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The URC's Contributions to Automotive Innovation

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Michigan is the birthplace of the modern automotive industry, where the automobile was catapulted from a novel product to an everyday necessity. Since the beginning of the auto industry, intense competition, increasing consumer demands, and governmental regulations have created challenges for the auto industry. Automakers are responding to these challenges by innovating—improving their products and operations.

Michigan has been home to much of this innovation.This record of innovation has been assisted by the clustering of the original equipment manufacturers, their suppliers, and first-class universities, which include the University Research Corridor (URC) institutions of Michigan State University (MSU), the University of Michigan (U-M), and Wayne State University (WSU).

The focus of this report is auto innovation and the contributions the URC universities are making to new auto technologies and manufacturing processes. We find that the URC universities contribute to innovation in two important ways:

- **By educating more than 3,600 graduates annually who are ready for technical careers in the auto industry.**
  We estimate that the URC universities grant more than 1,100 degrees annually in the areas of mechanical, industrial, and manufacturing engineering. The URC universities grant another 2,500 degrees annually to students in disciplines like computer science, math, and physical sciences where students are prepared for a number of careers in the auto industry. Almost 13,000 URC graduates from all disciplines currently work at the Big Three (Ford, GM, and Chrysler) companies. During the last five years, URC engineering graduates have been hired by 84 companies in Michigan that engage in automotive R&D.

- **By performing research in auto-related areas totaling more than $300 million in the past five years. More than a quarter of this funding is by private industry, which is nine times more than the average share of industry support for R&D at the URC universities.**
  The URC universities perform basic and applied research that benefit the auto industry in two important ways. First, the URC universities perform basic research that raises the standard level of knowledge in the entire industry, allowing innovation to happen faster. Second, the URC universities work with specific companies and government sponsors to solve problems and assist in product development. Between FY 2007 and 2011, the URC universities spent $300 million on more than 1,400 auto projects. Nearly two-thirds of this research was funded by federal and state governmental agencies. Private industry provided 28% of auto research funding, which is *nine times more* than the average share of industry support for all R&D at these universities.

The research and development performed at the URC universities has allowed innovation to occur in areas such as improved vehicle quality and safety, reduced fossil fuel use, and improved engine performance and efficiency. Specific examples include: the 2mm project involving U-M and WSU, which limited and controlled the gaps between auto components; connected vehicle research at U-M and WSU that promises improved vehicle safety by allowing vehicles to “talk” to infrastructure and one another; and biofuels research being done by MSU on new types of feedstocks that can be grown more economically to lower fuel costs and improve fuel efficiency.

I. Introduction and Main Findings

REPORT PURPOSE

Michigan is the birthplace of the modern automotive industry, where the automobile was catapulted from a novel product to an everyday necessity. From the beginning, intense competition, increasing consumer demands, and governmental safety and environmental regulations constantly posed new challenges. The way that automakers respond to these challenges is through innovation—improving their designs, manufacturing processes, logistics, or other business practices.

Michigan has been home to much of this innovation. One key reason is the clustering of original equipment manufacturers (OEMs) and their suppliers in the state. The second reason is the presence of world-class research universities in the area, which have created and sustained a pool of talent and know-how that has attracted both domestic and international companies to locate their research and development (R&D) centers in the state. This is evidenced by the more than 300 OEMs and suppliers that have R&D tech centers in Michigan.[1]

The University Research Corridor (URC) universities of Michigan State University (MSU), University of Michigan (U-M), and Wayne State University (WSU) have played an important role in fostering innovation in the auto industry. The purpose of this report is to describe how the URC universities contribute to auto innovation, since it is through new technologies and research that the industry moves forward. Specifically, in this report we:

- Briefly discuss the scale, speed, and constant need for innovation in the automotive industry, and
- Describe how the URC universities contribute to Michigan auto companies' role in moving the industry forward.

OVERVIEW OF APPROACH

This report begins by identifying the past, current, and future challenges facing the automotive industry. We then discuss how the innovation process has allowed automakers to address these challenges, before describing how the URC universities' work fits into this process. The report concludes with specific data and concrete examples of how the URC universities have worked with automakers to innovate.

This report relies on data provided by the URC universities and a large number of interviews. We interviewed industry experts and researchers at the URC universities to learn how and why they work on advancing auto technology in partnership with both industry and government sponsors. All research funding data and alumni information are from the universities. We obtained information on degrees awarded by the universities from the Integrated Postsecondary Education Data System. See Appendix A for more details.

