent to 27.7 percent of the world total. China had the fastest growing output in the world, 16.5 percent average annual growth (South Korea's rate was second, with 14.1 percent); China's share rose from 1.6 percent to 7.5 percent of the world total. In 2007, China was the world's 2nd largest producer of S&E articles, followed by Japan, United Kingdom, and Germany—a meteoric rise from 15th place in 1995.[343]

S&E Labor Force

- The United States has historically had the largest reported number of researchers in the world, a number that increased by 42 percent between 1995 and 2007. Over the same 12-year period the number of researchers in China grew by 173 percent to more than 1.4 million in 2007—a rise from about half the U.S. number in 1995 to close to the estimated U.S. figure, and greater than that of the EU-27. South Korea's number of researchers also grew dramatically, by 121 percent, while Japan's number of researchers grew by only 5 percent over this period.[344]
- The United States has fallen from one of the top countries in terms of the ratio of first university natural sciences and engineering (NS&E) degrees to the college-age population (20-24-year-olds), to near the bottom of 23 countries for which data are available. The NSF reports that in 1975, only Japan had a higher ratio than the United States. By 1990, a few other countries/economies had higher ratios than the United States, and by 2005, nearly all nations in that group had surpassed the U.S. ratio.[345] In addition, the number of first university NS&E degrees grew sharply in China, more than trebling between 1998 and 2006, compared to an 18 percent increase for the United States. China has long surpassed the United States in total first university NS&E degrees. While it granted only slightly more degrees than the United States in 1998, it granted degrees to well over three times the U.S. figure in 2006.[346]
- In 2006, the United States awarded the largest number of S&E doctorates of any country (about 30,000), with China second (about 23,000), followed by Russia, Germany, and the United Kingdom. In terms of the number of NS&E doctoral degrees, the United States was number one again in 2006, but China has been rapidly catching up, and has possibly already surpassed the United States. The number of engineering doctorates follows a similar pattern (see figure 20), though China's engineering doctoral awards surpassed the number awarded by the United

States in 2002. Before 2002, the United States accounted for the largest number of such degrees (about 6,000) awarded in the world, and China awarded less than half that. In 2006, China granted 12,130 awards compared to 7,402 in the United States, and this differential appears to be steadily growing.[347]

Figure 20
Number of Engineering Doctorates Awarded, 1998-2006
U.S., Japan, Germany and China



Source: National Science Board, Science & Engineering Indicators, 2010

Many of these nations have implemented strategic industrial policies to strengthen their technological capabilities, innovation, and competitiveness built around investments to attract and build a strong, modern manufacturing base. U.S. policies in contrast have encouraged U.S. manufacturers to move more and more of their operations offshore, increasingly moving up the technological value chain, which has encouraged the migration of R&D capacity and technological know-how, and enhances the competitiveness of economic, and potentially military, competitors.

This diagnosis is sobering. The loss of skilled production workers, scientists, engineers, and technical and professional workers across the manufacturing sector means that the next best idea, the next innovation, and the next generation of products will be made somewhere else, not in the United States. This loss of manufacturing capacity—and the intellectual and technical capability to make things—is a profound threat to the nation's economy and national security. The seed corn of our future is being planted in someone else's economy.

V. Conclusion

Although America's manufacturing sector is still the largest, most productive, and most innovative in the world, the broad domestic and global economic trends examined in this report provide substantial evidence that the U.S. manufacturing base has been undergoing a steady and potentially dangerous erosion, especially over the last decade. Manufacturing's share of U.S. GDP has been falling steadily since the 1960s, but dropped since 2000 at twice the rate of the previous 15 years. Not only has the United States lost over 6 million manufacturing jobs—with manufacturing employment falling to its lowest level since 1940—nearly 60,000 manufacturing facilities of all sizes, including one-third of plants with over 500 employees, have disappeared from America's shores since 1998.

