Just How High-Tech is the Automotive Industry?

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Auto Alliance

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All statements, findings, and conclusions in this report are those of the authors and do not necessarily reflect those of the Alliance of Automobile Manufacturers.

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About CAR

The Center for Automotive Research is a non-profit organization based in Ann Arbor, Michigan. Its mission is to conduct research on significant issues related to the future direction of the global automotive industry, organize and conduct forums of value to the automotive community, and foster industry relationships.

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CENTER FOR AUTOMOTIVE RESEARCH

The Center for Automotive Research (CAR), a nonprofit organization, is focused on a wide variety of important trends and changes related to the automobile industry and society at the international, federal, state, and local levels. CAR conducts industry research, develops new methodologies, forecasts industry trends, advises on public policy, and sponsors multi-stakeholder communication forums. CAR has carried out the majority of national level automotive economic contribution studies completed in the United States since 1992.[1] The research for this study has been performed by the Sustainability and Economic Development Strategies (SEDS) group, led by Kim Hill, associate director of research. SEDS concentrates on the long-term viability and sustainability of the auto industry and the communities that lie at the heart of both the industry and the system.

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[1] These studies include: **Assessment of Tax Revenue Generated by the Automotive Sector.** Kim Hill, Debbie Maranger Menk and Joshua Cregger, Center for Automotive Research, Ann Arbor, MI, April 2012.; **Economic Impact of Hyundai in the United States.** Kim Hill, Debbie Maranger Menk and Joshua Cregger, Center for Automotive Research, Ann Arbor, MI, November 2011.; **Contribution of Toyota Motor North America to the Economies of Sixteen States and the United States in 2010**. Kim Hill and Debbie Maranger Menk, Center for Automotive Research, Ann Arbor, MI, March 2011.; **CAR Research Memorandum: The Impact on the U.S. Economy of the Successful Automaker Bankruptcies.** Sean McAlinden, Kristin Dziczek, Debbie Maranger Menk, and Joshua Cregger, Center for Automotive Research, November 2010.; **Contribution of the Automotive Industry to the Economies of All Fifty States and the United States**. Kim Hill, Adam Cooper and Debbie Maranger Menk. Center for Automotive Research. 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McAlinden, Adam Cooper and Debbie Maranger Menk, Center for Automotive Research, Ann Arbor, MI, May 2009.; **Contribution of Honda to the Economies of Seven States and the United States.** Sean P. McAlinden, Kim Hill, David Cole and Debbie Maranger Menk, Center for Automotive Research. Prepared for American Honda Motor Co., Inc., January 2009.; **CAR Research Memorandum: The Impact on the U.S. Economy of a Major Contraction of the Detroit Three Automakers.** Sean P. McAlinden, Kristen Dziczek and Debbie Maranger Menk, Center for Automotive Research, Ann Arbor, MI, November 2008.; **Contribution of a Vehicle Infrastructure System to the Economy of Michigan: Economic and Industrial Impacts Update and Benefit-Cost Analysis** -- Kim Hill and Debbie Maranger Menk, Center for Automotive Research. Prepared for Michigan Department of Transportation, June 2008.; **Contribution of Toyota Motor North America to the Economies of Sixteen States and the United States, 2006.** Kim Hill and Debbie Maranger Menk, Center for Automotive Research. Prepared for Toyota Motor North America, October 2007.; **Evaluation of Economic Impacts of the State of Michigan's Vehicle Infrastructure Integration Program** -- Kim Hill, Center for Automotive Research. Prepared for Michigan Department of Transportation, September 2007.; **Contribution of the Motor Vehicle Supplier Sector to the Economies of the United States and Its 50 States –** Kim Hill and Debbie Maranger Menk, Center for Automotive Research. Prepared for the Motor and Equipment Manufacturers Association, January 2007.; **Contribution of Toyota to the Economics of Fourteen States and the United States in 2003.** Kim Hill, Center for Automotive Research, June 2005.; **The Contribution of the International Auto Sector to the U.S. Economy: An Update.** Sean P. McAlinden and Bernard Swiecki, Center for Automotive Research, March 2005. Prepared for the Association of International Automobile Manufacturers, Inc..; **Contribution of the U.S. Motor Vehicle Industry to the Economies of the United States, California, New York, and New Jersey in 2003 –** Institute of Labor and Industrial Relations, University of Michigan and the Center for Automotive Research. Prepared for the Alliance of Automobile Manufacturers, Inc., May 2004.; **Economic Contribution of the Automotive Industry to the U.S. Economy – An Update –** Sean P. McAlinden et al., Center for Automotive Research. Prepared for the Alliance of Automobile Manufacturers, Fall 2003.; **Contribution of the Automotive Industry to the U.S. Economy in 1998: The Nation and Its Fifty States** – Sean McAlinden, Center for Automotive Research. George A. Fulton, Donald R. Grimes and Lucie G. Schmidt, Institute of Labor and Industrial Relations, University of Michigan. Barbara C. Richardson, Transportation Research Institute, University of Michigan. Prepared for the Alliance of Automobile Manufacturers, Inc. and the Association of International Automobile Manufacturers, Inc., Winter 2001.; and **The Contribution of the International Auto Sector to the U.S. Economy.** David E. Cole, Sean P. McAlinden and Brett C. Smith, Center for Automotive Research. George A. Fulton, Donald R. Grimes and Lucie G. Schmidt, Institute of Labor and Industrial Relations, University of Michigan. Prepared for the Association of International Automobile Manufacturers, Inc., Ann Arbor, March 1998.

Note: The research staff of the Center for Automotive Research performed a number of these studies while located at the University of Michigan's Office for the Study of Automotive Transportation.

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EXECUTIVE SUMMARY

Products manufactured by the automotive industry are among the most technologically sophisticated available to the general public. The vehicles American consumers drive off dealership lots across the country are the end result of a long series of high-tech stages encompassing education, research, testing, and manufacturing – leading to machines that typically operate for a decade or more and travel hundreds of thousands of miles in all types of weather and over all kinds of roads.

This report measures the technological nature of today's auto industry and compares it to other sectors of the economy often viewed as technologically advanced. Of course, defining "high-tech" in an ever-changing economic environment is challenging because it must include many and various metrics. After careful review of the works of several researchers and government agencies, the Center for Automotive Research (CAR) developed a working definition to differentiate high-tech industries from other sectors. To summarize, high-tech industries generally have the following characteristics:

- Significant Research & Development expenditures, often over three percent of output;
- Significant concentration of technical employees, often with engineers, technicians, scientists, and mathematicians comprising 10 percent or more of the workforce;
- Systematic application of scientific and technical knowledge in the design and/or production of goods or services;
- Continuous engagement in the design, development, and introduction of new products;
- Geographic clusters of educational institutions and research facilities to concentrate critical skills and talents to foster the proliferation of innovation and development of new technologies;
- Engagement in the design, development, and introduction of innovative manufacturing processes.

Using the definition above, this study finds the automotive industry is not only "high-tech," it is frequently a leader in technological developments and applications.

Research & Development

The automotive industry spends nearly $100 billion globally on R&D – $18 billion per year in the U.S. alone – or an average of $1,200 for research and development per vehicle. In fact, the auto industry provides 16 percent of total worldwide R&D funding for all industries. Despite the trend towards being evermore reliant on suppliers for R&D, large automakers are still among the top companies, worldwide, for R&D spending. One study found auto companies make up one-quarter of the top 20 corporate spenders on R&D globally. Also notable, unlike many other industries, automakers devote billions of dollars without the large amount of government support provided to other industries.

Employing a High-Tech Workforce

To remain competitive in today's fast-paced, global market, auto companies require educated workers, who quickly develop and adopt new technologies in vehicles and factories. Nearly 60,000 people in the U.S. alone are employed in automotive research and development activities. In raw numbers of electrical, industrial, and mechanical engineers, Michigan – the center of the U.S. automotive industry –

ranks second only to California. In terms of engineers per 1,000 jobs, Michigan vastly outranks all others. And the automotive industry as a whole employs more engineers per 1,000 jobs than other major sectors.

Scientific and Technical Knowledge

The level of education required to work in the automotive industry has risen significantly in recent decades. An increasing portion of workers have associate, bachelor's, and other advanced degrees. Automotive education programs have been created to provide the industry with a highly-skilled and educated workforce. Within Michigan, Indiana, and Ohio alone, there are more than 350 higher education institutions offering programs related to engineering, designing, producing and maintaining automobiles. In all, these institutions alone offer more than 1,900 distinct degrees pertinent to the auto industry.

Design, Development and Introduction of New Products

Automakers are constantly adding new high-tech content to their products, partly evidenced by thousands of patents the auto industry is awarded per year. As the complexity of technology in today's vehicles rises, the concomitant electronics content has also climbed dramatically, enabling the expansion of features that has improved safety, performance, and efficiency. An average vehicle contains around 60 microprocessors to run electric content – four times as many as a decade ago. More than 10 million lines of software code run a typical vehicle's sophisticated computer network – or over half the lines of code that reportedly run Boeing's 787 Dreamliner. Traditionally, three to five percent of all patents granted in the U.S. are awarded to the auto industry, a number that has risen to approximately 5,000 new patents per year. With automated and connected vehicle technologies, innovative materials, new joining methods, advanced powertrains, and alternative fuels, the technological development will further improve driving experiences in the future.

Geographic Cluster of Research Talent and Technological Expertise

In the Great Lakes region, an automotive R&D cluster has grown as companies sharing similar needs for talent and technology amassed, particularly in the state of Michigan. Today, Michigan alone is home to more than 330 automotive R&D companies and hosts R&D facilities for nine of the 10 world's largest automakers. Additionally, 46 of the 50 top global automotive suppliers have research facilities located in Michigan.

Innovative Manufacturing Processes

High-tech manufacturing methods are a trademark of the automotive industry. The automotive industry has historically been a major driver for the robotics industry, and continues to develop new ways to implement robotics systems in order to improve manufacturing precision and efficiency. The industry is also rapidly increasing its use of state-of-the-art processes and materials, such as new digital engineering and nanotechnologies to improve the design and production of vehicles.

I. INTRODUCTION

The automobile is a complex machine composed of many systems, a machine that contains a significant amount of high-tech content. The on-board electronics, computer systems, sensors, and software in today's vehicles make the automobile one of the more technologically sophisticated pieces of equipment consumers will ever own. Vehicles will continue to grow in complexity as energy, safety, and on-board entertainment systems become more advanced. The automotive industry was created by inventors and remains an industry that uses cutting-edge innovation, constant creativity and high-technology inputs. Innovation continues to transform the industry and its products while delivering more content, safety, reliability, and value to the consumers who buy its products. Companies must be on the cutting edge of advancing automotive technologies to remain competitive in a global market. Innovation in the automotive industry is driven by a confluence of factors that have greatly increased the need for automakers and suppliers to utilize technology to differentiate themselves from competitors while meeting increasingly stringent government regulations. Perhaps the factor most responsible for accelerating innovation in the automotive industry is the rise in competition among both automakers and suppliers due to the entry of a variety of overseas firms into the U.S. vehicle, component, and tooling markets. These firms have brought with them the best ideas they've developed around the world, and their American competitors have responded with their own innovations. The American consumer has been the benefactor of this competition; the number of vehicles offered in the American market has greatly expanded while those vehicles have become safer, more reliable, and more durable, and, in addition, offer a growing array of convenience and communication technologies.

Automakers and suppliers have developed a host of new products and technologies to meet increasingly stringent government regulations pertaining to fuel economy, emissions reductions, safety, and a variety of other factors. While these regulations may at first appear less likely to spur competition, as they apply to all automakers and suppliers, automotive firms have nevertheless found themselves competing to comply with these regulations with the greatest blend of speed and efficiency. These regulations have driven the development of entirely new technologies within the automotive industry, as well as increased collaboration with the electronics, materials, aerospace, and other industries.

The combined effect of these factors is such that the need to innovate and differentiate through technology has never been greater. The result is an automotive industry that stands among the nation's chief producers and consumers of technology, and is a key component of America's global technological leadership.

This study examines the latest developments in automotive technology–both for vehicles and in production processes–and reveals the extent to which the auto industry drives innovation in the economy. Finally, the study details discussions held with innovation executives from large auto companies and offers insights into corporate philosophies and practices in cultivating and commercializing new ideas for automotive products.

II. DEFINITION OF HIGH-TECH

There is no fixed official definition for the concept of high-tech. Numerous organizations and individuals have published reports categorizing firms, industries, states, and regions as high-tech, but there is no consensus on the definition of a high-tech industry. One commonly used definition, coined by the now defunct Congressional Office of Technology Assessment, described high-tech 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."[2]

While there are many definitions of high-tech, those definitions that are broadly used and less subjective or are widely used by high profile organizations, such as federal agencies, have more credibility. Some classifications define a high-tech industry based on its products while others define it by its processes or by the degree of training and education required of its workforce. A common metric used to differentiate high-tech industries from non-high-tech industries is based on the concentration of technical employees (such as engineers, technicians, scientists and mathematicians). Another common metric involves comparing research and development (R&D) expenditures across industries.

An early classification of high-tech industries that gained broad popularity in the 1980s stemmed from the book *High Tech America*.[3] This definition identified 29 high-tech industries using Standard Industrial Classification (SIC) codes.[4] Markusen et al. used occupation data (concentration of employed engineers, technicians, etc.) to identify manufacturing industries which had a concentration of technical employees greater than the average for all of manufacturing. At the time, the high-tech service sector had yet to emerge, so the focus on manufacturing was appropriate.

As time passed and industries evolved (high-tech services gained prominence), authors and researchers modified the definition of a high-tech industry to include emerging high-tech industries and removed some industries no longer considered high-tech. Definitions were also modified after the SIC system was replaced by the North American Industry Classification System (NAICS) in the late 1990s. Agencies and organizations such as the National Science Foundation (NSF), the Bureau of Labor Statistics (BLS), and the Tech America Foundation (formerly the American Electronics Association) currently use definitions of high-tech industries in published industry reports.

NATIONAL SCIENCE FOUNDATION DEFINITION

In a past edition of the NSF's "Science and Engineering Indicators" report, the authors note that, "No official list of high-technology industries or sanctioned methodology to identify the most technology-

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[2] OTA. (1982) "Technology, Innovation, and Regional Economic Development." U.S. Congress, Office of Technology Assessment. Washington, DC. Sept. 9, 1982.

[3] Markusen, Ann R., Peter G. Hall, and Amy Glasmeier. (1986). "High Tech America: The What, How, Where, and Why of the Sunrise Industries." Allen & Unwin, Boston, MA. 1986.

[4] The SIC system uses a four-digit code to classify industries. It was created in the 1930s and was used by U.S. government agencies to group industry areas, especially for the purposes of tracking and recording economic activity, such as employment, investment, and productivity statistics. In 1997, the North American Industry Classification System, was introduced to replace the SIC system.

intensive industries exists in the United States. The definition used here was developed by the U.S. Department of Commerce's Technology Administration in concert with the U.S. Department of Labor's Bureau of Labor Statistics."[5] The report describes work directed by Daniel Hecker using SIC codes that were later converted to NAICS codes.[6] The original work identified 31 R&D-intensive industries in which the number of R&D workers and technology-oriented occupations accounted for a proportion of employment that was at least twice the average for all industries surveyed.[7] These industries had at least 6 R&D and 76 technology-oriented workers per 1,000 workers. The BLS list included 27 manufacturing and 4 service industries. The conversion to NAICS involved combining and splitting codes, resulting in 39 categories that ranged from four- to six-digit detail, including 29 manufacturing industry codes and 10 service industry codes. The NAICS codes included in the NSF report can be seen in Table B1 in Appendix B.

Bureau of Labor Statistics Definition

As is true in the NSF document, the BLS list defers to work done by Hecker for defining high-tech industries. A recent report on high-tech industry employment and wage trends in Massachusetts also refers to Hecker's work.[8] The BLS report notes that high-tech describes occupations which may be located in both high-tech industries and non-high-tech industries that employ workers in technical occupations. Hecker's work notes that, "An industry is considered high-tech if employment in technology-oriented occupations accounted for a proportion of that industry's total employment that was at least twice the 4.9-percent average for all industries. With this relatively low threshold, 46 four-digit NAICS industries (listed in Table B2 in Appendix B) are classified as high-tech."[9] These 46 industries have at least ten percent of their employment in high-tech occupations and in proportions that range from two to five times the high-tech employment average for all industries. A listing of high-tech industries found in various BLS reports can be found in Table B3 in Appendix B.

Hecker's 1999 work identified the automotive industry as the second largest high-tech industry in the United States in terms of employment. In a 2005 update, the automotive industry is not included, although Hecker does note that it is the only industry with high R&D spending that was not included in the list. Hecker suggested that "at least some parts of motor vehicle manufacturing might be categorized as high-tech" due to the sector's high level of spending in R&D.[10] Hecker also noted that the

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[5] NSF. (2006). "Science and Engineering Indicators 2006." National Science Foundation. February 23, 2006. <http://www.nsf.gov/statistics/seind06/>.
[6] Hecker, Daniel E. (1999). "High-Technology Employment: A Broader View." Monthly Labor Review. Bureau of Labor Statistics. June 1999. <http://bls.gov/mlr/1999/06/art3full.pdf>. and Hecker, Daniel E. (2005). "High-Technology Employment: A NAICS-Based Update." Monthly Labor Review. Bureau of Labor Statistics. July 2005. <http://www.bls.gov/opub/mlr/2005/07/art6full.pdf>.
[7] Ibid.
[8] Gillham, Cynthia, Timothy Consedine, and Denis M. McSweeney, "High-tech Industries in Massachusetts: Employment and Wage Trends during the 2001–2009 Period." Regional Report. Bureau of Labor Statistics. November 2011. <http://stats.bls.gov/opub/regional_reports/mass_hightech/201111_mass_hightech.htm>. and Hecker. (2005). "NAICS-Based Update."
[9] Hecker. (2005). "NAICS-Based Update."
[10] Ibid.

automotive industry was included in lists of high-tech industries in three BLS papers: "Today and Tomorrow" (1983), "Another View" (1991), and " A Broader View" (1999).[11] Each of those studies used objective criteria related to R&D: technical employment or R&D spending. Hecker also noted that the automotive industry was not considered a high-tech industry in other definitions, such as those used in NSF's "Science and Engineering Indicators" (1998), the U.S. Department of Commerce's "Emerging Digital Economy II" (1999), or the American Electronics Association's "Cyber states 3.0" (1999). The "cyber states" and "digital economy" definitions, however, were arbitrarily chosen (subjective criteria).

Tech America Foundation Definition

Statistics in Tech America Foundation reports use a definition of high-tech that is defined by NAICS codes. The industries included in the Tech America list of high-tech industries incorporate computers, software, Internet services, communications, consumer electronics, electronic components (including semiconductors), space and defense systems, measurement and control instruments, electro-medical equipment, photonics, engineering services, and R&D services.[12] The industries included in Tech America's definition are displayed in Table B4 in Appendix B.

While Tech America lists specific high-tech industries on its website, the organization's site does not describe the methodology used to select these particular industries. The list is identical to the one used in the most recent "Cyberstates" report. It is likely that this list was compiled subjectively, as Tech America's predecessor, the American Electronics Association, used a subjective definition in earlier "Cyberstates" reports. (CAR has documented the shortcomings of this high-tech definition in previous reports.[13])

Summary: A Working Definition for 'High-Tech' in Modern America

As seen in the definitions discussed above and based on criteria commonly used by a variety of researchers, a high-tech industry may generally be defined as one that has these characteristics:

- Has R&D expenditures equal or greater than 3 percent of output[14]
- Requires a concentration of ten percent or more of technical employees – such as engineers, technicians, scientists and mathematicians[15]
- Uses the systematic application of scientific and technical knowledge in the design and/or production of goods or services
- Is engaged in the design, development, and introduction of new products
- Has a geographic cluster of innovation and development that concentrates a critical mass of skills and talents and allows new ideas and technologies to proliferate
- Is engaged in the design, development, and introduction of innovative manufacturing processes

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[11] Hecker. (1999). "A Broader View."

[12] TechAmerica. (2012). "TechAmerica's NAICS-based Definition of High Tech." TechAmerica Foundation Website. Accessed November 26, 2012. <http://www.techamerica.org/naics-definition>.

[13] McAlinden, Sean P. and Abel Feinstein (2002). "Michigan: The High Technology Automotive State." Center for Automotive Research and Altarum Institute. August 2002.

[14] The national average is 3 percent

[15] The national industry and services average is approximately five percent

The automotive industry meets and exceeds these common elements, making it, by definition, a high-tech industry.