1. This is based on 2007 data provided by the Michigan Economic Development Corporation.

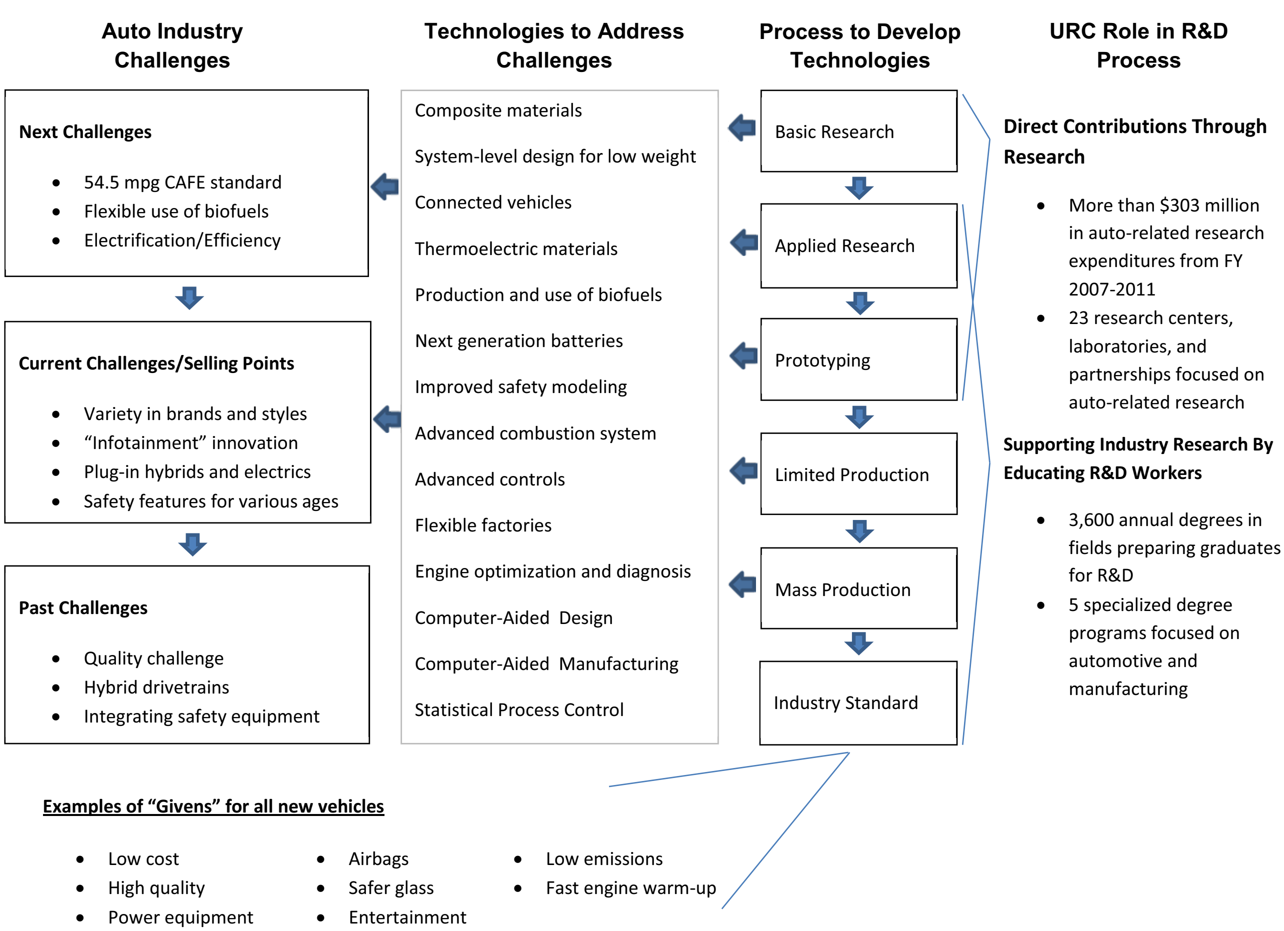
SUMMARY OF FINDINGS

Our analysis produced the following key findings.

1. *The auto industry faces ever-higher demands to improve performance and quality at a lower cost. The URC universities are involved in every step of the innovation process to meet these challenges.*

The process to develop new technologies involves the following steps: basic research, applied research, prototyping, limited production, and finally mass production. The URC universities are involved in every step of this process through their basic and applied research, and by providing talent for the industry. We show an overview of the process in Figure 1 below, and highlight the URC's role to the right of graphic. See "The Role of the URC in Auto Industry Innovation" on page 16.

FIGURE 1. University Role in Technology Development of the Auto Industry



Source: Anderson Economic Group, LLC

2. The URC universities supply talented workers to the auto industry, conferring more than 3,600 degrees annually in "auto-ready" disciplines.

The most significant contribution the URC universities make to the auto industry is providing a steady stream of educated workers. The education that students receive at URC schools in rigorous scientific methods and practical problem-solving skills enables them to join the global auto workforce upon graduation and contribute to the innovation process.

Each year, the URC universities award degrees to more than 3,600 graduates in auto-ready majors that prepare them well for technical careers in the auto industry, as shown below in Table 1. During the past five years, more than 19,000 students have graduated with degrees in engineering, computer sciences, math, and physical sciences. See "URC Degrees Conferred in Related Technical Areas" on page 20.

TABLE 1. Number of URC Auto-Ready Graduates, 2006-2010

	2006	2007	2008	2009	2010	Total
Undergraduate	2,345	2,261	2,411	2,467	2,303	11,787
Advanced	1,513	1,462	1,530	1,410	1,346	7,261
Total	**3,858**	**3,723**	**3,941**	**3,877**	**3,649**	**19,048**

Source: IPEDS, degree completions
Analysis: Anderson Economic Group, LLC

3. The URC universities play a direct role in auto industry innovation by spending more than $303 million R&D dollars on auto-related research and development over the past five years.

The URC universities perform basic and applied research that benefit the auto industry in two important ways. First, the URC universities perform basic research that raises the level of knowledge in the entire industry, allowing innovation to happen faster. Second, the URC universities work on applied research, often with specific companies and government sponsors, to solve problems and assist in product development.

During the past five years (FY 2007-11), the URC universities had more than 1,400 auto-related research projects, and spent more than $300 million on this research, or 4.6% of their R&D expenditures during this time period.[2] Last year alone (FY 2011), the URC universities spent more than $65 million on auto-related research.