U.S. manufacturing competitiveness also has been declining in global markets, as indicated by America's massive and steadily growing trade deficits in goods—alleviated only by the recent recession—including growing trade deficits in advanced technology products, once a major area of American comparative advantage, and rapidly increasing foreign import penetration into U.S. markets.

Even economic indicators that some analysts point to as indicators of manufacturing's strength show clear evidence of weakening upon closer examination. While U.S. manufacturing's real value-added has generally been positive, its annual rate of growth since 2000 has been substantially lower than its growth rates in previous decades. Similarly, manufacturing industrial capacity growth and capacity utilization have been much lower since 2000 compared to previous periods.

These trends are replicated in nearly every major industry within the manufacturing sector. Industries as far-ranging as semiconductors, printed circuit boards, machine tools, advanced materials, ball bearings, optoelectronics, and even aircraft manufacturing have experienced the movement of significant, and in some cases large, shares of their production capacity to lower-cost foreign locations. Since a wide variety of manufacturing industries are inclusive of subsectors that supply products, components and technologies that the Pentagon considers important to defense—and are critical sources of innovation, the significant declines in plant capacity and jobs raise serious concerns about their long-term ability to remain sufficiently innovative and robust to meet military supply needs, especially during periods of international crisis.

The erosion and overseas migration of domestic manufacturing is also weakening America's R&D and innovation capacity, and undermining its global technological leadership. As shown in this report, the design, development and production of commercial and defense-specific technologies and products are tightly linked. In every industry sector examined, R&D capacity has been following production offshore or, in the case of aerospace, has been purposely given to foreign producers in offset arrangements attached to sales contracts. If the civilian manufacturing base that is critical to maintaining the national innovation system deteriorates, and America's innovative capacity moves overseas to be closer to production and the necessary support base, the underlying technological capability for the nation's defense industrial base, also will deteriorate. And as the United States loses its technological edge through movements of R&D offshore, underinvestment in R&D by U.S. private industry, and lack of attention to this critical loss by the U.S. government—with the shedding of millions of skilled workers as a result—the know-how needed for maintaining and advancing U.S. technology leadership vital for national security, and embodied in those displaced workers, is being lost as well.

Indeed, as shown in a number of studies discussed here, U.S. manufacturing and technological leadership has been slipping over the past decade, not only relative to its traditional trading partners—Europe and Japan—but to major emerging economies, most notably China and India, but also to other Asian nations, such as Korea, Singapore, Taiwan, and Malaysia. For example, a recent joint study by Deloitte Touche Tohmatsu and the U.S. Council on Competitiveness, ranked the United States fourth—*after* China, India and Korea—in its multifaceted global manufacturing competitiveness index. For each of the leading Asian countries, strength in research and development, innovation, and the availability of highly skilled workers, scientists, researchers, and engineers were identified as key drivers in their competiveness designation. Meanwhile, the United States was projected to fall to fifth place in the rankings, overtaken by Brazil, in 5 years.[348]

The findings of this report point to important implications regarding public policies for strengthening the nation's defense industrial base. Programs such as the Pentagon's "trusted" investments in critical defense technologies for which domestic capacity has all but disappeared, and the more controversial "Buy America" requirements on defense procurement remain important, and should be supported. However, as one defense analyst quipped, referring to the DOD's "trusted" approach for the PCB industry, it is no more effective than "putting a Band-Aid on a bullet hole."[349] Only a comprehensive strategy aimed at reversing the erosion in the nation's overall manufacturing base will be sufficient for preserving and revitalizing the nation's defense industrial base in the coming decades.

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Endnotes

I. Introduction

1 Although the focus of this report is on the defense industrial base, we can think in terms of national security industrial base which encompasses those industries needed to support not only the Pentagon and the military services, but the missions of the Department of Homeland Security, the federal intelligence agencies, and even the capabilities of some civilian agencies, such as the Department of Energy, which manages national labs and nuclear weapons systems, and the National Aeronautics and Space Administration. Hence, the findings of this report are relevant for maintaining the strength of the whole national security base.