The automotive industry compares well with other industries defined as high-tech and is, in fact, often a leader with respect to the sheer number of technical employees in the industry or R&D spending by its companies. It has a long and complex supply chain. Unlike many high-tech industries in the U.S., a significant amount of production is still done domestically by the auto industry. When using metrics, such as the concentration of technical employees or the intensity of R&D spending, automotive may compare less favorably with industries which have only a small manufacturing component or which import most manufactured content from abroad, but have significant research, development, and design activities based in the United States.[16]

Assessing the degree to which the industry's products or production methods are high-tech is an excellent vantage point from which to showcase the high level of advanced materials, vehicle electronics, or powertrain systems incorporated into the modern vehicle. Furthermore, new technology development and an increasingly rapid rate of new technology adoption have helped keep the auto industry in the forefront of technology employment and R&D spending. Similarly, one unfamiliar with the automotive industry might imagine that vehicles are produced in dark factories using the same technologies that produced vehicles 50 years ago. In reality, the automotive industry has been a major impetus in production technology development – utilizing a high degree of automated systems and leading in quality manufacturing systems.

As discussed in the following pages, the automotive industry is a leader in all of the areas defined as important to being considered "high-tech."

[16] Woodward, Curtis (2013). "MIT Report: U.S. Manufacturing Hits a Wall When It's Time to Scale." Xconomy. February, 2013.

III. THE AUTOMOTIVE INDUSTRY'S HIGH-TECH ACTIVITIES

"[Manufacturing is] the vanguard of innovation in our economy…manufacturing accounts for

- 35 percent of engineers,
- 69 percent of private R&D, and
- 90 percent of our patents."[17]

The auto industry is a major driver of the 12 percent contribution by manufacturing to the U.S. GDP. There are more than 12 million manufacturing jobs in the economy.[18] It is a huge consumer of goods and services from numerous other sectors, including raw materials, construction, machinery, legal, computers and semi-conductors, financial, advertising, and healthcare. Due to the industry's consumption of products from many other manufacturing sectors, it is difficult to imagine manufacturing surviving in this country without the automotive industry.

The automobile is the most complex item most consumers will ever purchase. Correspondingly, the automotive industry requires high-technology inputs and continuous innovation to both products and manufacturing processes. Industry adoption of new vehicle technologies relating to emissions, vehicle electronics, connectivity, fuel economy, safety and powertrain is constantly evolving–challenging automakers to remain globally competitive in research, design, production processes, and product appeal to consumers.

Research and Development

Automotive R&D spending and needs are expanding rapidly to keep pace with the demands for ever more sophisticated and effective new technologies. Worldwide, automakers spend an average of $1,200 for research and development per vehicle.[19] They provide 16 percent of total worldwide R&D funding for all industries, trailing only the computer and electronics industry and healthcare research.[20] Furthermore, although auto industry research spending is smaller than the computer and electronics industry (which provides more than a quarter of all global R&D funding), growth in automotive R&D spending is on a par with both industries, increasing the amount spent on R&D by more than $7 billion from 2012 to 2013.

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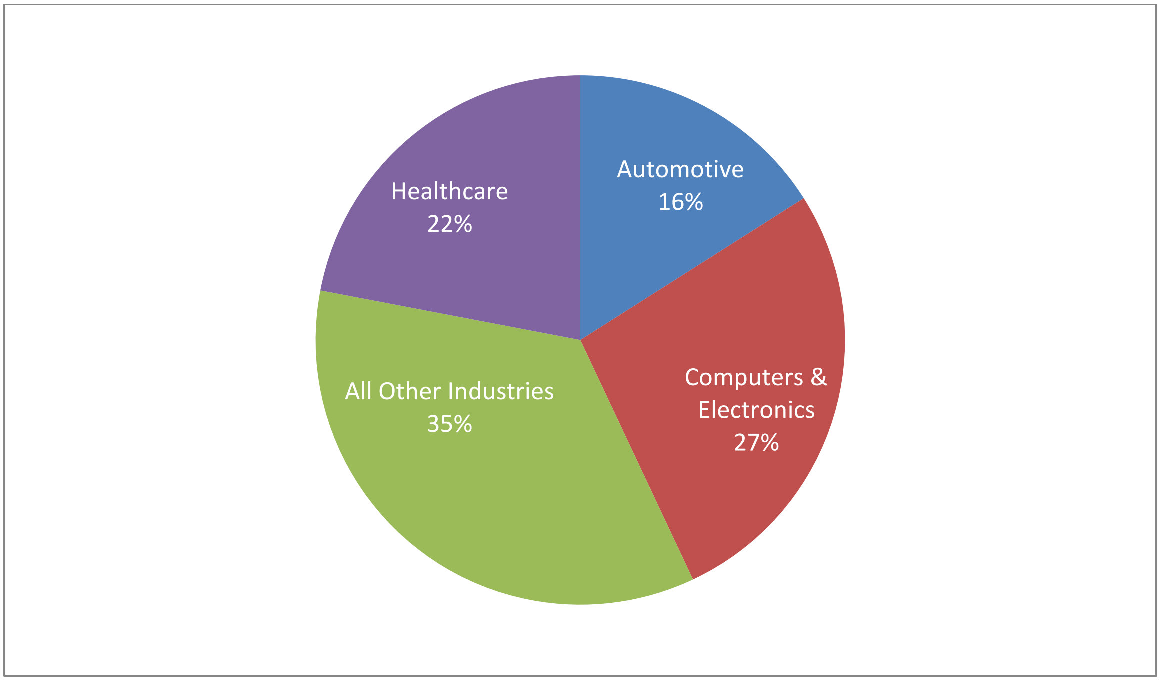
[17] Bruce Katz from Brookings Institute as quoted in Minter, Steve. (2013). "US Manufacturing: The Misunderstood Economic Powerhouse." Industry Week. January 15, 2013. < http://www.industryweek.com/innovation/us-manufacturing-misunderstood-economic-powerhouse>.

[18] BLS. (2013.) "Occupational Employment Statistics." Bureau of Labor Statistics, U.S. Department of Labor. November 2013. <http://www.bls.gov/>

[19] Jaruzelski, Barry, John Loehr, and Richard Holman. (2012). "The Global Innovation 1000: Navigating the Digital Future." Booz & Co. Issue 73, Winter 2013. <http://www.booz.com/media/file/BoozCo_2013-Global-Innovation-1000-Study-Navigating-the-Digital-Future.pdf>. and Wards. (2011). "Corporate Profits and Research and Development Spending." 2010 Ward's Motor Vehicle Facts & Figures. 2011.

[20] Ibid.

Figure 1: Percentage of Global R&D Spending by Industry, 2013



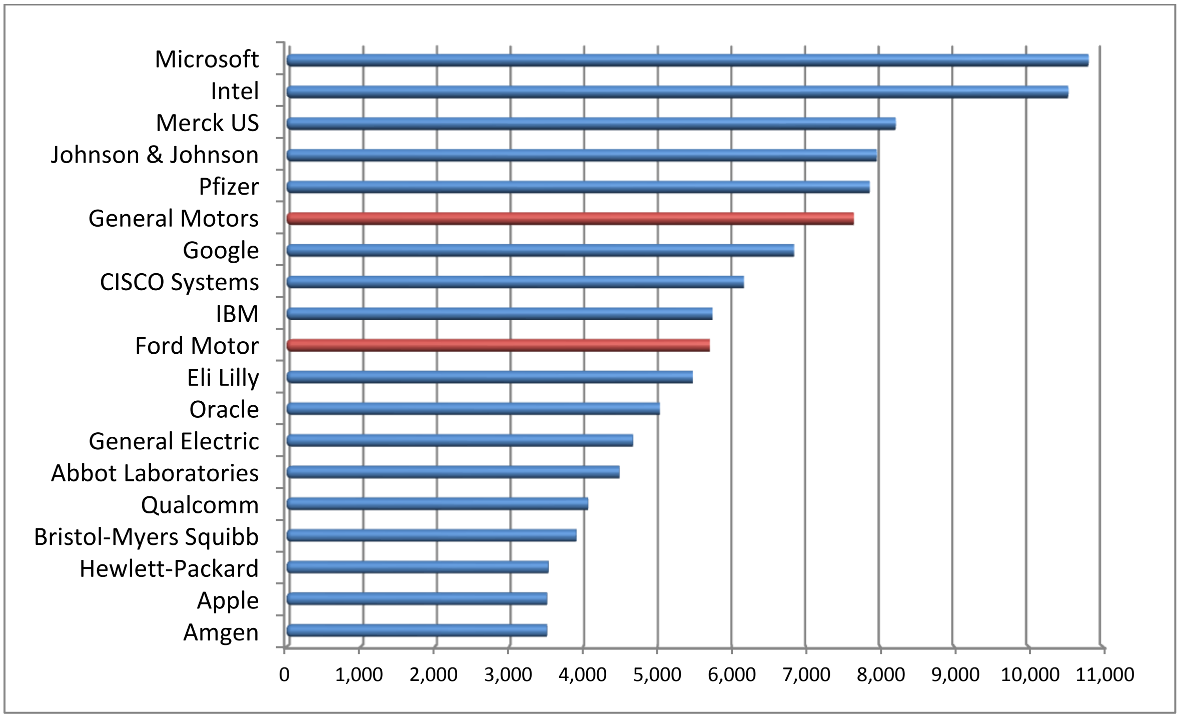
Source: Booz & Company "Global Innovation"; Battelle R&D Magazine; Center for Automotive Research 2012

Five automakers–Volkswagen, Toyota, General Motors, Honda, and Daimler–are among the top 20 in all corporate research and development spending as ranked by Booz's annual global R&D report.[21] Volkswagen is first, with more than $11 billion in spending. According to Battelle's R&D Magazine, the entire amount spent in the U.S. for aerospace, defense, and security R&D is close to that figure at slightly over $12 billion.[22] The healthcare industry has 7 of the top 20 companies, while computer, electronics, and software companies make up the remaining 8 companies.

[21] Ibid.

[22] Battelle. (2013). "2014 Global R&D Funding Forecast." Battelle. December 2013. <http://www.rdmag.com/sites/rdmag.com/files/gff-2014-5_7%20875x10_0.pdf>.

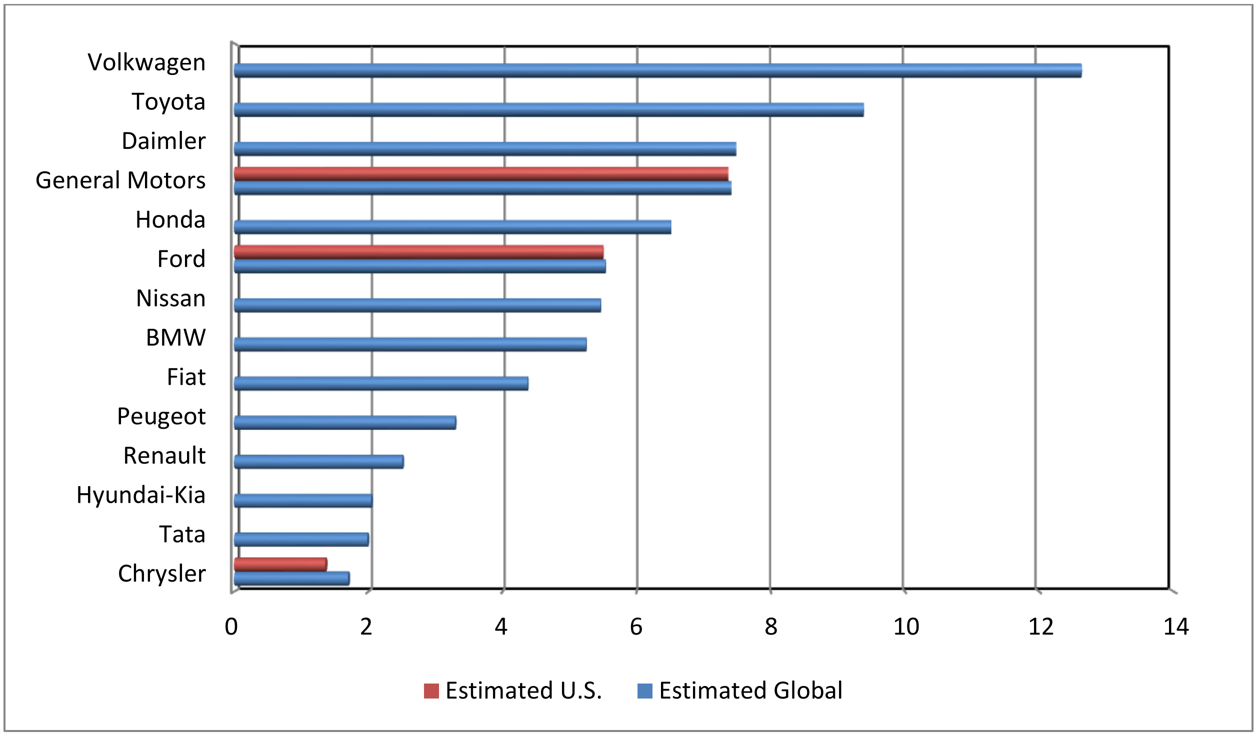
Figure 2: Sample of 2012 R&D Spending by Leading U.S. Companies (in millions USD)



Source: IRI 2013

Since recovering from the economic recession, the auto industry spent nearly $100 billion globally, and an estimated $18 billion in the U.S., for R&D. Tier 1 auto supply companies provided nearly one-third of these funds.

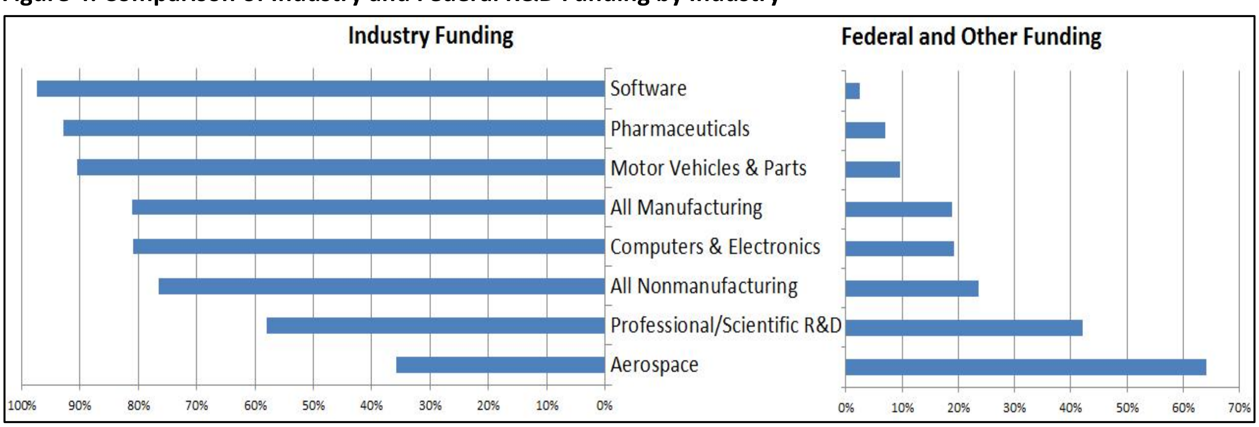
Figure 3: Estimated R&D Spending (global and U.S.) by Selected Automakers for 2013 in billions of dollars ($)



Source: Wards 2011; IRI 2013a; and Center for Automotive Research 2013

Automotive R&D spending in the U.S. is dominated by a dozen companies, collectively accounting for 80 percent of total R&D spending, or more than $14 billion. These companies include both automakers and Tier 1 parts suppliers. Worldwide, five automakers–Volkswagen, Toyota, General Motors, Honda, and Daimler–are among the top 20 companies for all corporate research and development spending as ranked by Booz's annual global R&D report.[23] Volkswagen is first, with more than $11 billion in spending.

Figure 4: Comparison of Industry and Federal R&D Funding by Industry



Source: NSF 2012 (based on the latest year for this survey, 2007)

[23] Ibid.

Nearly three percent of U.S. GDP is spent on R&D. The auto industry spends on average four percent of revenues, which is a third more than the national average. For larger automotive companies, R&D spending is at an even higher level that typically ranges above the five percent of revenues mark. The auto industry also usually funds a greater share of its R&D activities than do other industries. Prior to the recession, industry funding for R&D averaged above 98 percent; government and other sources covered the remainder. With the recovery, government and non-industry research interest in clean energy and connected vehicle technology has spurred new and significant R&D investment by these entities. It is estimated that non-industry funding now supports nearly 10 percent of total auto industry R&D activities (see Figure).[24]

Corporate research and development activities encompass a complex variety of endeavors. These efforts include research into such areas as:

- Vehicle Development
  - Safety systems (crashworthiness, restraints, active/passive safety devices)
  - Customer interface
- Energy and Environment
  - Combustion
  - Electrochemical
  - Recycling
- Systems and Electronics
  - Sensors
  - Vehicle controls
  - Telematics/vehicle communication
- Materials
  - Advanced lightweight materials
  - Biomaterials
- Manufacturing Systems
  - Manufacturing processes
  - Robotics
  - Computer-Aided Engineering
  - Nanotechnology

Appendix C (based on reviews of General Motors and Toyota R&D structures) diagrams a typical research and development structure at a large automotive company.

Automotive R&D spending goes towards many different expenses. The largest component of expenditures is paying the salaries, wages, and other compensation for full-time and temporary workers. Materials, equipment, and supplies, as well as the depreciation of assets constitute a large portion of spending as well. Figure 5 provides a breakdown of the various costs that make up automotive R&D spending.

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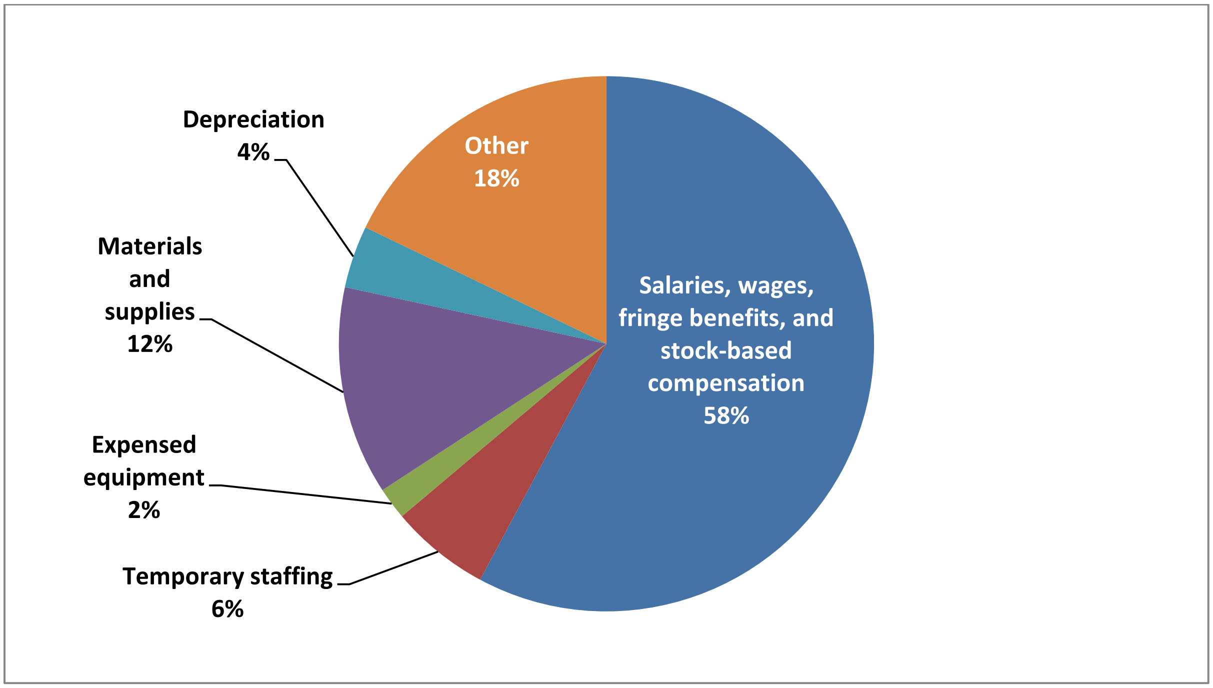
[24] NSF. (2012). “BRDIS and SIRD.”

