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Michigan: The High-Technology Automotive State

by

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OFFICE FOR THE STUDY OF AUTOMOTIVE TRANSPORTATION
UNIVERSITY OF MICHIGAN TRANSPORTATION RESEARCH INSTITUTE

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INTRODUCTION

Definitions of the “new economy” abound in the ninth consecutive year of economic growth in the United States. Various organizations and individuals have issued such labels as the “information age,” “Internet economy,” “dot.com economy,” “web economy,” “silicon states,” or cyber-states,” and so on. Categorizations of firms, industries, states, and regions in the United States as high technology and/or fast growth appear regularly. Despite record low unemployment in almost every industry and region in the United States, economic development authorities continue to show great concern about the ranking of their state or community in terms of advanced economic activity. Presumably this concern is fueled by a growing belief that the economy is fundamentally changing in many important structural parameters. It also reflects a widely held belief that all industries, including the “newest,” agglomerate their activities in geographic regions. Since the fastest-growing new industries are presumably still deciding where to locate their operations, it is thought critical to advertise the business suitability of a region and put in the best possible light the region’s potential in terms of employees costs, markets, and infrastructure. This is especially the case when the targets of business attraction are information technology and other high-tech companies.

This report investigates the contribution of Michigan’s automotive industry to the high-technology sector of the state’s overall economy. Of course, the largest U.S. automotive firms have concentrated much of their employment, the bulk of their engineering, and their headquarters in Michigan for a full century. However, automotive production no longer dominates the Michigan economy to the extent it once did. Yet, many outside observers paint a picture of Michigan as an automotive manufacturing state and not much more. This erroneous perception is especially troublesome when the state is ranked on the basis of its high-technology activity and infrastructure. Many definitions of the new economy exclude the auto industry as a high-technology sector. The reasons for excluding the industry usually focus on its maturity, its heavy manufacturing orientation, or even the fact that it is a manufacturing industry.

The automotive industry is currently the largest manufacturing industry in the world with over $1 trillion in annual sales. The industry also generates the largest net earnings and has linkages to a larger number of other industries and economic sectors that produce both services and goods, than any other industry in the world. However, a popular conclusion is that the auto industry is mature and cannot match the growth rates of "new" industries and therefore is clearly not influencing the change to a new economy in the United States. Since Michigan is thought to be dominated by this "older" industry, it has been excluded by several recent studies of high-technology activity from the top rank of high-technology regions.

We will take issue with the characterization of the automotive industry as "low-tech." The industry's major product, the modern motor vehicle, is one of the most important host products for delivering advanced technologies directly to the consumer in the world today. The industry leads all others in spending on research & development and the rate of product and manufacturing innovation. Finally, the industry's recent massive commitment to e-commerce may be one of the most important developments in the economic potential of the World Wide Web since its introduction. Michigan fully shares in the high-technology activities of the United States and world auto industry. In fact, Michigan's auto industry is different than the overall U.S. industry because the greatest share of automotive technology is located in this one state. A careful measurement of this special role of the auto industry in Michigan allows this study to assess the state as a high-technology region.

This report begins with a review of several recent high-technology assessment reports issued by special interest organizations. These reports have received some amount of public attention. We then turn to a consistent set of measures of technology-intensive activity and employment drawn from data published by U.S. government agencies. We propose a compromise ranking of U.S. states based on criteria set by the American Electronics Association (AEA), one of the best known nongovernmental ranking research organizations, and definitions used by the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor. The BLS ranking methodology will be applied to U.S. employment data for states and industries to produce a new list of U.S. states ranked by high-technology activity. Finally, we will review the high-technology content of the motor vehicle itself using information collected in a special survey of auto manufacturers. The sum result of this investigation provides a more accurate understanding and appreciation of Michigan as the high-technology automotive state.

I. RANKING STATES BY HIGH-TECHNOLOGY ACTIVITY

The AEA is the largest electronic industry trade association in the United States with over 3,000 member firms and organizations. The Washington, D.C. and California headquartered association publishes a series of annual reports on high-technology economic activity in states, various metro areas, and at the national and international levels. The AEA annual report of most interest for this report is *Cyberstates*, a ranking and description of high-technology activity, as defined by AEA, for the 50 United States.[1] The heart of the *Cyberstates* methodology is its selection of 45 U.S. industries that constitute the high-technology sector of the U.S. economy. The 45 industries are selected from hundreds of “4-digit” industries classified according to the Standard Industrial Classification (SIC) coding system used by U.S. government statistical agencies (see appendix I). *Cyberstates* ranks states according to their total employment in these 45 defined industries. Employment data are gathered from the USDOL, BLS publication, *Covered Employment and Wages, Annual Averages*. A secondary ranking of states, which also produced by the AEA on the basis of “hi-tech average wage,” also uses USDOL information.[2]

The AEA segregates their list of 45 industries into three large sectors: high-tech manufacturing, communication services, and software and computer-related services. The high-tech manufacturing list of industries includes computer and office equipment, consumer electronics, semiconductors, electronic components and accessories, and defense electronics. The communications sector includes such industries as telephone communications, cable and pay television, and radiotelephone communication. Finally, the AEA software sector includes such industry groups as software services, data processing and rental; maintenance and other computer related services.[3]

The AEA does not describe in their *Cyberstates* publication how they arrived at the 45-industry definition list for high-technology activity in the United States. This list of industries is similar to a much more comprehensive list of high-technology industry groups suggested by the BLS that is described below. However, the AEA excludes nonelectronic, high-technology industries that are listed by the BLS.

Cyberstates may represent a category of ranking methodology that can be labeled as "industry self-defined." The AEA methodology is open to at least three areas of criticism:

1. **Industry Definition.** The AEA list of 45 high-technology industries clearly excludes some of the most advanced scientific and engineering-intensive industries in the United States. These industries include those performing biotechnology and health research, advanced industrial equipment, engineering and architectural services, research and testing services, and all government and academic (university) science, health, and engineering research activity. To be fair, the AEA researchers admit this deficiency, yet still claim their definition is "solid" and "conservative." The AEA maintains that there is "no consensus on the definition of the high-tech industry," and that there is "no clear consensus on the definition of the bio-technology industry." [4]
2. **Product Technology Content**. The AEA list of 45 high-technology industries includes some that now produce products with low technology or science content. In particular, a number of the AEA industries are now largely composed of companies producing commodity products with low rates of product innovation. These would include many areas of consumer electronics or even many types of semiconductors and other electronic components.
3. **Ranking by Total Industry Employment**. *Cyberstates* provides useful information on payroll and export activity. The AEA also provides information on R&D activity and educational performance by state in other publications. However, the essential core ranking of states is based on total employment in the 45 selected high-tech industries. Needless to say, states with the largest populations such as California or Texas fare very well in this type of analysis just on the basis of size. Yet a more serious flaw in the use of total employment as an indicator of high-technology activity is that it categorizes all jobs within an industry as "high tech" including custodians or low-wage clerical and production labor positions. Employment in many occupations, of course, can be generated by high technology but is not intrinsically high tech. For example, California could outrank Massachusetts in *Cyberstates* if the former state contained higher total employment in high-tech industries but fewer scientists, engineers, or other research workers than the latter state. In fact, Mexico would outrank many American states because of its large number of electronic manufacturing plants. Also, the communications services group of industries is not generally identified by the BLS as a high-tech industry because of their relatively low employment of technology-oriented workers, a criterion we shall emphasize later in this study.

The 1999 publication of *Cyberstates* ranks Michigan as seventeenth among the fifty states as a high-technology state on the basis of 96,013 jobs in the 45 defined high-technology industries in 1997. The motor-vehicle and motor-vehicle-equipment industry is not recognized by the AEA as a high-tech industry.[5]

Another recent ranking of U.S. states in the "new economy" has been published by the Progressive Policy Institute (PPI), an organization maintained by the Democratic Leadership Council.[6] *The State New Economy Index* is a report that purports to measure the differences and assess states' progress as they adapt to the "new economic order" of the "new economy."[7] The new economy is defined simply as "a knowledge and idea-based economy where the keys to wealth and job creation are the extent to which ideas, innovation and technology are embedded in all sectors of the economy.[8]"

The PPI authors do not identify specific industries in the New Economy, or the New Economy's share of GDP, total employment, average wages or any other traditional measure of economic activity or presence. Instead, the institute authors state that it includes "powerful personal computers and the Internet," but assert that it is about much more than high technology or the Internet.[9] The PPI appears to lean towards a definition that favors economic change of almost any kind ("economic churning and dynamism" are favored words along with "new"). The PPI perhaps tips its hand by identifying "five key policy strategies states need to follow…to foster success in the New Economy." The policy slate is somewhat reflected in the seventeen index measures the PPI uses to measure state performance in the New Economy.

The seventeen index measures are grouped by PPI into five categories "that best capture what is new about the New Economy." The first group includes separate indicators that measure the share of total jobs in offices and employment in managerial, professional, and technical jobs. In other words, states are penalized for high levels of employment in any type of blue collar work, no matter how precision or craft oriented the training may be, or how advanced the manufacturing technology. Not surprisingly, Michigan received a low score for this group of measures: thirty-fourth. States dominated by employment in the finance and insurance sector (which certainly includes some very old companies), such as Massachusetts (1) or Connecticut (2) score very well on these measures.[10]

A second category of measures attempts to gauge the extent to which states are connected to ongoing globalization. The first indicator is the number of 1992 jobs in manufacturing companies that are dependent on exports. Michigan fares well on this measure although the rationale for preferring export-related jobs over import-competing jobs isn't given. The second index, the percentage of each state's workforce employed by foreign companies, is justified by the claim that such local foreign competition spurs productivity change within a state. The automobile industry is specifically given as an example of the competitive effect of foreign direct investment.[11]

The major PPI category where Michigan scores lowest is "economic dynamism." The indicators in this group include (1) the share of jobs in "fast-growing gazelle firms (growth of 20 percent a year in sales for four years)," (2) the degree of jobs churning measured by business start-ups and business failures, and (3) the value of companies' IPOs in a state.[12] States with high employment in large corporations such as Michigan (ranking of forty-one) fare very poorly on these measures because much of their employment is located at established firms.[13]

By focusing exclusively on small firms, the PPI measure of economic dynamism, however, ignores the major structural changes that have undeniably occurred within America's largest companies over the last fifteen years. Ford and DaimlerChrysler, for example, are two of the most productive and profitable firms in the world. The current operating performance of these companies was achieved through radical restructuring of their organizations over the previous decade. The economic share of the largest 500 firms in the United States is enormous, and to delete change within these firms from any definition of the new economy is to miss much of the change that has actually occurred in the U.S. economy.

The final two groups of measures provided by the PPI are the digital economy and innovation capacity. The former category includes available measures of Internet use in the population, the education system, and in government (digital government). The last category, innovation capacity, includes some more standard indicators of high-technology activity within a state. A number of measures are very similar to those employed by U.S. government agencies for the categorization of high-technology industries: the share of scientists and engineers as a percentage of the labor force, the number of patents issued to companies per worker, and private sector investment in research and development as a share of gross state product (GSP). Michigan scores very well in both patents and R&D activity (number one), of course, because of its high-tech automotive industry. Michigan scores poorly, however, in the last innovation measure, venture capital investment as a share of GSP, possibly because of a strong automotive tradition of funding investment from retained earnings.[14]

In summary, it is very difficult to finally judge or use the PPI index of the new economy because the subject itself, the new economy, is undefined (except for being "new"). Perhaps the PPI in some other study correlates the new economy with traditional measures of economic well being, such as growth in output, personal income, or the standard of living—but clearly they do not do so in their state index report. Michigan fares very poorly overall in the PPI study for the reasons discussed above, with an overall rank of thirty-four.

The BLS Approach

The BLS has long shown an interest in the definition and measurement of high-technology industry employment. BLS researchers have tracked definitions of high-technology industries, occupations and products since at least 1983.[15] A favorite definition of high technology for the BLS was published in 1982 by the Congressional Office of Technology Assessment. It described high-technology firms as those "that are engaged in the design, development, and introduction of new products and innovative manufacturing processes, or both, through the systematic application of scientific and technical knowledge."[16]

Other definitions noted by BLS researchers included the use of research and development expenditures as a percent of industry value added or the identification of products by the U.S. Bureau of the Census that embody new or leading-edge technologies falling in ten advanced technology areas.[17]

The BLS has modified its own definition of high technology several times. In 1983, the BLS used a combination of measures that included expenditures for R&D, the use of technology-oriented workers, and the last two measures combined. In 1991, the BLS used a definition of high technology based on the proportion of workers in an industry who spend the majority of their time in R&D, as determined by their employer. The 1991 study categorized an industry as high technology, "Level 1," the proportion of R&D employment was at least 50 percent higher than the average for all industries surveyed. Thirty industry groups fell into this category. Level-two industry groups were those that fell in the average-to-50-percent-above-average range. The motor-vehicle-industry group (SIC 371) easily qualified as a high-technology industry with 8.5 percent of its employees engaged primarily in R&D activity. The 1991 study also contained a rare ranking of states based on the share of total employment located in high-technology industries (somewhat different from the AEA method). Michigan ranked number two among the fifty states. Only Delaware exceeded Michigan in high-technology industry employment as a share of total employment (16.7 percent) according to the BLS in 1991.[18]

The BLS published a recent revision of their list of high-technology industries in the summer of 1999.[19] The new approach is based on the employment of scientific and technical personnel and research intensity. The BLS researchers identify specific high-technology occupations: "engineers; life and physical scientists; mathematical specialists; engineering and science technicians; computer specialists; and engineering, scientific and computer managers."[20] Individuals employed in these occupations are collectively referred to as technology-oriented workers. The BLS uses survey data from the BLS's Occupational Employment Survey (OES) for 1993-1995 to total the two types of occupational employment for their study. In the new BLS analysis, "industries are considered high tech if employment in both research and development and in all technology-oriented occupations accounted for a proportion of employment that was at least twice the average for all industries in the Occupational Employment Survey."[21]

Typically, the BLS applies their analysis to three-digit SIC industry because needed data is not available at the more detailed four-digit level. Twenty-nine 3-digit industry groups, 25 in manufacturing and 4 in the service sector, are identified by the BLS as high-technology industries. These industries all have at least 6 R&D workers and 76 technology-oriented workers per thousand employees (see appendix II). The motor-vehicle industry qualified again for the BLS list of high-technology industries. A subset of ten industry groups, those with ratios at least five times the average, are characterized by BLS as high-technology-intensive industries. These industry groups have at least 15 research and development workers per 1,000 workers and 190 technology oriented workers per 1,000 workers.[22]

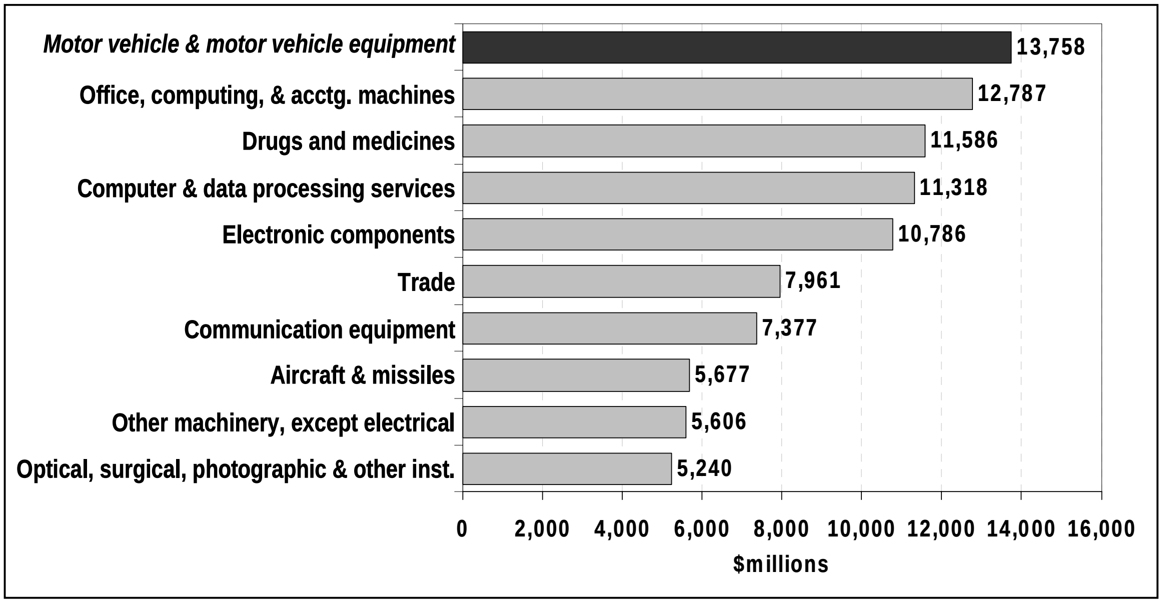
In terms of total employment, the motor-vehicle industry was the second largest BLS high-technology industry. Only the service industry group, computer and data processing services, had higher total employment. Significantly, the engineering and architectural services industry was one of the four high-technology service industries identified in the study. As will be shown, this industry is heavily involved with the auto industry in Michigan. The BLS occupational approach used in 1999 heavily influences the compromise method used in this study.