2 Aerospace Industries Association (AIA), "AIA White Paper on the Industrial Base Provisions (Title VIII, Subtitle B) in the House of Representatives version of the FY 2004 National Defense Authorization Act H.R. 1588)," (Washington, D.C., July 7, 2003).

3 "Assessment Of Industrial Base Assessments: There Is Little To Worry About, Or Is There?" *Manufacturing & Technology News (M&TN),* Vol. 12, No. 6 (March 22, 2005), 3-4. See also Department of Defense (DOD), *Annual Industrial Capabilities Report to Congress*, (Washington, DC: February 2005); —, *Foreign Sources of Supply: Assessment of the United States Defense Industrial Base* (Washington, DC, November 2004). These and other defense industrial base capabilities studies are available on the Internet, http://www.acq.osd.mil/ip).

4 AIA, "AIA White Paper on the Industrial Base Provisions."

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6 For example, see Michael Webber, "Erosion of the Defense Industrial Support Base." In Richard McCormack (ed.) *Manufacturing A Better Future For America,* (Washington, DC: The Alliance for American Manufacturing, 2009), 245-280; Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, National Academy of Sciences (NAS), National Academy of Engineering, Institute of Medicine, *Rising Above the Gathering Storm* (National Academies Press, Washington, DC: October 2005); Department of Defense Advisory Group on Electron Devices (AGED), *National Technology Leadership Forum Microelectronics Study,* Washington, DC. (September 24, 2002).

7 Paul Kennedy, *The Rise and Fall of the Great Powers* (New York: Vintage Books, 1989), 539.

II. Indictors of Decline

8 See BEA online, *www.bea.gov/industry/iedguide.htm#gdpia_ou*, and also U.S. Department of Commerce, Bureau of Economic Analysis, *Measuring the Nation's Economy: An Industry Perspective, A Primer on BEA's Industry Accounts,* Washington, DC, August 2009.

9 See online Federal Reserve Board (FRB) databases: *www.federalreserve.gov/econresdata/releases/statisticsdata.htm*. According to the Federal Reserve Board, which tracks and generates data on industrial capacity, capacity utilization, and industrial production "[t]he capacity indexes capture the concept of sustainable practical capacity, which is defined as the greatest level of output that a plant can maintain within the framework of a realistic work schedule after taking account of normal downtime and assuming sufficient availability of inputs to operate the machinery and equipment in place." See *Carol Corrado, Charles Gilbert, and Richard Raddock,* "Industrial Production and Capacity Utilization: Historical Revision and Recent Developments," *Federal Reserve Bulletin*, vol. 83 (February 1997), 67-92.

10 See BLS, *QCEW* online, *http://www.bls.gov/cew/cewsize.htm*. The establishment size categories include establishments with less than 5 employees, with 5 to 9 employees, 10 to 19 employees, 20 to 49 employees, 50 to 99 employees, 100 to 249 employees, 250 to 499 employees, 500 to 999 employees, and 1,000 or more employees. Establishments with fewer than 50 employees accounted for 85 percent of all manufacturing establishments in 2004, up one percentage point from the share this size category maintained throughout the 1990s. Plants with 50-249 employees accounted for a little less than 14 percent in 2004, a drop from a little less than 15 percent, the share that this size category maintained prior to 1999. Similarly, the share of plants with over 500 employees also dropped slightly from 1.2 percent to 1 percent over the same period. This reflects the relatively larger numbers of medium-to-large establishments that closed compared to small manufacturing shops that closed over the last 6 years.

11 The trade data used in this report is from the Foreign Trade division of the U.S. Census Bureau, which is considered the official source for U.S. export and import statistics and responsible for issuing regulations governing the reporting of all export shipments from the United States (see http://www.census.gov/foreign-trade/). Detailed import and export data for industries and products are also available from the U.S. International Trade Commission website (see dataweb.usitc.gov).