2. This calculation is based on research awards data provided by the URC universities. We prorated the amount spent on each award evenly over the length of the project to determine an average research award amount for the three universities between FY 2007-11, which totaled $1.4 billion in 2011.

A full 64% of this research was done in engineering departments while another 29% was done in special automotive and transportation research centers, such as U-M's Transportation Research Institute (UMTRI), MSU's Composite Vehicle Research Center, and WSU's National Biofuels Energy Laboratory. Another 2.5% was done in medical and public health programs, while the remaining work was done in a variety of departments, including agricultural sciences. See "Auto-Related Research Funding Awards" on page 28.

4. Private industry funded 28% of all auto research at the URC universities in the past five years.

More so than in other fields, industry funds a significant amount of the auto research at the URC universities. During the past five years, private industry has provided $83 million to fund auto research at the URC universities, or 28% of all funding. This is nine times the average share of industry funding for all university R&D at these institutions.

While industry is an important contributor to research funding, the largest funder of research are federal and state governmental agencies. The URC received $198 million in funding during the past five years from governments, or 65% of all funding. Much of this funding came from federal sources, like the Department of Defense and the Environmental Protection Agency, bringing dollars that would not have otherwise come to the state. See "Auto-Related Research Funding Awards" on page 28.

5. URC researchers have helped automakers improve vehicle quality and safety, improve engine efficiency and performance, and reduce fossil fuel use through new auto approaches.

The industry faces challenges on many fronts, including: reducing fossil fuel use and improving quality, safety, and engine performance and efficiency. Figure 2 on page 5 shows examples of URC research projects contributing to each of these challenges.

FIGURE 2. URC Research Examples Addressing Challenges in New Auto

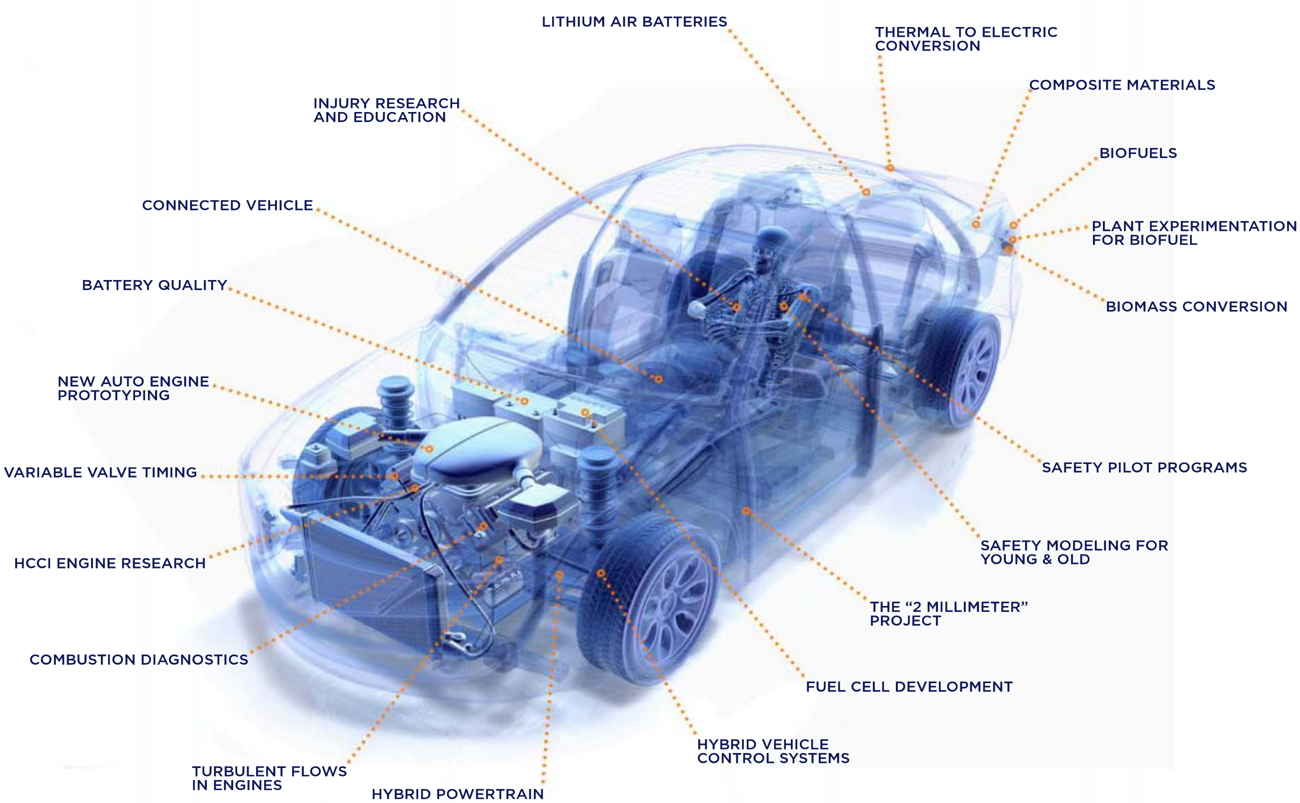


Image created by Michigan State University
Analysis: Anderson Economic Group, LLC of research examples provided by URC universities

Specific examples of URC contributions to innovation include:

- *The 2mm project housed at U-M with participation from WSU that improved the quality of domestic autos.*
  In the mid 1990's, a consortium of auto manufacturers, suppliers, and universities assembled to advance the industry's performance on product quality. The goal of this project was to limit the gaps between auto body components to a 2mm (six sigma) variation in order to limit leaks, wind noise, and squeaks and rattles in vehicles. At the time, only Japanese auto manufacturers consistently achieved the level of performance targeted by the project. The project used real-time data from production lines to diagnose and correct problems. As a result of this project, GM and Chrysler implemented new procedures for reducing variation.
- *Connected vehicle research that is currently being done at U-M and WSU to improve vehicle safety.*
  Vehicles that "talk" to one another and to infrastructure through wireless communications are a promising way to improve safety and mobility on the nation's roads. U-M's Transportation Research Institute (UMTRI) has won a $22 million contract from the U.S. Department of Transportation to conduct the first on-road test of the technology. The Safety Pilot Model Deployment will involve

monitoring 3,000 instrumented cars, trucks, and buses driving on the streets of Ann Arbor over a 12-month period. Results of this test will provide information on how this technology can be implemented going forward.

- *Engine research at MSU, U-M, and WSU that has improved performance and increased efficiency.*
  Research at U-M on variable valve timing, or improving the control of when air is allowed to move in and out of a piston, had a major impact on power output and the efficiency of engines, and is now used in nearly every gasoline engine in the world. Research is currently being done at MSU on new combustion systems of gasoline and diesel engines, as well as unique engines and controls for hybrids that would allow for greater fuel efficiency, while reducing vehicle weight and emissions. WSU researchers are working on advanced diagnostics of the combustion of fuels to improve engine efficiency and reduce emissions.
- *Research into the next generation of biofuels at MSU and WSU that will lower fossil fuel use and help autos meet new regulations.*
  MSU is working with local industry and the state government to explore the possibilities of using pennycress (a common weed) as a biofuel feedstock. This weed naturally absorbs heavy metals from the soil as it grows and could be grown in Detroit to clean-up contaminated sites while providing a less expensive feedstock. WSU researchers working through the National Biofuels Energy Laboratory developed a standard for diesel fuel that allowed for the coordination of investment and product development actions of fuel refiners and engine manufacturers. Research at the laboratory has also led to the development of catalysts that can expand the set of substances that can be converted into biofuels economically.

See "URC Research Addressing Auto Industry Challenges" on page 38 for more examples.

ABOUT ANDERSON ECONOMIC GROUP

Anderson Economic Group, LLC (AEG) offers research and consulting services in economics, public policy, finance, and market analysis. AEG completes two annual studies for the University Research Corridor. The first report is an assessment of the URC's economic impact on the state of Michigan, which is released every fall. The second report is an assessment of how the URC universities contribute to an important economic sector in the state, which is released every spring. For past reports and more information on AEG, see Appendix B and visit www.AndersonEconomicGroup.com.

II. Auto Industry Overview and Challenges

This section provides important background information that sets the stage for understanding the URC universities' role in auto industry innovation. It first provides a brief history of the automotive industry, focusing on Michigan's auto industry against a background of global trends in sales, employment, and innovation. It then provides an overview of the current state of the auto industry in Michigan, including locations of key facilities in the state, employment in the state, and the market share of the Michigan-based auto companies. The section closes with a discussion of the challenges—past, current, and future—that drive innovation in the auto industry.

BRIEF HISTORY OF THE AUTO INDUSTRY

The automobile is a global product, with inventors from across the globe providing incremental breakthroughs to produce the vehicles we know today. Michigan, however, is where the automobile was catapulted from a novel product to an everyday necessity for the masses.

The first automobile is widely credited to Nicolas-Joseph Cugnot who, in 1770, demonstrated a steam-driven tractor for moving artillery. Improvements to the design were slow (as was the vehicle, with a top speed of 2.25 miles per hour). The 1850s and 1860s brought about the development of 4-cycle internal combustion engines, with Italian and German inventors taking the lead. Soon after, in 1885, German inventor Karl Benz became the first to start production of a car with an internal combustion engine. The first automobile manufacturing company in the United States was formed by Charles and Frank Duryea in 1893 in Springfield, Massachusetts.

Origins of the Big Three

In 1897, Mr. Ransom Eli Olds, an inventor and businessman, founded Olds Motor Works in Lansing, Michigan. In 1901, the company became the first to mass-produce an automobile, producing 425 Curved Dash Oldsmobile's within the first year. They produced 2,500 in 1902 and built 19,000 in total before the model was retired in 1907. The Curved Dash was a two-passenger runabout, priced at $650, featuring two forward gears, one reverse, and a top speed of 20 miles per hour. It was built in an Olds Motor Works plant in Detroit. The business was acquired by Detroit-based General Motors in 1908, and the vehicles became known as Oldsmobiles. Ransom Olds continued independently in the industry by forming the REO Motor Car Company in Lansing.

Henry Ford was not far behind Ransom Olds. In 1901 he started the Henry Ford Company, and by 1903 he had launched the Ford Motor Company in Detroit.[3] It

3. Mr. Ford would leave the Henry Ford Company in 1902, taking with him the rights to his name. Upon Mr. Ford leaving, the company was reorganized as the Cadillac Motor Company.

was not, however, until 1913 that Ford introduced the first moving assembly line, and began to truly mass produce the Model T. This milestone not only made it much quicker and less costly to produce a car, but also reshaped the nation's labor market as worker pay was increased, profit sharing introduced, the work week was reduced, and demand for employees increased to meet growing demand for the vehicles. These labor market changes at Ford were often benchmarks against which workers at other firms measured their progress.