A Reranking of U.S. States in Terms of High-Technology Activity

Our state ranking analysis recognizes the auto industry's presence in the Michigan economy. The BLS has consistently listed the auto industry as a high-tech industry and, furthermore, most of the industry's high-tech functions are located in Michigan. What makes Michigan exceptional among the states where the auto industry operates is that Michigan is the headquarters for the three largest auto companies' in the United States. As a result, most of these companies high-tech research, design, engineering, computer facilities, and staff are located in Michigan. In addition, because of the growing interdependence between the auto manufacturers and their supplier firms many suppliers have located their technology-intensive operations in Michigan. In other words, Michigan's automotive industry is far more technology intensive than the U.S. automotive industry in general.

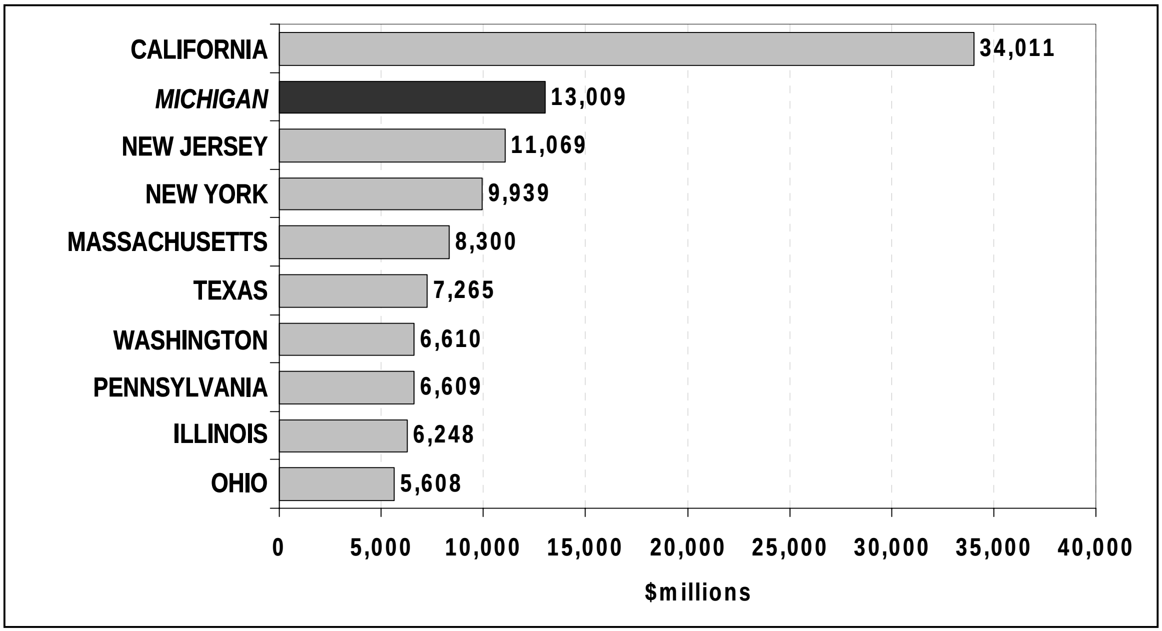
The National Science Foundation (NSF) publishes an annual table of industries showing private R&D spending in the United States. Figure 1 shows the most recent industry ranking based on survey data collected by the NSF for 1997. The motor-vehicle and motor-vehicle and equipment industry ranked first on the list with $13.8 billion in R&D spending.[23] Recently, the NSF has published a new report based on corporate data issued in public reports for the 500 largest R&D spending corporations. Based on corporate reports, the motor-vehicle industry spent $18.4 billion on R&D in 1997.[24]

The motor-vehicle industry's high level of R&D spending naturally influences Michigan's position in a similar ranking of states. Figure 2, shows that Michigan ranked second among the fifty states in total private spending on R&D at $13 billion.[25] A similar analysis of U.S. Patent Office information on patents received by state shows Michigan ranked in sixth position. The rankings based on this measure are shown in figure 3.[26]



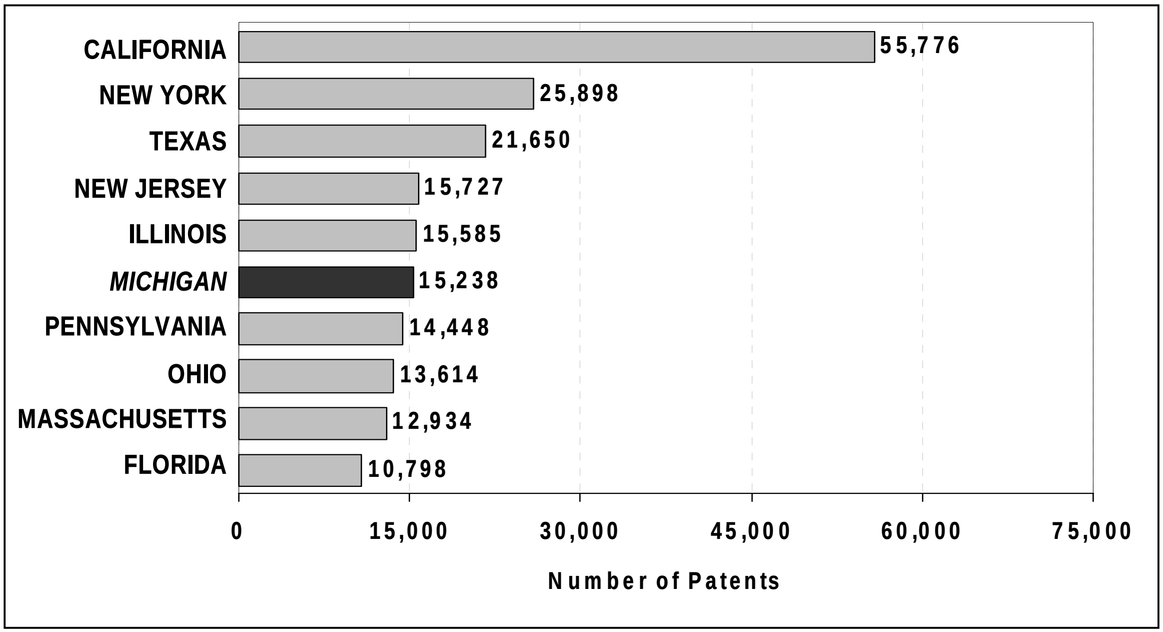
Source: National Science Foundation/SRS, Survey of Industrial Research and Development:1997

Figure 1
R&D Spending by Industry – 1997
Motor Vehicle is 1st of 39 Major U.S. Industries



Source: National Science Foundation

Figure 2
States Ranked by Industrial Research & Development – 1997
Michigan Ranked 2nd of the 50 States

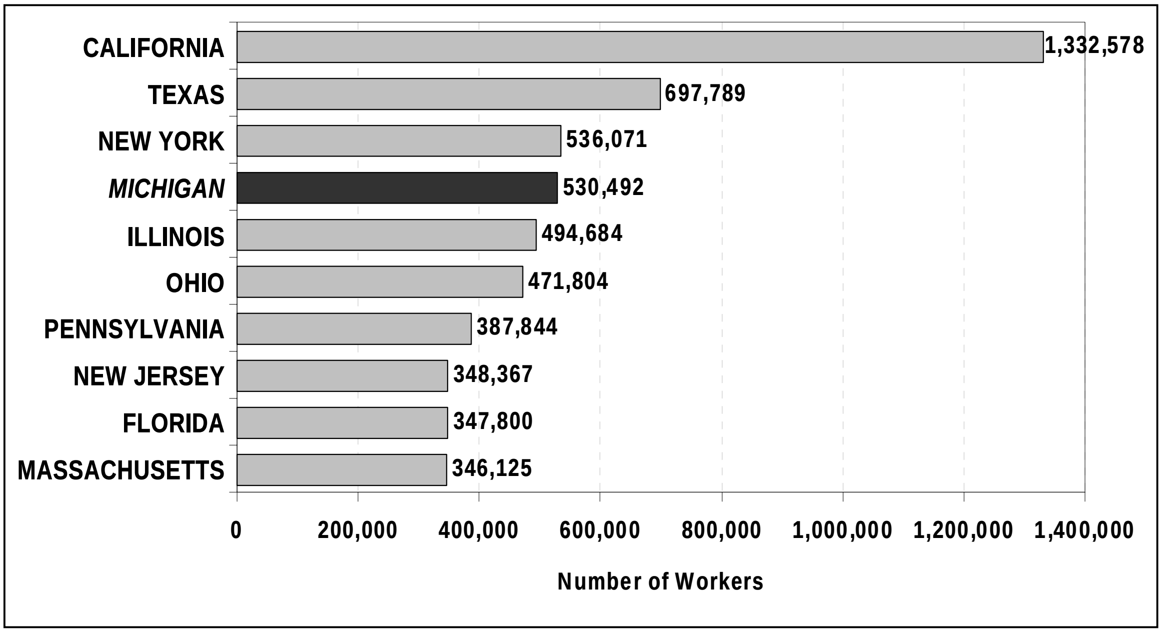


Source: U.S. Department of Commerce, Patent and Trademark Office

Figure 3
States Ranked by Patents Received 5-Year Period: 1994 to 1998
Michigan Ranked 6th of the 50 States

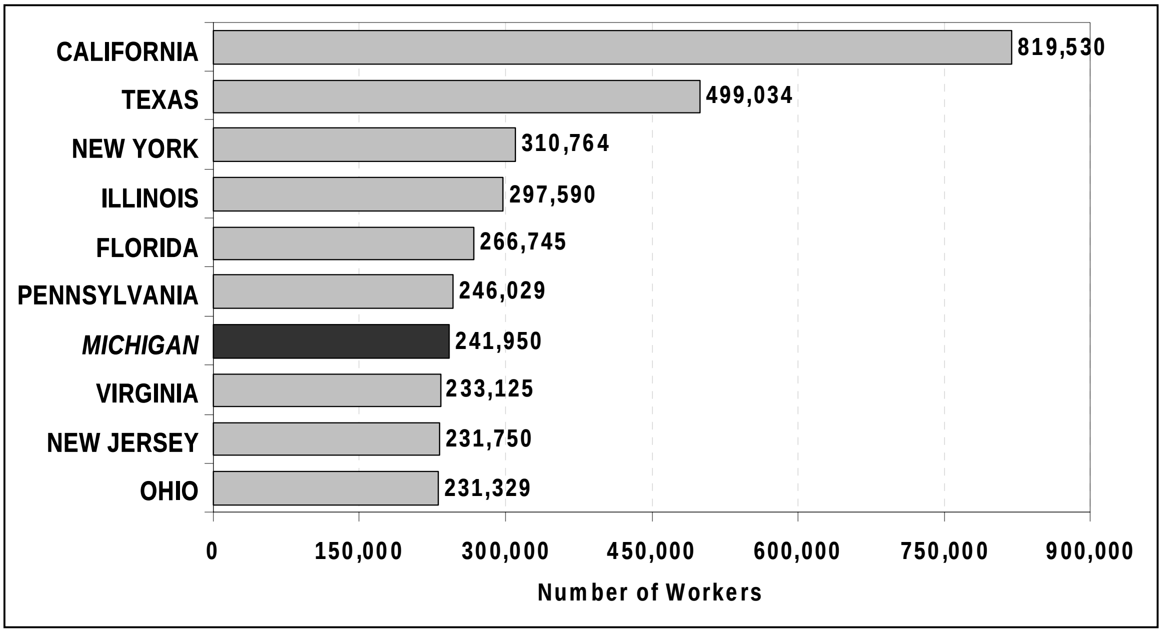
As discussed above, the BLS recently identified twenty-nine industry groups in the United States as high-technology industries. Industries were defined as “high tech” if the proportion in their work force of both R&D and technology-oriented jobs was twice the average for all industries. The Bureau’s list of high-tech industry groups is shown in appendix II, and the motor-vehicle-industry group appears on the list. If states are ranked by their total employment (the AEA method) according to the BLS lists of industries, Michigan would rank fourth, as shown in figure 4**.** It is interesting to note that if we had added motor-vehicle-industry employment to the AEA list of high-technology total employment, Michigan’s rank climbs from seventeenth to third among the fifty states**.** Both the AEA numbers and the numbers for total auto industry employment are from the Bureau of Labor Statistics’ Covered Employment and Wages database.[27]

A more meaningful ranking of states in terms of high-technology employment would simply count the number of workers for each state in technology-oriented occupations as defined by the BLS. The occupations counted as high-tech are natural scientists, engineers, engineering and science technicians and computer professionals. These occupations are essentially the same in both the Bureau of Labor Statistics study and the AEA Cybereducation list.[28] This ranking is shown in figure 5. The source of the data is a special tabulation from the U.S. Census Bureau’s Current Population Survey. Michigan ranks seventh in total high-tech occupational employment. These employment totals can be regenerated to exclude federal and other government workers except at universities. This ranking is shown in figure 6. Michigan ranks sixth in high-tech occupational employment in these sectors.[29]



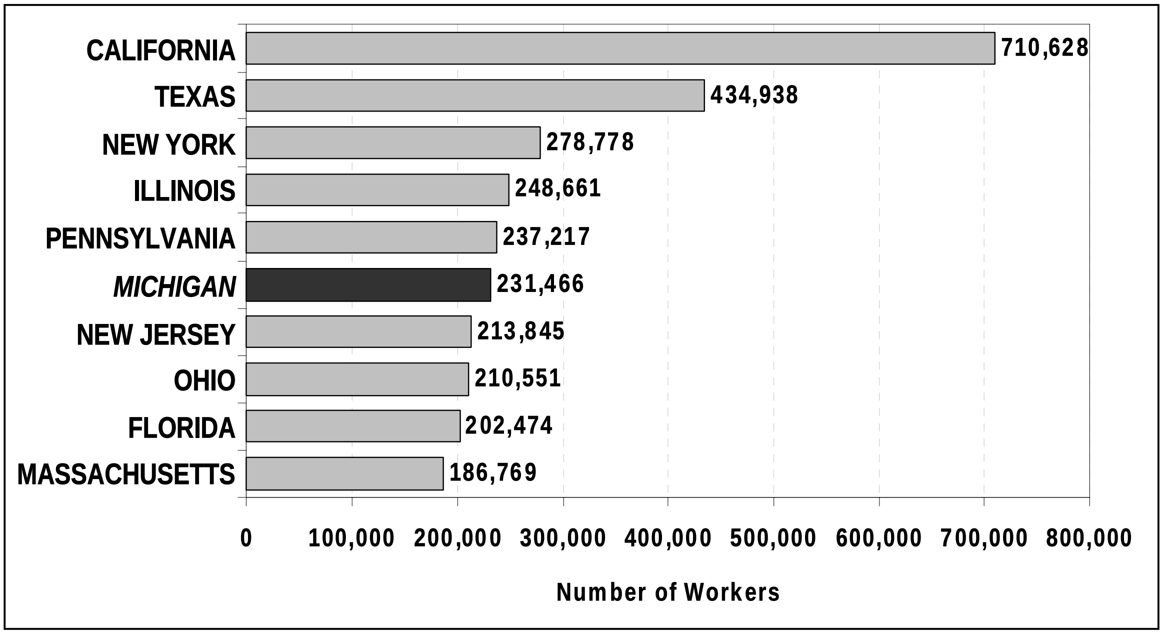
Source: U.S. Bureau of Labor Statistics, Covered Employment and Wages: U.S. Bureau of Census, County Business Patterns

Figure 4
Employment in BLS High-Tech Industries Ranked by State – 1997
Michigan Ranked 4th of the 50 States