Figure 5: U.S. Automotive R&D by Type of Cost



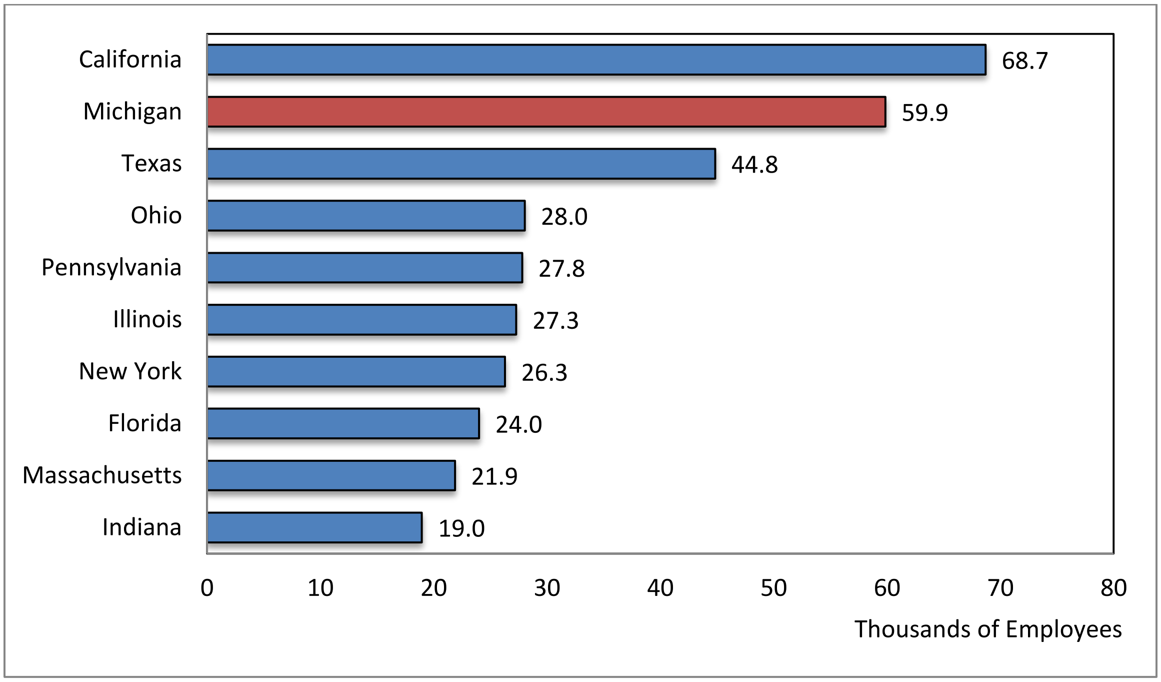
Source: NSF 2013(based on the latest year for this survey, 2010)

EMPLOYMENT

California is often considered the capital of high-technology and U.S. R&D. This is supported by engineering employment levels: California has the highest number of engineers, at nearly 62,000. However, Michigan, far from Silicon Valley and with a much smaller population and labor force, is a very close second with nearly 60,000 engineers in the state's labor force. While state-level statistics for employment by industry are not published, it is safe to say that the preponderance of engineers in Michigan is due to the presence of the automotive industry. [25]

[25] BLS. (2011). "Occupational Employment Statistics." Bureau of Labor Statistics, U.S. Department of Labor. May 2011. <https://www.bls.gov/>.

Figure 6: Top States for Electrical, Industrial & Mechanical Engineering Employment, 2012

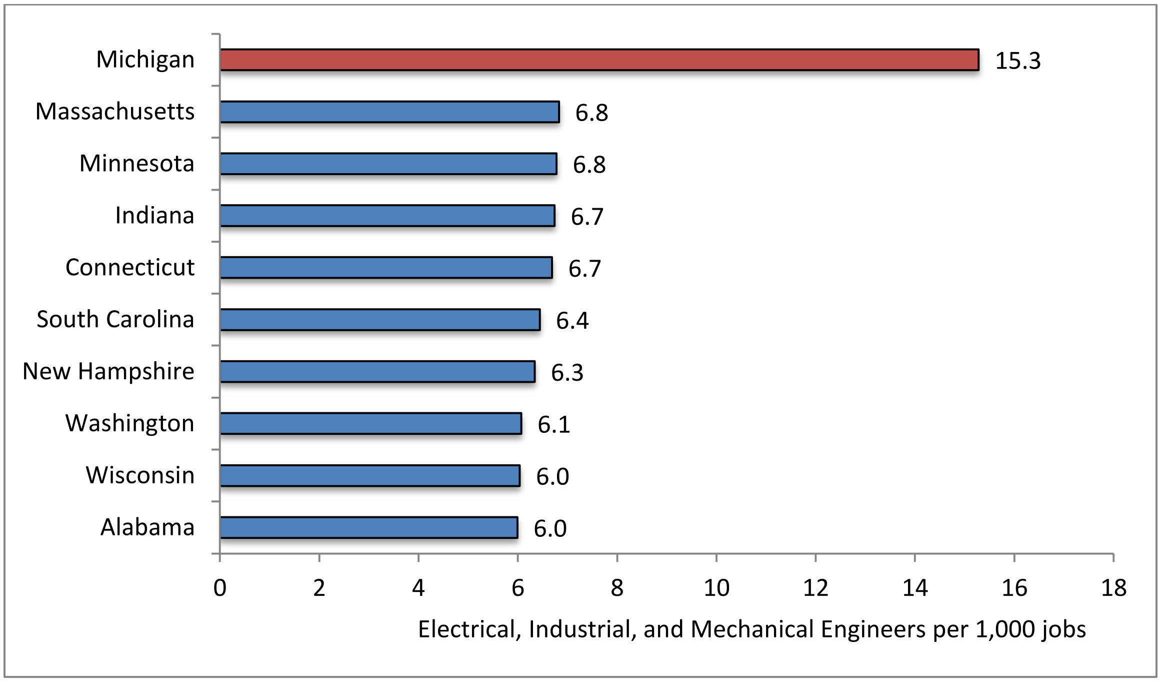


Source: BLS 2012

The list of top 10 states changes dramatically if we alternatively consider the *employment density* of engineering occupations, which arguably provides a more appropriate view of the distribution of high-tech employment than does the absolute employment levels: employment levels largely correlate with population size, while employment density provides insight into the particular specialization of a region. The engineering employment density for the state of Michigan is highest among all states, at 15.3 electrical, industrial, and mechanical engineers per 1,000 jobs. The state with the second highest engineering employment density is Massachusetts, at 6.8. Again, the presence of the automotive industry is the driving force behind Michigan's high ranking. [26]

[26] Ibid.

Figure 7: Top States for Engineering Density, 2012



Source: BLS 2012

In 2012, the United States boasted 674,000 electrical, industrial, and mechanical engineers in the labor force. More than half of these engineers were employed in the manufacturing sector. Within the manufacturing sector, the automotive industry employs more than 10 percent, or over 35,000 engineers.[27]

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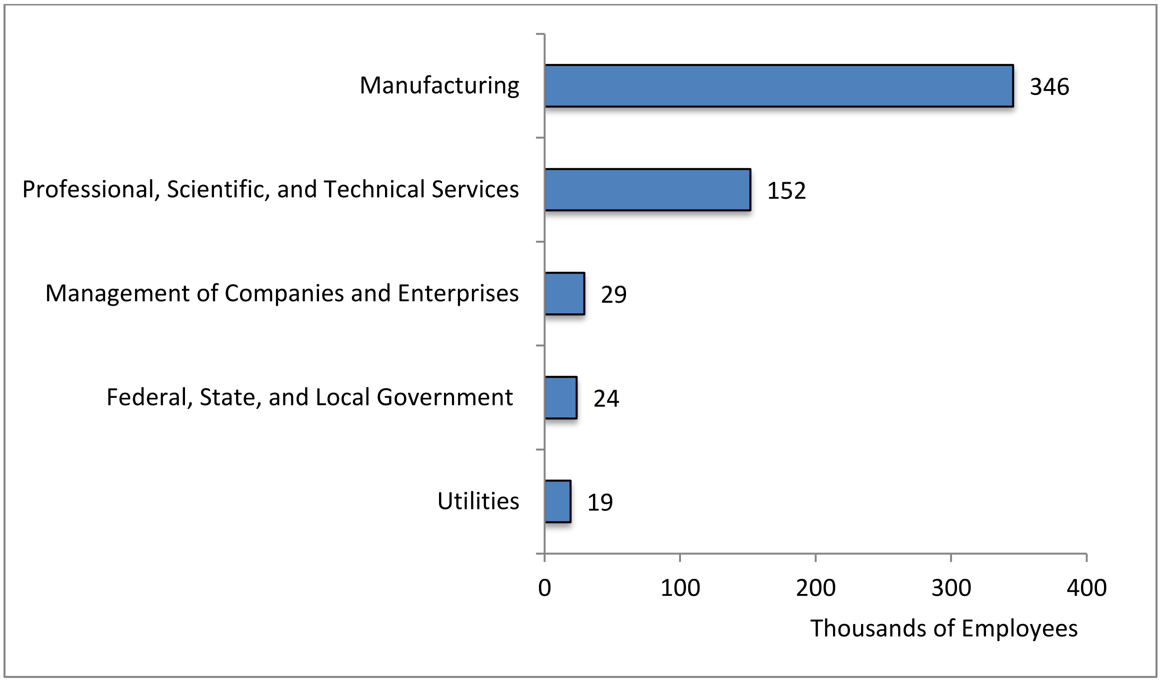
[27] Ibid.

Figure 8: Engineering Employment by Major Sector, 2012

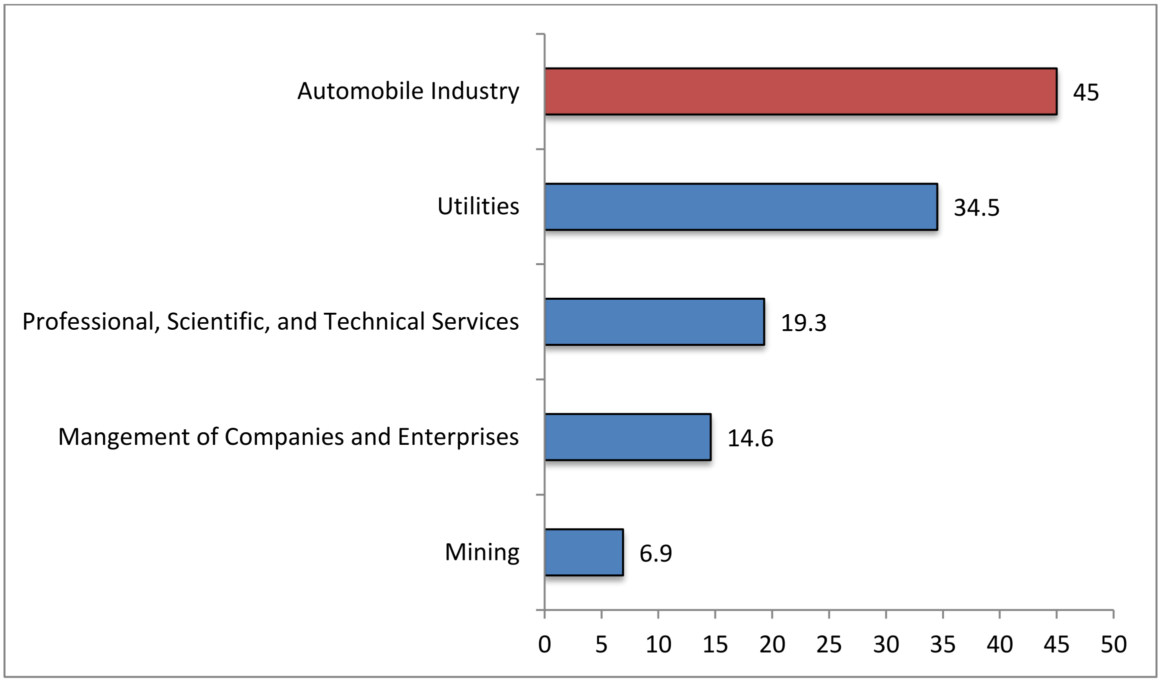


Source: BLS 2012

In reviewing engineering employment density by sector, the automotive industry ranks the highest with an engineering employment density of 45.[28] The utilities sector is found to rank second, with an engineering density of 34.5 electrical, industrial, and mechanical engineers per 1,000 workers.

[28] Ibid.

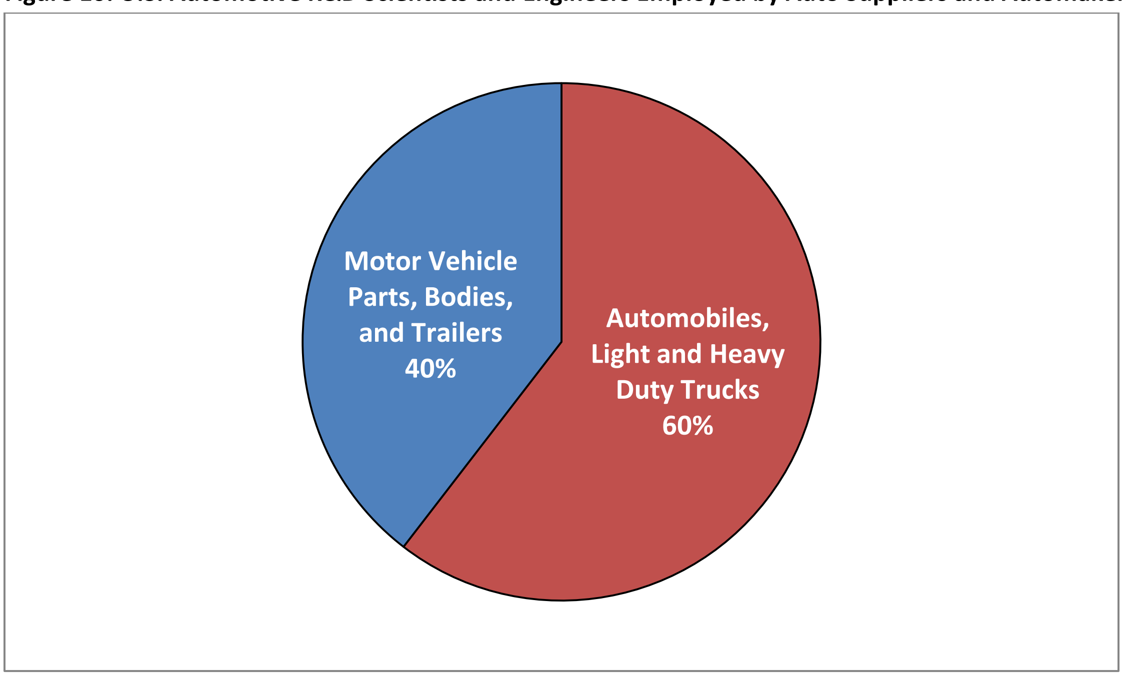
Figure 9: Engineers per 1,000 jobs, 2012



Source: BLS 2012

In addition to employment within the automotive industry, academic and government laboratories employ people working on automotive technologies. Within the industry, automotive parts suppliers employ approximately 40 percent of all R&D scientists and engineers, while the automakers employ 60 percent. This split reflects the growth in R&D efforts by the supply chain.

Figure 10: U.S. Automotive R&D Scientists and Engineers Employed by Auto Suppliers and Automakers



Source: NSF 2013 (based on the latest year for this survey, 2010)

The automotive industry employs 60,000 people in R&D activities in the U.S.[29] The automotive industry employs workers in high-tech occupations other than engineering. In the last two decades, many of these positions were often outsourced, but there is now a drive to re-integrate. A recent example of this is found in General Motors. In 2012, CIO Randy Mott provided details on GM's plan to transform information technology at the company. Where the company once had 90 percent of its IT functions performed by outside companies, part of the three year IT transformation plan calls for this to reverse, with 90 percent of IT functions to be carried out by internal staff.[30]

Detroit has long been considered the home and birthplace of the automotive industry. Today, Detroit also represents the R&D heartland of the industry. All the major automotive companies – whether a company is U.S.-based or foreign-based, OEM or supplier – all have tech centers and R&D facilities located in the Detroit area. Through these facilities, all major automotive producers are tied to the Detroit area and the innovation coming from the city. There is a nucleus of technology and a critical mass of companies, engineers, innovators and entrepreneurs all competing and simultaneously contributing to the innovation that regularly takes industry developments to the next level. Much as Silicon Valley exemplifies the technological prowess of the computer industry, so too does Detroit provide a similar picture for the automotive industry. Anecdotal evidence abounds of how the innovative contributions of the auto industry have spread throughout the Detroit area as shown in this example of recent technology investment in the city:

> "'We selected Detroit because of the combination of social and technological innovation here,' Open Technology Institute Director of Field Operations Joshua Breitbart said. 'The city is not just a backdrop for this network. The residents are playing an active role as designers and engineers. We are building the workforce here, piloting innovative applications here, and learning from how entrepreneurs…make use of it here before we distribute this groundbreaking technology around the world.'"[31]

EDUCATION

The advanced technology in vehicles and the manufacturing process dictate that jobs in the automotive industry require workers with high levels of skill. Cars of the future will continue to encompass ever more sophisticated technology, continuing also to change the skills demanded of auto designers, engineers and production workers. The auto jobs of today and the future belong to those who have the advanced skills necessary for designing, building and maintaining the high-tech content inherent in motor vehicles.

Within Michigan, Indiana, and Ohio, more than 350 higher education institutions offer programs related to the engineering, design, production, and maintenance of automobiles. In total, these institutions

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[29] BLS Occupational Employment Statistics, May, 2012

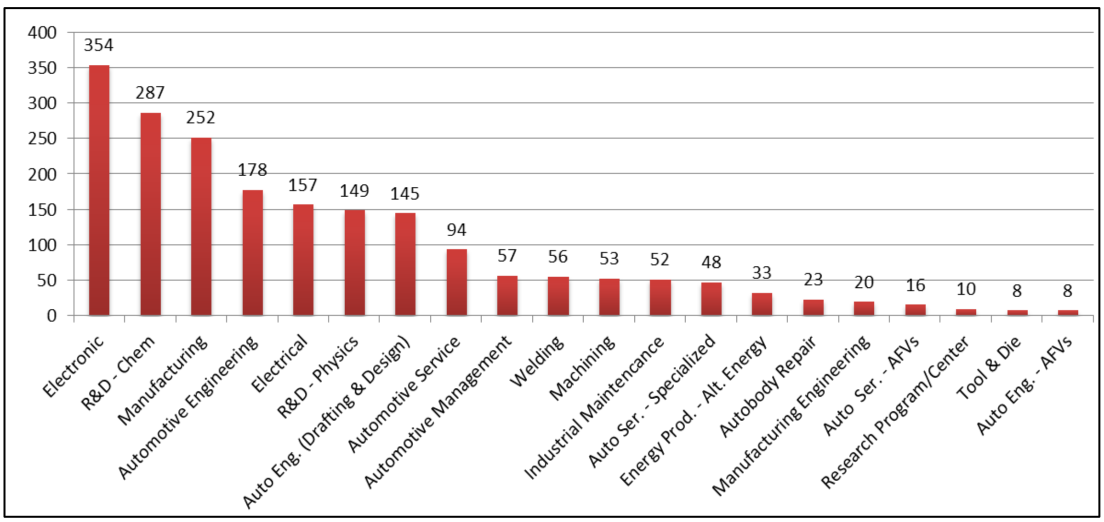
[30] Murphy, Chris. (2012). "General Motors Will Slash Outsourcing In IT Overhaul." *Information Week.* July 9th, 2012. <http://www.informationweek.com/global-cio/interviews/general-motors-will-slash-outsourcing-in/240002892>.

[31] Muller, David. (2012). "Detroit Has Become an Open-Source Wireless Technology Guinea Pig." MLive. December 20, 2012. <http://www.mlive.com/business/detroit/index.ssf/2012/12/detroit_has_become_an_open-sou.html>.

offer more than 1,900 distinct degrees pertinent to the automotive industry. Figure 11 (below) highlights some of the many specialized fields of study offered for those who want to work in the automotive industry. These degrees include Certificates, Associate of Science (AS), Bachelor of Science (BS), Master of Science (MS), and Doctor of Philosophy (PhD) degrees.[32]

Engineering research laboratories make it possible for both faculty and students to work on the next generation of theory, concept, and products. There are valuable research laboratories at many large universities. As an example, the University Research Corridor in Michigan (composed of The University of Michigan, Michigan State University, and Wayne State University) has undertaken 1,400 automotive-related projects, spending $300 million over the last 5 years.[33] The University of Michigan has a collaborative research center with GM working on cutting edge fuel and power train technology that may prove to be the next generation for the automobile industry. Ohio State University has the Center for Automotive Research, sponsored in part by Honda. The Center is an interdisciplinary research facility in the college of engineering; focusing on intelligent transportation systems and automated vehicles, vehicle chassis systems, and vehicle and occupant safety. Various other universities in the North American Midwest also have research centers that contribute to the advancement of the automotive industry.