In 1908, William "Billy" Durant, a horse-drawn carriage manufacturer from Flint, Michigan and grandson of Michigan Governor Henry H. Crapo, incorporated General Motors Corporation. At the time Mr. Durant was the president of the Buick Motor Company (formed in 1903 in Detroit, then moved to Flint in the same year). Durant, a natural salesman, quickly turned Buick into the nation's largest car maker. The profits were soon used to acquire Oldsmobile and Pontiac (Oakland, MI at the time) in 1908, Cadillac in 1909, and Chevrolet in 1917.[4]

Chrysler took root in 1904 when the Maxwell-Briscoe Company of Tarrytown, New York was formed. The company was moved to Detroit in 1913, but by 1920 was deeply in debt. Walter P. Chrysler, a former GM executive and president of Buick, took over the struggling firm and in 1925 reincorporated as the Chrysler Corporation. It acquired Dodge in 1927, and by 1928 Chrysler surpassed Ford in terms of annual sales.

The Motor City is Born

The period from 1900 to 1930 was the automobile industry's equivalent of the more recent dotcom bubble. More than 1,000 different automakers, from ABC to Zip, opened and shut during this period.[5] Many could not survive the economic conditions of the Great Depression combined with the steep competitive advantage that Detroit's General Motors, Ford, and Chrysler possessed when it came to financial strength, innovation, and sales network.

The Big Three also began to benefit from a rapidly growing network of supplier businesses that also opened in and around Detroit. This growth attracted new workers to the industry, many moving to Michigan from across the country. Soon there was no turning back: The Motor City was born and growing too rapidly for any other location to stake a claim as home to the automotive industry.

4. Mr. Durant was ousted from GM in 1910, and founded Chevrolet in 1913. He began acquiring shares of GM, and by 1917 was back at the helm of the world's largest auto maker.
5. See Farber and Associates, LLC, "American Automobiles-Manufacturers," available at: http://www.american-automobiles.com/

An Era of Innovation

The years leading up to World War II saw significant expansion in the American auto industry, thanks in large part to the Federal Aid Road Act of 1916 and the Federal Aid Highway Act of 1921. These helped bring tens of thousands of miles of paved road to the United States that, combined with low cost vehicles from Ford and others, helped create a huge demand for automobiles. In response to this demand, automakers were quick to innovate and offer new designs, improved quality, and more amenities. The cars available in 1941 were markedly improved compared to those available 30 years earlier.

Production Hits the Breaks, Innovation Goes On

Automobile production in the United States came to a sudden end in 1942 as the country was drawn into World War II. All factories were quickly converted to support the war effort, with Detroit's automakers turning to tank, aircraft, and other military vehicles manufacturing and in the process becoming "the arsenal of democracy." This, however, did not at all slow the advancement of the automotive industry. Detroit automakers emerged after World War II with new technologies and improved designs for vehicles with more powerful engines, better fuel economy, and improved durability. These innovations, along with the country's prosperity after the war, fueled continued demand for new vehicles, many with radical styling and more horsepower compared to pre-war vehicles.

Regulation to the Forefront

As more cars took to the roads, and cars became faster and larger, safety and environmental issues emerged, as did state and federal regulations to address the concerns. States began mandating seat belts in 1962, and new federal standards required automakers to install front shoulder belts and head restraints, energy-absorbing steering columns, and padded interiors by 1968. The Clean Air Act of 1963 and the Vehicle Air Pollution and Control Act of 1965 required manufacturers to reduce emissions, phase out leaded gasoline, and introduce catalytic convertors.

Gasoline prices had dramatic affects on the industry in 1973, and again in 1979. The U.S. government introduced the Corporate Average Fuel Economy (CAFE) requirements in 1975. This required automakers to meet new fuel efficiency standards by 1978. For the first time Detroit automakers struggled to innovate at a rate fast enough to hold off emerging foreign competitors. The smaller vehicles built by the Big Three to meet fuel efficiency requirements did not meet customer expectations. At the same time Japanese car companies began opening plants in the United States, and producing models like the Corolla and Civic that exceeded the quality offered by domestic manufacturers. By 1980 foreign automakers accounted for more than 20 percent of domestic sales for the first time.

Calm Before the Storm

The 1980s brought the return of lower gasoline costs, and better times for Detroit's automakers. Chrysler introduced the first minivan in 1984 and soon after acquired the Jeep brand. This unofficially marked the beginning of the SUV era that would propel American auto companies into the 21st century.

The SUV emerged in part due to the interaction between consumer preferences and specific features of CAFE requirements, which required lower average efficiency for light trucks than cars. Automakers found that they could satisfy the demand for the "roomy vehicles" market segment by producing SUVs (which classified as light trucks) instead of large cars. SUVs were also more profitable than cars, and soon were core to domestic automakers' business plans. Foreign manufacturers, meanwhile, continued improving the vehicles and establishing new plants in southern U.S. states where labor costs were low relative to unionized factories in northern states. The costs and benefits of these differing paths became apparent in the late 1990s and through the first decade of the 2000s as foreign vehicle sales grew, increasing gas prices stalled the SUV segment domestic manufacturers strongly relied on, and employment costs for both current workers and retirees put increasing cost pressure on the Big Three.