Source: Special Tabulation from the U.S. Bureau of the Census' Current Population Survey

Figure 5
State Ranking of Total High-Tech Occupational Employment – 1998
Michigan Ranked 7th of the 50 States

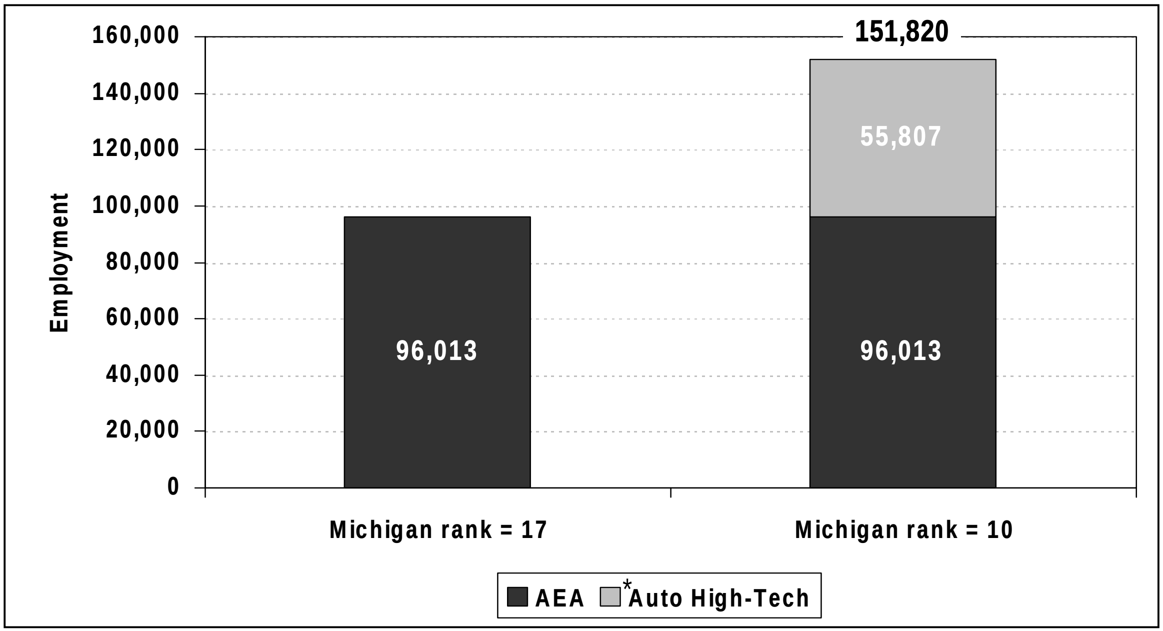


Source: Special Tabulation from the U.S. Bureau of the Census' Current Population Survey

Figure 6
State Ranking of High-Tech Occupational Employment (Private Sector & University):
1996 to 1998 avg.
Michigan Ranked 6th of the 50 States

A reasonable compromise between the AEA ranking of states on high-technology employment and the occupational approach just shown is difficult. The AEA ranks states by total employment in its defined list of high-tech industries regardless of whether these workers are in technology-intensive occupations or not. On the other hand, the occupational ranking emphasizes technology-oriented employment within a state. One compromise is to recognize the automotive technology-oriented employment in Michigan as high-tech employment and then add this figure to AEA-defined high-tech employment in Michigan. In essence, this compromise approach combines the total employment of Michigan's AEA-defined high-tech industries with the technology-oriented employment of the state's automotive industry. This method does not correct the previously mentioned flaw of using high-tech industry total employment as a measure of high-technology activity in a state. The bulk of jobs in AEA industries in Michigan are generated by high-technology activity. Many of these jobs, however, are not directly involved in high-technology activity. On the other hand, we believe that the majority of automotive high-technology-oriented employment in Michigan is directly involved in high-technology activity within the state's automotive industry.

This approach is illustrated in figure 7. The AEA credited Michigan with 96,013 high-tech jobs in *Cyberstates*. This was the total Michigan employment in the AEA-defined 45 high-technology industries in 1997. We add to this AEA total the employment of scientists, engineers, engineering and science technicians, and computer professionals (and the managers of these employees) working in the auto industry. There were about 56,000 such automotive workers employed in Michigan on average during 1989-1998 according to a special tabulation from the U.S. Census Bureau's Current Population Survey. Inclusion of this technology-related automotive employment brings Michigan's high-technology employment to 151,820. The same process was repeated for the other 49 states. About 51,000 technology-oriented jobs in the auto industry were located outside of Michigan. Our results by state are shown in table 1. Michigan's AEA ranking, with the inclusion of automotive technology-related employment, therefore, improves from seventeenth to tenth.



*Source: * The source of the high-tech auto (SIC371) employment numbers for all states is a special tabulation of the U.S. Bureau of Census Current Population Survey 1989-98. High-tech occupational employment in the auto industry is defined based on the high-tech degrees listed in the AEA's CyberEducation report.*

Figure 7
High-Tech Employment Comparison:
AEA, AEA and Auto High-Tech Employment

Table 1
High-Tech State Rankings Comparison
AEA, AEA and Auto High-Tech Employment

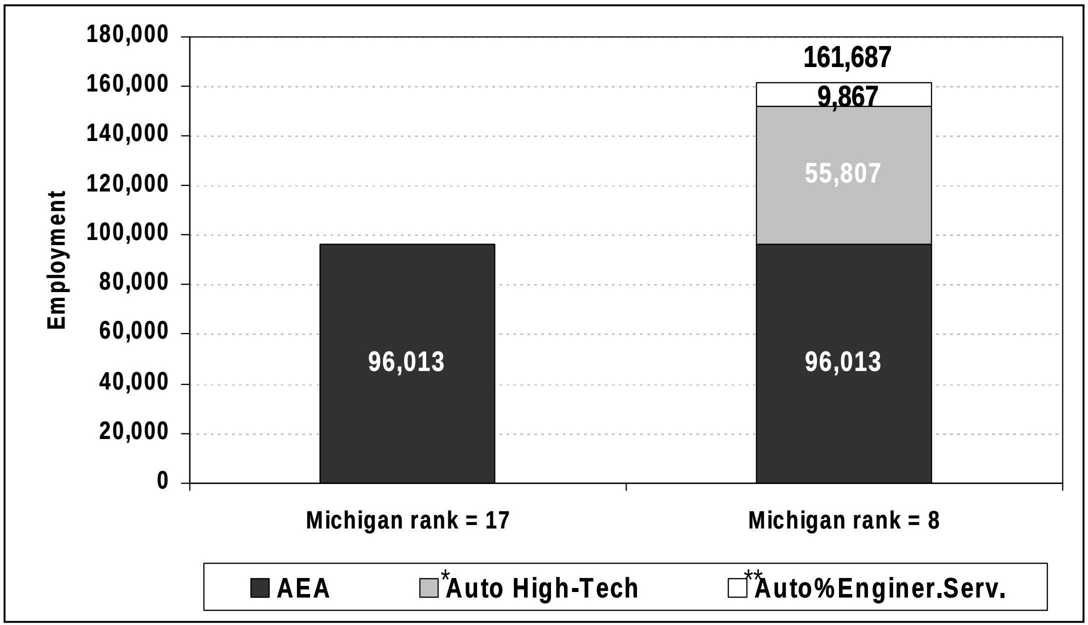
AEA			AEA + AEA Auto High-Tech Employment	
State	Number	Ranking	State	Number
CALIFORNIA	784,151	1	CALIFORNIA	787,367
TEXAS	375,933	2	TEXAS	376,505
NEW YORK	320,410	3	NEW YORK	323,464
ILLINOIS	207,201	4	ILLINOIS	209,004
MASSACHUSETTS	205,091	5	MASSACHUSETTS	205,321
FLORIDA	193,559	6	FLORIDA	194,423
NEW JERSEY	179,528	7	NEW JERSEY	179,965
PENNSYLVANIA	159,952	8	PENNSYLVANIA	161,008
VIRGINIA	154,712	9	VIRGINIA	154,975
GEORGIA	132,524	10	*MICHIGAN*	*151,820*
OHIO	132,076	11	OHIO	140,666
COLORADO	131,854	12	COLORADO	134,530
MINNESOTA	123,866	13	GEORGIA	132,839
NORTH CAROLINA	119,831	14	MINNESOTA	124,421
MARYLAND	97,484	15	NORTH CAROLINA	121,136
WASHINGTON	97,025	16	MARYLAND	97,824
MICHIGAN	*96,013*	*17*	WASHINGTON	97,773
ARIZONA	89,174	18	ARIZONA	89,450
MISSOURI	72,332	19	MISSOURI	74,001
CONNECTICUT	71,507	20	CONNECTICUT	71,839

*Source: * The source of the high-tech auto (SIC371) employment numbers for all states is a special tabulation of the U.S. Bureau of Census Current Population Survey 1989-98. High-tech occupational employment in the auto industry is defined based on the high-tech degrees listed in the AEA's CyberEducation report.*

Michigan's automotive high-technology employment isn't just located in the motor-vehicle manufacturing industry. The BLS study identified the engineering-and-architectural-services industry as one of four high-technology service industries in the U.S. economy. More than 42,000 workers are employed in this industry, in Michigan. In 1998 the Office for the Study of Automotive Transportation surveyed 64 of the 525 Michigan companies in this industry that employed ten workers or more. Not surprisingly, 78 percent of these firms reported their work as being "primarily automotive." When weighted by employment, and adjusting for firms with fewer than 10 workers, the primarily automotive portion of Michigan engineering service jobs can be estimated at 68 percent.[30]

This percentage can be used to help determine the number of engineering-services workers in Michigan who are both high-tech and auto-related. The first step in the calculation is to apply the high-tech (BLS and AEA occupations) share of employment in the latest available Occupational Employment Statistics (OES) survey to the 1997 Michigan engineering-services employment total. Second, we apply the estimated automotive share of engineering-services employment (68 percent as noted above[31]) to our first calculation, which computed high-tech-oriented employment in Michigan's engineering-services industry. The final output of these calculations is a figure of 9,867 technology-oriented workers employed in the automotive-related segment of Michigan engineering services.

Michigan's technology-related employment total can now be further adjusted to reflect the automotive activity in Michigan's engineering-services industry. The rationale is that engineering services in Michigan is virtually an extension of the auto companies' R&D and product-development efforts. Many of the auto companies' high-tech design-and-engineering operations are housed in the engineering services industry. This adjustment is highlighted in figure 8 and a new ranking for the top 20 states is shown in table 2. This table sums high-tech auto industry jobs in all states with the auto-related portion of high-tech jobs (9,867) in Michigan's engineering-services industry and AEA total employment. In other words, Michigan's AEA technology employment is now supplemented by technology-oriented workers in the motor-vehicle industry itself and technology-oriented workers in the engineering-services sector whose work is primarily automotive. The new high-technology employment total is 161,687. This level would increase Michigan's standing in the AEA ranking from seventeenth to eighth.[32]



*Source: * The source of the high-tech auto (SIC371) employment numbers for all states is a special tabulation of the U.S. Bureau of Census Current Population Survey 1989-98. High-Tech occupational employment in the auto industry is defined based on the High-Tech degrees listed in the AEA's CyberEducation report. **Engineering Services (SIC8711) high-tech occupations are defined in the same way as auto high-tech. The employment figure is computed by: (1) Applying the high-tech share of employment in the latest available Occupational Employment Statistics(OES) survey to the 1997 Michigan Engineering Services total. (2) Applying the auto share-68% according to a recent OSAT survey. Auto-related high-tech employment in Engineering Services is calculated at 9,867 in 1997.*

Figure 8
High-Tech Employment Comparison:
AEA, (AEA, Auto High-Tech and Auto % Mich. Engineering Service) Employment

Table 2
High-Tech State Rankings Comparison
AEA, (AEA, Auto High-Tech and Auto % Mich. Engineering Service) Employment

AEA			AEA + AEA Auto High-Tech + Auto % Mich. Engrg. Svc. Employment	
State	**Number**	**Ranking**	**State**	**Number**
CALIFORNIA	784,151	1	CALIFORNIA	786,575
TEXAS	375,933	2	TEXAS	376,425
NEW YORK	320,410	3	NEW YORK	323,015
ILLINOIS	207,201	4	ILLINOIS	208,473
MASSACHUSETTS	205,091	5	MASSACHUSETTS	205,215
FLORIDA	193,559	6	FLORIDA	194,123
NEW JERSEY	179,528	7	NEW JERSEY	179,762
PENNSYLVANIA	159,952	8	*MICHIGAN*	*161,687*
VIRGINIA	154,712	9	PENNSYLVANIA	160,722
GEORGIA	132,524	10	VIRGINIA	155,059
OHIO	132,076	11	OHIO	138,253
COLORADO	131,854	12	GEORGIA	132,799
MINNESOTA	123,866	13	COLORADO	131,854
NORTH CAROLINA	119,831	14	MINNESOTA	124,319
MARYLAND	97,484	15	NORTH CAROLINA	121,240
WASHINGTON	97,025	16	WASHINGTON	97,795
MICHIGAN	*96,013*	*17*	MARYLAND	97,684
ARIZONA	89,174	18	ARIZONA	89,481
MISSOURI	72,332	19	MISSOURI	73,673
CONNECTICUT	71,507	20	CONNECTICUT	71,735

*Source: * The source of the high-tech auto (SIC371) employment numbers for all states is a special tabulation of the U.S. Bureau of Census Current Population Survey 1989-98. High-tech occupational employment in the auto industry is defined based on the High-Tech degrees listed in the AEA's CyberEducation report. **Engineering Services (SIC8711) high-tech occupations are defined in the same way as auto high-tech. The employment figure is computed by:(1) Applying the high-tech share of employment in the latest available Occupational Employment Statistics(OES) survey to the 1997 Michigan engineering Services total. (2) Applying the auto share-68% according to a recent OSAT survey. Auto-related high-tech employment in Engineering Services is calculated at 9,867 in 1997.*

Finally, the Office for the Study of Automotive Transportation conducted a special survey (fall of 1999) of the three largest motor-vehicle-manufacturing firms in the United States (General Motors, Ford, and DaimlerChrysler) to directly tabulate their high-tech employment. The three automotive firms were asked to provide their year-end, 1998, U.S. and Michigan employment in the BLS (and AEA) list of technology-oriented occupations. As shown in table 3, technology-oriented U.S. employment for the three firms totaled 47,548 in 1998. The Big Three employed 37,489 of these employees in Michigan. In other words, almost 79 percent of Big Three, U.S., technology-oriented employees were working in the State of Michigan in 1998. Furthermore, our results show that about 16 percent of the three companies' employment in Michigan falls into the high-tech category compared with only 4 percent of their employment in the other 49 states (see table 4). The BLS definition of a high-technology intensive industry calls for the employment of at least 190 technology-oriented workers out of every 1,000 workers. The Big Three in Michigan employ 160 technology-oriented workers out of every 1,000 employees, a level that almost qualifies the industry for the BLS category of a high-technology-intensive industry.

Table 3
Big Three Auto
Technology Employment Questionnaire Results

Total 1998	U.S.	Michigan	Michigan %
Auto Employment	492,887	235,807	47.8%
High-Tech Auto Employment	47,548	37,489	78.8%

Table 4
1998 High-Tech Employment
as Percentage of Total Big Three Auto Employment

Other States	Michigan
3.9%	15.9%

We firmly believe that this pattern of Michigan location also holds for high-tech activity of the major U.S. automotive suppliers. A special survey of automotive parts and component supplier R&D and technical centers in the United States was conducted by *Wards Auto World* magazine in 1994. The magazine identified 92 of the total of 112 U.S. supplier facilities as being located in Michigan, or 82 percent. The 92 Michigan facilities employed almost 13,000 employees.[33] When this supplier activity is combined with the location of the largest vehicle-firm research centers in Michigan, one can categorically state that the high-technology end of the U.S. auto industry is located in Michigan.