12 The import penetration rate (IPR) for a given product for a particular period is calculated by first subtracting exports (Ex) from total production shipments (PS) for that product, and then adding imports (Im), and finally, dividing this value by total imports (i.e., IPR=(PS-Ex+Im)/Im).

13 See Alan Tonelson and Sarah Linden, "Import Growth Depressing U.S. Industrial Output, Advanced U.S. Manufactures Keep Losing Ground in Home Market," *USBIC Import Penetration Survey 2010*, (Washington, DC: U.S. Business and Industry Council, 2010); Alan Tonnelson and Peter Kim, "Imports Seizing U.S. Market Share Throughout Manufacturing Sector; "High-tech" sectors just as vulnerable as "low-tech." USBIC Research Alert (Washington, DC: U.S. Business Industry Council, December 4, 2006).

14 The Bureau of Economic Analysis provides time series data on this contribution, which, BEA notes, depends on both an industry group's real growth rate and its relative size. It—what is "it"??? is the product of its share of current-dollar GDP and its real GDP-by-Industry growth rate.

15 Data source is BEA: *http://www.bea.gov/industry/gdpbyind_data.htm*.

16 Data is derived from Federal Reserve Board (FRB), *Federal Reserve Statistical Release, Industrial Production and Capacity Utilization, Industrial Capacity: Manufacturing, Mining & Utilities* (Washington, DC: April 10, 2006), Tables 7 & 8; G.17 Supplement Tables 2, 3. Selected high-tech industries include computers, communications equipment, and semiconductors and related electronic components, which comprise the NAICS 3-digit subsector 324, computer and related products manufacturing.

17 These declines occurred in 2004 for manufacturing, and 2003 and 2004 for manufacturing excluding high-

tech industries.

18 Data in this discussion derived from FRB, *Federal Reserve Statistical Release* (2006).

19 BLS, *QCEW.* Establishments with fewer than 50 employees accounted for 85 percent of all manufacturing establishments in 2004, up one percentage point from the share this size category maintained throughout the 1990s. Plants with 50-249 employees accounted for a little under less than 14 percent in 2004, a drop from a little under less than 15 percent, the share that this size category maintained prior to 1999. Similarly, the share of plants with over 500 employees also dropped slightly from 1.2 percent to 1 percent over the same period. This reflects the relatively larger numbers of medium-to-large establishments that closed compared to small manufacturing shops that closed over the previous 6 years.

20 BLS, *QCEW*. Leather and allied products, a much smaller sector than apparel, also lost more establishments over the first period than the second. Printing and related support activities lost in both periods, but well over three times the number in the latter than the former period. In contrast, the beverage and tobacco products sector was the only 3-digit manufacturing industry to actually gain establishments over both periods, though it lost a net number of establishments of over 500 employees in the latter period.

21 BLS, *QCEW.* Other large net losers of establishments with 500 or more employees after 1998 include textile mills and leather and allied products sectors saw over half their plants of this size close, while apparel suffered a loss of 45 percent in this size category—also wood products (a 35.6 percent loss), plastics and rubber products (31.1 percent), paper (27.6 percent), and furniture and related products (24.6 percent).

22 All manufacturing employment data is categorized according to the NAICS, and originates from the Bureau of Labor Statistics (BLS) online tables, http://www.bls.gov.

23 Data source is the BLS.

24 A note of caution is warranted, however. The correlation between establishments closing and jobs being lost is not one to one. Both sets of data show net figures, reflecting what remains after numerous establishments are started as well as closed, and jobs created as well as terminated. Second, the loss of an establishment does not necessarily determine the fate of its workforce. For example, when a plant closes, not all of its workers may lose their jobs, as many could be transferred to other facilities owned by the same company, or re-employed by other manufacturing enterprises of different sizes. Plants can also consolidate their workforces, which can decrease the number of plants of one size, while increasing the numbers in a larger category, without necessarily shedding workers. Job losses also occur for many other reasons not associated with establishment closures. For example, a company may offshore only a portion of its work—or cutback its workforce for any number of reasons—resulting in a mass layoff but not a plant closure (though that establishment may drop to a smaller size category).