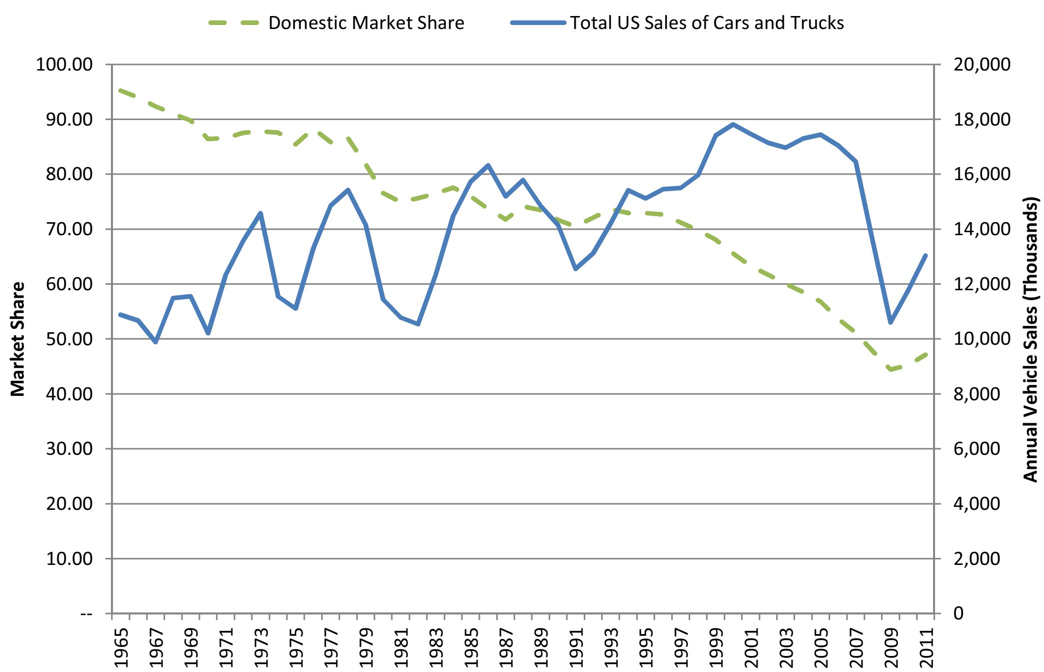
CURRENT STATE OF MICHIGAN'S AUTO INDUSTRY

Big Three Market Share. Michigan's automobile manufacturers remain among the world's leaders, with General Motors holding the top-spot in terms of global sales for 2011. General Motors also has the largest share of the U.S. vehicle market (19.2 percent in 2011), with Ford (16.5 percent) in second and Chrysler (10.5 percent) in fourth. Toyota, with 12.6 percent, was third.

The domestic auto industry has faced an increasingly competitive market during the past several decades. Michigan's Big Three have traditionally held the majority of the market share in the United States and as recently as 1997 they combined for over 70 percent of U.S. sales. However, domestic market share has fallen steadily since the late 1970's, as shown in Figure 3 on page 11, even as total vehicle sales has remained within a range of 10 million to 18 million per year.

In each year prior to 2008, domestic vehicles accounted for more than 50 percent of vehicle sales in the U.S. It was not until 2006 that a major import brand (Toyota) surpassed the smallest of the Big Three (Chrysler) in terms of market share. The Big Three hit bottom in 2009, when General Motors and Chrysler went through bankruptcy. That year, only 44.4 percent of domestic sales went to General Motors, Chrysler, or Ford. Only two years later, Chrysler and General Motors had reorganized, Ford had grown stronger, and the Big Three combined for 47.15 percent of the domestic market in 2011.[6]

FIGURE 3. U.S. Auto Market, Total Sales and Domestic Market Share, 1961-2010



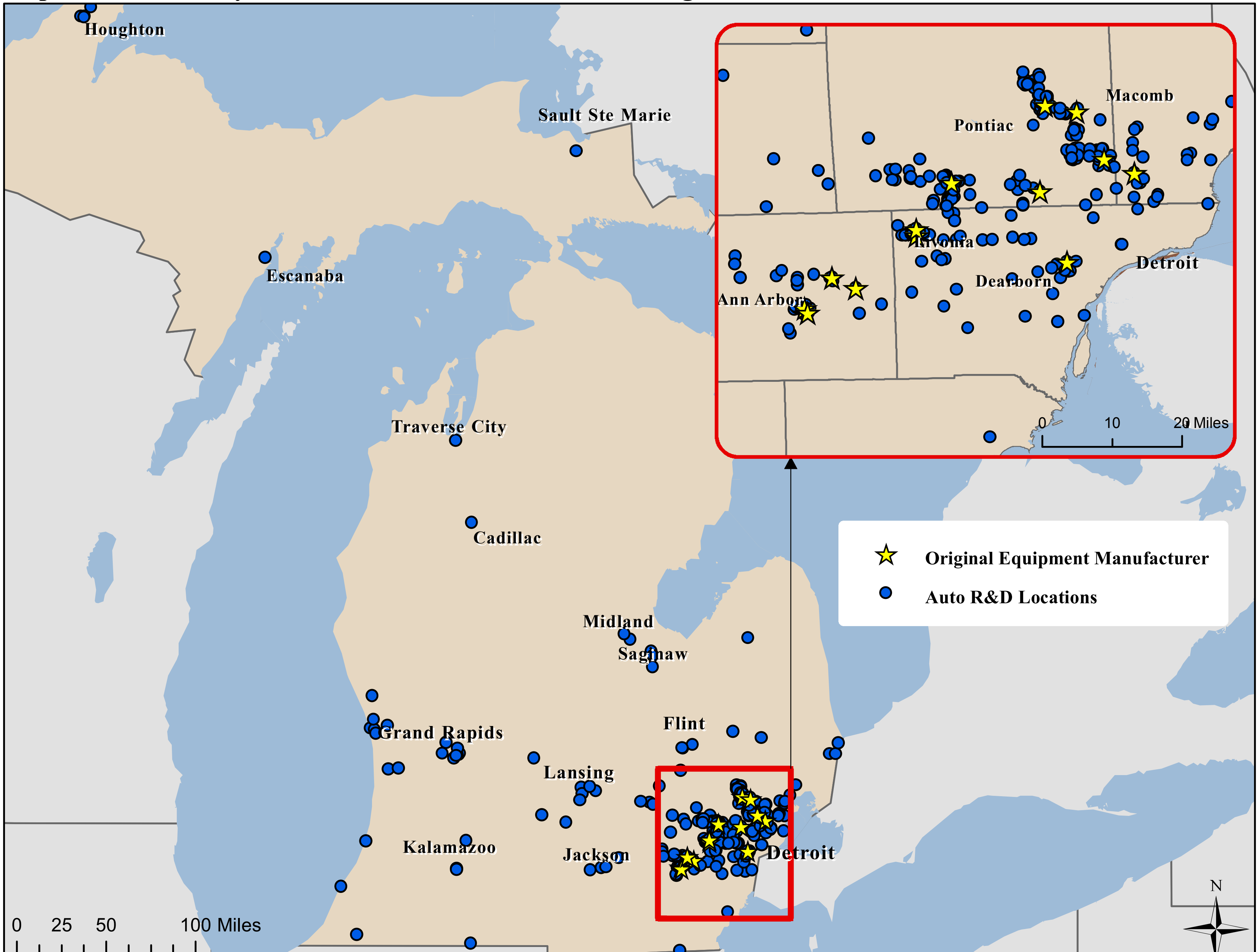
Source: WardsAuto
Analysis: Anderson Economic Group, LLC