II. TECHNOLOGY ASSESSMENT OF THE MOTOR VEHICLE

The motor vehicle has been viewed traditionally as a low-tech product of an established smokestack industry—in a sense, a low-tech appliance produced by a low-tech industry. And, although it is true that the modern automobile contains many proven and very familiar components and systems, it is also true that the motor vehicle contains an impressive number of advanced products developed through extensive industrial research and development. The modern vehicle is designed and manufactured today through the use of advanced manufacturing-and-design systems that match or exceed the technical intensity of those employed in any other industry. The AEA, and several other organizations, define high tech primarily in terms of electronic content. However, it is essential that a more comprehensive definition of a high-tech product also include advanced materials, design tools, manufacturing processes, and other technologies that are important in the development, manufacture, and use of many high-tech products. The sum totals of such work by the automotive industry are significant in economic terms. In 1997, the three largest U.S. vehicle producers alone spent no less than $18.4 billion on R&D worldwide. These expenditures for R&D largely motivate the annual capital expenditures of over $27 billion by these firms. The total, world auto-industry spending levels for R&D and capital investment are easily twice the total for the Big Three alone.

This report has reviewed several methods used to define high-tech industries. One high-tech definition—that suggested by the U.S. Bureau of Census (BOC)—is based on first identifying industry products that employ or result from leading-edge technologies in ten advanced areas. The automobile industry uses—or develops internally—components from four of the advanced areas listed by the BOC: 1) computers and telecommunications, 2) electronics, 3) computer-integrated manufacturing and 4) materials design. On the basis set forth by the BOC, the automobile itself can be described as a host platform for leading-edge technologies, and the industry as a producer of these technologies.

This section, then, will have two primary goals. The first is to describe the high-tech nature of the automobile by illustrating the depth and breadth of current automotive research activity. We will emphasize several automotive systems in particular: advanced materials, chassis technologies, powertrain technologies, and electronics. We rely heavily on OSAT's Delphi X: Forecast and Analysis of the North American Automotive Industry[34] forecast of the automotive industry for assessment of current research and development in these systems. Our second goal is to quantify the electronic content in the vehicle through information collected directly from automotive manufacturers.

Finally, it is helpful to separate high-tech, automotive, research-and-development activity into three separate areas. A first category is the refinement of traditional mechanical components to improve the performance of the motor vehicle (e.g., the introduction of antilock brakes). The second type involves the introduction of new technologies that either replace traditional components or introduce entirely new features in the vehicle (e.g., in vehicle telematics). Finally, a third area is basic research and development such as that carried out at the automotive industries' company research science labs under the auspices of the United States Council for Automotive Research (USCAR). Such work is intended to develop new industry technology paradigms (e.g., development of automotive fuel-cell technology).

USCAR

Since 1992, DaimlerChrysler, Ford, and General Motors have cooperated on a plethora of advanced research topics under the umbrella of the United States Council for Automotive Research (USCAR). These precompetitive research activities include the development of lightweight materials, advanced manufacturing processes, and a new generation of vehicle powertrains. Currently, USCAR monitors and coordinates much of the basic, "epochal" research within the industry. This consortium of companies and the federal government demonstrates the value of technology sharing between industry participants, national labs, and leading research universities throughout the country.

Manufacturing and materials

The automotive industry has traditionally been viewed as a steel-and-cast-iron industry. However, federal-government-mandated Corporate Average Fuel Economy standards (CAFE) and emissions regulations have prompted the industry to increasingly research and experiment with the use of lightweight materials. The industry continues to refine traditional materials, for example high strength steels (i.e., yield strength of 210-550Mpa), and even ultrahigh-strength steels (i.e. yield strength of 550Mpa or greater) are seeing increased application. The industry is also increasing its use of aluminum and magnesium alloys and fiber-reinforced composites. Industry participants including the manufacturers as well as key suppliers are involved in advanced research that may lead to the development of a new materials paradigm for the automotive industry.

Since its very beginning, the automotive industry has had a steel orientation both in facility layout and engineering knowledge. Even today, the industry remains focused on steel despite the significant effort to develop alternative materials for many automotive applications. The influences of experience, past investment cost, and even environmental concerns lead the industry to favor steel and, to a lesser extent, aluminum. Yet there are many examples of advanced manufacturing and materials development within the current steel paradigm for motor vehicles.

Preliminary results from the OSAT's Delphi X: Forecast and Analysis of the North American Automotive Industry Materials Volume indicate that there are several advanced manufacturing technologies that will be important drivers of the increased use of high-strength steel. According to this report, technologies such as tailor-welded blanks, hydroforming, "intelligent" (i.e. computer controlled) spot welding, and laser welding are critical to the increased application of high-strength steel. Significantly, the Delphi survey respondents report that these same technologies will also be important drivers of aluminum usage.

The automotive industry has teamed with steel manufacturers to develop a lighter-weight, higher-strength steel body and body components. This effort has significantly altered the perception of steel as a low-tech material. The American Iron and Steel Institute, through the Ultralight Steel Auto Body (ULSAB) research project and other research efforts, has demonstrated outstanding examples of cooperation between the automotive manufacturers and steel suppliers. The ULSAB concept is an automotive "body-in-white" (that is, the steel body of a car before painting) that is designed to be built within the current manufacturing paradigm at a cost, weight and stiffness comparable to lightweight alternative materials such as aluminum and composites.[35]

Advanced-technology, high-strength, and ultrahigh-strength steel accounted for 90 percent of the ULSAB research body-in-white mass. Notably, the use of tailor-welded blanks and hydroforming were an important manufacturing enabler for the ULSAB body-in-white. Tailor-welded blanks are made by welding different types of steel together to allow engineers to accurately match the properties of the steel with the structural requirements of the part. The strategic placement of the different grades of steel allows the overall weight of the part to be decreased, while increasing performance characteristics. Tailor-welded blanking, through the use of advanced-material science and computer-aided design and manufacturing, is an illustration of the industry's advanced design and manufacturing capabilities.

Figure 9 illustrates a tailor-welded blank. The side inner blank is composed of five separate pieces of high-strength steel welded together using laser technology. Stronger steels were used in the upper portions of the part (1, 2, and 3), to give the roofline structural rigidity. The actual stamped piece is shown on the right.

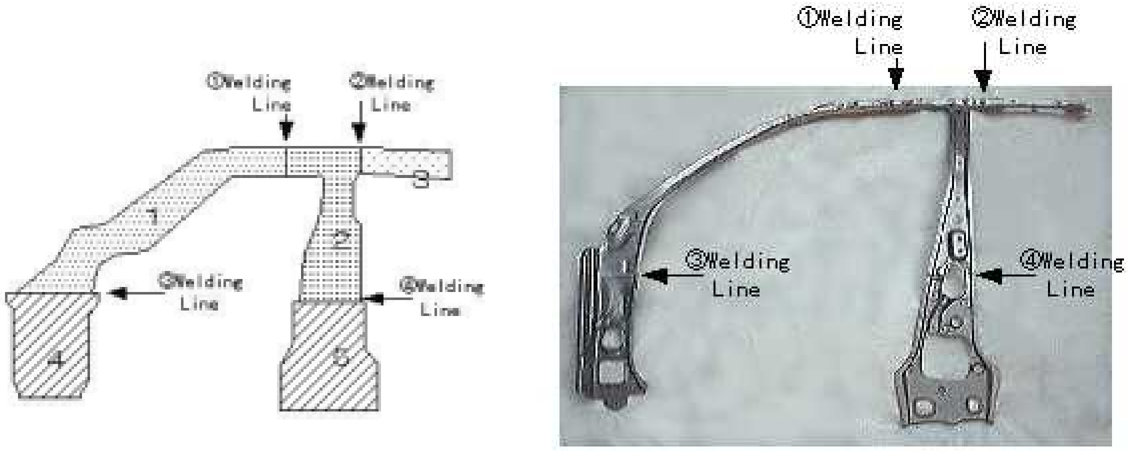


Diagram courtesy of OSAT Manufacturing Systems Group

Figure 9
High-Strength Steel Tailor-Welded Blank Technology

Although the use of composites is not necessarily advanced technology) the low-volume niche vehicle Chevrolet Corvette has used composite body panels since the 1950s) the challenge lies in producing composite components at cost and cycle times required for high-volume production. According to preliminary results from Delphi X: Forecast and Analysis of the North American Automotive Industry Materials Volume, manufacturing cost is considered the most important issue for the increased application of composites in structural applications. The Delphi survey results further indicate that tooling costs and molding processes are critical drivers of overall cost. The challenge to the industry is to develop advanced manufacturing processes that reduce the required cycle time and simultaneously reduce the production cost of composites for structural applications.

An example of the industry meeting this challenge through the development of advance manufacturing processes is the composite pickup-truck bed for the 2001 Chevrolet Silverado full-size pickup. Automotive manufacturers have tried for decades to develop a composite pickup-truck bed liner. Recent manufacturing advances have allowed General Motors to finally produce a composite box with the use of advanced SRIM (structural reaction injection molding) for the bed inner, and RRIM (reinforced reaction injection molding) for the outer. This technology reduces the vehicle weight by 50 pounds.[36] The new truck-bed manufacturing process, based partially on knowledge gained by the USCAR automotive composites consortium, produces a complete box inner as one molded headboard, with a cycle time of about 4.5 minutes.[37] The box will be priced competitively versus the current, steel bed/ plastic liner.

Carbon fiber and other exotic composites present the automotive industry with a significant opportunity to reduce vehicle weight. However, cost is a serious barrier to the use of new composites. To date, the industry used advanced composites for high-mileage research vehicles such as those being developed for the USCAR Partnership for a New Generation of Vehicles (PNGV) program.[38]

Chassis Technologies

Stability control exemplifies the increasingly advanced technology of the automotive chassis. Stability control has been developed in recent years as a means of adding safety and control to vehicles using existing antilock-brake (ABS) and engine-control technology.

The automotive industry has offered antilock brakes as an option or standard equipment for several years. This technology uses microprocessor technology to monitor and modulate wheel spin in order to prevent tire lock-up and skidding on slippery road surfaces. Stability control, with yaw control, uses antilock-brake systems (ABS) and traction-control technologies combined with yaw-stability assist to correct the vehicle’s actual path to that of the intended path. Using a yaw-rate sensor, a lateral accelerometer, and wheel-speed sensors, stability control computationally monitors the vehicle’s actual path relative to the intended path (i.e., calculated through steering wheel angle). The system then modulates individual tire spin (via the ABS) and reduces engine speed (via ignition retardation) to correct for understeer or oversteer. The result is significantly increased vehicle stability and concomitant increases in safety.

It is interesting to note that respondents to the Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume forecast a very low penetration rate for stability control in the coming decade—less than 10 percent. Stability control, much like ABS and traction control is already being used in luxury vehicles. While current penetration rates are approximately 1 to 2 percent, the availability of stability control as an option on the 2001 Ford Focus indicates that system costs may be decreasing to the point where widespread application is possible. The system used on the Focus relies on seven sensors to check vehicle behavior 150 times per second. Key to the Ford system is the application of an extremely sensitive yaw-rate sensor that is monitored by two independent microprocessors every seven milliseconds.

Vehicle Electronics

The automobile has traditionally used a 12-volt electrical system (in reality, it is a 14-volt system operating as a 12-volt system). According to Dr. William Powers, vice president of technology, Ford Motor Company, there is need for change.[39] "Power demand is growing at four percent annually, and we're already passing two kilowatts of requirement on many modern vehicles. That is significant because three kilowatts presents a sort of 'breaking point'." At three kilowatts, the belt-drive alternator becomes a problematic appendage. For example, alternator noise escalates to an objectionable level.

According to Powers, the need to find alternative means of power has led the industry to pursue the beltless engine. The goal is to develop an electronic system that drives the advanced technology electronics. Powers adds that the near-term future will likely see parallel systems where the current 12-volt system would power the traditional electric/electronics such as light bulbs, while the 42-volt system would power the more demanding electronics.

There are many advantages and opportunities presented by the move from 12- to 42-volt electrical systems in the vehicle. One such advantage noted by Powers is the ability to integrate the starter into the back of the engine, with a flywheel to allow for automatic shut-offs at stop lights and during idle operation (*note*: automatic shut-off is currently offered by Honda with their gasoline/electric hybrid model, the Insight). An automatic shutoff feature will lead to increased fuel economy and decreased emissions.

The 42-volt system would aid implementation of advanced engine technology. The use of electronically actuated valve control for engines could become a viable option for further reducing mechanical losses and helping to improve thermal efficiency. Adding to the list of advances hastened by the switch to 42 volts is drive-by-wire, the electronic replacement of traditional shafts and cables. In the most basic form, drive-by-wire replaces the throttle cable with a wire that carries a signal directly to the electrically actuated controlled throttle. Alternatively, the system could include a microprocessor that determines the most efficient means of adjusting the vehicle speed by adjusting such variables as spark timing or air intake.

Vehicle Interior and Safety Systems

In recent years there has been substantial growth in the development of advanced interior and safety technologies. Consumer electronics, advanced airbags, ABS, and even stability control are just a few of the more obvious applications. Yet, the near future is likely to bring advanced technology into the vehicle's interior at an even more impressive rate. Heat-sensing night vision and telematics are among the many near-term advances that may significantly increase consumer satisfaction and safety in the coming years.

One of the great challenges the automotive industry faces is that of delivering advanced technologies at affordable prices. The industry is challenged to simultaneously increase the durability of new technology, reduce the size and weight, while significantly decreasing the price of advanced technologies.

On a per-mile basis, driving at night is more than three times as likely to result in a fatality as driving during daylight. While many factors contribute to this, poor visibility certainly plays a significant role.[40] The ability to employ infrared detection to enhance night vision has been used by the military for several years, yet cost has prohibited the application into an obvious market—the automobile. General Motors has recently introduced an infrared night-vision system that is designed to enhance the driver's vision by projecting, via a heads-up display, a monochromatic image of the road. The image is projected to a focal point that allows drivers to easily focus on the image, with little effort.

The system uses an uncooled infrared technology, which detects the thermal energy of objects that are invisible to the human eye. The thermal energy is focused on the detector placed at the front of the vehicle and processed electronically to create the monochromic image. Although night vision is not likely to see high penetration rates in the near future, it illustrates the industry's ability to adapt extremely advanced technology to the demands of motor vehicle use for the purpose of increasing the safety of vehicle occupants.

A new automotive development involves a major increase in the planned introduction of telematics—the combination of telecommunications and the microprocessor.[41] Technological advances have made it possible for real-time data and voice communication to and from vehicles. Several manufacturers have offered, for some time, emergency communications, where in the case of an accident, a distress signal is automatically sent via cellular communication to a monitoring system that immediately contacts the appropriate emergency personnel. OnStar, a service provided by General Motors is currently the most complete of this first generation of telematics services. The service provides remote diagnostics, theft notification and tracking, remote door-unlock, a database containing the driver's medical information for emergency requirements, and a concierge service. This is accomplished through the use of a three-button pad integrated into the interior of the vehicle. The driver communicates with OnStar advisors through a hands-free microphone. The system combines cellular communication with a global positioning system to monitor the vehicle.

The Jaguar S-Type is the first vehicle to provide voice recognition technology. The system, developed by Visteon, enables the driver to control a number of in-car systems simply by speaking. Drivers can switch to voice activation at any time by pressing a "voice" button on steering wheel. They can then control the audio systems, climate control system and telephone functions by using simple voice commands.

Yet, OnStar and voice activation merely scratch the surface of the potential of telematics. In the near future, manufacturers and suppliers will be offering in-vehicle Internet access, real-time traffic advisories, reconfigurable displays, and other advanced telematic accessories. The Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume addresses future penetration rates for telematics. The forecast of key engineering leaders in table 5 suggests significant penetration of several key technologies in the coming decade not only in luxury vehicles, but also in nonluxury segments. Such increases in electronics, and the concomitant power requirements reaffirm the need for a shift to a 42-volt electrical system.

Table 5
Automotive Telematics Forecast

Tech-58: Telematics is a combination of information technology and communications. Please provide your estimate of what percentage of vehicles in 2009 will incorporate telematics features. For vehicles that incorporate telematics, what percent of their total cost will be attributable to these features?