25 Because of the severe recession, which dampened demand for all goods, the goods deficit dropped significantly to 501.3 billion USD in 2009. All the trade data is Census Basis and from the U.S. Census Bureau.

26 All the data are for NAICS-based products. The balances are calculated using the F.A.S. ("free alongside ship") Value Basis for estimating exports and Consumption Imports using the Customs Value Basis.

27 U.S. Census Bureau.

28 To calculate the ATP trade balance, the U.S. Census Bureau tracks the trade flows for about 500 products from recognized high technology fields which represent leading-edge technologies in those fields and that constitute a significant part of all the items covered in the selected classification.

29 See Tonelson and Linden, *USBIC Import Penetration Survey 2010*. The outlier industries that have actually seen their IPRs decline over the decade include computer storage devices (a 1.8 percent decline, 66.7 percent in 1997 to 64.9 percent in 2007), electric capacitors and parts (a 6.9 percent decline, 69.1 percent down to 62.1 percent), and heavy-duty trucks and chassis (down 10.8 percent, from 62.5 percent to 55.8 percent).

30 In 1997, the Census Bureau and the other federal statistical agencies (i.e., BLS, BEA, etc.) started to switch over from the older Standard Industrial Classification (SIC) system to the National Industrial Classification System (NAICS), in how it collected, categorized, and reported industrial statistics (employment, value of shipments, value-added, capital expenditures, industrial output, capacity utilization, etc.). The USBIC study found that IPRs have been increasing from as early as 1992 when data was collected under the SIC system.

31 For discussion of the productivity vs. trade debate see: Josh Bevins, "Trade, jobs, and wages," *EPI Issue Brief #244* (Washington, DC: Economic Policy Institute, May 6, 2008); —, "Trade deficits and manufacturing job loss: Correlation and causality," *EPI Issue Brief #171* (Washington, DC: Economic Policy Institute, March 13, 2006) online: *http://www.epi.org/authors/bio/bivens_josh/*; —, "Shifting blame for manufacturing job loss: Effect of rising trade deficit shouldn't be ignored," *EPI Issue Brief #149* (Washington, DC: Economic Policy Institute, April 8, 2004). For additional literature on trade and job displacement including the impact of

NAFTA, and other trade agreements, see: Robert E. Scott, "Trade Policy and Job Loss, U.S. Trade Deals with Colombia and Korea Will be Costly," *EPI Working Paper #289,* (Washington, DC: Economic Policy Institute, February 25, 2010); —, "The Burden of Outsourcing, U.S. non-oil trade deficit costs more than 5 million jobs," *EPI Briefing Paper #222* (Washington, DC: Economic Policy Institute, October 2, 2008); —, "NAFTA's Legacy, Rising trade deficits lead to significant job displacement and declining job quality for the United States," *EPI Briefing Paper #173,* (Washington, DC: Economic Policy Institute, September 28, 2006).

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33 See Ibid.; Bivens, "Shifting blame."

34 Bivens, "Trade, jobs, and wages."

35 Scott, "Trade Policy and Job Loss."

36 Scott, "NAFTA's Legacy."

37 Robert E. Scott, "Costly Trade With China: Millions of U.S. jobs displaced with net job loss in every state," *EPI Briefing Paper #188* (Washington, DC: Economic Policy Institute, May 1, 2007), online: http://www.epi.org/authors/bio/scott_robert_e/.

38 Robert E. Scott, "The China Trade Toll, Widespread wage suppression, 2 million jobs lost in the U.S.," *EPI Briefing Paper #219* (Washington, DC: Economic Policy Institute, July 20, 2008).