Automotive Manufacturing in Michigan. The automotive industry today remains a large part of Michigan economy, and Michigan remains a large part of the United States' automotive industry. In February 2012, there were 136,400 jobs in Michigan's automotive manufacturing sector.[7] This accounted for more than 28 percent of the 484,500 jobs within the sector nationally.[8]

Michigan's world-class research universities have created and sustained a pool of talent where both domestic and international companies choose to locate their research and development centers. Today, almost all of the original equipment manufacturers and numerous suppliers have R&D tech centers located in the state. As shown in Map 1 on page 12, there are more than 300 total OEMs and suppliers with R&D centers in Michigan.

6. Market share data from WardsAuto.com. Domestic market share calculated to include Ford, General Motors, and Chrysler, as well as domestic truck makers International and PACCAR. For years prior to 1988, the domestics also included American Motors. Diamond REO, White, and Studebaker were also included in earlier years.
7. Sector defined to include motor vehicle manufacturing (NAICS 3361) and motor vehicle parts manufacturing (NAICS 3363).
8. U.S. Bureau of Labor Statistics, Current Employment Statistics, February 2012.

Map 1. Auto Industry R&D Locations with Southeast Michigan Detail



*Note: Many companies have mulitple tech centers in the state. We show one location per company on this map due to data we were provided.

Data: Michigan Economic Development Corporation 2007; URC Universities; ESRI Inc.
Analysis: Anderson Economic Group, LLC 2012

CHALLENGES DRIVING INNOVATION

The auto industry faces constant pressure to improve and innovate. Rising incomes, changes in family needs, innovations by competitors, and government safety and environmental regulations (often based on innovations by one company in the industry) constantly pose new challenges. Each challenge is addressed in different ways by different companies in the industry, resulting in constantly moving targets for features, prices, and market share. Innovative auto companies can rarely rest on their laurels for long as, over time, the solutions to each challenge become assimilated into customers' expectations of what counts as a "standard" car.

This can be illustrated by using examples of past, present, and future ("next") challenges facing the industry.

Past Challenges. Most of the differences between the "standard" car of the 1960's and the car of today represent past challenges met by the industry. A small selection of countless possible examples includes:

- Standard power windows and air conditioning brought by a combination of rising consumer incomes and industry innovation to lower costs.
- Standard safety features such as air bags and energy-absorbing "crumple zones" included in vehicle designs.
- Dramatically improved vehicle quality and reliability. The quality control techniques used by Japanese manufacturers in the 1980's and early 1990's to improve quality and market share are now widely used. Now all cars sold in the USA have quality ratings that beat the "world-class" quality of the top performers of the 1990's. Furthermore, customers now routinely buy used cars with 60,000 to 100,000 miles, which was near the end of life for cars of the 1960's.
- Over a decade of mass-produced hybrid vehicle drivetrains.
- Plants that are much more automated and are able to produce different types of models as required.

Current Challenges. The industry is moving rapidly on other fronts with a set of current widespread innovations, including:

- Dramatically increased variety in body styles (such as "crossover" vehicles) and customizations.
- Increased competition and branding based on the "infotainment" features of the vehicles, with internet connections and rich media environments increasingly available as affordable options.
- The development of improved battery performance, allowing mass production of "plug-in" hybrid vehicles (which use both the electric grid and the gas pump for energy) and electric vehicles.
- Improved safety performance that addresses an aging and heavier population, and the desire for improved safety for children.