	Median responses			
	Non-luxury (Less than $25,000)		Luxury (Greater than $25,000)	
Vehicle Telematics	Percent of vehicles with these features	Percent of cost per vehicle (for those vehicles with these features)	Percent of vehicles with these features	Percent of cost per vehicle (for those vehicles with these features)
Developed technologies (e.g., Navigation systems, security systems"	30%	5%	75%	5%
Emerging technologies (e.g. traffic information, drowsy driver detection)	10	4	40	3

Reprinted from the Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume

Alternative Powertrain Technologies

The internal combustion engine has undergone extensive development over the years. Advanced technologies including materials, electronic manufacturing and design have been critical to the dramatic progress made in all facets of engine performance. Federal and state emission requirements and federal corporate average fuel economy (CAFE) standards have been major forces prompting the application of these, while still satisfying the customers performance requirements. Although the past 25 years (since the introduction of CAFE) have seen unprecedented gains in advanced engine technology the next five to ten years will likely see even greater change.[42]

The automotive industry enters the 21st century amidst much speculation regarding a new powertrain paradigm. The internal combustion engine, which has been the driving force for the first 100 years will undoubtedly be challenged in the coming decades. Yet, before any new paradigm shift in engine technology takes place, there are many significant technical and economic hurdles to overcome.

Most major vehicle manufacturers are expected to have saleable gasoline/electric hybrid vehicles within the next few years. However, these vehicles are not expected to be cost-effective (i.e., profitable) for several years. Yet, there is increasing belief that over the longer term they may provide for significantly increased fuel mileage and emissions reduction with minimal cost penalty. Manufacturers have also stated that they will produce a few fuel-cell-powered vehicles within the next five years. Although significant advances have been and are being made, it is unlikely that fuel cells will be a cost-effective power source during the coming decade. Importantly, the gasoline/electric hybrid and the fuel cell are indicative of the significant changes that could take place in the coming decade, and therefore should be closely monitored.

In the Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume engineering executives predict that by 2009, three percent of passenger cars sold will be gasoline/electric hybrid vehicles and one percent will be powered by fuel cells. Although one percent powered of the total market may not seem newsworthy, if the technology panel's forecast comes to fruition, it would mean that given a market similar to 1999 (17 million units), 170,000 vehicle sold in 2009 would be driven by fuel-cell technology heretofore considered aerospace technology.

Gasoline/electric hybrid vehicles

Manufacturers face global pressure to reduce the emission of carbon dioxide, which is a standard product of combustion, and traditional harmful emissions such as unburned hydrocarbons and nitrogen oxides. The 1997 United Nations Convention on the World Climate in Kyoto, Japan, solidified the environmental concerns of many and is an indication that fuel economy must continue to be improved. Alternative power plants and new fuels could help reduce the production of carbon dioxide, which is being implicated as contributing to global warming.

California's requirement for zero-emissions vehicles (ZEV) may have served as a wake-up call for both industry and government. Although the mandate (scheduled to be phased-in during the late nineties) was delayed, it served as a warning to vehicle manufactures that further legislation requiring alternative power sources was likely. Conversely, the inability of the manufacturers to meet the ZEV requirements due to technical and economic challenges gave notice to government agencies that there are difficult barriers that must be overcome.

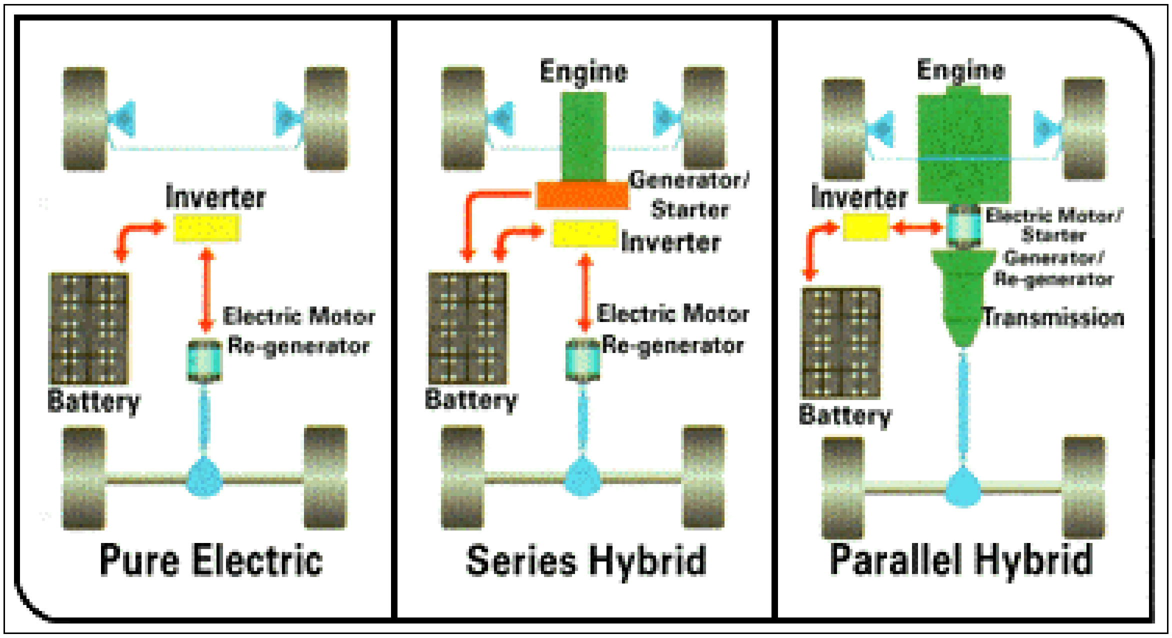
Those hurdles are best illustrated by the lack of success of the General Motors EV1. While most manufacturers attempted to satisfy California ZEV regulations by building so-called "gliders" (merely replacing the internal combustion powertrain in a current product with an electric powertrain) the EV1 was designed from its inception to be an electric vehicle. Yet, even given its use of lightweight materials, regenerative braking, and other highly advanced power-saving technologies, the vehicle's market success was greatly limited due to cost and the battery's range limitations. Although there have been significant strides in many areas critical to the viability of electric vehicles, the greatest stumbling block remains the electric storage battery itself. The lead-acid battery has been the dominant battery system for most electric vehicles, although it does not meet customer requirements for range and life. Much work has gone into the development of alternatives to the lead-acid battery and some EV's are beginning to employ nickel metal hydride designs. The energy density of this batter is approximately twice that of the lead-acid battery, but cost is quite high. The Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume forecasts application of several alternative battery technologies (table 6), yet cautions that "it must be kept in mind that we know the fundamental potential of various battery types regarding energy and power density. Only a few hold significant promise, even if various technical and commercial problems can be resolved.[43]"

Table 6
Hybrid Vehicle Battery Forecast

TECH-7: What percent of electric or hybrid passenger cars will utilize the following battery types in 2004 and 2009		
Types of batteries	Median response	
	2004	2009
Lead acid	50%	30%
Lithium ion	10	15
Lithium-polymer	7	14.5
Nickel-cadmium	5	5
Nickel-metal hydride	25	30
Zinc-air	2	5

Reprinted from the Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume

Figure 10 illustrates three alternative powertrains currently under development by the automotive industry participants. As described earlier, the electric vehicle will likely not be viable unless a system is developed. The gasoline/electric hybrid does, however, offer the opportunity to reduce emissions and increase mileage. There are two basic architectures for hybrid vehicles. The series hybrid uses a power source (generally a combustion engine) to generate electrical power, which is then stored in a battery and/or used to drive an electric motor connected to the drive wheels. The parallel hybrid uses both an internal combustion engine and the electric motor to drive the wheel, with one or the other or both driving the wheels, depending on the vehicle's power needs. There are many variations in the hybrid architecture including whether it can be tied to the electric grid (e.g., overnight charging) or used with engine fuel as the only energy source. Obviously the use of an internal combustion engine, an electric drive train, and a substantial battery creates cost challenges. Less than half (47 percent) of the Delphi X technology panelists expect vehicles with electric powertrains to reach cost parity with the internal combustion engine/transmission, with little expectation for cost parity before 2015.



Source: Delphi Automotive (used with permission)

Figure 10
Alternative Vehicle Power Technologies

No final copower source with the electric engine has been determined. The Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume forecast suggests that diesel and spark ignition (i.e., the traditional gasoline engine) will be used (table 7). Diesel engines offer the opportunity for increased mileage. However, due to stricter emissions standards, diesel engines, with high nitrogen oxide and particulate emissions, may not be a viable option.

Table 7
Hybrid Vehicle Combustion Engine Forecast

TECH-8: What percent of passenger cars with hybrid electric/combustion engine propulsion will utilize the following types of combustion engines in 2005 and 2009?		
Types of batteries	Median response	
	2004	2009
Compression ignition, Diesel	25%	30%
Gas turbine	0	3
Spark ignition	70	50
Stirling	0	0

Reprinted from the Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume

Ford and General Motors have recently delivered “proof of concept vehicles” as required by the PNGV. These vehicles are demonstrations of technologies that deliver the PNGV’s stated goal of an 80-mile-per-gallon (90 mpg for diesel) five-passenger vehicle that meets current customer performance requirements. Cost parity with current vehicle remains an elusive goal.

The Ford Prodigy is a parallel hybrid vehicle that uses a diesel engine mated to an electric motor. "Prodigy is an extremely fuel-efficient, full-function family vehicle," says Neil Ressler, vice president of Research and Vehicle Technology and Ford Motor Company's chief technical officer. "It represents an interim stage between our P2000 research programs and our plans for an affordable, production hybrid in 2003."[44]

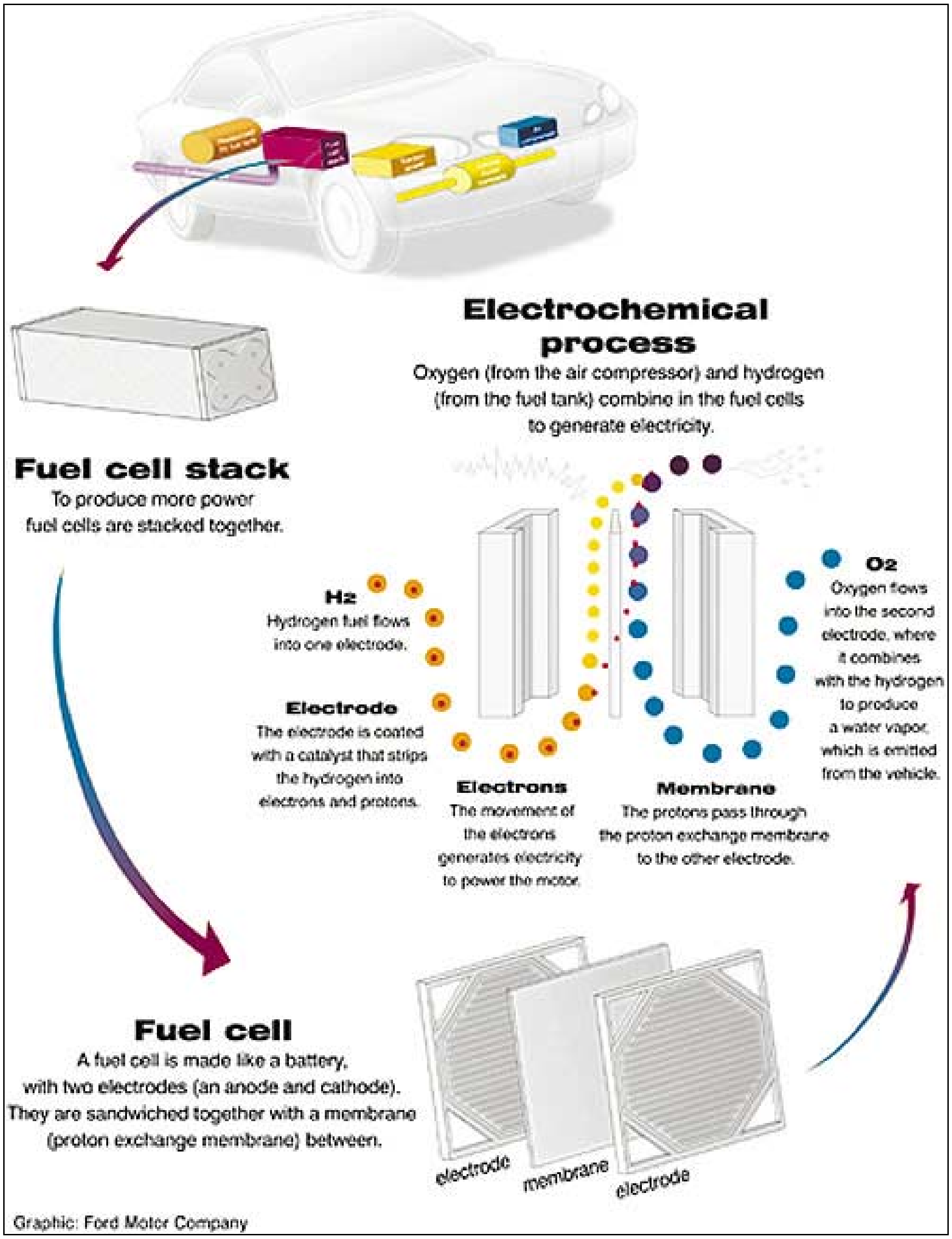
The Prodigy employs an aluminum diesel DIATA (direct injection, aluminum through-bolt assembly) engine. The DIATA engine is about 35 percent more efficient than conventional gasoline engines. The 1.2-liter direct-injection engine generates 74 horsepower at 4,100 rpm.

The General Motors concept, Precept, similarly uses direct-injection diesel technology in parallel with an electric motor. The Precept uses all-wheel-drive, not for performance reasons, but instead to allow regenerative braking at all four wheels to increase mileage by 13 mpg over a vehicle without regenerative braking.[45] Both the Ford and GM vehicles are purpose-built vehicles that use a host of advanced technologies to reduce fuel consumption.

DaimlerChrysler has also been actively developing a hybrid-powered vehicle. Their proof-of-concept vehicle, the ESX3, is powered by a 1.5-liter, three-cylinder turbo-diesel, with a permanent magnet electric motor. The ESX3 is slightly larger than either the Precept or Prodigy. Consequently, it gets slightly lower gas mileage. The ESX3 has a unique body made of large injection-molded body panels mounted on an aluminum space frame. In November of 1999, the company introduced a Dodge Durango Sport Utility Gasoline electric hybrid vehicle that will be soon brought to market. The hybrid Durango delivers a 20 percent increase in fuel economy over the V8 Durango. While not made of the advanced materials that comprise the Precept and Prodigy, the hybrid Durango delivers advanced powertrain technology at a price that (given proposed subsidies) may be competitive with current SUVs.

Fuel-cell-powered vehicles

Fuel-cell power is the most intriguing and the most high tech of the next generation powertrain technologies currently under development. It also requires the most invention before it can achieve commercialization. Figure 11 illustrates the concept of the fuel cell as a power source. Fuel cells use continuous electrochemical reactions to convert chemicals, in most cases hydrogen and oxygen, into direct electrical current. In essence, the fuel-cell-powered vehicle would be similar in concept to the series hybrid, with the fuel cell replacing the combustion engine and battery to send electric current to the drive.



Source: Ford Motor Company (used with permission)

Figure 11
Fuel Cell Power Source

It is important to note that the fuel cell is the subject of intense research, and no short-term payoff is expected. In an era of limited capital resources, companies must balance the importance of environmentally sustainable transportation with that of developing other advanced technologies such as those illustrated in this paper. In an effort to minimize research expenditures, industry participants have partnered with competitors. Ford and DaimlerChrysler have teamed with Ballard, a fuel-cell company, while General Motors has entered a collaborative effort with Toyota to develop alternative-powered vehicles.

III. VEHICLE ELECTRONICS CONTENT ASSESSMENT

There are several current estimates of the electronics content of motor vehicles. The estimates usually take one of two forms: dollars of electronic content per vehicle, or electronics content as percentage of vehicle cost. These estimates typically suffer from problems of limited coverage and changing definitions. For example, DaimlerChrysler has recently stated that electronics comprise 30 percent of the total cost of Mercedes Benz vehicles. DaimlerChrysler has also stated that Mercedes vehicles typically contain about 80 microprocessors. Of course, Mercedes cars are overwhelmingly high-end, luxury-segment vehicles, which would typically contain a significantly higher level of electronics than the average North American vehicle.

Semiconductors are integral parts in many automotive components. One recent estimate suggests that there are from 20 to 30 microprocessors in the average vehicle.[46] Table 8 shows a dollar forecast of computer chip automotive sales from a well-known automotive electronics consultant. The table charts the growth in chip usage for automotive applications for the years 1993 to 1998, and provides a forecast of automotive chip sales through 2004. As can be seen, the growth in dollar value is impressive during the period 1993 to1997. However, the relative flatness of chip sales to the auto industry in 1997 and 1998 probably reflects price pressures faced by chip manufacturers with overcapacity during this period. This underscores the flaw in dollar assessments of electronic content in the motor vehicle. Many electronics components have faced declining price schedules in recent years. Yet the electronics content of the vehicle has clearly increased.