Figure 11: Automotive Education Degree Programs by Subject, 2010



Note: Figure includes automotive programs only from institutions based in Michigan, Indiana, and Ohio.
Source: CAR 2011a

[32] CAR. (2011a). "Automotive Technology: Greener Jobs, Changing Skills Educational Needs Report." Prepared for the U.S. Employment and Training Administration. Center for Automotive Research. May 2011. <http://www.drivingworkforcechange.org/reports/electronics.pdf>.

[33] CBS. (2013). "The Fruits of Michigan University Research Are on the Auto Show Floor." CBS Detroit. January 17, 2013. <http://detroit.cbslocal.com/2013/01/17/the-fruits-of-michigan-university-research-are-on-the-auto-show-floor/>.

IV. THE AUTOMOTIVE INDUSTRY'S HIGH-TECH PRODUCT CLUSTER

Automakers are integrating a variety of new technologies into their products. Although virtually every aspect of the modern automobile can either be described as high-tech or as having been developed through high-tech processes, several areas of technological prowess stand out. This section describes a few examples of high-tech systems that can already be found in new vehicles. The three topics discussed include automotive electronic systems (including advanced safety systems, such as automated and connected vehicle technologies), innovative materials, new joining methods, advanced powertrain systems, and alternative fuels.

AUTOMOTIVE ELECTRONIC SYSTEMS

Road transportation and air transportation are sibling rivals for serving as images of high technology. However, in the time that automobiles have evolved from slow horseless-carriages powered by gasoline to faster horseless-carriages powered by gasoline, aircraft have evolved from drifting balloons filled with hot air to awe-inspiring machines capable of supersonic flight and leaving the Earth, journeying to the moon and beyond. Surface transportation appears overdue for a paradigm shift. The basic human concept of roads is timeless, but we can certainly improve the way we travel on them. Advanced vehicle technologies and in-vehicle electronics are bringing a revolutionary shift in road transportation—*automated and connected vehicles*.

In-Vehicle Electronics

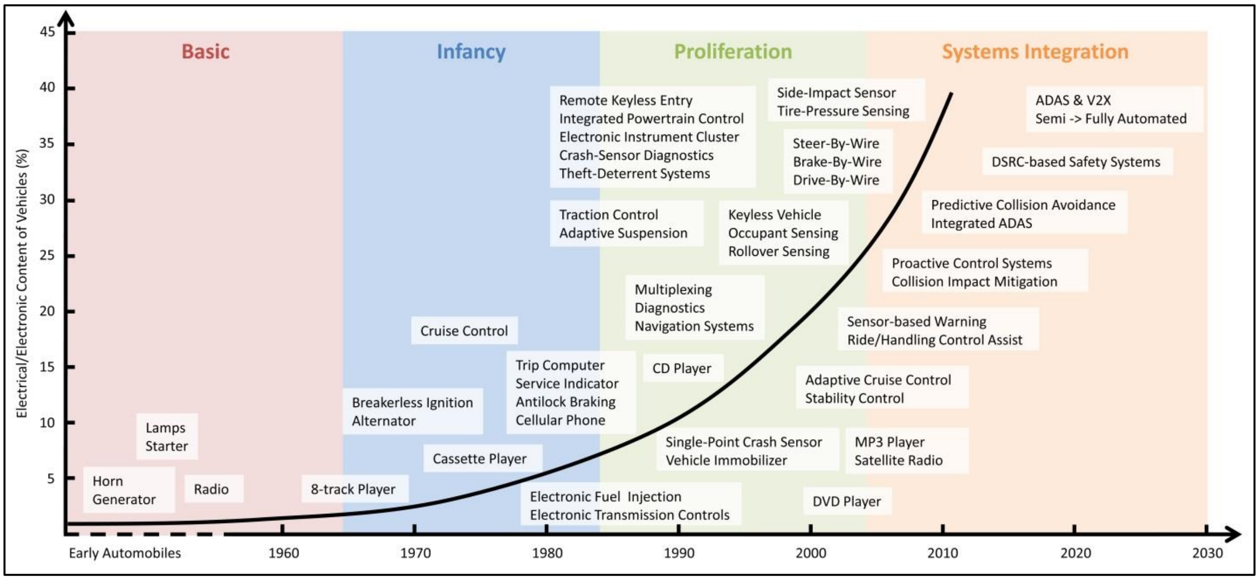
In-vehicle electronics allow automakers to provide consumers with ever-increasing levels of safety, fuel economy, information and connectivity. Figure shows the accelerating pace of change in developing electronics for cars. As companies increasingly rely on vehicle electronics to comply with environmental and safety requirements, the automotive electronics market is expected to expand even more rapidly. An average vehicle might contain around 60 microprocessors to run its electrical content, as compared to around only 15 microprocessors in a vehicle just 10 years ago.[34] A hundred or more sensors located in almost every part of the car are providing data to these microprocessors. As much as a mile of wiring connects everything,[35] while more than 10 million lines of software code run this sophisticated

[34] Barkholz, David. (2010). "Fixing cars' brains saves Ford millions." Automotive News. May 10, 2010. <http://www.autonews.com/article/20100510/OEM06/305109998>. and CAR. (2011). "Automotive Technology: Greener Vehicles, Changing Skills Electronics, Software & Controls Report." Prepared for the U.S. Employment and Training Administration. Center for Automotive Research. May 2011. <http://www.drivingworkforcechange.org/reports/electronics.pdf>.

[35] Smedley, Peggy. (2012). "Computers on Wheels." Connected World. March/April 2012. Pages 47-50.

computer network.[36] In fact, some luxury vehicles may have many times the standard 10 million lines of code. As a comparison, the Boeing 787 Dreamliner reportedly runs with 18 million lines of code.[37]

Figure 12: Growth of Vehicle Electronic Content



Source: CAR 2013, adapted from Hellestrand 2005 and Fedewa 2013.

It is estimated that, currently, vehicle electronics make up as much as 40-50 percent of the total cost of the vehicle. This is up from 20 percent less than a decade ago. As companies increasingly rely on vehicle electronics to comply with environmental and safety requirements, the automotive electronics market is expected to expand even more rapidly.

Electronics, in the form of sensors, actuators, micro-processors, instrumentation panels, controllers, and displays, appear in nearly all major vehicle systems, including:

- Engine controllers and sensors
- Safety systems
- Chassis control
- Measurement and diagnostics
- Entertainment
- Navigation systems
- Communications
- Emissions monitoring

[36] Automotive News. (2010). "PACE jury honors automotive innovators." Automotive News. April 19, 2010. <http://www.autonews.com/article/20100419/OEM06/304199985>. and Chappell, Lindsay. (2011). "Center stack is new high-stakes battleground: Showdown is coming with safety regulators." Automotive News. September 5, 2011. <http://www.autonews.com/article/20110905/OEM06/309059991/1182>.
[37] Mann, Charles C. (2012). "Look Out—He's Got a Phone!" Vanity Fair. December 19, 2012. <http://www.vanityfair.com/culture/2012/12/microcomputers-weapons-smartphone>.

The following quote provides an example of the current sophistication of simple vehicle functions:

> "When drivers screech to a sudden stop, for instance, sensors in the wheels detect the slowdown and send the information to a microprocessor. If one wheel is rotating more slowly than the others – an indicator of brake lock – the microprocessor overrides the brake and the accelerator, preventing the skid. Even as it fights the skid, the computer reaches into the seatbelt controls, tightening the straps to prevent passengers from slipping under them in case of an accident. The software for these complex, overlapping functions is formidable…."[38]

Consumers accept that typical electronics products will have relatively short lifespans. A smartphone is expected to last only 2 or 3 years, while computers are generally replaced every 3 to 4 years.[39] Conversely, autos have a useful lifecycle of 12 years or more. They must function in extreme temperatures and all types of weather as well as in a variety of uses in congested city driving, long-range road trips, and off-road adventures. A motor vehicle is the only consumer electronic product expected to survive so long and under such conditions.

Vehicles that combine automated and connected vehicle technologies — Converged vehicles — could provide numerous benefits to both individual users and society in general. Converged vehicles could enhance safety, increase road capacity, reduce congestion, and save fuel. The converged vehicle can use sensors and wireless communication to collect data from the environment, use this information to efficiently navigate around traffic and other obstacles, and transmit its own data to surrounding vehicles to improve travel for other users. The possibility of a converged—automated and connected—vehicle is truly paradigm shifting.

Automated Vehicle Technologies

Remember "Knight Rider"?: having received the directive from Michael Knight's wristwatch, *KITT*—a modified sports coupe—pinpoints Michael's location. KITT quickly calculates the optimum route and springs into action. KITT's powerful engine is paired with a powerful computer that can interpret and react to the road at a fraction of the speed of a human brain, allowing KITT self-piloted navigation to Michael at high speeds through crowded city streets. This scenario was considered science-fiction in the 1980's TV series, "Knight Rider." Today, with rapidly advancing automated vehicle technologies, such a concept seems completely possible.

The pace of technological advancement in recent years is remarkable. While KITT's grappling-hook feature has not been duplicated, nearly every major auto manufacturer has initiated research and development of automated vehicle systems that could soon match KITT's self-driving capabilities. Additionally, high-tech firms such as Bosch, TRW, Delphi, and others are developing advanced technologies, both in cooperation with and independent from the traditional manufacturers. In perhaps the most notable example, Google engineers have already recorded hundreds of thousands of miles in vehicles modified with advanced automated vehicle technology.

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[38] Ibid.
[39] Smedley, Peggy. (2012). "Computers on Wheels."

The first automated vehicle technologies were designed only to supplement the human operator. For example, anti-lock brakes (ABS) and electronic stability control (ESC) interpret the intention of the driver and use automated engagement of braking system components to improve driver performance. Some of the latest automated vehicle technologies are designed to operate in the event of operator error. In the near future, automated vehicle technologies may not require operator input at all. Many industry stakeholders and analysts believe that fully automated vehicles may be possible within ten years.

Today, anti-lock brake systems may be so commonplace as to seem mundane. But ABS is a key automated vehicle technology; it uses sensor input to decide how the brakes should be applied. Yet ABS is designed only to *assist* the driver to stop faster when the driver engages the brakes in an emergency stop. Electronic stability control was the next step in the evolution of automated vehicle systems. ESC interprets driver intent, road conditions, and vehicle dynamics to actuate the brake system, but not to *stop* the vehicle. The ESC keeps the vehicle safely moving on an intended path when the driver may have otherwise lost control.

Anti-lock braking systems work only when the vehicle is already in an emergency stop, and electronic stability control engages only when the vehicle is already losing traction. Today's more advanced technologies attempt to anticipate and prevent emergency maneuvers. For example, automated emergency braking (AEB) systems sense impending impacts and react by automatically engaging the braking system, whether or not the driver has pressed the brake pedal. Also, *automated lane-keep assist* systems can sense a vehicle's location within a lane and in relation to other vehicles, and can actuate the brakes to "nudge" the vehicle back into a lane to prevent lane-drifting or merging into other vehicles. These advanced options are becoming increasingly common on new vehicles.

So far, we have discussed only automated vehicle technologies that actuate the vehicle brake. Advanced automated collision avoidance systems can also take control of the steering and/or throttle. Some ABS and ESC systems already incorporate throttle control. Soon, vehicles may be fitted with automated emergency steering (AES), as well. Nissan has promoted a prototype AES system coupled to its "steer-by-wire" system that has been designed for production. Continental claims to have an AES system production-ready, as well.

Beyond preventing and mitigating collisions, automated vehicle technologies can also assist with everyday driving. Adaptive cruise control (ACC) has been available since the late 1990s, and has been extended as an option, even on lower cost vehicles like the Ford Focus. ACC automatically adjusts vehicle speed to maintain an appropriate distance from a leading vehicle. Manufacturers may soon offer vehicles that combine ACC with *active lane keeping*—automatically controlling the vehicle's speed, steering, and brakes while engaged in highway driving. VW calls its prototype system, "Temporary Auto-pilot." So far, no manufacturer has offered such an option on a production vehicle. However, it has been reported that Cadillac is essentially production-ready with just such a "Super-cruise" option. Similarly, Volvo and Ford are readying "Traffic-jam Assist" systems that will be capable of fully automated operation in low-speed stop-and-go conditions.

Active parking assistance has been an option on some high-end vehicles for several years, in the form of driver feedback via cameras and/or sensors. Currently deployed automated parking systems require the driver to work the brakes while the vehicle steers. However, as automated vehicle technology systems become more robust, eventually even the driver may become unnecessary. It is expected that as the technology is proven, drivers will be able to choose a parking spot, leave the car, and allow the car to park itself. This would permit parking in spaces that would otherwise be too narrow to allow the driver to exit or enter the car.

The final frontier of automated vehicle technology is automated operation in mixed-traffic on surface streets. The complex nature of congested urban and suburban roads can be confusing for even the best of human drivers. Developing an automated vehicle able to cope with such a complex environment is difficult, yet multiple stakeholders are working to make this happen. Google is famously running fully automated vehicles on roads in Nevada and California. Automakers, such as Volkswagen and Toyota, are also developing advanced automated functionality. Additionally, suppliers of simpler automated systems frequently acknowledge combining these various functions to progressively relieve drivers of responsibility. The culmination of this process is expected to result in fully automated vehicles at some future time. The only question is how long we will have to wait.

Connected Vehicle Technologies

Michael Knight's wristwatch communication link to KITT was a fictional example of connected vehicle technology. Yet, today's car-owners can already locate and start their car remotely by cellular phone. This is only the beginning of a transformation promised by connected vehicles. What if every vehicle on the road had the ability to transmit and receive information like KITT? These vehicles could potentially be sharing a plethora of information which could be used to enable an endless array of applications with the power to improve vehicle safety, enhance user mobility, and reduce the environmental costs associated with transportation.

While initial deployments of connected vehicles may fall short of the action-packed episodes of "Knight Rider," vehicle connectivity is a major enabler of intelligent mobility. As with automated vehicle technologies, nearly every major automotive manufacturer has initiated research and development for connected vehicle systems. High-tech automotive suppliers such as Delphi, Denso, and Visteon have been developing connected vehicle equipment, as have companies specifically focusing on communications technology, such as Arada Systems, Cohda Wireless, and Savari Networks.

Applications using vehicle connectivity can prevent crashes, optimize travel routes, issue road condition warnings, and generate environmental benefits by taking advantage of continuous, real-time connectivity to vehicles, infrastructure, and wireless devices. In safety applications, these systems can use cues such as sounds, lights, displays, and seat vibrations to alert drivers to the presence of various threats. Advanced connected vehicle systems that make use of automated technology could allow vehicles to actively avoid threats, e.g., by automatically applying the brakes when a hazard is detected ahead.

An example of a system where connectivity has enabled automated or at least semi-automated driving is the European proof-of-concept project, SARTRE, in which vehicles form convoys or "road trains" where the lead vehicle is driven by a human, but all other vehicles require no driver input and instead follow the lead vehicle. Connected vehicle technology is used by vehicles to enter or exit a "road train" and/or mimic the motions of the lead vehicle. This technology is augmented by camera, laser, and radar technology in order to make the "road train" possible.

A wide array of communications technologies may be used for connected vehicle communications (e.g., 5.9 gigahertz Dedicated Short Range Communications (DSRC), third-generation (3G) and fourth generation (4G) cellular communications, Wi-Fi, and Bluetooth). Experts note that DSRC will be required for safety applications, but that other technologies (especially cellular communications) will be able to support additional applications.

Connected vehicle technology consists of several types of communication: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-device. V2V refers to communication directly between vehicles. V2I involves communication between vehicles and the roadway, traffic signals, and other pieces of infrastructure, such as bridges. Vehicle-to-device allows vehicles to communicate with devices such as cellular phones or pedestrian transmitters, permitting vehicles to gather additional information about their surroundings. Vehicles equipped with communication capabilities broadcast information as they are driven, such as brake status, GPS location, rate of acceleration, speed, and steering-wheel angle. This data can then be received and used by other participants in the connected vehicle system.

Many valuable safety applications require only V2V communications. For instance, using V2V, a connected vehicle system can support blind spot warnings, cooperative adaptive cruise control, cooperative collision warnings, emergency electronic brake lights, lane change warnings, road condition warnings, and approaching emergency vehicle warnings. Several of these applications can also use sensor-based solutions that rely on cameras, radar, and lasers, but connected vehicle technology may be cheaper and more flexible to implement.

V2I applications can issue warnings for curve speed, school zones, construction, and other conditions, and duplicate relevant signs within the vehicle. They can also improve intersection safety by notifying the driver of a potential collision with other vehicles that are currently out of sight. V2I communications can also alert drivers of stop sign or traffic signal violation warnings and can even obtain information from traffic signals as to their phase timing, allowing drivers to optimize driving speed and route to limit time spent waiting at red lights. The technology used for V2I communications could also replace older forms of connected vehicle technology such as that used for emergency vehicle signal preemption or electronic tolling transaction services.

Vehicle-to-device technology could use cellular applications or specialized DSRC transponders to include pedestrians and bicyclists in the connected vehicle realm. Pedestrian applications could include warnings to drivers if pedestrians are in, or near, crosswalks. Such a feature could be particularly useful in specific situations, such as when the dark of night, the glare of the sun, or weather events result in low-visibility conditions. In addition, people using public transportation could have access to real-time data on arrival and departure times for busses and trains through their connected devices. Another option that vehicle-to-device communications users would have is to optimize their travel across multiple modes of transportation.

The potential benefits of connected vehicles have convinced vehicle manufacturers, auto suppliers, government agencies, and research organizations to collaboratively test and develop these systems. The largest connected vehicle testing deployment is currently underway in Ann Arbor, Michigan under a directive of the U.S. Department of Transportation (USDOT). The tests will feature nearly 3,000 vehicles equipped with various types of vehicle communications devices, including vehicles with integrated systems from Ford, General Motors, Honda, Hyundai-Kia, Mercedes-Benz, Nissan, Toyota, and Volkswagen. If the results of the project are as positive as stakeholders are expecting, new vehicles may begin to come standard with connected vehicle capability. As connected vehicles represent an increasingly higher percentage of vehicles on the roadway, road transportation may become drastically smarter, safer, and more efficient.

Advanced Materials

As the automobile evolves, it is continually adopting new materials and material processes. Achieving greater fuel economy is a main driver for many of these materials and processes. Fuel economy and emissions reduction efforts favor vehicle lightweighting; every 10 percent reduction in vehicle mass leads to a 5 to 7 percent decrease in fuel consumption.[40] Another key driver for using new and more highly engineered materials is to improve vehicle safety and crashworthiness. Reducing the carbon footprint of materials is another desirable outcome of lightweight materials; some materials can be recycled at a great energy savings over virgin material. Companies can also use bio-based materials, derived from plant matter, to decrease a vehicle's environmental impact and reduce oil dependence.

From 1995 to 2010, there were sustained changes in the materials used to create vehicles. During that time period, there was increased use of advanced high strength steel (AHSS), plastics/composites, and aluminum, as well as a decrease in the use of iron castings and regular (mild) steel. The material infrastructure and supply chains, including the design software, welding technology, coatings, tooling industry, assembly operations, recycling system, and repair services, support use of mild steel, AHSS and aluminum (the closest competition to mild steel). Because the infrastructure and supply chain is extremely complex, the automotive industry changes individual components and subsystems from mild steel to AHSS, aluminum, or composites incrementally rather than changing materials throughout the entire vehicle at once.

Advanced High Strength Steel

New AHSS implementations are developed every year. By using high strength steel over mild steel, companies can create thinner components (decreasing vehicle weight) while achieving the same crash performance, although the adoption of high strength steel poses some challenges to the manufacturing

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[40] NHTSA. (2012a). "Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks." National Highway Transportation Safety Administration, U.S. Department of Transportation. Pages 435-436. August 2012. <http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/FRIA_2017-2025.pdf>.

process. As is typical of continuous innovation in the industry, third generation steels are being developed that are ultra-high strength, but can be cold-formed like mild steel. These steels are currently being developed and could be used in vehicles in the near future.

Aluminum

Aluminum is already a dominant material in powertrain, heat exchangers, and road wheels, and is an emerging material for all vehicle closures (30 percent of hoods on new vehicles are aluminum). Currently, the average car is about 8 percent aluminum; aluminum in vehicles is expected to double to 16 percent by 2025. Replacing steel with aluminum typically reduces weight by 35-45 percent. Although the design, fabrication and joining of aluminum is different than for steel, it has many similarities. The cost premium is a few hundred dollars for an aluminum-intensive vehicle. Joining parts and components is one of the more challenging aspects of using aluminum in vehicles, and recent developments in aluminum joining allow it to be joined using methods similar to those used in joining steel.