39 Ibid.; See also Robert E. Scott, "U.S.-China Trade, 1989-2003, Impact on jobs and industries, nationally and state-by-state." A Research Report Prepared for the U.S.-China Economic and Security Review Commission, *EPI Working Paper #270,* (Washington, DC: Economic Policy Institute, January 2005).

40 Kate Bronfenbrenner et al, "Impact of US.-China Trade Relations on Workers, Wages, and Employment Pilot Study Report," Submitted to the US-China Security Review Commission/US Trade Deficit Review Commission (Washington, D.C., June 30, 2001); Kate Bronfenbrenner and Stephanie Luce, "The Changing Nature of Corporate Global Restructuring: The Impact of Production Shift on Jobs in the US, China, and Around the Globe," Submitted to the US-China Economic and Security Review Commission (Washington, D.C., October 14, 2004).

41 They further report that out of announced or confirmed shifts of 48,417 jobs out of the United States, 23,396 went to Mexico, 8,283 to China, 3,895 to India, 5,511 to other Latin American countries, 4,419 to other Asian countries, and 2,933 to all other countries. They note that nearly half the recent production shifts were "simultaneous shifts to 'near-shore' countries in Latin America (primarily Mexico) and to China and other 'offshore' countries in Asia," unlike in 2001, where most of the shifts were simple site-to-site shifts—one company shifting production from the US to a single destination country." Bronfenbrenner and Luce, "The Changing Nature."

42 These reports include: AFL-CIO Industrial Union Council, *Ohio Job Exports* (September 22, 2004); —*Washington State Job Exports: An Analysis of the Role Trade Plays in Manufacturing Job Loss,* Washington, DC (October 12, 2004); —*Wisconsin Job Exports: An Analysis of the Role Trade Plays in Manufacturing Job Loss* (October 18, 2004); and —*Pennsylvania Job Exports: An Analysis of the Role Trade Plays in Manufacturing Job Loss* (October 18, 2004). A fifth report, using a truncated methodology based solely onto Trade Adjustment Assistance (TAA) certification data from the U.S. Department of Labor, shows a similar result in Minnesota: AFL-CIO IUC, *Minnesota Job Exports: An Initial Analysis of the Role Trade Plays in Manufacturing Job Loss,* (October 27, 2004).

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44 Susan Houseman, Christopher Kurz, Paul Lengermann, and Benjamin Mandel, "Offshoring and the State of American Manufacturing," *Upjohn Institute Working Paper No. 10-166* (W.E. Upjohn Institute for Employment Research, June 2010); Susan Houseman, "Outsourcing, Offshoring, and Productivity Measurement in U.S. Measurement," *Upjohn Institute Staff Working Paper No. 06-130* (W.E. Upjohn Institute for Employment Research, June 2006, Rev. September 2006, April 2007).

III. Eroding Industrial Sectors

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46 NRC, *Defense Manufacturing in 2010,* 11.

47 Webber, "Erosion," 251.

48 *The Defense Production Act of 1950, As Amended* (50 U.S.C. App.§ 2061 *et seq*.) Current through P.L. 107-47, enacted October 5, 2001 (Washington, D.C., April 2002), Sec. 702(6)/(7), 33. A domestic source is a "business concern" that "performs in the United States or Canada substantially all research and development, engineering, manufacturing, and production activities required of such business concern under a contract with the United States relating to a critical component or a critical technology item." This includes businesses that procure from such business concerns "substantially all of any components and assemblies required under a contract with the United States relating to a critical component or critical technology item."

49 U.S.-China Economic and Security Review Commission (USCC), *2005 Annual Report to Congress*, (Washington, DC, November 2005), 85-86.

50 DOD, *Annual Industrial Capabilities Report* (2005), 36-37.

51 Ibid.

52 DOD, *Annual Industrial Capabilities Report* (2005), 35-36.

53 "Defense Department Hires Science Academy To Assess Vulnerability of U.S. Circuit Board Industry," *Manufacturing & Technology News,* vol. 12, No. 3 (February 9, 2005), 1ff .