Table 8
World Wide Annual Motor Vehicle Computer Chip Usage (actual and forecast)

Year	Total value ($ millions)	Average Content per Vehicle
1993	$4,300.8	$91.47
1994	5,840.6	109.48
1995	6,826.8	122.83
1996	8,037.3	134.74
1997	8,427.9	134.42
1998	8,393.2	128.99
1999*	10,003.3	148.55
2000*	11,127.4	156.88
2001*	12,209.3	161.68
2002*	13,195.5	172.38
2003*	14,001.2	178.82
2004*	15,103.7	182.94
* Forecast		

Source: Zgymont, Jeff, Automotive Electronics Explores New Fronts in Electric Drive and the Internet. 1999 Ward's Automotive Yearbook, Ward's communication, pp.68-70

Another estimate of automotive electronics content in the vehicle is available from the results the Delphi X: Forecast and Analysis of the North American Automotive Industry Technology Volume. The OSAT study produces an estimate of current and future electronic content in vehicles sold in North America. The Delphi technology survey relies on responses from 86 industry executive panelists surveyed in 1999. The panelists were asked for their estimate of overall electronics content as a percentage of current vehicle cost. The median response was 10 percent. The panelists also forecast that by 2009, electronics will account for 20 percent of the cost of a vehicle.

Vehicle Electronics Content Assessment Survey Results

OSAT recently surveyed the three largest Michigan vehicle firms on the subject of electronic content in the motor vehicle. The three firms were asked to compute electronic content, as a percentage of cost, for six vehicle systems/component groups. The companies were also asked to estimate overall electronic content in the total vehicle. The six vehicle systems/component groups are:

Engine (including, but not limited to):
Engine Control Module (ECM) - Computer that controls engine fuel, ignition, and emission control systems; throttle position sensor, mass airflow meter, engine speed sensor, oil temperature sensor, oil pressure sensor, electronic ignition system, diagnostic systems monitor, drive-by-wire

Transmission (including, but not limited to):
Locking torque converter – controlled by ECM, shift speed control, vehicle speed sensor

Chassis (including, but not limited to):
Antilock brake system, traction control, power steering electronic control for steering effort, tire pressure sensing devices, brake-by-wire, steer-by-wire, active suspension, semi-active suspension

Safety (including, but not limited to):
Airbag actuators, GPS/cellular-phone-based safety systems (On-Star), blind-spot detection, collision warning systems, Navigation systems, in-vehicle message systems, automatic toll collection, self-dimming rear-view mirror, passenger sensing to control airbag-deployment rate

Interior (including, but not limited to):
Radio, CD player, electronic instrumentation/gauges, voice-activated controls, cellular phone, memory seats, air conditioning controls, trip computer (fuel economy, distance, etc.), controls for heated seats, rear view mirrors and windows, digital compass, outside air temperature readout, Instrument panel light dimmer switch, clock

Miscellaneous (including, but not limited to):
Antitheft system, cruise control, adaptive cruise control, electronic keyless entry, pulsed windshield wipers, battery saver – timed accessories, voltage regulator, alternator

The companies were also asked to provide separate estimates for five vehicle segments: small car, medium car, large car, and large truck. The responding firms were also asked to estimate the percentage of electronic content in each component group produced within the traditional automotive industry (i.e., not including components supplied by firms primarily associated with other industries, such as computer chip manufacturers). This estimate is meant to separate the value of electronics produced within the auto industry from that purchased from other (electronic) industries. The questionnaire is shown in appendix IV. It should be noted that several of the responding firms strongly suggested that the definition for traditional automotive suppliers include companies such as computer chip manufacturers—for the respondents certainly considered them as such. However, the survey instructions clearly asked respondents to consider such electronic content as nonautomotive in origin.

A complication in the overall assessment was that one of the firms failed to estimate overall electronics content in the vehicle. This forced the study authors to rely on separate, although dated, information concerning the component group shares in overall vehicle parts costs.[47] Table 9 shows our method of estimating the electronic content share of total vehicle parts cost. Column 1 contains the independent estimate of component share of total vehicle parts cost for three final groups: powertrain (engine and transmission), chassis, and vehicle interior. Reliable estimates for the share of safety systems and other miscellaneous electronics were not available to the study. A number of the constituent components for these two last systems, therefore, were included in the content of the other three systems. For example, powertrain systems are assumed to comprise 35 percent of total vehicle parts cost. Powertrain systems now include such miscellaneous components as alternators and voltage regulators.

Table 9
The Share of Electronics in Vehicle Parts Cost

	System Share of Vehicle Parts Cost	Electronics Share of Systems Cost	Electronics Share of Total Vehicle Parts Cost	Share of System Electronics Produced in Auto Industry	Electronics Share of Total Vehicle Parts Cost Produced in Auto Industry
Powertrain	34.9%	9.8%	3.4%	77.1%	2.6%
Chassis	20.8%	6.2%	1.3%	91.2%	1.2%
Interior	17.9%	16.3%	2.9%	91.2%	2.7%
			7.6%		6.5%

Column 2 contains the company's estimates of the proportion of systems group cost that can be attributed to electronics. The company answers were weighted by company sales in each segment in 1999. For example, about 9.8 percent of powertrain-systems costs are attributed to electronics. The fraction in column 2 is multiplied by the vehicle-parts share shown in column 1, in the same row, to estimate system electronic contribution to total vehicle-parts cost. This product is shown in column 3. For example, we estimate that 3.4 percent of total vehicle-parts cost can be attributed to powertrain electronics. The sum of the three systems in column 3 yields a total contribution of electronics to vehicle-parts cost. We estimate that 7.60 percent of total vehicle-parts cost is composed of electronics parts cost.

Column 4 contains the companies' estimates of the automotive share of electronics cost percentages shown in column 3. This allows the computation of the percentages shown in column 5, or the share of vehicle-parts cost comprised by electronics produced within the auto industry. The sum across the system percentages for this last value was 6.45 percent. In other words, almost 6.5 percent of total vehicle-parts and components costs are made up by the value of electronics produced within the auto industry.

How large are the markets for in-vehicle electronics in the United States and world motor-vehicle industries? Table 10 contains summary information that can be combined with the results shown in table 9 to provide a partial answer to these questions. The USBOC 1997 Census of Manufactures[48] estimates that U.S. light-vehicle assembly facilities purchased $137.47 billion in materials in 1997. This would imply a $10.45 billion U.S. automotive electronics market in 1997 on the basis of our estimated share of 7.60 percent for vehicle electronics. About $8.87 billion of this market (85 percent) is composed of components produced within the auto industry itself. U.S. production of light vehicles amounted to 22.7 percent of world vehicle production in 1997. The world market for automotive electronics could amount to $46.09 billion if in-vehicle electronics make the same share of vehicle-parts costs in the world auto industry as is the case in the U.S. industry (higher content in Japan, lower content in emerging markets). About $39.13 billion of the worldwide automotive-electronics-market products would be produced within the auto industry itself.

Table 10
The Size of the Automotive Electronics Market

1997 Auto. & Light Truck Cost of Materials[1]	$137,473,493,000
Auto. & Light Truck Cost of Electronic Materials	$10,447,320,000
Auto. & Light Truck Cost of Electronic Materials produced by auto industry	$8,869,264,000
1997 U.S. Vehicle Production[2]	12,119,000
1997 World Vehicle Production[2]	53,463,000
1997 U.S. Production Share	22.7%
Adjusted World 1997 Light Vehicle Cost of Electronic Materials	$46,088,407
Adjusted World 1997 Light Vehicle Electronic Materials Produced by Auto Industry	$39,126,803

Sources:
1: 1997 Economic Census, U.S. Census Bureau, U.S. Department of Commerce
2: Motor Vehicle Facts & Figures 1998, American Automobile Manufacturers Association

CONCLUSION

Ranking States by High-Technology Activity

This research memorandum has reviewed several methods and reports that rank states in terms of high-tech activity. We have conducted our own review of Michigan's relative position in this area and have measured the contribution of Michigan's auto industry to the state's high-technology sector. Because there is no conclusive definition of "high tech," we chose indicators that are fundamental and widely used. Research and development spending, the rate of patent activity, and scientific and engineering employment are all generally accepted measures of technological activity. The basic conclusion of our tables is the same: Michigan is one of the leading high-tech states. Regardless of the indicator used, Michigan is listed consistently among the top ten states in the technology rankings. Our findings include the following findings.

1) Michigan ranks second among the fifty states in total private spending on research and development activity.
2) Michigan ranked sixth among the fifty states in terms of average number of patents received during 1994-98.
3) Michigan ranks third among the fifty states in terms of total employment in high-tech industries as defined by the BLS.
4) Michigan ranks seventh among the fifty states in terms of employment in high-technology oriented occupations. If government employment is excluded from this measure, Michigan's rank rises to sixth.
5) Michigan ranks tenth in terms of high-tech employment when automotive technology-oriented employment is added to employment in AEA-defined high-tech industries for all states. The state's overall rank improves to eighth when automotive related, high-tech engineering-services employment is also added to the state's high-tech employment.
6) Finally, the three largest vehicle producers in the United States reported in a recent survey that they locate 79 percent of their technology-oriented employment in Michigan.

Technology Assessment of the Motor Vehicle

High-technology firms are defined by the agencies of the U.S. government as those that are engaged in the design, development, and introduction of new products and innovative manufacturing processes, or both, through the systematic application of scientific and technical knowledge. This report has reviewed a number of near-term innovative products that the automotive industry will incorporate into vehicles. Our review of high technology in the motor vehicle concentrates on future innovation because it is the dominant subject of the bulk of current industry research and development activity. In other words, we describe in our assessment a representative list of actual technologies that are the focus of the technology-oriented employees listed in section 1 of this report.

A challenge faced by the automotive industry is the perception that much of automotive technology is somehow commodity driven since the final product will be produced at high volumes. Although many of the technologies we discuss are not necessarily new, they are most certainly technologies used in innovative applications that require significant research design and development to bring to market.

It is also important to remember the severity of the environment in which automotive high-technology products must perform. For example, the powertrain control module, a complex, computer-management system for the engine and transmission, must tolerate temperatures variations between 30 and 40 degrees below zero to 200 degrees within minutes and operate flawlessly for ten or more years. Consumers expect, and rightfully so, that their automobiles operate reliably and without failure. The all-too-common “system crashes” (either hardware of software induced) associated with some high-technology products are, for obvious reasons, unacceptable traits in automotive applications. The challenge to automotive companies, similar to that confronting the aerospace industry, is not only to implement high technology, but introduce it into a harsh environment, with unfailing reliability all at prices that allow for consumer acceptance. Also, emissions regulations demand a very high level of reliability and durability for engine-related electronics.

Vehicle Electronics Content Assessment

Products that incorporate electronics technology are often labeled as “high tech.” If this is a viable categorization, the modern motor vehicle can be viewed as a product that contains significant technological content. This content will significantly increase in future motor vehicles. Our current estimate of vehicle electronics content is based on direct survey response from the technical centers of the three largest vehicle manufacturers in North America. We estimate that at least 7.6 percent of the parts and component cost of manufactured vehicles is composed of electronic components. These components are generally more functional and significant than the simple semiconductors or microprocessors they contain. That is why we estimate that almost 85 percent of the value of these products are produced within the automotive industry itself. The true meaning of a “core” technology lies in its application to achieve a meaningful end.

Appendix I

AEA High-Tech Definition by Standard Industrial Classification Codes

High-tech manufacturing

Computers and office equipment
- 3571 Electronic computers
- 3572 Computer storage devices
- 3575 Computer terminals
- 3577 Computer peripherals
- 3578 Calculating and accounting machines
- 3579 Office machines

Consumer electronics
- 3651 Household audio and video equipment
- 3652 Phonographic records and prerecorded tapes and disks

Communications equipment
- 3661 Telephone and telegraph apparatus
- 3663 Radio and TV broadcast and communications equipment
- 3669 Other communications equipment

Electronic components and accessories
- 3671 Electronic tubes
- 3672 Printed circuit boards
- 3675 Electronic capacitors
- 3676 Electronic resistors
- 3677 Electronic coils, transformers and Inductors
- 3678 Electronic connectors
- 3679 Other electronic components

Semiconductors
- 3674 Semiconductors and related devices

Industrial electronics
- 3821 Laboratory apparatus
- 3822 Environmental controls
- 3823 Process control instruments
- 3824 Fluid meters and counting devices
- 3825 Instruments to measure electricity
- 3826 Laboratory analytical instruments
- 3829 Other measuring and controlling devices

Photonics
- 3827 Optical instruments and lenses
- 3861 Photographic equipment and lenses

Defense electronics

- 3812 Search and navigation systems, instruments and equipment

Electromedical equipment

- 3844 X-ray apparatus and tubes and related irradiation apparatus
- 3845 Electromedical and electrotherapeutic apparatus

<u>Communication services</u>

- 4812 Radiotelephone communications
- 4813 Telephone communications
- 4822 Telegraph and other message communications
- 4841 Cable and other pay television services
- 4899 Other communications services

<u>Software and computer related-services</u>

Software services

- 7371 Computer programming services
- 7372 Prepackaged software
- 7373 Computer integrated systems design

Data processing and information services

- 7374 Computer processing and data preparation
- 7375 Information retrieval services
- 7376 Computer facilities management services

Rental, maintenance and other computer-related services

- 7377 Computer rental and leasing
- 7378 Computer maintenance and repair
- 7379 Other computer-related services

Source: AEA, Cyberstates 3.0, 1997

Appendix II

BLS High-Tech Industry Groups

281,6	Industrial chemicals
282	Plastics materials and synthetics
283	Drugs
284	Soaps, cleaners, and toilet goods
285	**Paint and allied products**
287	Agricultural chemicals
289	Miscellaneous chemical products
291	Petroleum refining
348	Ordnance and accessories
351	Engines and turbines
353	Construction and related machinery
355	Special industrial machinery
356	**General industrial machinery**
357	**Computer and office equipment**
361	Electric distribution equipment
362	Electrical industrial apparatus
365	Household audio and video equipment
366	Communications equipment
367	Electronic components and accessories
371	Motor vehicles and equipment
372,6	Aerospace
381	Search and navigation equipment
382	Measuring and controlling devices
384	Medical equipment, instruments, and supplies
386	Photographic equipment and supplies
737	Computer and data processing services
871	Engineering and architectural services
873	Research, development, and testing services
874	Management and public relations services

Source: Hecker, Daniel, "High-technology employment: A broader view," Monthly Labor Review, June 1999, p.20

Appendix III

Table 1
Ranking by Industry of Company Funds for Industrial Research & Development: 1997
(Excludes Federal)

Industry	SIC code	Funds	Rank
All Industries		$133,611	
Motor vehicles & motor vehicle equipment	***371***	***13,758***	***1***
Office, computing, and accounting machines	357	12,787	2
Drugs and medicines	283	11,586	3
Computer and data processing services	737	11,318	4
Electronic components	367	10,786	5
Trade	50-59	7,961	6
Communication equipment	366	7,377	7
Aircraft and missiles	372,376	5,677	8
Other machinery, except electrical	351-56,358-59	5,606	9
Optical, surgical, photographic & other inst.	384-87	5,240	10
Industrial chemicals	281-82,286	4,970	11
Research, development, and testing	873	4,782	12
Other electrical equipment	361-64,369	4,432	13
Scientific & mechanical measuring instruments	381-82	3,719	14
Other manufacturing industries 1	27,31,39	2,642	15
Other chemicals	284-85,287-89	2,072	16
Telephone communications	481	1,826	17
Food, kindred, and tobacco products	20,21	1,787	18
Fabricated metal products	34	1,669	19
Petroleum refining and extraction	13,29	1,612	20
Other nonmanufacturing industries 1	07-12, 14, 15,161-162,17	1,541	21
Finance, insurance, and real estate	60-65, 67	1,500	22
Paper and allied products	26	1,456	23
Rubber products	30	1,372	24
Engineering, architectural, and surveying	871	781	25
Health services	80	679	26
Other transportation and utilities	40-42, 44-47	670	27
Stone, clay, and glass products	32	606	28
Textiles and apparel	22,23	476	29
Other services	701, 72, 75-79, 81,	446	30
Ferrous metals and products	331-32,3398-99	414	31
Nonferrous metals and products	333-36	353	32
Lumber, wood products, and furniture	24,25	348	33
Other engineering and management services	872, 874	347	34
Other transportation equipment	373-75,379	307	35
Electric, gas, and sanitary services	49	258	36
Other business services	731-736, 738	242	37
Radio and TV receiving equipment	365	152	38
Other communications	482-484, 489	58	39