Composites

Composites also have great potential for a variety of applications, as they can be customized by varying the mix of polymers and reinforcement fibers to meet the specifications of particular components. Advancements in colors, feel (soft skin feel), resistance to ultraviolet rays, and proper management of thermal expansion properties have enabled the use of composites for many components both inside and outside the vehicle (fascias, lids, air foils, knobs, and other components). A significant portion of the interior seating and trim involves plastic, rubber, and composites.

Bio-based materials

Bio-based materials are industrial products made from renewable agricultural and forestry feedstocks, which can include wood, grasses, and crops, as well as wastes and residues. These materials may replace fabrics, adhesives, reinforcement fibers, polymers, and other, more conventional, materials. There are several ways bio-based materials may be used in automotive components. Beyond traditional uses (such as wood trim, cotton textiles, and leather seats), there are two primary ways these materials are used: to create polymers or as reinforcement and filler. Bio-based polymers can be made from a variety of sources—including soybean, castor bean, corn, and sugar cane—which can be fermented and converted into polymers. Bio-based composites may be reinforced or filled using natural fibers, such as hemp, flax, or sisal.[41]

Bio-based materials have been tested and deployed in a number of automotive components. Flax, sisal, and hemp have been used in door interiors, seatback linings, package shelves, and floor panels. Coconut fiber and bio-based foams have been used to make seat bottoms, back cushions, and head restraints. Cotton and other natural fibers have been shown to offer superior sound proofing properties and are used in interior components. Abaca fiber has been used to make underbody panels.

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[41] Hill, Kim, Bernard Swiecki, and Joshua Cregger. (2012). "The Bio-Based Materials Automotive Value Chain." Center for Automotive Research. April 2012. <http://www.cargroup.org/?module=Publications&event=View&pubID=29>.

Although still in its infancy, bio-based material use in automobiles has been gradually accelerating over the last several years. The industry's new emphasis on environmentally-friendly materials and technologies has been spurred by government regulations, consumer preferences, and, in some cases, financial savings that can be realized from the adoption of these materials and technologies. After years of research, bio-based plastics are now closer to meeting or exceeding performance and cost parameters of conventional plastics than ever before.

Despite these advancements, however, there are still some drawbacks which prevent bio-based materials from seeing wider application in the automotive industry. Since there is intense price competition in the automotive industry, automakers are generally unwilling to pay a premium on parts and components. Suppliers therefore must address any shortcomings of bio-based materials. Further, bio-based components must be price-neutral compared with their conventional counterparts—which is a significant challenge for a new product to overcome.[42]

Forming, Joining, and Modeling

In addition to the materials themselves, much of the advancement in the automotive materials sector is in the methods used to apply and assess materials. Some of the biggest developments in materials technology involve joining (resistance spot welding, fasteners, adhesives, weld bond adhesive, laser welding), fabrication methods (hot forming, thin-wall die casting, composite molds), and CAE to model new materials (mold flow analysis, formability, and crash simulations).

By 2020, it is expected that vehicle body weight will be reduced by 10 to 20 percent. Most of that weight reduction will come from the vehicle body (35 percent weight reduction) and the chassis & suspension (25 percent weight reduction). Between now and then, the use of AHSS, sheet (rolled) aluminum, composites, and advanced forming and joining techniques will all continue to increase.

Advanced Powertrain and Alternative Fuels

Vehicle manufacturers are developing a wide range of advanced powertrain technology options. While the spark-ignited internal combustion engine (ICE) will remain the dominant technology, other powertrain options will see increased market acceptance. Having a variety of powertrain options allows consumers an ever increasing array of choices, while government regulation and energy prices will likely also be key drivers for powertrain technology development and market penetration in the United States automotive market during the coming years.

Ongoing developments and improvements in various powertrain technologies will be essential to meet federal and state environmental regulations, consumer preferences and energy-saving goals. Uncertainty remains among vehicle manufacturers as to which technologies will best meet energy efficiency goals and also be understood and purchased by consumers. Areas of technology growth related to powertrain systems include advanced internal combustion engines (gasoline and diesel), transmissions, vehicle electrification, and alternative fuels. Each of these categories presents a wide range of technology options and cost considerations.

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[42] Hill, Kim, Bernard Swiecki, and Joshua Cregger. (2012). "The Bio-Based Materials Automotive Value Chain."

Internal Combustion Engines

The ICE has undergone remarkable change in the past decade. That pace of change is likely to increase in the coming years. In the past few decades, spark-ignited (SI) gasoline engine technology has shifted from carburetor to port fuel injection (PFI), and from pushrod toward greater application of overhead camshafts. In essence, engines went from low-tech and low precision to high-tech and high precision, and will require even higher precision in the coming years. The next major step in this evolution is the move from PFI toward increased application of gasoline direct injection (GDI) engines. GDI engines require high pressure injection systems (although not as high as direct injection, compression ignition—i.e., diesel).

The internal combustion engine (both spark-ignited gasoline and compression-ignition direct injection) accounts for well over 99.5 percent of all light-duty vehicles sold in the U.S. market. Even given recent hype for alternatives, the ICE will likely maintain a dominant market position for the next decade. In order to meet upcoming fuel economy and CO_2 regulations, however, the ICE will undergo significant, and potentially costly, development. Some methods or techniques that will be used to improve engine efficiency include increased use of variable valve timing, cylinder deactivation, and forced induction (turbocharging or supercharging) technologies.

Transmission Systems

Transmission systems have also been changing in recent years. In the near future, dual-clutch transmissions (DCTs) are expected to see increased market penetration. DCTs are 4 to 5 percent more efficient than similar geared transmissions. In addition, more efficient, higher-speed automatic transmissions (8- or 9-speed) will be made more widely available in coming years. Another option to increase the efficiency of the transmission system is the use of a continuously variable transmission (CVT). CVTs currently represent 5 to 7 percent of the U.S. market, and will likely see additional growth (particularly on hybrid electric vehicles) in coming years.

Vehicle Electrification

Electric vehicles hold both promise and uncertainty. The Tesla Model S and Nissan Leaf, two highly visible battery electric vehicles, have entered the mainstream—but certainly not the mass market. Vehicle electrification—including mild hybrid or motor assist (MA), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), extended range electric vehicles (EREV), or battery electric vehicles (BEV)—is highly dependent upon further battery development. HEV will likely continue to capture the most market share, but there is no general consensus as to which of the other forms of electrification (MA, PHEV, EREV, or BEV) might be most likely to find a niche with consumers in the near future.

Alternative Fuels

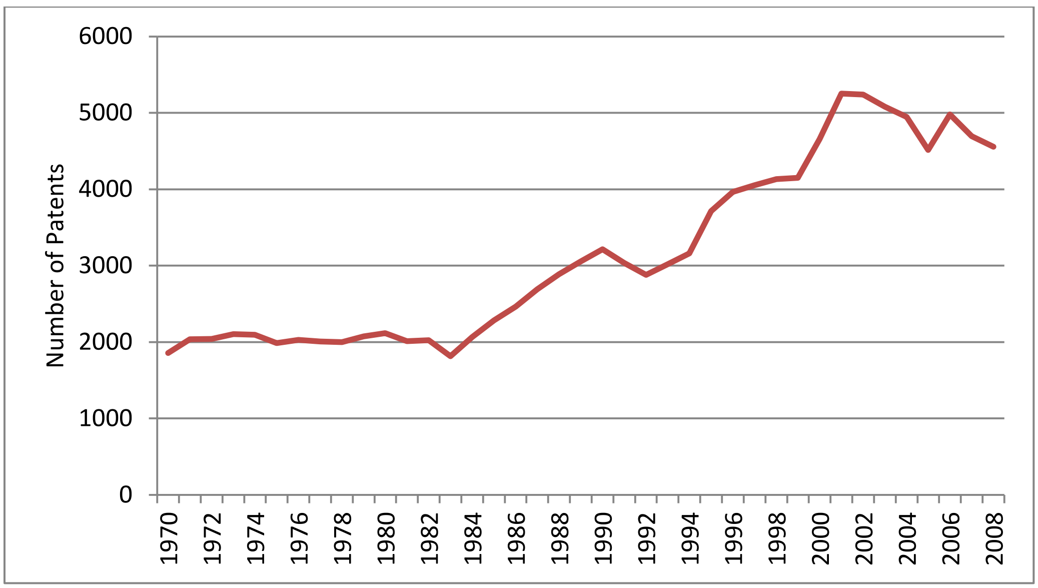
Alternative fuels will likely continue to play a role in advanced powertrain development. Fuels such as natural gas, biofuels, and hydrogen have all received support over the years. Natural gas has been used for light-duty vehicles for many years, but has been mostly limited to fleet applications. Promoters of natural gas suggest that its abundance and relatively clean-burning characteristics make it an ideal candidate for increased usage in motor vehicles. Bio-fuels (e.g., ethanol and biodiesel) have grown in recent years. They will continue to play a role, but have many challenges to overcome before they can achieve broader use. Hydrogen is farther off than other alternative fuels mentioned, although Toyota has announced that it will market a fuel cell electric vehicle (FCEV) in 2015. Other manufacturers (e.g., Honda, General Motors, and Mercedes) continue to develop hydrogen-powered fuel cell technology and have offered FCEVs to consumers in highly controlled market/technology evaluations.

Patents

The auto industry is extraordinarily well-positioned for sustained growth. Automakers and parts suppliers have not only weathered a severe recession, but they have used that time to align capacity, revamp manufacturing processes, and focus on product development and design. Going forward, success in this industry will be driven by new developments in technology.

Traditionally, the auto industry is awarded in about 3-5 percent of all patents granted in the U.S. Since 1999, patents awarded to all manufacturing industry sectors have increased in number by only 3 percent. Patents awarded to the auto industry have increased by 10 percent in the same period, while patents awarded to all other manufacturing sectors, with the exception of computers and electronics, have declined by an average of 37 percent (The slack in patents awarded has been almost entirely filled by the computers and electronics industry, which has seen growth of over 50 percent during this time).

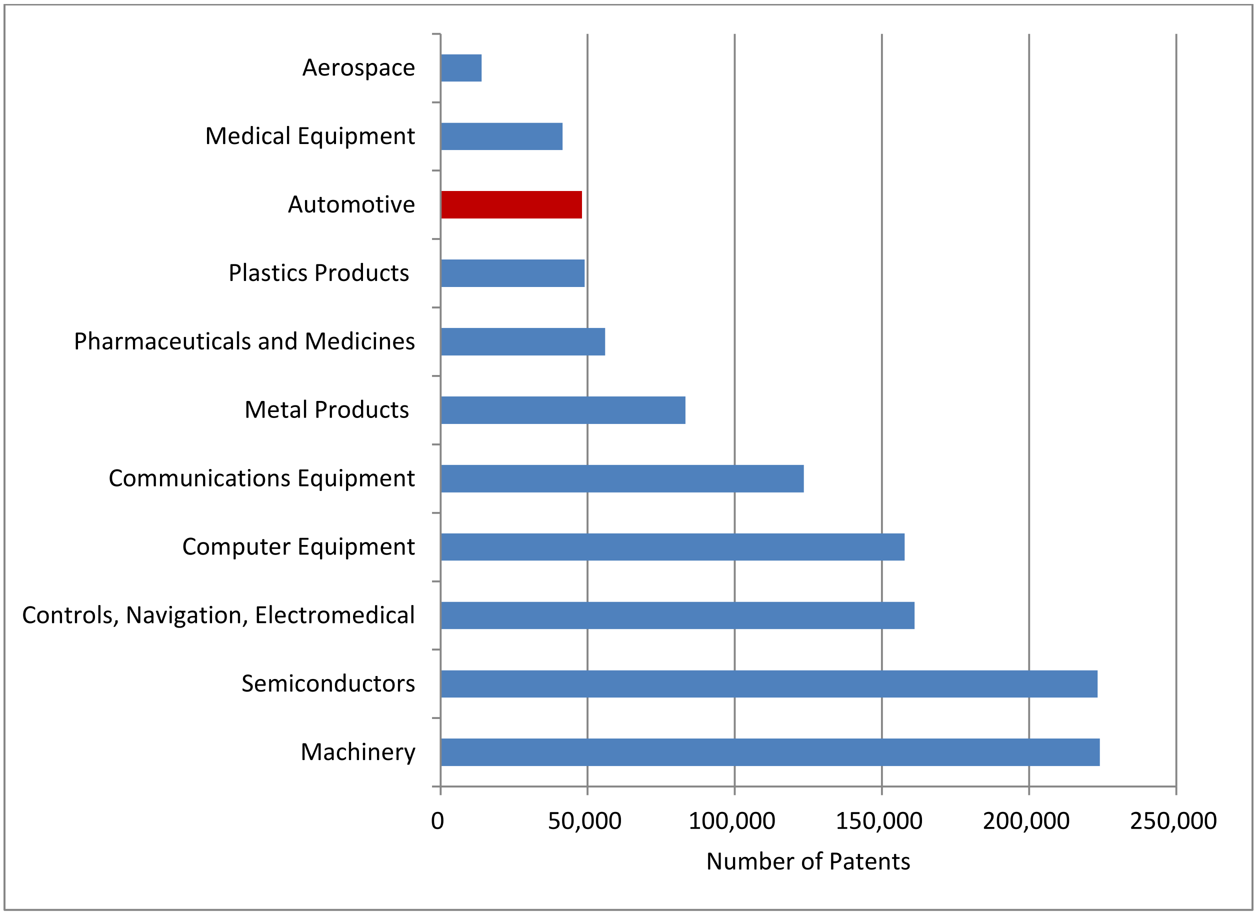
Figure 13: Patents Granted to the Automotive Industry, 1970 to 2008



Source: U.S. PTO 2012

Approximately 4,800 patents per year are granted to the auto industry, with a total awarded nearing 50,000 from 1999 to 2008.

Figure 14: Patents Granted by Industry in Ten Year Period (1999-2008)



Source: U.S. PTO 2012

V. THE AUTOMOTIVE INDUSTRY'S HIGH-TECH MANUFACTURING CLUSTER

Research activities, highly skilled employees, patents, and high-tech products are commonly thought of as hallmarks of high-tech industries. Less commonly understood, however, are the necessities of geographic clusters for maintaining high levels of innovation and synergies, as well as high-tech manufacturing processes. In fact, among the industries considered to be high-tech, the automotive industry not only is engaged in research and development, but it leads the way in domestic manufacture of its products. Furthermore, its manufacturing activities are very much high-tech, advanced manufacturing activities.

THE AUTOMOTIVE INDUSTRY HIGH-TECH CLUSTER

Among the industries typically considered to be high-tech, creative, innovative and entrepreneurial[43], one attribute essential to creativity and innovation is the clustering of major entities within the industry. Examples are the very familiar Silicon Valley for software and the bio-tech hubs of California, Massachusetts, Pennsylvania and the Carolinas. A bio-tech journalist succinctly explains the importance of research clusters:

> "This question about…clusters matters to a lot of people, because years of research in business and economics tells us that the clustering effect is essential for complex industries….The network of researchers, venture capitalists, entrepreneurs, business executives, service providers and more all need to be able to collaborate, preferably in close proximity to one another, to achieve hard goals like developing a new…."[44]

In fact, to be considered high-tech, an industry must have a geographic and innovative hub of activity. Advanced industries cannot have concentrated efforts to drive research and innovation into their products if the people with the ideas and innovation are widely dispersed. Further, that an industry has a geographic cluster for research and development is evidence that the industry is high-tech, because such a cluster is the result that talent and skilled innovators have come together.

The auto industry, while easily recognized as being centered around the Great Lakes region, may still not be thought of as having its own high-tech cluster. However, as well as being the traditional center for automotive manufacturing, Michigan is the dominant location in the United States for conducting automotive R&D. The state is home to more than 330 automotive R&D companies and hosts R&D facilities for 9 of the 10 world's largest automakers. Additionally, 46 of the 50 top global automotive suppliers have research facilities located in Michigan. The map in Figure 15 displays the geographic distribution of automotive R&D facilities in the United States, including automaker, supplier, university, and federal facilities. The inset emphasizes the concentration of facilities in southeast Michigan.

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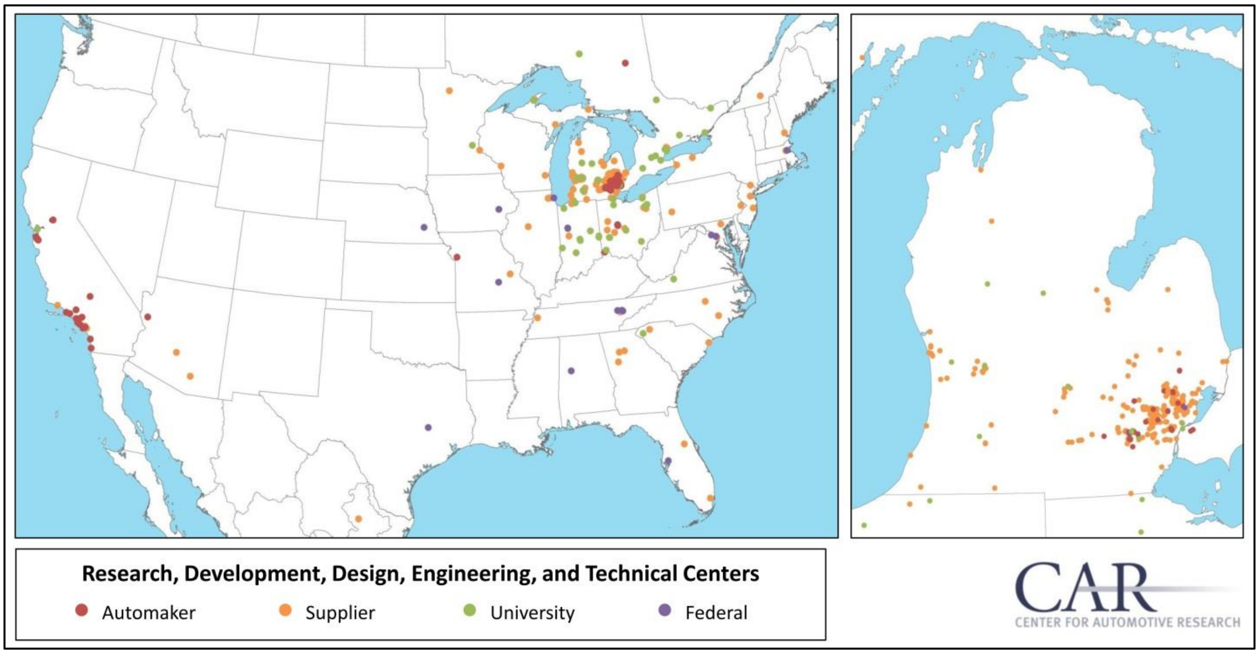
[43] E.G., software development, bio-tech and pharmaceuticals

[44] Timmerman, Luke. "Someone Needs to Rank U.S. Biotech Hubs." Xconomy. 2013

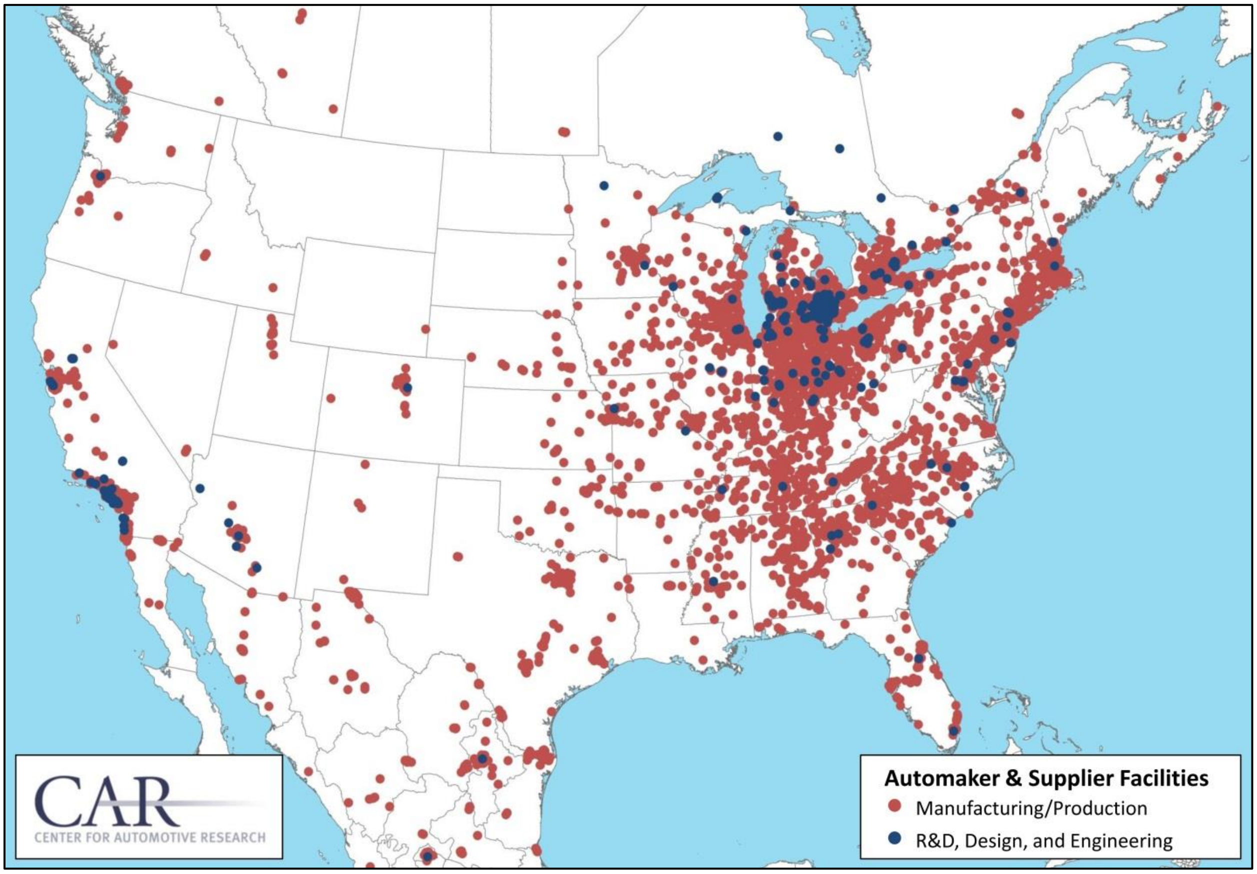
In a second map, displayed in Figure 16, these automotive research, development, design, engineering, and technical centers (blue) are overlaid on top of the automotive manufacturing footprint (red). (The manufacturing footprint includes production facilities for automakers and suppliers). As depicted on the map, the core of the automotive industry runs from the Great Lakes region (Ontario, Michigan, Illinois, Indiana, and Ohio) to the southern states of Alabama, Mississippi, Louisiana, and Texas, and down into Mexico. Despite the relatively broad footprint of the automotive manufacturing industry, R&D is fairly concentrated in the Great Lakes region.