54 NRC, *Defense Manufacturing in 2010,* 32-33.

55 Webber, "Erosion," 251. Webber used the following criteria in selecting industries that make up manufacturing support base: "Their technological advances impact the capabilities of upstream producers or integrators; their output is embedded, integrated or involved in the manufacturing of larger systems; and their output must be integrated into more than one type of system." For example, he notes that electronics fits into a range of consumer, military and other integrated products. On the other hand, jet engines do not qualify, as they are dedicated to one type of system. His study also does not encompass the chemicals, pharmaceutical or software production industries, because their connection to mechanical systems is not explicit, "though clearly they are an important area for continued innovation of U.S. industry." At the same time, machine tool industries are included, explains Webber, because "the ability to manufacture more complicated forms with better machine tools enables many more design possibilities." That is, machine tools are an enabler and play an essential function in innovation. On the other hand, his study does not encompass the automotive, agricultural or aerospace equipment industries, as they are integrated systems that "do not qualify as components of the underlying manufacturing support base."

56 Ibid., 275.

57 William J. Spencer, "New Challenges for U.S. Semiconductor Industry," *Issues in Science and Technology* (Winter 2004), 79-86:81.

58 USCC, *2005 Annual Report*, 97

59 Spencer, "New Challenges," 79.

60 Department of Defense (DOD) Office of the Under Secretary for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on High Performance Supply* (Washington, DC: February 2005), 27.

61 Spencer, "New Challenges," 79.

62 AGED, *National Technology Leadership Forum*. Also cited in "DOD Technology Advisory Group Says Military Capability Is In Doubt Due To Loss Of Electronics Industry," *Manufacturing & Technology News,* Vol. 10, No. 10 (May 16, 2003), p.1, 4-5.

63 Board on Science, Technology and Economic Policy, National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry* (Washington, DC: National Academies Press, 2003). See also "U.S. Semiconductor Industry Is In Trouble, Says National Academy of Sciences Panel," *Manufacturing & Technology News,* Vol. 10, No. 10 (May 16, 2003), 8.

64 USCC, *2005 Annual Report*, 85-112, esp. 104-105.

65 Semiconductor Industry Association (SIA), *China's Emerging Semiconductor Industry* (Washington, DC, October 2003).

66 Senator Joseph I. Lieberman, *White Paper: National Security Aspects of the Global Migration of the U.S. Semiconductor Industry* (Washington, DC, June 2003).

67 Webber, "Erosion," 269. He reports that employment in this industry dropped more than one-third, from 310,000 in 2001 to 200,000 in August 2008, which is below the levels at the end of the 1991 recession. GDP dropped from approximately 76 billion USD in 2000 to 49 billion USD in 2001 and then rose up to 60 billion USD in 2005. The number of establishments (all sizes) fell from 1,640 in 2001 to 1546 in 2004, rose to 1,683

in 2006, before falling back to 1,564 in 2008. Establishment numbers are from *Bureau of Labor Statistics, Quarterly Census of Employment and Wages* (QCEW).

68 Tonelson and Linden, *USBIC Import Penetration Survey 2010*.

69 DOD, *Report of the Defense Science Board*, 28.

70 Ibid., 20-21, 28

71 "U.S. Becomes A Bit Player In Global Semiconductor Industry," *Manufacturing & Technology News (M&TN)*, Vol. 17, No. 3 (February 12, 2010), 1, 6-7. Europe and the Middle East each had 11 percent of world capacity, China had 9 percent (up from 2 percent in 2001), and Southeast Asia had 6 percent.

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73 Ibid.

74 Cited in ibid., 7

75 U.S. Government Accountability Office (GAO), *Offshoring, U.S. Semiconductor and Software Industries Increasingly Produce in China and India,* [GAO-06-423] (Washington, DC, September 2006).

76 DOD, *Report of the Defense Science Board*, 19.

77 "U.S. Becomes A Bit Player," *M&TN*.