Source: National Science Foundation/SRS, Survey of Industrial Research and Development: 1997

Table 2
States Ranked by Industrial Research and Development - 1997
($ millions)

Area	Federal	Company	Total	Rank	Area	Federal	Company	Total	Rank
CALIFORNIA	5,977	28,034	34,011	1	TENNESSEE	(D)	(D)	1,089	27
MICHIGAN	***121***	***12,888***	***13,009***	***2***	UTAH	199	829	1,027	28
NEW JERSEY	117	10,952	11,069	3	DELAWARE	8	1,001	1,009	29
NEW YORK	2,078	7,861	9,939	4	SOUTH CAROLINA	83	700	783	30
MASSACHUSETTS	1,397	6,903	8,300	5	RHODE ISLAND	(D)	(D)	704	31
TEXAS	784	6,481	7,265	6	NEW HAMPSHIRE	(D)	(D)	652	32
WASHINGTON	(D)	(D)	6,610	7	ALABAMA	189	399	589	33
PENNSYLVANIA	672	5,937	6,609	8	IOWA	(D)	(D)	578	34
ILLINOIS	163	6,085	6,248	9	OKLAHOMA	45	383	428	35
OHIO	604	5,004	5,608	10	NEVADA	(D)	(D)	380	36
NORTH CAROLINA	111	3,478	3,590	11	KENTUCKY	3	356	359	37
FLORIDA	1,461	1,981	3,442	12	VERMONT	(D)	(D)	246	38
MINNESOTA	362	2,754	3,116	13	LOUISIANA	(D)	(D)	172	39
CONNECTICUT	307	2,707	3,014	14	ARKANSAS	(D)	(D)	118	40
INDIANA	(D)	(D)	2,677	15	MONTANA	(D)	(D)	92	41
COLORADO	525	1,723	2,248	16	HAWAII	55	32	87	42
ARIZONA	677	1,177	1,854	17	MAINE	(D)	(D)	83	43
VIRGINIA	851	916	1,767	18	MISSISSIPPI	(D)	(D)	73	44
WISCONSIN	29	1,678	1,707	19	NEBRASKA	(D)	(D)	71	45
MARYLAND	456	970	1,425	20	NORTH DAKOTA	0	33	33	46
NEW MEXICO	(D)	(D)	1,310	21	WYOMING	0	28	28	47
MISSOURI	30	1,260	1,290	22	SOUTH DAKOTA	0	26	26	48
GEORGIA	212	1,062	1,273	23	ALASKA	(D)	(D)	24	49
IDAHO	(D)	(D)	1,181	24	DISTRICT OF COLUMBIA	(D)	(D)	(D)	NR
KANSAS	(D)	(D)	1,136	25	WEST VIRGINIA	(D)	(D)	(D)	NR
OREGON	28	1,075	1,102	26					
					UNDISTRIBUTED FUNDS	1,056	6,154	7,211	
					U.S. TOTAL	23,928	133,611	157,539	

Source: National Science Foundation   D = Non-disclosure   NR=Not Ranked

Table 3
Ranking of States by Patents Received: 5Yr. Period 1994-98

(excludes design and botanical patents)

State	Total 1994-98	Rank
CALIFORNIA	55,776	1
NEW YORK	25,898	2
TEXAS	21,650	3
NEW JERSEY	15,727	4
ILLINOIS	15,585	5
MICHIGAN	***15,238***	***6***
PENNSYLVANIA	14,448	7
OHIO	13,614	8
MASSACHUSETTS	12,934	9
FLORIDA	10,798	10
MINNESOTA	9,449	11
CONNECTICUT	7,804	12
WISCONSIN	6,563	13
COLORADO	6,290	14
WASHINGTON	6,260	15
NORTH CAROLINA	6,117	16
INDIANA	6,013	17
MARYLAND	5,755	18
ARIZONA	5,554	19
GEORGIA	4,871	20
VIRGINIA	4,408	21
OREGON	4,010	22
MISSOURI	3,590	23
TENNESSEE	3,244	24
UTAH	2,749	25
IDAHO	2,421	26
OKLAHOMA	2,402	27
SOUTH CAROLINA	2,346	28
NEW HAMPSHIRE	2,302	29
IOWA	2,288	30
DELAWARE	2,072	31
LOUISIANA	2,034	32
KENTUCKY	1,516	33
ALABAMA	1,485	34
KANSAS	1,418	35
NEW MEXICO	1,315	36
RHODE ISLAND	1,187	37
VERMONT	1,141	38
NEVADA	984	39
NEBRASKA	837	40
WEST VIRGINIA	726	41
MISSISSIPPI	688	42
ARKANSAS	609	43
MAINE	545	44
MONTANA	534	45
HAWAII	380	46
NORTH DAKOTA	278	47
DISTRICT OF COLUMBIA	267	48
ALASKA	231	49
WYOMING	220	50
SOUTH DAKOTA	216	51
U.S. TOTALS	**314,911**	

Source: U.S. Department of Commerce, Patent and Trademark Office

Table 4
Employment in BLS High-Tech Industries Ranked by State – 1997

State	High-Tech Employment	Rank	State	High-Tech Employment	Rank
CALIFORNIA	1,332,578	1	KANSAS	109,540	27
TEXAS	697,789	2	ALABAMA	109,425	28
NEW YORK	536,071	3	LOUISIANA	91,395	29
MICHIGAN	***530,492***	***4***	OKLAHOMA	88,458	30
ILLINOIS	494,684	5	UTAH	87,804	31
OHIO	471,804	6	IOWA	79,178	32
PENNSYLVANIA	387,844	7	NEW HAMPSHIRE	62,141	33
NEW JERSEY	348,367	8	ARKANSAS	55,978	34
FLORIDA	347,800	9	NEW MEXICO	49,469	35
MASSACHUSETTS	346,125	10	NEBRASKA	49,155	36
VIRGINIA	283,417	11	MISSISSIPPI	46,496	37
NORTH CAROLINA	269,652	12	DISTRICT OF COLUMBIA	46,182	38
INDIANA	258,660	13	DELAWARE	42,221	39
WASHINGTON	250,168	14	IDAHO	38,998	40
GEORGIA	216,212	15	WEST VIRGINIA	32,858	41
MINNESOTA	204,869	16	NEVADA	30,019	42
WISCONSIN	195,071	17	RHODE ISLAND	26,532	43
TENNESSEE	190,277	18	MAINE	22,206	44
MISSOURI	189,718	19	SOUTH DAKOTA	20,757	45
MARYLAND	182,711	20	VERMONT	20,000	46
CONNECTICUT	175,170	21	MONTANA	13,503	47
COLORADO	171,518	22	HAWAII	10,808	48
ARIZONA	168,544	23	NORTH DAKOTA	10,533	49
SOUTH CAROLINA	129,087	24	ALASKA	8,160	50
KENTUCKY	118,110	25	WYOMING	6,591	51
OREGON	111,384	26			
			U.S. TOTAL	**9,766,859**	

Note: High-tech industries are those defined in U.S. Bureau of Labor Statistics, Monthly Labor Review, June 1999

Source: U.S. Bureau of Labor Statistics, Covered Employment and Wages; U.S. Census Bureau, County Business Patterns

Table 5
State Ranking of Total High-Tech Occupational Employment – 1998

State	High-Tech Employment	Rank	State	High-Tech Employment	Rank
California	819,530	1	Oregon	71,982	27
Texas	499,034	2	Iowa	63,142	28
New York	310,764	3	Kansas	62,007	29
Illinois	297,590	4	Kentucky	61,239	30
Florida	266,745	5	Oklahoma	59,099	31
Pennsylvania	246,029	6	Utah	53,138	32
Michigan	***241,950***	***7***	New Mexico	44,320	33
Virginia	233,125	8	Mississippi	41,044	34
New Jersey	231,750	9	New Hampshire	35,009	35
Ohio	231,329	10	Arkansas	34,470	36
Maryland	227,663	11	Nebraska	32,906	37
Massachusetts	184,006	12	Idaho	27,595	38
Colorado	172,948	13	West Virginia	23,369	39
Georgia	166,347	14	Rhode Island	23,203	40
North Carolina	164,623	15	Nevada	20,581	41
Washington	163,869	16	Delaware	18,894	42
Minnesota	124,644	17	Maine	18,781	43
Wisconsin	109,528	18	Alaska	14,183	44
Arizona	107,008	19	Hawaii	13,293	45
Indiana	103,714	20	Montana	13,293	46
Missouri	102,195	21	Vermont	12,974	47
Tennessee	98,437	22	District of Columbia	10,233	48
Connecticut	92,874	23	South Dakota	9,341	49
Alabama	82,514	24	North Dakota	9,044	50
South Carolina	79,471	25	Wyoming	8,356	51
Louisiana	78,821	26			
			United States	**6,218,004**	

Note: High-tech occupations are defined as engineers, math. & computer scientists, engineering technicians, science technicians and computer programmers

Source: Special tabulation from the U.S. Bureau of the Census' Current Population Survey

Table 6
State Ranking of High-Tech Occupational Employment: Private Sector + University

1996-98 avg.

State	High-Tech Employment	Rank	State	High-Tech Employment	Rank
California	710,628	1	Iowa	59,524	27
Texas	434,938	2	Oregon	53,610	28
New York	278,778	3	Kansas	51,959	29
Illinois	248,661	4	Oklahoma	48,698	30
Pennsylvania	237,217	5	Kentucky	48,454	31
Michigan	***231,466***	***6***	Utah	46,114	32
New Jersey	213,845	7	New Mexico	32,265	33
Ohio	210,551	8	New Hampshire	31,397	34
Florida	202,474	9	Arkansas	25,664	35
Massachusetts	186,769	10	Mississippi	25,398	36
Virginia	161,461	11	Idaho	22,447	37
Georgia	154,677	12	Nebraska	22,296	38
Maryland	147,074	13	Nevada	22,013	39
North Carolina	134,926	14	Rhode Island	19,333	40
Colorado	134,506	15	West Virginia	18,651	41
Washington	122,435	16	Delaware	17,878	42
Minnesota	114,879	17	Maine	16,345	43
Wisconsin	110,838	18	Vermont	12,629	44
Indiana	102,644	19	Hawaii	10,245	45
Missouri	97,665	20	Alaska	9,533	46
Connecticut	94,996	21	Montana	9,306	47
Tennessee	88,789	22	South Dakota	8,586	48
Arizona	85,096	23	DC	7,296	49
Alabama	75,394	24	North Dakota	6,606	50
Louisiana	66,503	25	Wyoming	5,926	51
South Carolina	63,273	26			
			United States	5,342,656	

Note: High-tech occupations are defined as engineers, math. & computer scientists, engineering technicians, science technicians and computer programmers.

Source: Special tabulation from the U.S. Bureau of the Census' Current Population Survey.

Table 7
High-Tech Employment Rankings Comparison-2
AEA, (AEA, Auto High-Tech and Auto Share Mich. Engineering Services)

AEA High-Tech Employment			AEA *plus* Auto High-Tech Emp.* *plus* Auto Share of Mich. Engineering Services High-Tech Employment**		
State	**Number**	**Ranking**	**State**	**Number**	**Ranking**
CALIFORNIA	784,151	1	CALIFORNIA	786,575	1
TEXAS	375,933	2	TEXAS	376,425	2
NEW YORK	320,410	3	NEW YORK	323,015	3
ILLINOIS	207,201	4	ILLINOIS	208,473	4
MASSACHUSETTS	205,091	5	MASSACHUSETTS	205,215	5
FLORIDA	193,559	6	FLORIDA	194,123	6
NEW JERSEY	179,528	7	NEW JERSEY	179,762	7
PENNSYLVANIA	159,952	8	***MICHIGAN***	***161,687***	***8***
VIRGINIA	154,712	9	PENNSYLVANIA	160,722	9
GEORGIA	132,524	10	VIRGINIA	155,059	10
OHIO	132,076	11	OHIO	138,253	11
COLORADO	131,854	12	GEORGIA	132,799	12
MINNESOTA	123,866	13	COLORADO	131,854	13
NORTH CAROLINA	119,831	14	MINNESOTA	124,319	14
MARYLAND	97,484	15	NORTH CAROLINA	121,240	15
WASHINGTON	97,025	16	WASHINGTON	97,795	16
MICHIGAN	***96,013***	***17***	MARYLAND	97,684	17
ARIZONA	89,174	18	ARIZONA	89,481	18
MISSOURI	72,332	19	MISSOURI	73,673	19
CONNECTICUT	71,507	20	CONNECTICUT	71,735	20
OREGON	70,488	21	INDIANA	71,594	21
INDIANA	65,528	22	OREGON	70,954	22
WISCONSIN	54,586	23	WISCONSIN	57,342	23
ALABAMA	48,359	24	ALABAMA	49,337	24
TENNESSEE	42,016	25	TENNESSEE	44,926	25
UTAH	41,075	26	UTAH	41,729	26
NEW HAMPSHIRE	39,660	27	NEW HAMPSHIRE	39,698	27
OKLAHOMA	33,797	28	IOWA	34,497	28
IOWA	33,671	29	OKLAHOMA	34,198	29
KENTUCKY	31,008	30	KENTUCKY	31,910	30
KANSAS	30,037	31	KANSAS	30,607	31
NEBRASKA	29,864	32	NEBRASKA	30,355	32
SOUTH CAROLINA	28,632	33	SOUTH CAROLINA	29,757	33
LOUISIANA	22,119	34	LOUISIANA	22,119	34
IDAHO	21,984	35	IDAHO	21,984	35
NEW MEXICO	21,324	36	NEW MEXICO	21,464	36
ARKANSAS	18,601	37	ARKANSAS	18,841	37
SOUTH DAKOTA	14,538	38	SOUTH DAKOTA	14,606	38
VERMONT	14,437	39	VERMONT	14,507	39
DIST. OF COLUMB.	14,324	40	MISSISSIPPI	14,351	40
MISSISSIPPI	14,182	41	DIST. OF COLUMB.	14,324	41
RHODE ISLAND	13,999	42	RHODE ISLAND	14,004	42
NEVADA	13,372	43	NEVADA	13,383	43
MAINE	10,511	44	MAINE	10,609	44
WEST VIRGINIA	9,912	45	WEST VIRGINIA	9,939	45
DELAWARE	7,533	46	DELAWARE	7,731	46
HAWAII	6,996	47	HAWAII	6,996	47
NORTH DAKOTA	5,298	48	NORTH DAKOTA	5,364	48
MONTANA	4,068	49	MONTANA	4,093	49
ALASKA	3,517	50	ALASKA	3,517	50
WYOMING	1,710	51	WYOMING	1,713	51

The source of the High-tech auto (SIC371) employment numbers for all states is a special tabulation of the U.S. Bureau of Census Current Population Survey 1989-98. High-tech occupational employment in the auto industry is defined based on the high-tech degrees listed in the AEA's CyberEducation report.