Figure 15: Automotive R&D Facilities across the United States and in Michigan



Source: Center for Automotive Research, 2012

Figure 16: North American Automotive Manufacturing and R&D Facilities



Source: Center for Automotive Research, 2012

This intense clustering of automotive research, development, engineering technical and testing facilities provides the auto industry a geographical high-tech base that draws talented researchers, educational resources and public and private investment. The synergies afforded by a high-tech geographical cluster include highly specialized support and supply chains, public policies created to retain, grow and enhance a 'knowledge-based economy' and gains from "localized knowledge externalities."[45]

[45] Stuart, Toby and Olav Sorenson. "The geography of opportunity: spatial heterogeneity in founding rates and the performance of biotechnology firms." Elsevier Science. 2003. http://dimetic.dime-eu.org/dimetic_files/Lect-to-Sorenson_Stuart-SorensonRP03.pdf

High-Tech Manufacturing

The automotive industry has always been at the forefront of high-tech manufacturing. The modern assembly line was developed in 1901 to enable mass production of the Curved Dash Oldsmobile. The assembly line required the use of interchangeable parts and resulted in a much higher degree of standardization in the automotive industry. By 1913, Henry Ford advanced the concept to create the moving assembly line for Model T production--vastly improving productivity, shortening vehicle build time, and reducing production costs.

Contemporary automotive manufacturing makes use of high-tech tools (e.g., advanced robotics) and uses computer design and simulation software to reduce costs while improving quality. The industry has evolved to become increasingly more standardized; parts are often interchangeable--not only within a model but between several models, using a technique called carryover parts. Automakers are using common global platforms which allow sharing of major components and systems between families of vehicles across all markets. In order to remain competitive, manufacturing operations must also be lean and flexible.

Precision and Standards

One characteristic of high-tech industries is the extent to which precision and standards in production must be maintained. Few industries have such demanding standards and zero tolerance levels for manufacturing products as the auto industry. The requirements have become so high that traditional approaches are no longer sufficient, and advanced new technologies and innovations have had to be created by the industry. Even minute deviation from a part's requirement (measurements, heat/cold tolerance, etc.) can have vast repercussions, as many systems or parts may be affected from even the smallest misalignment. For parts and systems suppliers, quality issues could result in expensive scrappage or lost contracts. For automakers, a small defect may result in lost sales as customers migrate to other companies for their next vehicle purchase. For such a large purchase, consumers do not give second chances: a single bad experience will inform a lifetime of decision making. Larger quality problems may lead to expensive recalls and potential fines. Even a single instance of poor quality causes lasting damage to the reputations of both brand and company.

Maintaining consistently high quality for hundreds of thousands of vehicles produced across far-flung production facilities is a complex undertaking which, in itself, requires precision and technology to accomplish. Worldwide, the Ford Focus is assembled at nine separate facilities. All vehicles, regardless of the specific plant from which they are made, must conform to the same high-quality standard. Dr. Jay Zhou, Executive Technical Leader for Quality at Ford Motor Company, summarizes the Ford quality control system, stating that, "The key with Ford quality is standardization – one process for quality and product development." Ford has implemented a single, standardized quality operating system, both within its facilities and at supplier facilities. Included in this are standardized measures of product quality and customer satisfaction, and the communication of product-specific customer feedback directly to those workers involved in production. These data aid in identifying shortcomings and allow tracking of trends in product quality to ensure that quality is continuously improving. Further, the standardized quality operating system is itself continuously refined, with best practices adopted from across the globe.[46]

At Toyota's production facilities, every worker is involved in product quality, inspecting both their own work and that of co-workers. Further, any individual worker can call a stop to production to address problems with the production process or product quality.[47] Every production worker at Toyota's Kentucky plant has access to an "andon"' cord which, when pulled, signals that a production or quality issue has been identified.[48] The andon cord system identifies both the existence of a production or quality concern and its exact location along the production line. While a short buffer time exists, if the concern cannot be quickly rectified, the entire line will shut down until the problem is resolved. Once assembled, every vehicle undergoes rigorous testing and inspection. To further refine production processes and quality control, Toyota encourages its workers to suggest possible improvements; more than 90,000 suggestions are adopted each year. [49]

The quality control processes developed and implemented by the automotive industry have long been highlighted as the standard other industries should strive to attain. An article in the journal *Clinical Chemistry* evaluates different quality control methods which might be implemented to address inconsistency of quality in the operations of medical testing laboratories. The quality control successes of Toyota and its suppliers are specifically highlighted:

> "Several independent sources have indicated that Toyota and its suppliers consistently maintain nonconformity rates <50 ppm. The proprietary benchmarking study showed that Toyota achieves this high degree of quality while spending <3% of its total production budget on quality-control-related factors."[50]

More recently, the U.S. Food and Drug Administration issued a report on quality control in the medical device industry. This report finds that the automotive and aerospace industries are examples of best practices in quality control:

> "There exists tremendous opportunity [for the medical device manufacturing industry] to adopt learning and best practices from the automotive and aerospace industries that are far more advanced in this domain."[51]

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[46] Zhou, Jay. (2012). "Excellence Is Not an Event; It's a Habit." *Quality Digest*. December 4th, 2012. <http://www.qualitydigest.com/inside/quality-insider-column/excellence-not-event-it-s-habit.html>.
[47] TMMK. (2013). "Toyota Quality." Toyota Motor Manufacturing, Kentucky, Inc. Accessed January 14, 2013. <http://www.toyotageorgetown.com/qualdex.asp>.
[48] Williams, Stephen. (2009). "Toyota Quality Control Includes 'Popeye' and 'Greensleeves'." *The New York Times.* September 4th, 2009.
[49] TMMK. (2013). "Toyota Quality."
[50] Hinckley, C. Martin. (1997). "Defining the best quality-control systems by design and inspection." *Clinical Chemistry* 43 no. 5: May 1997.
[51] FDA. (2011). "Understanding Barriers to Medical Device Quality." U.S. Food and Drug Administration. October 31, 2011. <http://www.fda.gov/downloads/AboutFDA/CentersOffices/CDRH/CDRHReports/UCM277323.pdf>.

Another passage describes the quality control practices which the medical device industry should adopt, and concludes:

> "All of these tools are used routinely in the automotive and aerospace industries for product development and process control."[52]

To be held up as *the* example for other industries to emulate, clearly, the automotive industry has a firm grasp on implementing and continuously executing quality control best practices.

Robotics

The automotive industry is the most extensive user of robotics and automation.[53] Since the earliest days of robotics use, the automotive industry has been of immense importance to the industrial robotics industry, as both a customer and a partner. According to the International Federation of Robotics publication, *World Robotics*, the industry is the largest purchaser of industrial robots. In 2011, the global auto industry installed nearly 60,000 new robots, accounting for 36 percent of the total annual supply of industrial robots.

The use of robotics is a key enabler of modern automotive production strategies. The largest user of industrial robots is in the automotive sector. Robotic automation of automobile production began in the 1970s with the adoption of simple "pick and place" robots. Robotic technology advanced significantly, due in great part to demand from the automotive industry. Today's automotive factories need large numbers of robots; a modern body shop contains 300 to 600 robots.

There have been major technological changes in robotics over the years as a result of the scale of automotive demand. The industry moved from using hydraulic robots to electronic robots; the payload capacity of robots increased significantly; costs for robots decreased by as much as 70 percent (from approximately $60k-70k to $20k); and quality improved dramatically ("mean time to fail" used to be hours, now it is measured in years). Automakers use robots not just to replace labor, but also to improve product quality, because they can repeat motions precisely without fatigue. Robots can also be used to increase flexibility by allowing automakers to reduce the amount of fixtures they use. Reducing fixtures saves money and permits faster factory startup with new models.

General Motors has 25,000 manufacturing robots, and purchases roughly 3,000 more each year.[54] GM's involvement with robotics has a history spanning more than half a century. In 1961 the first-ever installation of an industrial robot took place at the General Motor's Turnstedt Plant in New Jersey.[55] GM

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[52] Ibid.
[53] NIST. (2011). "Manufacturing: Advanced Robotics and Intelligent Automation." National Institute of Standards and Technology, U.S. Department of Commerce. August 2011. Page 9. <http://www.nist.gov/tip/wp/upload/manufacturing_adv_robotics_intelligent_automation_wp_08_11.pdf>.
[54] GM. (2012). "Manufacturing Robots Send Holiday Greetings." General Motors. December 14, 2012. <http://media.gm.com/content/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2012/Dec/1214_holiday-robots.html>.
[55] GM. (2012). "Manufacturing Robots." and IFR. (2013) "History." International Federation of Robotics. Accessed February 6, 2013. <http://www.ifr.org/history/>. And NIST. (2011). "Advanced Robotics."

launched a joint-venture, FANUC, in 1982. Today, it is one of the largest global producers of industrial robots.[56]

Ford uses more than 700 advanced industrial robots at its Louisville Assembly Plant. Among these are robots which use laser- and camera-based sensors to detect and automatically adjust for minor differences between vehicles. Robots also ensure that components such as panels and windshields seamlessly fit together. Other robots run a sealed paint shop so that no humans need enter the zones where paint is applied.[57]

In addition to industrial robotics, many automakers have introduced or developed exoskeletal and wearable robotics systems to reduce worker fatigue, lowering the chance of workplace injury and increasing worker productivity.

Figure 17: Wearable Robotics Currently Under Review by Ford

Source: Equipois 2013

Beyond the new industrial robots at Louisville Assembly, Ford Motor Company has been evaluating the x-Ar Exoskeletal Arm system at its Kentucky Truck Plant.[58]

[56] GM. (2012). "Manufacturing Robots."
[57] Ford. (2012). "Robots with Laser Eyes and Suction Cup Hands Boost Quality of Louisville Assembly Plant and the All-New Ford Escape." Ford Motor Company. April 11th, 2012. <http://media.ford.com/article_display.cfm?article_id=36329>.
[58] Gatto, Katie. (2011). "Equipois Inc. sells lightweight robot arms to space human labor." Phys.org. June 16th, 2011. <http://phys.org/news/2011-06-equipois-lightweight-robot-arms-space.html>.

Figure 18: Human Assist Grasp Device Developed by GM and NASA

Source: GM 2012

In 2007, General Motors entered into collaboration with NASA to develop a service robot for the International Space Station. This collaboration has continued, with development of a wearable robotic glove, called the Human Assist Grasp Device, for use by astronauts and factory workers.[59] Honda has long been active in the field of robotics (although not always with applications for the auto industry) through their well-known ASIMO android program.

Figure 19: Honda's ASIMO Android Program

Source: Honda 2011

[59] GM. (2012). "GM, NASA Jointly Developing Robotic Gloves for Human Use." General Motors. March 13, 2012. <http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2012/Mar/0313_roboglove.html>.

Digital Engineering
Another key enabler of modern automotive production strategies is the adoption of digital engineering. During the pre-launch phase of a car (once the tools are built but before the factory is launched), the old-fashioned process involved physical prototypes and physical development (actually putting cars together manually to see if parts will fit). Today's vehicles are far more complex than previous generations. Advances in safety, fuel efficiency, and connectivity require considerable resources during development, validation, and manufacturing. To achieve such results while maintaining quality and launch timing, the automotive industry is leveraging the latest advances in computing technology.

Ford, for example, has teamed up with Oakridge National Laboratory to use some of the most state of the art supercomputers in the country. These supercomputers are being used to model such things as airflow around the engine compartment to improve fuel efficiency.[60] At General Motors, engineers are using advanced 3D scanning tools to benchmark competition to improve the quality of their products. In addition, the scan can be used to compare prototype parts to math data as well as to digitally assemble the prototype part to verify manufacturing processes.[61]

Through these advanced tools, automakers can assemble the car virtually after scanning with a "blue light scanner" to validate the fit-up of parts. Computer-Aided Engineering (CAE) is used to determine how to make parts and define materials. CAE is also used to determine whether a vehicle design is structurally sound as well as to simulate and analyze noise, vibration, harshness (NVH), and stiffness. Today, designers use 3-D virtual simulations to model and analyze fitting parts together, manufacturing processes, vehicle packaging (design), and crashworthiness evaluation of the structure.

Nanotechnology
Nanotechnology involves science, engineering, and manufacturing that is applied to extremely small things; the nanoscale is about 1 to 100 nanometers (1 millimeter is equal to 1,000,000 nanometers). Materials can be fabricated or modified at the nanoscale to alter properties, such as strength, weight, chemical reactivity, and light spectrum interactions. Scaled-up, reliable, and cost-effective production is already in place for many nanotechnology applications.[62] The automotive sector is a major consumer of advanced materials, many of which already use or could be improved using nanotechnologies. Areas within motor vehicles that can benefit from nanotechnology applications include the body and chassis, powertrain, tires, interiors and exteriors, and electronic systems.[63]

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[60] Oak Ridge National Laboratory. (2013). "ORNL's Supercomputer Gets Under the Hood." http://www.ornl.gov/ornl/news/features/2013/007b46da-122d-4029-9e44-cf7757af05c8

[61] Automotive World. (2013). "GM uses digital tools to dissect the competition." http://www.automotiveworld.com/news-releases/gm-uses-digital-tools-dissect-competition/

[62] Nano.gov. (2013). National Nanotechnology Institute. Website. Accessed April 2, 2013. <http://www.nano.gov/>.

[63] Nanowerk. (2010). "Nanotechnology in the Automotive Industry." Nanowerk. November 12, 2010. <http://www.nanowerk.com/spotlight/spotid=18972.php>.

Additive nanoparticles have a variety of benefits depending on the application – such as wear resistance, improved surface quality, increased strength, and light weighting. In 2002, General Motors began production of nanocomposite exterior panels. These nanocomposites used nano-sized clay in place of larger traditional fillers such as talc or glass. Mercedes-Benz uses nano-sized silica particles to improve scratch resistance and appearance of their paint. Another promising filler is the use of carbon nano-tubes. In fact, the automotive industry has been using carbon nano-tubes for well over 20 years as to protect electrical equipment in the vehicle.[64]

Nanotechnologies applied to vehicle bodies can be used to reduce vehicle weight while adding strength and improving crashworthiness. In the realm of powertrain, nanotechnologies can be used in coatings, lubricants, catalysts, and fuel additives. In addition, these technologies can improve the performance of batteries, fuel cells, and fuel injection systems. Nanotechnologies can be used to optimize the rubber and filler material mix in tires to alter properties, such as grip, resistance to abrasion and wear, and tear propagation. Interior and exterior materials applications include improvements in paint quality, glare, scratch resistance, UV-resistance. Advanced options, such as switchable colors, shape-shifting skin, dirt-repellent surfaces, and self-repairing materials, are also made possible by nanotechnologies. Beyond battery improvements, nanotechnologies can be used to produce miniaturized electronic systems, decrease power consumption from vehicle electronic systems, and improve solar cells for sunroofs and other vehicle surfaces.[65]

Lean Manufacturing

The concept of lean manufacturing stems from early lessons learned by Henry Ford, which were refined in Japan and returned to the United States in the form of the Toyota Production System (TPS). The three major objectives in the TPS are to remove overburden (muri), remove inconsistency (mura), and eliminate waste (muda). The TPS identifies seven forms of waste: excessive production, idle time, transportation, processing, stock, movement, and defective products. The uses of strategies such as continuous improvement, visual management, and "pull system" (production based on actual demand) rather than "push system" (production based on forecast demand) are examples of the TPS. Virtually every major auto company today incorporates some form of TPS in their production systems.

Flexibility

Today, flexibility in automotive production means the ability to build multiple models on the same line, one after another, without changing equipment. One example of an automotive assembly plant which has been designed for cutting-edge flexibility is the Michigan Assembly Plant, which can produce traditional internal combustion engine, hybrid, plug-in hybrid, and battery electric vehicles sequentially on the same line. Automakers frequently use robots to add flexibility, as they can be programmed to treat different models appropriately. In addition, flexible plants allow for faster production launches;

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[64] PlasticTechnology (2004). "Chasing Nanocomposites." PlasticTechonogy. November, 2012. <http://www.ptonline.com/articles/chasing-nanocomposites>.

[65] Ibid.

the addition of vehicle models or the changeover from one model to another can occur more rapidly than in plants with a lower degree of flexibility.

Standardization

In order to reduce costs and support global platforms, automakers are designing plants with overlapping Bills of Process, meaning that each plant has similar body shop, final assembly, and paint shop configurations. Similarly, automakers have standardized their Bill of Materials, meaning that parts, manufacturing equipment, designs, processes, and part specifications are also overlapping. Automakers are designing standardized underbody structures in order to keep the same material handling equipment and streamline retooling when model changeovers occur.

In order to remain competitive while offering unique products, automakers are designing vehicles with unique components in visible locations (e.g., the outside of the car) but standard components in less-visible areas (e.g., under the car). In line with this strategy, they are reducing the number of platforms on which their vehicles are built, resulting in more models on each platform. This strategy results in less engineering and development and more shared parts across models. Another result is that automakers are more reliant on global suppliers in their supply chains so they can have access to identical vehicle parts around the world.

VI. THE AUTOMOTIVE PROCESS OF TECHNOLOGY DEVELOPMENT AND INNOVATION

In order for the automotive industry to develop and produce the high-tech products it creates, the industry itself has had to become high-tech in its practices and structure.

The automotive industry is both a producer and a consumer of high-tech products. High-tech products developed within the industry are conceived and created by both automakers and suppliers, often in collaborative efforts. In the instances when components are purchased from other industries, the incorporation of these products is seldom a simple installation in the vehicle. The process generally requires automakers and suppliers to leverage their technological expertise to integrate these products into the vehicle itself, as well as synchronize with other systems in the vehicle with which the purchased components will function.

The Automotive Process of Innovation

While individual companies' processes for innovation and product development are generally treated as closely guarded secrets, automakers and suppliers have, over time, developed innovation processes that tend to share several common characteristics.

There is generally a need to separate more common engineering from true innovation. Common engineering results in incremental product improvement while true innovation creates products that become differentiators in the marketplace and serve as competitive advantages for the companies that develop them. Automakers and suppliers generally have a stage-gate process for product development and innovation. Ideas with the potential to result in new, innovative products are typically identified and fast-tracked through a process intended to vet the concept and determine whether it has the potential to succeed. The ideas determined to have the greatest potential for breakthrough products receive the greatest share of development effort and funding.

Automakers and suppliers use a variety of strategies to ensure that the ideas conceived by their employees are brought to the attention of decision makers within the company. These strategies include formal idea suggestion procedures, periodic reviews with employees, and meetings between various levels of management and technical staff.