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79 Ibid., 18-19.

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82 "Loss of 50 Percent Of U.S. Commercial Mask Industry Raises National Security Alert," *Manufacturing & Technology News,* Vol. 11, No. 22 (December 17, 2004), 1ff. The article reports that as of December 2004, one of two U.S. photomask companies – DuPont Photomasks – was in the process of being acquired by Japan's Toppan Printing Co. Once the acquisition is complete, only one remaining merchant mask house will be left in the United States: Photronics, though IBM, Intel and Micron still retain captive mask operations for their own fab lines. Nevertheless, these four together, industry executives warn, will not be able to fund the investment in R&D needed to stay in the global game.

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84 Spencer, "New Challenges," 84.

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90 DOD, *Report of the Defense Science Board*, 28.

91 Ibid., 22.

92 Ibid. A Trojan horse is a program that disguises itself as another program. Similar to viruses, these programs are hidden and usually cause an unwanted effect, such as installing a back door to a computer system that can be used by hackers.

93 Ibid., 25.

94 Committee on Manufacturing Trends in Printed Circuit Technology, Board on Manufacturing and Engineering Design, National Research Council (NRC), *Linkages: Manufacturing Trends in Electronics Interconnection Technology* (Washington, DC: National Academies Press, 2005.

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96 NRC, *Linkages.* See also "Defense Department Hires" *M&TN.*

97 "America's Oldest Printed Circuit Board Company Closes Its Doors," *Manufacturing & Technology News,* Vol. 16, No. 13 (July 28, 2009).

98 "A conversation with ... Michele Nash-Hoff: author, can American manufacturing be saved: why we should

and how we can." *Products Finishing*. 2010. *HighBeam Research.* (July 3, 2010). http://www.highbeam.com/doc/1G1-218592026.html.

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104 Roy Sakelson, "America's dynamic duo: two American printed circuit makers—Electropac and Hallmark—are on opposite sides of the country. . . . the harsh realities of the global economy," *CircuiTree*. March 1, 2005. *HighBeam Research.* (July 3, 2010).

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110 NRC, *Linkages.*

111 Mike DuBois, "An Inside Look."

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114 "Ex-Marine Tells It Like It Is," *M&TN*.

115 NRC, *Linkages*, 9-10.

116 "Ex-Marine Tells It Like It Is," *Manufacturing & Technology News* (July 21, 2004), ibid.

117 "Defense Department Hires" *M&TN.*

118 "Ex-Marine Tells It Like It Is," *M&TN*.

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179 Platzer, "U.S. Aerospace Manufacturing."

180 BLS, *QCEW*.

181 BLS, *QCEW*. The largest losses were in plants of over 500 employees—almost one-fifth the number of employees over the decade

182 BLS, *QCEW*. This still was not as great a loss as the 30 percent and 26 percent decline, respectively, in these segments between 1990-1999—again, the biggest losses in plants with over 500 employees—largely due to the recession and post-Cold War restructuring early in the decade.

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score, it is still ranked second, ahead of Japan, Germany and the UK.

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338 NSB, *S&E Indicators 2010.*

339 NSB, *S&E Indicators 2008.* The NSF notes however that these are estimates, as given the lack of R&D-specific exchange rates, it is difficult to draw conclusions about China's absolute R&D volume.

340 NSB, *S&E Indicators 2010.*

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[342] NSB, *S&E Indicators 2010,* fig 4-16.

[343] NSB, *S&E Indicators 2010,* Table 5-14. Only a small number of countries account for most of the publications in the world—the top five producers—U.S., China, Germany, Japan and the UK—accounted for more than 50 percent of the world total S&E article output in 2007.

[344] NSB, *S&E Indicators 2010,* Fig 3-48. An important caution in interpreting these data is that although countries used a common definition of "researcher" when reporting their data to OECD, there are many judgments necessary to translate from a wide variety of national data systems to the OECD definition.

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IV. Conclusion

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