***Engineering Services (SIC8711) high-tech occupations are defined in the same way as auto high-tech. The employment figure is computed by (1) applying the high-tech share of employment in the latest available Occupational Employment Statistics (OES) survey to the 1997 Michigan Engineering Services total. (2) applying the auto share-68% according to a recent OSAT survey. Auto-related high-tech employment in engineering services is calculated at 9,867 in 1997.*

Table 8
High-Tech Employment Rankings Comparison-1: AEA, AEA and Auto High-Tech

AEA High-Tech Employment			AEA *plus* Auto High-Tech Employment*		
State	**Number**	**Ranking**	**State**	**Number**	**Ranking**
CALIFORNIA	784,151	1	CALIFORNIA	787,367	1
TEXAS	375,933	2	TEXAS	376,505	2
NEW YORK	320,410	3	NEW YORK	323,464	3
ILLINOIS	207,201	4	ILLINOIS	209,004	4
MASSACHUSETTS	205,091	5	MASSACHUSETTS	205,321	5
FLORIDA	193,559	6	FLORIDA	194,423	6
NEW JERSEY	179,528	7	NEW JERSEY	179,965	7
PENNSYLVANIA	159,952	8	PENNSYLVANIA	161,008	8
VIRGINIA	154,712	9	VIRGINIA	154,975	9
GEORGIA	132,524	10	***MICHIGAN***	***151,820***	***10***
OHIO	132,076	11	OHIO	140,666	11
COLORADO	131,854	12	COLORADO	134,530	12
MINNESOTA	123,866	13	GEORGIA	132,839	13
NORTH CAROLINA	119,831	14	MINNESOTA	124,421	14
MARYLAND	97,484	15	NORTH CAROLINA	121,136	15
WASHINGTON	97,025	16	MARYLAND	97,824	16
MICHIGAN	***96,013***	***17***	WASHINGTON	97,773	17
ARIZONA	89,174	18	ARIZONA	89,450	18
MISSOURI	72,332	19	MISSOURI	74,001	19
CONNECTICUT	71,507	20	CONNECTICUT	71,839	20
OREGON	70,488	21	INDIANA	71,544	21
INDIANA	65,528	22	OREGON	70,793	22
WISCONSIN	54,586	23	WISCONSIN	56,936	23
ALABAMA	48,359	24	ALABAMA	49,942	24
TENNESSEE	42,016	25	TENNESSEE	44,640	25
UTAH	41,075	26	UTAH	41,433	26
NEW HAMPSHIRE	39,660	27	NEW HAMPSHIRE	39,810	27
OKLAHOMA	33,797	28	OKLAHOMA	34,200	28
IOWA	33,671	29	IOWA	34,143	29
KENTUCKY	31,008	30	KENTUCKY	31,767	30
KANSAS	30,037	31	KANSAS	30,355	31
NEBRASKA	29,864	32	NEBRASKA	30,125	32
SOUTH CAROLINA	28,632	33	SOUTH CAROLINA	29,954	33
LOUISIANA	22,119	34	LOUISIANA	26,253	34
IDAHO	21,984	35	IDAHO	22,831	35
NEW MEXICO	21,324	36	NEW MEXICO	21,358	36
ARKANSAS	18,601	37	ARKANSAS	18,765	37
SOUTH DAKOTA	14,538	38	SOUTH DAKOTA	14,613	38
VERMONT	14,437	39	VERMONT	14,487	39
DIST. OF COLUMB.	14,324	40	DIST. OF COLUMB.	14,360	40
MISSISSIPPI	14,182	41	MISSISSIPPI	14,355	41
RHODE ISLAND	13,999	42	RHODE ISLAND	14,028	42
NEVADA	13,372	43	NEVADA	13,404	43
MAINE	10,511	44	MAINE	10,763	44
WEST VIRGINIA	9,912	45	WEST VIRGINIA	9,988	45
DELAWARE	7,533	46	DELAWARE	7,753	46
HAWAII	6,996	47	HAWAII	7,151	47
NORTH DAKOTA	5,298	48	NORTH DAKOTA	5,322	48
MONTANA	4,068	49	MONTANA	4,094	49
ALASKA	3,517	50	ALASKA	3,525	50
WYOMING	1,710	51	WYOMING	1,721	51
UNITED STATES	4,566,056		UNITED STATES	4,673,431	

** The source of the high-tech auto(SIC371) employment numbers for all states is a special tabulation of the U.S. Bureau of Census Current Population Survey 1989-98. High-tech occupational employment in the auto industry is defined based on the high-tech degrees listed in the AEA's CyberEducation report.*

APPENDIX IV

Please estimate the following percentages with regard to the specified vehicle types. Definitions are provided at the bottom of the page.

Vehicle System / Component Group	Small Car		Medium Car		Large Car		Small Truck		Large Truck	
	Content[A]	Auto Share[B]	Content[A]	Auto Share[B]	Content[A]	Auto Share[B]	Content[A]	Auto Share[B]	Content[A]	Auto Share[B]
Engine (including, but not limited to): Engine Control Module (ECM) - Computer that controls engine fuel, ignition, and emission control systems; Throttle position sensor, Mass airflow meter, Engine speed sensor, Oil temperature sensor, Oil pressure sensor, Electronic ignition system, Diagnostic systems monitor, Drive-by-wire										
Transmission (including, but not limited to): Locking torque converter – controlled by ECM, Shift speed control, Vehicle speed sensor										
Chassis (including, but not limited to): Anti-lock brake system, Traction control, Power steering electronic control for steering effort, Tire pressure sensing devices, Brake-by-wire, Steer-by-wire, Active suspension, Semi-active suspension										
Safety (including, but not limited to): Airbag actuators, GPS/cellular phone based safety systems (On-Star), Blind spot detection, Collision warning systems, Navigation systems, In-vehicle message systems, Automatic toll collection, Self-dimming rear-view mirror, Passenger sensing to control airbag deployment rate										
Interior (including, but not limited to): Radio, CD player, Electronic instrumentation/gauges, Voice-activated controls, Cellular phone, Memory seats, Air conditioning controls, Trip computer - -fuel economy, distance, etc., Controls for heated seats, rear view mirrors and windows, Digital compass, Outside air temperature readout, Instrument panel light dimmer switch, Clock										
Miscellaneous (including, but not limited to): Anti-theft system, Cruise control, Adaptive cruise control, Electronic keyless entry, Pulsed windshield wipers, Battery saver – timed accessories, Voltage regulator, Alternator										
Product specific software services (including, but not limited to): Computer programming services, computer integrated systems designs										
Total electronic content as a percent of vehicle value										

A: The total percentage of the value of the specified vehicle system or component group provided by electronic content.

B: The total percentage of the value provided in A which is produced by traditional auto industry participants (i.e., not supplied by firms primarily associated with other industries, such as computer chip manufacturers).

ENDNOTES

1. Michaela D. Platzer, et al. Cyberstates 3.0: A State-by-State Overview of the High-Technology Industry, American Electronics Association, Washington D.C., Santa Clara, California, 1999.

2. Ibid., pp.103-107.

3. Ibid., pp.103-104.

4. Ibid., p.103.

5. Ibid., p.51.

6. Atkinson, Robert D., Randolph H. Court, and Joseph M. Ward, The State New Economy Index, Benchmarking Economic Transformation in the States, Progressive Policy Institute, Technology & New Economy Project, Washington, D.C., July 1999.

7. Ibid., p.3.

8. Ibid., p.3.

9. Ibid., p.3.

10. Ibid., p.4.

11. Ibid., pp.13-16.

12. Ibid., pp.17-19. Clearly the productivity effect of foreign investment should have had its greatest impact on the automotive state of Michigan, yet the state only ranks twenty-eighth on this measure. The Foreign Direct Investment argument probably does have meaning for industries, but not necessarily for states

13. For example, if 1999 Big Three automotive sales increased at 20 percent a year for four years they would expand to almost $900 billion.

14. Presumably this set of measures updates of the observations of the small-business researcher, David Birch, who long ago noted that small firms create (and destroy) the bulk of new jobs in the economy. The PPI has modified to “small firms that are publicly traded.”

15. Richard W.Riche, Daniel E. Hecker, and John U. Burgan, “High technology today and tomorrow: a small slice of the employment pie," Monthly Labor Review, November 1983.

16. Technology, Innovation, and Regional Economic Development, Washington, U.S. Congress, Office of Technology Assessment, Sept. 9, 1982.

17. Paul Hadlock, Daniel Hecker, and Joseph Gannon, "High technology employment: another view," Monthly Labor Review, Vol. 114, pp. 26-30. (July 1991).

18. Ibid., p.29.

19. Daniel Hecker, "High-technology employment: a broader view," Monthly Labor Review, Vol. 122 no. 6. pp. 18-28. (June 1999).

20. Ibid., p.19.

21. Ibid., p.19.

22. Ibid., pp. 19-20.

23. The research and development (R&D) rankings contained in this report were compiled from the following source: *National Science Foundation, Division of Science Resources Studies, Research and Development in Industry: 1997*, NSF 99-358, Project Officer and Principal Author, Raymond M. Wolfe (Arlington, VA 1999). The Industry funds data are derived from table A-8, the State funds data from table A-49 and the Science & Engineering employment data from table A-53. These tables can be accessed on the Internet at: http://www.nsf.gov/sbe/srs/nsf99358/secta.htm#list

24. From National Science Foundation and United States Department of Commerce, U.S. Corporate R&D. Volume I: Top 500 Firms in R&D by Industry Category. NSF-00-301, Authors, Carl Shephard, Department of Commerce/Office of Technology Policy, and Steven Payson, National Science Foundation/Division of Science Resources Studies (Arlington, VA 1999). September 1999. pp. 1-6.

25. Due to space limitations, we truncate our 50-state rankings in this section of the report. The full 50-state lists are shown in appendix III.

26. The ranking of patents by state is compiled from: U.S. Patent and Trademark Office, Office for Patent and Trademark Information/ TAF Program, Patent Counts by Country/State and Year, Utility Patents, January 1, 1963 - June 30, 1999: August 1999. This report is available on-line at: http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm

27. The industries used to calculate the high-tech industry employment rankings by state are those defined in U.S. Department of Labor, Bureau of Labor Statistics, Monthly Labor Review, "High-technology employment: a broader view," Daniel Hecker, June 1999. This article provided employment data for these industries at the national level only. The OSAT project consultant calculated the state level data. The primary source for the state industry employment numbers is the U.S. Department of Labor, Bureau of Labor Statistics, Covered Employment and Wages program. This data set can be accessed at: http://stats.bls.gov/cewhome.htm. The Covered Employment and Wages data were supplemented in a limited number of cases with industry data from the U.S. Department of Commerce, Bureau of the Census, County Business Patterns: 1997. This data set can be accessed at: http://tier2.census.gov/cbp/index.html-ssi

28. Daniel Hecker, "High-technology employment: a broader view," Monthly Labor Review, Vol. 122 no. 6. p. 9 (June 1999)

29. The high–tech occupational employment rankings by state are compiled from a special tabulation of the U.S. Bureau of the Census, Current Population Survey. Prof. David Macpherson, Department of Economics, Florida State University, Tallahassee, Florida, prepared this tabulation. This is also the source of the data used in one of the comparison tables, on High-Tech occupational employment in the auto industry by state.

30. Sean P. McAlinden and Brett C. Smith. *The Michigan Automotive Policy Survey.* UMTRI-99-1. Ann Arbor, MI: University of Michigan Transportation Research Institute, Office for the Study of Automotive Transportation, 1999.

31. Our assumption of 65 percent automotive employment in Michigan's engineering services industry is based on the survey estimate of 85 percent of engineering services employment in firms with 10 or more in employment and an assumption of 0 percent for firms with less than 10 in employment.

32. The source of the American Electronics Association (AEA) High-Tech employment numbers is the 1999 report published by the association cited above: *Cyberstates v3.0*. The estimate of auto-related High-Tech employment in Michigan's Engineering Services industry combines information from two sources. These are the Occupational Employment Statistics Survey conducted by the Michigan Department of Career Development and a survey conducted by OSAT to assess inter-industry auto linkages in Michigan's economy. The source for total Auto Industry employment, in the remaining comparison table, is the Covered Employment and Wages program referenced in note #27 above.

33. Michigan Employment Security Commission, *Michigan Statistical Abstract – 1996 Edition* (Detroit Michigan: 1996). Published by the University of Michigan Press (Ann Arbor, Michigan))

34. David E. Cole et al., Technology, vol. 2 of Delphi X, Forecast and Analysis of the North American Automotive Industry, (Ann Arbor: University of Michigan Transportation Research Institute, Office for the Study of Automotive Transportation, Forthcoming).

35. American Iron & Steel Industry. Press Releases. http://www.ulsab.org.

36. General Motors Corporation. *GM to Offer Composite Pickup Truck Box*. Press Release. http://media.gm.com/nao/99news/n990805a.html. August 1999.

37. Gerry Kobe, "Making the Bed," Automotive Industries, October 1999, 63-64

38. Finally, it is essential to illustrate the research and development done by the thousands of scientists, engineers, mathematicians and others within the industry. As described earlier in this paper the industry employs thousands of scientists and engineers in the development of advanced technologies. While there are hundreds of outstanding examples of work being done by engineers, we have chosen one that illustrates the sharing of knowledge with disciplines outside the automotive industry. During 1999 the scientists from Ford Motor Company assisted AmericaOne, the San Francisco based America's Cup Challenger in the development of their entry into the 2000 America's Cup regatta. The America's Cup class of sailboats uses extensive amounts of carbon fiber, titanium, and fluid dynamics as well as other advanced technologies that are of great interest to the automotive industry participants. (Information gathered from Ford Motor Company press release, August 23, 1999.)

Ford scientists contributed to the AmericaOne program in several advanced technology areas. Highly complex analysis software designed by Ford made it possible for the team to evaluate numerous boats and sail performance profiles before on-the-water testing. The software was also used to make real-time measurements during a race, including wind speed and direction, temperature, boat heading and key control surface positions. The real time information combined with the historical design and performance data was used to make strategic decisions during the race. These analysis tools are similar to those used by Ford engineers to develop engine controls. Ford also contributed math-based or computer-aided surface modeling for the boat's hull and keel. Using math-based modeling allowed the team to electronically test and evaluate dozens of hull designs to determine the optimal hull, keel, and sail design.

The partnership gave Ford scientist the opportunity to refine computational fluid dynamic models. Such models are used to reduce vehicle wind noise and increase fuel economy. The lessons learned modeling the aerofoil-like behavior of the boat's keel and winglets have direct application to spoiler design on passenger vehicles.

The AmericaOne program offered Ford engineers an outstanding opportunity to gain experience with carbon fiber. Ford's capabilities in non-destructive Testing (NDT) were used to examine for minor imperfections the carbon fiber hull. Under Ford's guidance, the team used thermography, an NDT process that records the heat emissions patterns from a surface by using rapid remote and noncontacting real-time scanning techniques to examine the hull. The Ford scientists hope to take the lessons learned from the partnership and apply them to next generation vehicles.

39. William Powers, "Environmental Challenges, Consumer Opportunities," Speech presented at the University of Michigan Management Briefing Seminars, Traverse City, Michigan on August 5, 1999.

40. General Motors Corporation. *Technical Backgrounder: Cadillac's Night Vision System.* Press Release. http://media.gm.com/cadillac/98news/1980820d.htm. August 1998.

41. Paul Eisenstien, "Telematics maps the road to the future." Automotive Industries November 1999, insert pp a3-a14.

42. William Powers, "Environmental Challenges, Consumer Opportunities," Speech presented at the University of Michigan Management Briefing Seminars, Traverse City, Michigan on August 5, 1999.

43. David E. Cole et al., Technology, vol. 2 of Delphi X, Forecast and Analysis of the North American Automotive Industry, (Ann Arbor: University of Michigan Transportation Research Institute, Office for the Study of Automotive Transportation, Forthcoming), 32.

44. Ford Motor Company. *New Ford hybrid electric car tops 70 MPG.* Press Release. http://media.ford.com/article_display.cfm?article_id=3481. December 1999.

45. Lindsay Brooke, "The shape of tomorrow." Automotive Industries, January 2000, 23-26.

46. Daniel Holt, "How many IC's" Automotive Engineering International, September 1999, 6.

47. Systems group share of vehicle parts cost was generated with the use of stylized vehicle component cost figures computed in the Michigan Department of Commerce, Auto-in-Michigan project: Andrea, David J., Mark Everett, and Daniel Luria, "Automobile Company Parts Sourcing: Implications for Michigan Suppliers," Auto-In-Michigan Project Newsletter, Office for the Study of Automotive Transportation, University of Michigan Transportation Institute, Ann Arbor, MI, May 1988; and Luria, Daniel, Calculating Big Three Vertical Integration, Industrial Technology Institute, Ann Arbor, MI, August 1990.

48. U.S. Census Bureau, U.S. Department of Commerce, Economics and Statistics Administration, Automobile Manufacturing, 1997 Economic Census, Manufacturing, Industry Series, Washington D.C., October 12, 1999, p. 7; and, Light Truck and Utility Vehicle Manufacturing, 1997 Economic Census, Manufacturing, Industries Series, Washington D.C., October 12, 1999, p.7. Unfortunately, direct accounting of the use of electronics components in automotive manufacturing is not available through these Census publications in the "materials consumed by kind" data because of restrictions on disclosure. An exception is the purchase of semiconductors and related devices by U.S. passenger car manufacturing facilities in 1997. The Census figure for these materials was $963.3 billion.