Innovation in the Automaker/Supplier Relationship

Automakers compete intensively to develop new innovations that will give them a strategic advantage over their competitors. They maintain a diverse array of laboratories, test centers, and test tracks around the world to develop and validate these products. The automotive industry, however, is also highly dependent on suppliers for components as well as leading edge technology development. These contributions to the automotive value chain account for roughly three quarters of the content of the typical vehicle. They likewise play a critical role in developing the innovations that make the automotive industry high-tech.

Virtually all automotive suppliers maintain considerable engineering capability to develop products and integrate those products into automakers' vehicles. Many also have significant advanced development capabilities and produce highly sophisticated technologies that serve to differentiate them from their competitors.

The automotive industry has standard practices to ensure that suppliers who develop a technologically advanced product are able to negotiate with potential customers without fear that their technology is at risk of being revealed to competitors. Automakers typically sign confidentiality agreements that prohibit them from sharing sensitive information with competing suppliers. Even in cases where an automaker jointly develops a technology with a supplier, an arrangement is typically reached allowing the supplier to sell the given product to other automakers, though generally either at a higher price or after a given period of time. These approaches make it possible for new high-tech products to be developed and adopted rapidly, with minimal delay from the time an idea is conceived to when a consumer can benefit from it.

Collaborative Technological Development

The development of entirely new technologies by the automotive industry often begins with basic research that is considered to be of a non-competitive nature. It is in the individual automakers' and suppliers' own applications of these technologies where the firms' unique capabilities tend to be applied. For this reason, the automotive industry has developed a number of approaches to collaborative research. These approaches allow new technologies to be generated faster, at a lower cost, and with less duplication of effort than would otherwise be the case if each firm were working separately.

Direct alliances between automakers for the purpose of joint development of new technologies have become more common over the last decade. Prominent examples include a partnership between Ford Motor Company and General Motors to jointly develop the basic technology behind new lines of six-speed automatic transmissions. Following a period of collaborative development of the basic technology, each firm went on to enhance its own products, which compete in the market place. Technological development alliances between automakers are often global in nature, with each automaker involving the most appropriate technological staff from its bank of global facilities. Additionally, in early 2013, Ford, Daimler, and the Renault-Nissan alliance signed a pact to jointly develop fuel cell technology that will allow vehicles to run on emissions-free hydrogen fuel.

Both automakers and suppliers also make extensive use of a variety of not-for-profit and government-supported entities which assist these firms in sharing knowledge about emerging technologies. While these organizations are too numerous to mention in their entirety, prominent examples include the Society of Automotive Engineers (SAE) and the Argonne National Laboratories. As is the case with the high-tech research performed in company alliances, the information shared in these organizations' publications and events is of a pre-competitive nature, and is then applied by these firms as they continue with their own technology development processes.

THE GLOBAL NATURE OF AUTOMOTIVE INNOVATION

The largest automakers and suppliers are global firms, with global resources for the development of new technologies. Over time, automakers have generally consolidated the platforms, or architectures, on which they build their vehicles throughout their global operations. This means that, while a given vehicle sold in the U.S. may be optimized for local customer preferences, much of the underlying technology and componentry is shared with other vehicles the automaker builds on the same platform.

Similarly, rising fuel prices and increasingly stringent government regulations pertaining to fuel economy, emissions reduction, and safety are largely a global phenomenon, driving both automakers and suppliers to meet these challenges in all of the markets in which they appear. Automakers and suppliers have therefore structured their R&D organizations along functional, rather than geographic, lines.

In this competitive global environment, North America remains the world's strongest base of automotive research development. As discussed throughout this paper, the technological leadership shown by the automotive industry makes it a key asset in America's challenge to rival economies from around the world.

VII. CONCLUSION

The automotive industry is a high-tech industry. The automotive industry was pioneered by inventors and its core remains based in cutting-edge innovation, constant creativity, and high-technology inputs. Automakers must be quick to develop and adopt advancing technologies in both their vehicles and factories to remain competitive in today's fast-paced, global market. The U.S. automotive industry is among the nation's chief producers and consumers of technology and is a key component of America's global technological leadership.

Based on the metrics most commonly used by researchers to differentiate high-tech industries from other sectors, this report used a working definition for high-tech industry to understand how the automotive industry creates, leads and uses high-tech products and processes. By any definition, the automotive industry qualifies as a high-tech industry. The automotive industry:

- Has R&D expenditures equal or greater than 3 percent of output
- Requires a concentration of ten percent or more of technical employees – such as engineers, technicians, scientists, and mathematicians
- Uses the systematic application of scientific and technical knowledge in the design and/or production of goods or services
- Is engaged in the design, development, and introduction of new products
- Has a geographic cluster of innovation and development that concentrates a critical mass of skills and talents and allows new ideas and technologies to proliferate
- Is engaged in the design, development, and introduction of innovative manufacturing processes

In addition, throughout this report, it has been demonstrated that the automotive industry even exceeds these metrics:

- it is constantly innovating – based in part on R&D expenditures ($18 billion in annual expenditures and 4% of industry output) and numbers of patents produced,
- it requires a technically skilled workforce – with increasingly higher numbers of workers with degrees beyond high school, and a growing number of auto specialty courses,
- it has one of the largest geographic industry R&D clusters,
- the industry uses sophisticated design and production methods – including highly precise quality control measures, digital engineering, robotics and nanotechnology,
- and automakers manufacture products with high-tech content and highly sophisticated capabilities.

Innovation in the automotive industry is driven by a confluence of factors that have greatly increased the need for automakers and suppliers to utilize technology to differentiate themselves from competitors while meeting increasingly stringent government regulations. Automakers use the best ideas developed around the world, as well as creating innovative processes and products here in the U.S. Furthermore, in the search for new products and more efficient processes, the auto industry collaborates with the electronics, materials, aerospace, and other industries and well as developing entirely new technologies on its own. The American consumer has been the benefactor of this innovation; the number of vehicles offered in the American market has greatly expanded while those vehicles have become safer, more reliable, and more durable, and, in addition, offer a growing array of convenience and communication technologies.

This industry has never been able to rest on its achievements, and as such, the need to innovate and differentiate through technology has never been greater. The result is an automotive industry that stands among the nation's chief producers and consumers of technology, and is a key component of America's global technological leadership.

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APPENDIX A: ABBREVIATIONS

Abbreviation	Phrase
3G	third-generation
4G	fourth generation
ABS	anti-lock brakes
ACC	adaptive cruise control
AEB	automated emergency braking
AES	automated emergency steering
AHSS	advanced high strength steel
AS	Associate of Science
BEV	battery electric vehicle
BLS	Bureau of Labor Statistics
BS	Bachelor of Science
CAE	Computer-Aided Engineering
CAFE	Corporate Average Fuel Economy
CAR	Center for Automotive Research
CVT	continuously variable transmission
DCT	dual-clutch transmission
DSRC	Dedicated Short Range Communications
EREV	extended range electric vehicle
ESC	electronic stability control
FCEV	fuel cell electric vehicle
GDI	gasoline direct injection
GHG	greenhouse gas
HEV	hybrid electric vehicles
ICE	internal combustion engine
MA	motor assist
MPa	megapascals
MPG	miles per gallon
MS	Master of Science
NAICS	North American Industry Classification System
NSF	National Science Foundation
NVH	noise, vibration, and harshness
PFI	port fuel injection
PhD	Doctor of Philosophy
PHEV	plug-in hybrid electric vehicle
R&D	research and development
SAE	Society of Automotive Engineers
SEDS	Sustainability and Economic Development Strategies
SI	spark-ignited
SIC	Standard Industrial Classification
TPS	Toyota Production System
USDOT	U.S. Department of Transportation
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle

APPENDIX B: NAICS DEFINITIONS OF HIGH-TECH

Table B1: 1997 NAICS Codes That Constitute High-Technology Industries

NAICS code	Industry
32411	Petroleum refineries
3251	Basic chemical manufacturing
3252	Resin, synthetic rubber, and artificial and synthetic fibers and filaments manufacturing
3253	Pesticide, fertilizer, and other agricultural chemical manufacturing
3254	Pharmaceutical and medicine manufacturing
3255	Paint, coating, and adhesive manufacturing
3256	Soap, cleaning compound, and toilet preparation manufacturing
3259	Other chemical product and preparation manufacturing
332992	Ordnance & accessories manufacturing—small arms ammunition manufacturing
332993	Ordnance & accessories manufacturing—ammunition (except small arms) manufacturing
332994	Ordnance & accessories manufacturing—small arms manufacturing
332995	Ordnance & accessories manufacturing—other ordnance and accessories manufacturing
3331	Agriculture, construction, and mining machinery manufacturing
3332	Industrial machinery manufacturing
3333	Commercial and service industry machinery manufacturing
3336	Engine, turbine, and power transmission equipment manufacturing
3339	Other general purpose machinery manufacturing
3341	Computer and peripheral equipment manufacturing
3342	Communications equipment manufacturing
3343	Audio and video equipment manufacturing
3344	Semiconductor and other electronic component manufacturing
3345	Navigational, measuring, electro-medical, and control instruments manufacturing
3346	Manufacturing and reproducing magnetic and optical media
3353	Electrical equipment manufacturing
33599	All other electrical equipment and component manufacturing
3361	Motor vehicle manufacturing
3362	Motor vehicle body and trailer manufacturing
3363	Motor vehicle parts manufacturing
3364	Aerospace product and parts manufacturing
3391	Medical equipment and supplies manufacturing
5112	Software publishers
514191	On-line information services
5142	Data processing services
5413	Architectural, engineering, and related services
5415	Computer systems design and related services
5416	Management, scientific, and technical consulting services
5417	Scientific research and development services
6117	Educational support services
811212	Computer and office machine repair and maintenance

Source: NSF 2006

Table B2: Level I, II, and III High-Tech Industries

NAICS	Level-I Industries
3254	Pharmaceutical and medicine manufacturing
3341	Computer and peripheral equipment manufacturing
3342	Communications equipment manufacturing
3344	Semiconductor and other electronic component manufacturing
3345	Navigational, measuring, electro-medical, and control instruments manufacturing
3364	Aerospace product and parts manufacturing
5112	Software publishers
5161	Internet publishing and broadcasting
5179	Other telecommunications
5181	Internet service providers and Web search portals
5182	Data processing, hosting, and related services
5413	Architectural, engineering, and related services
5415	Computer systems design and related services
5417	Scientific research-and-development services
NAICS	**Level-II industries**
1131, 32	Forestry
2111	Oil and gas extraction
2211	Electric power generation, transmission, and distribution
3251	Basic chemical manufacturing
3252	Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing
3332	Industrial machinery manufacturing
3333	Commercial and service industry machinery manufacturing
3343	Audio and video equipment manufacturing
3346	Manufacturing and reproducing, magnetic and optical media
4234	Professional and commercial equipment and supplies, merchant wholesalers
5416	Management, scientific, and technical consulting services
...	Federal Government, excluding Postal Service
NAICS	**Level-III industries**
3241	Petroleum and coal products manufacturing
3253	Pesticide, fertilizer, and other agricultural chemical manufacturing
3255	Paint, coating, and adhesive manufacturing
3259	Other chemical product and preparation manufacturing
3336	Engine, turbine, and power transmission equipment manufacturing
3339	Other general-purpose machinery manufacturing
3353	Electrical equipment manufacturing
3369	Other transportation equipment manufacturing
4861	Pipeline transportation of crude oil
4862	Pipeline transportation of natural gas
4869	Other pipeline transportation
5171	Wired telecommunications carriers
5172	Wireless telecommunications carriers (except satellite)
5173	Telecommunications resellers
5174	Satellite telecommunications
5211	Monetary authorities, central bank

Source: Hecker 2005

Table B3: Silicon Valley High-Tech Industries

NAICS	Industry
3341	Computer and peripheral equipment manufacturing
5415	Computer systems design and related services
3344	Semiconductor and electronic component manufacturing
*	Internet, telecommunications, and data processing
5112	Software publishers
5417	Scientific research and development services
3345	Electronic instrument manufacturing
5413	Architecture and engineering services
3342	Communications equipment manufacturing
3254	Pharmaceutical and medicine manufacturing
3364	Aerospace product and parts manufacturing

***Includes* 516, 5173, and 5175 from 2002 NAICS and 51913 from 2007 NAICS

Source: Luo and Mann 2011

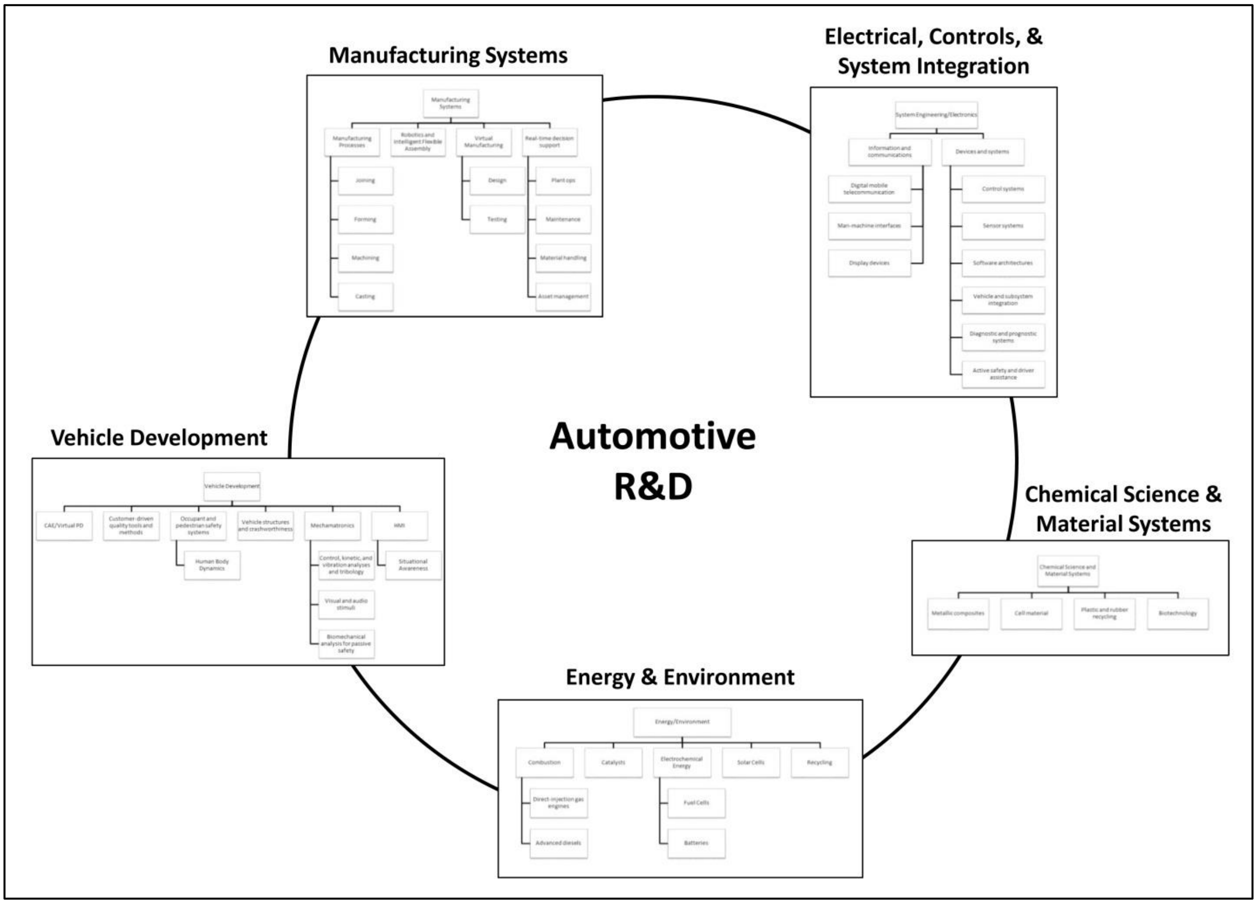
Table B4: Tech America High-Tech Industries

NAICS	High-Tech Manufacturing
Computer & Peripheral Equipment	
334111	Electronic Computers
334112	Computer Storage Devices
334113	Computer Terminals
334119	Other Computer Peripheral Equipment
Communications Equipment	
334210	Telephone Apparatus
334220	Radio & TV Broadcasting & Wireless Communications Equipment
334290	Other Communications Equipment
335921	Fiber Optic Cables
Consumer Electronics	
334310	Audio & Video Equipment
Electronic Components	
334411	Electron Tubes
334412	Bare Printed Circuit Boards
334414	Electronic Capacitors
334415	Electronic Resistors
334416	Electronic Coils, Transformers, & other Inductors
334417	Electronic Connectors
334418	Printed Circuit Assembly
334419	Other Electronic Components
335911	Storage Batteries
335999	Other Miscellaneous Electrical Equipment and Components
Semiconductors	
334413	Semiconductor & Related Devices
333295	Semiconductor Machinery
Space and Defense Systems	
334511	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical Systems and Instruments
336414	Guided Missile and Space Vehicles
336415	Guided Missile and Space Vehicles Propulsion Units and Parts
336419	Other Guided Missile, Space Vehicle Parts, and Auxiliary Equipment
Measuring & Control Instruments	
334512	Automatic Environmental Controls
334513	Industrial Process Control Instruments
334514	Totalizing Fluid Meter & Counting Devices
334515	Electricity Measuring & Testing Equipment
334516	Analytical Laboratory Instruments
334519	Other Measuring & Controlling Instruments
Electro-medical Equipment	
334510	Electro-medical & Electrotherapeutic Apparatus
334517	Irradiation Apparatus
Photonics	
333314	Optical Instrument & Lens
333315	Photographic & Photocopying Equipment
NAICS	**Communications Services**
Telecommunications and Internet Services	
517110	Wired Telecommunications Carriers
517210	Wireless Telecommunications Carriers (except Satellite)
517410	Satellite Telecommunications
517911	Telecommunications Resellers
517919	All Other Telecommunications
518210	Data Processing, Hosting, & Related Services
519130	Internet Publishing and Broadcasting and Web Search Portals
NAICS	**Software Services**
Software Publishers	
511210	Software Publishers
Computer Systems Design & Related Services	
541511	Custom Computer Programming
541512	Computer Systems Design
541513	Computer Facilities Management
541519	Other Computer Related Services
NAICS	**Engineering And Tech Services**
Engineering Services	
541330	Engineering Services
R&D & Testing Labs	
541380	Testing Laboratories
541711	Research & Development in Biotechnology
541712	Research & Development in the Physical, Engineering, & Life Sciences
Computer Training	
611420	Computer Training

Source: Tech America 2012

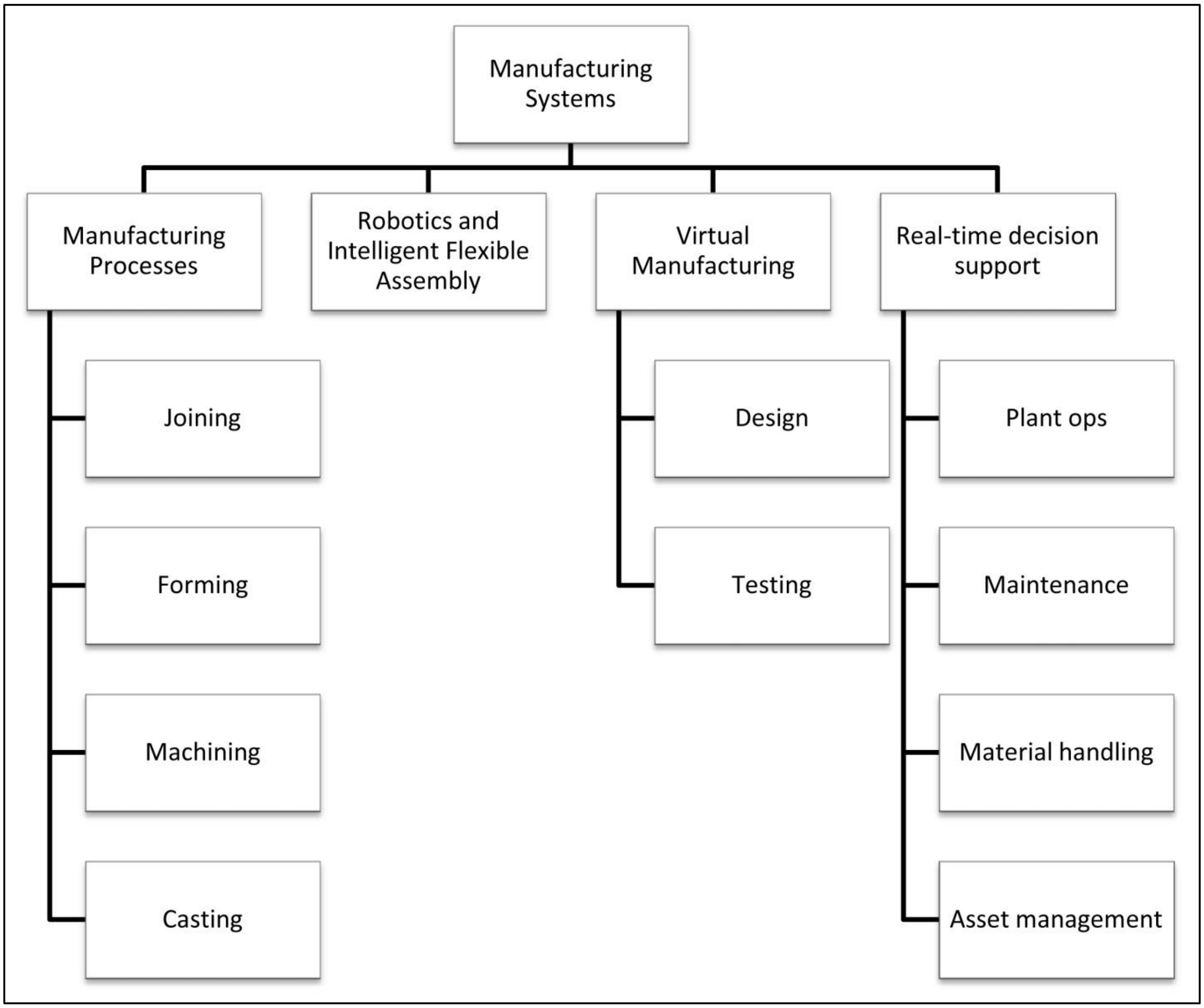
APPENDIX C: R&D STRUCTURE OF A TYPICAL LARGE AUTOMAKER

Figure C1: Typical Large Automaker R&D Structure: Overview of R&D Divisions



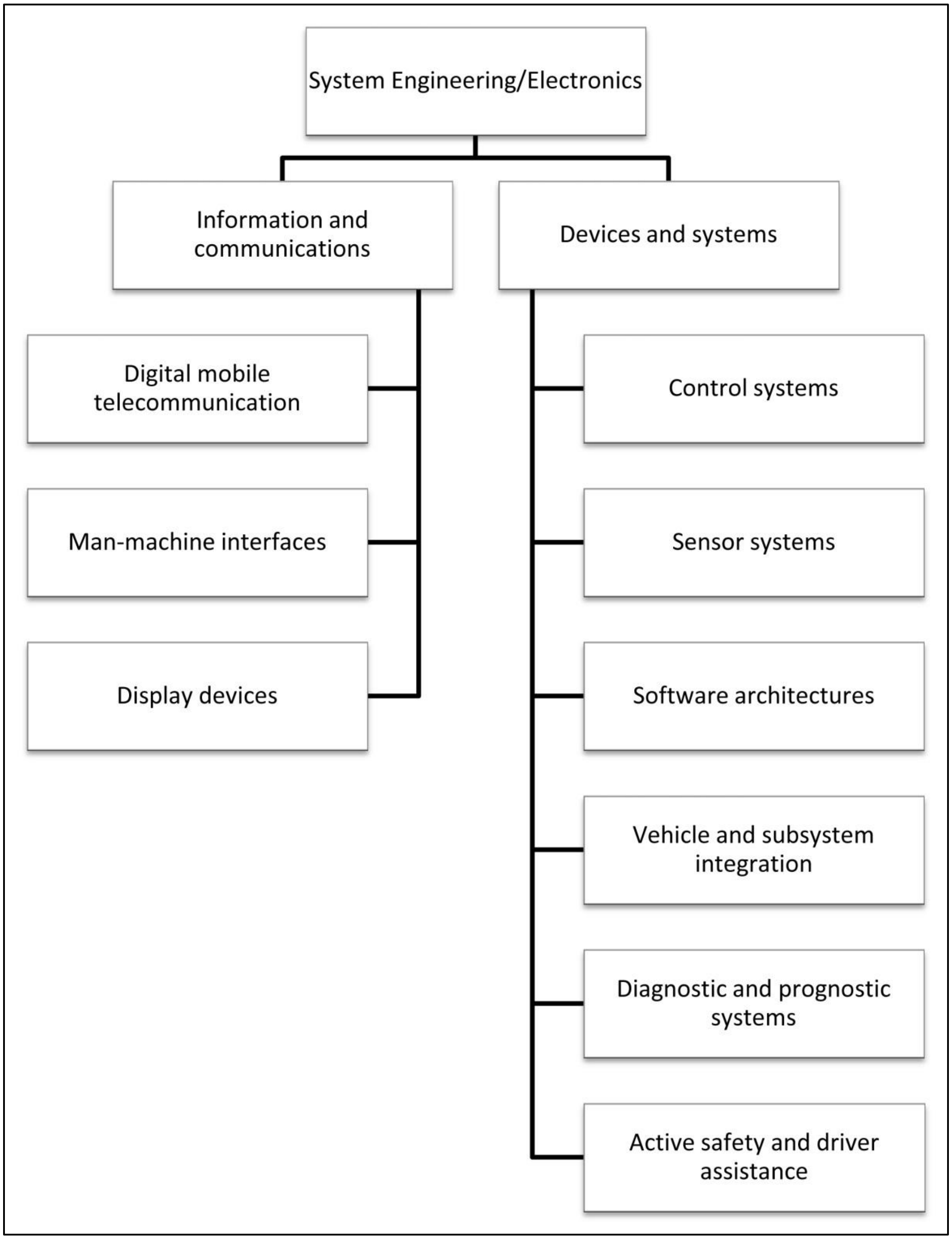
Source: Center for Automotive Research 2011

Figure C2: Typical Large Automaker R&D Structure: Manufacturing Systems



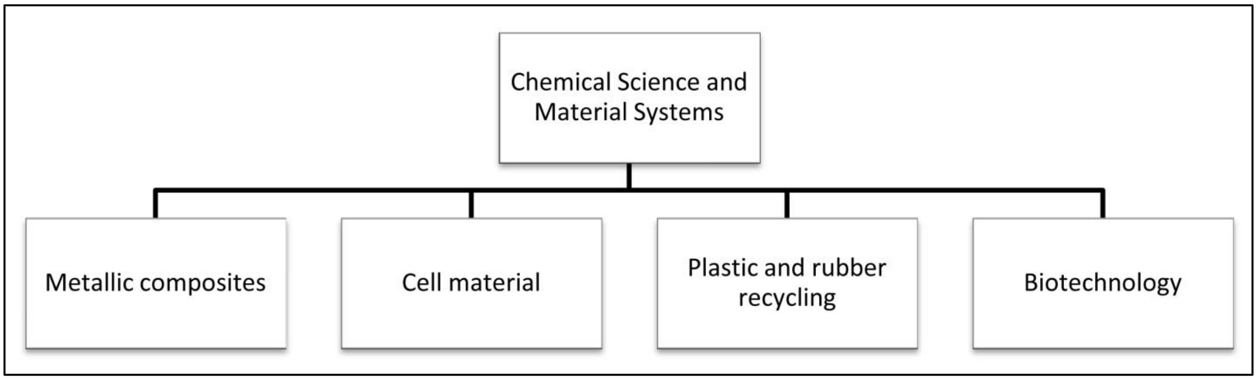
Source: Center for Automotive Research 2011

Figure C3: Typical Large Automaker R&D Structure: Electrical, Controls, and System Integration



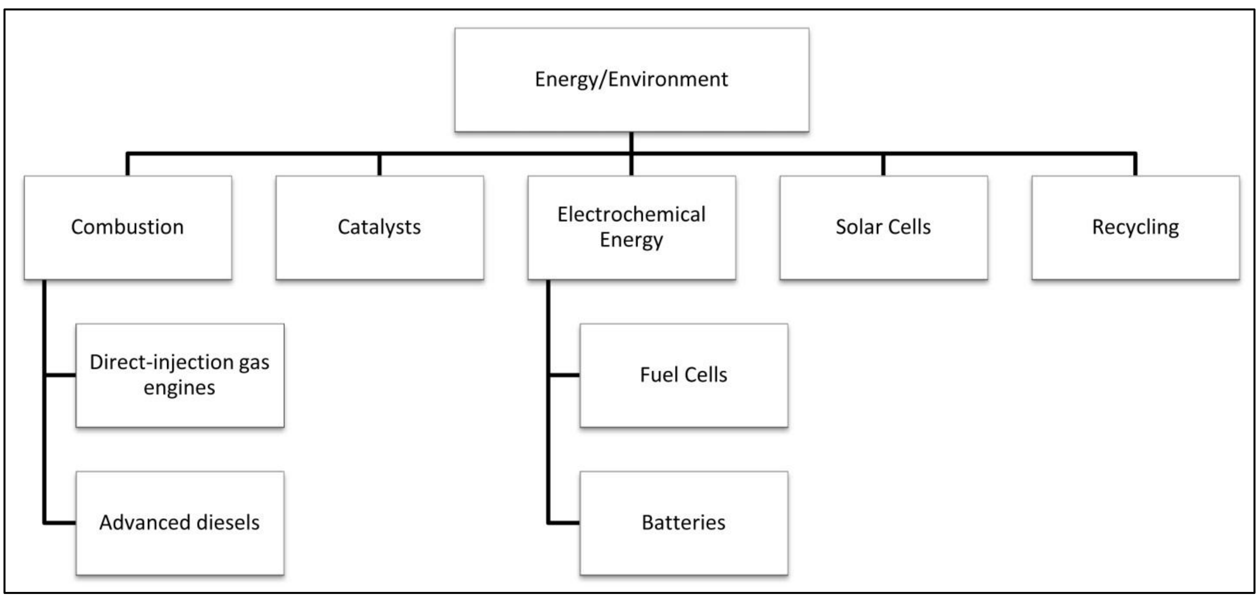
Source: Center for Automotive Research 2011

Figure C4: Typical Large Automaker R&D Structure: Chemical Science and Material Systems



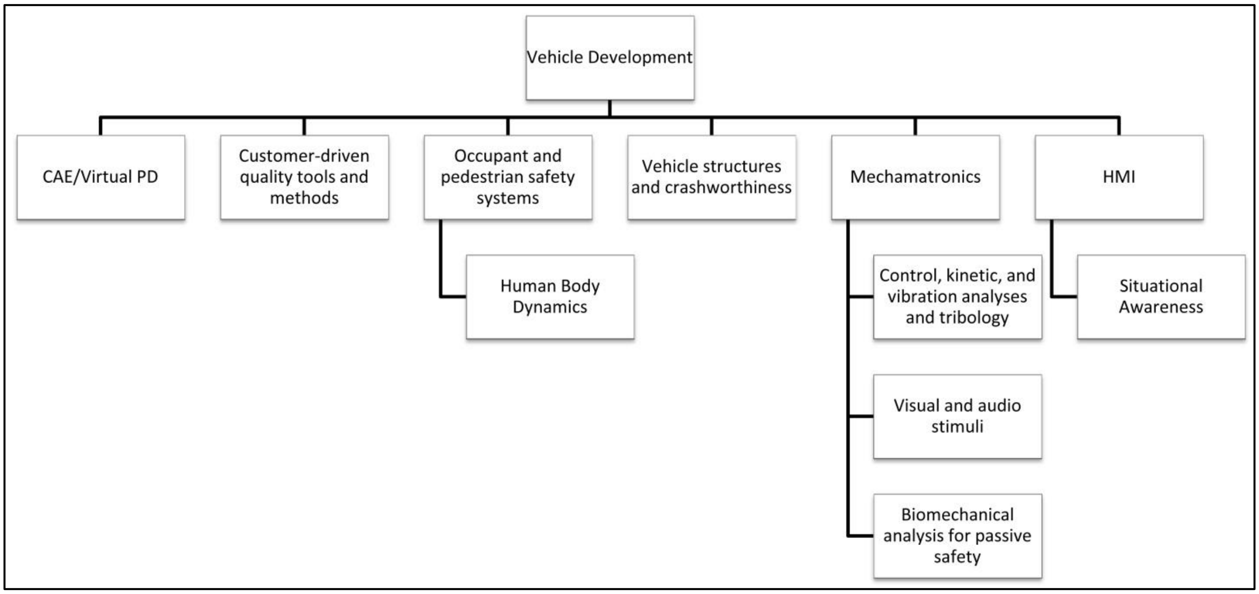
Source: Center for Automotive Research, 2011

Figure C5: Typical Large Automaker R&D Structure: Energy and Environment



Source: Center for Automotive Research 2011

Figure C6: Typical Large Automaker R&D Structure: Vehicle Development

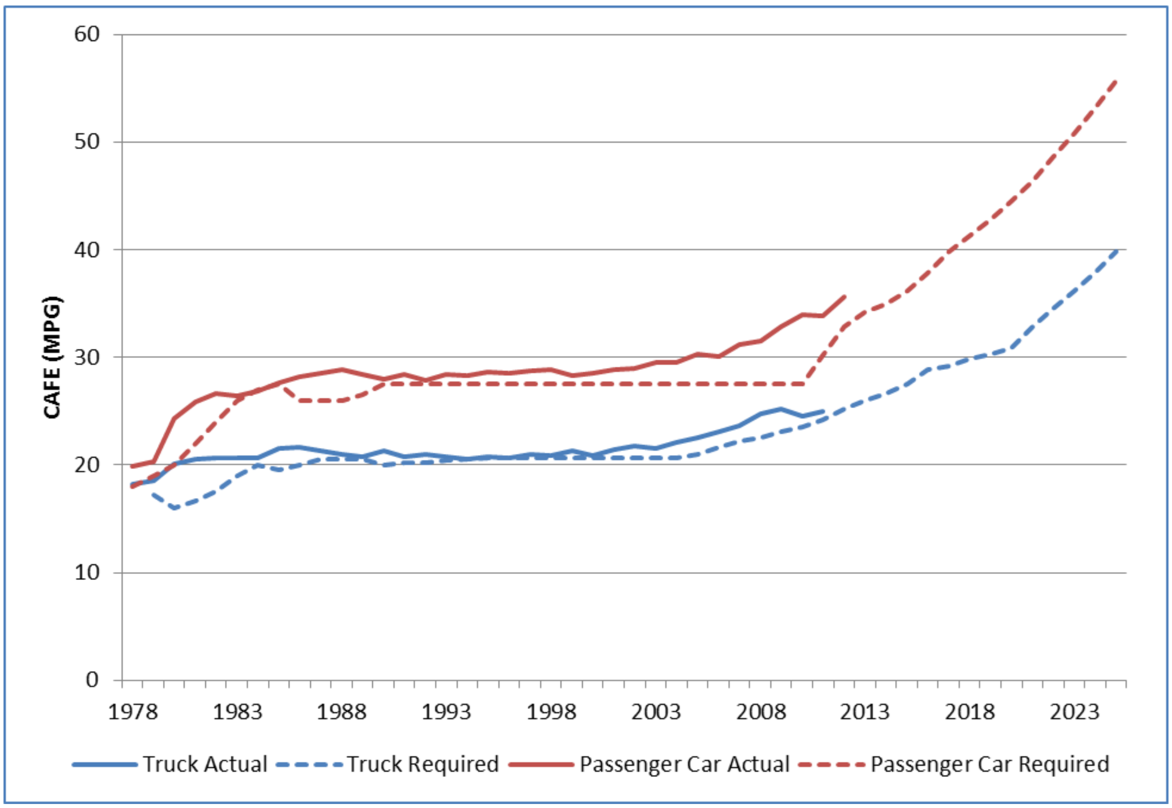


Source: Center for Automotive Research 2011

APPENDIX D: GREENHOUSE GAS AND FUEL ECONOMY REGULATION

Recent changes to federal automotive greenhouse gas (GHG) and fuel economy legislation are a significant challenge to industry. Corporate Average Fuel Economy (CAFE) was first enacted by Congress in 1975 as a policy to increase fuel economy of passenger cars and light duty trucks. By 2016, the combined required CAFE for light duty truck fleets and passenger car fleets will be 35.5 miles per gallon (MPG), approximately double the initial 1970's requirement of 18 MPG for passenger cars only. By 2025, regulations are in place to increase the stringency of CAFE/GHG regulations even further to an estimate 54.5 MPG. The increase in CAFE has already had an impact on the fuel economy of vehicles. For the first time, the combined fleet wide CAFE for passenger cars and light duty trucks exceeds 30 MPG (see below).

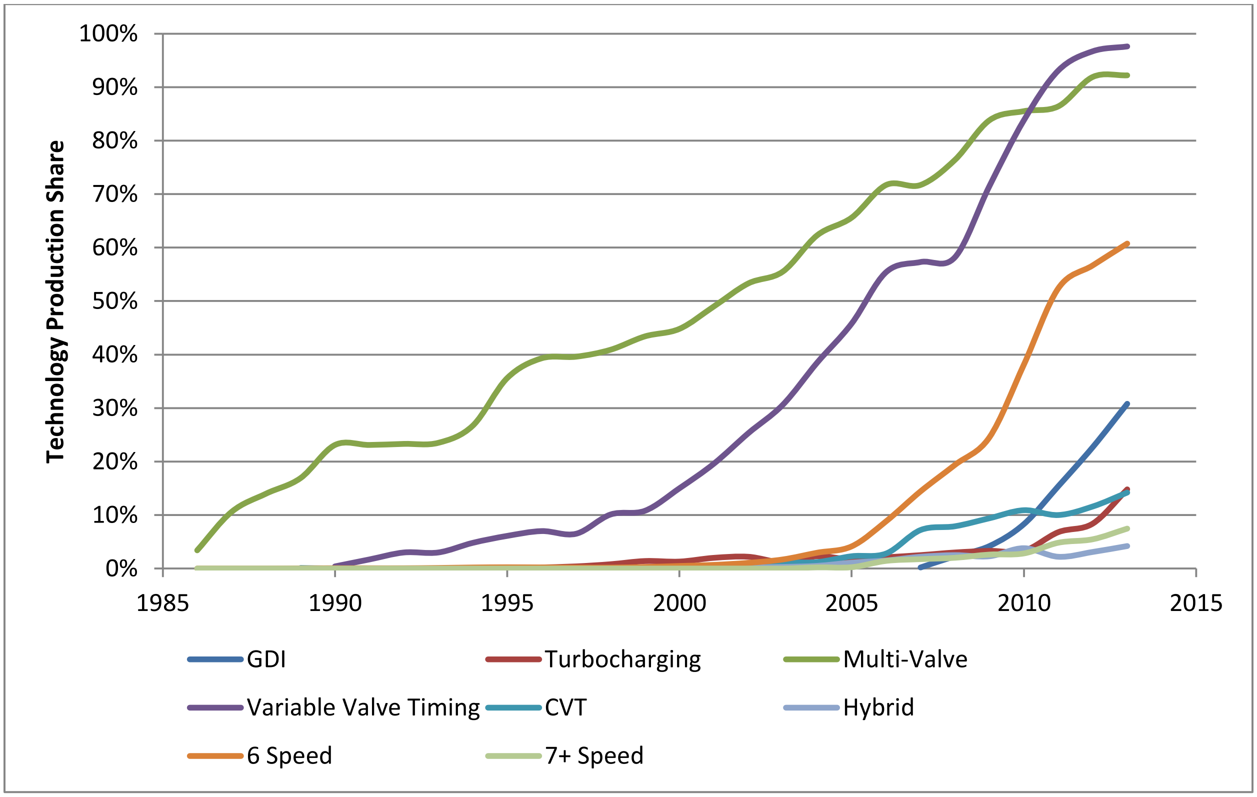
Figure **D1: Fleet Wide Corporate Average Fuel Economy**



Source: NHTSA 2012b

There have been significant technology advancements as a result of meeting the fuel efficiency demands of consumers and regulations. Advances with variable valve timing, turbocharging, multivalve engines, gasoline direct injection, higher gear transmissions, hybrid vehicles, and diesel vehicles have already shown increase market share in the market place. The industry is continuing to meet the requirements of regulators while also providing technologies that consumers want (see below).

Figure D2: Production Share of Fuel Efficient Technologies



Source: EPA

Proposed regulations from California's Advanced Clean Cars program demand new research to achieve zero-emission technologies through full battery electric cars, newly emerging plug-in hybrid electric vehicles or hydrogen fuel cell cars. The regulations, when finalized, are likely to be adopted by more than a dozen other states. The State of California estimates there could be more than 200,000 zero emission vehicles (battery electric or fuel cell electric) on the road in California by 2025.