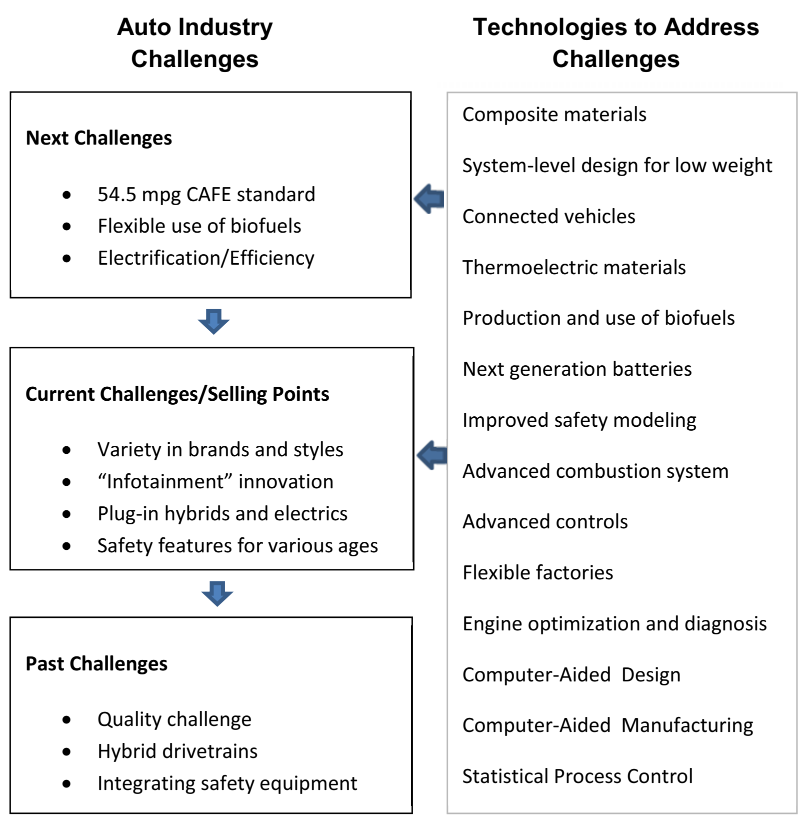
Next Challenges. As the industry grapples with the current challenges on its plate, there are additional challenges further on the horizon, including:

- Continued dramatic fuel efficiency gains to meet the future CAFE standard requirement of 54.5 mpg.
- The infrastructure required to support new types of electric vehicles and new types of fuels.
- The potential quantum leap in safety and convenience that may be possible from increased vehicle-to-vehicle communication, vehicle-to-infrastructure communication, and even cars that "drive themselves."
- Maintaining or improving performance with a wide variety of possible mixes of fuels, including blends of petroleum and bio-based fuels, to increase the flexibility of vehicles in the face of unpredictable oil markets.

ADDRESSING CHALLENGES USING INNOVATION

Auto companies face challenges by innovating—improving their designs, manufacturing processes, logistics, or other business practices to satisfy customer demands and regulatory requirements. Often, the introduction (and continued development and improvement) of a new technology is what makes the difference in moving a "current challenge" to the past. It is this innovation process, the "new auto" techniques and technologies developed by the industry to address these challenges, that is the focus of this report. (See Figure 4 below.)

FIGURE 4. Auto Industry Challenges and Technologies



Source: Anderson Economic Group, LLC

Not all challenges are "solved," because there are always opportunities for improvement. For example, consumers see more engine power and efficiency for the same price as an improvement. Nevertheless, such challenges can vary in intensity over time. While quality improvements have always been rewarded, the intensity of the need for this was ratcheted up during the 1990's when Japanese manufacturers began to increase their market share largely on the strength of a their reputation for quality (as discussed in "Brief History of the Auto Industry" on page 7).

III. The Role of the URC in Auto Industry Innovation

This section lays out the broad picture of how the URC universities contribute to continued innovation in the auto industry. It begins with a brief discussion of the idea-to-product cycle and where in it universities generally help industries of the size and maturity of the current global auto industry. It then uses this framework to show how the URC universities contribute to the "new auto" innovation process by providing research and education of students to help the industry address the specific challenges facing the industry today (as discussed in "Challenges Driving Innovation" on page 13 in the previous section).

The final three sections of the report provide specific information about the size and scope of URC universities' education and research operations that contribute to auto industry innovation.

HOW ARE NEW AUTOMOTIVE TECHNOLOGIES DEVELOPED?

The auto industry is a mature industry. Unlike internet companies, for example, which can go from idea to industry leader in a few years, the auto industry is long past the days of Ransom E. Olds and Henry Ford founding multiple companies in rapid succession and offering game-changing new products (as discussed in "Brief History of the Auto Industry" on page 7). For mature industries, technological advances often require significant research and development activity and a skilled workforce to implement them.

This makes the continuous innovation shown by the industry all the more impressive. Most parts of a car, from the engine to the glass to the tires, are so advanced that most innovation takes the persistent effort of experienced engineers and scientists. The process can take years to go from a basic idea to a working prototype to something that can be produced at the massive scale required by most auto companies' operations. We describe the major components of the process below, and show further how the universities contribute at each step in Figure 5 on page 18.

Basic Research. Basic research is not specifically focused on creating new technologies that have an immediate impact in the marketplace. Rather, it is a first step intended to improve researchers' broad understanding of a problem, a material, or a process. For example, basic research may involve simply gaining an understanding of how a new material behaves in different environments, such as at different temperatures, when exposed to different mechanical forces, or when an electric current is applied to it.

Applied Research. Applied research can begin when the fundamental science questions have been answered and the problem is fairly well-understood. The process of innovation may often begin here as innovation relies on improvement to an existing technology. For example, producing lighter-weight, high-strength steel may involve intensive development and experimentation, but does not rely on fundamentally new materials.

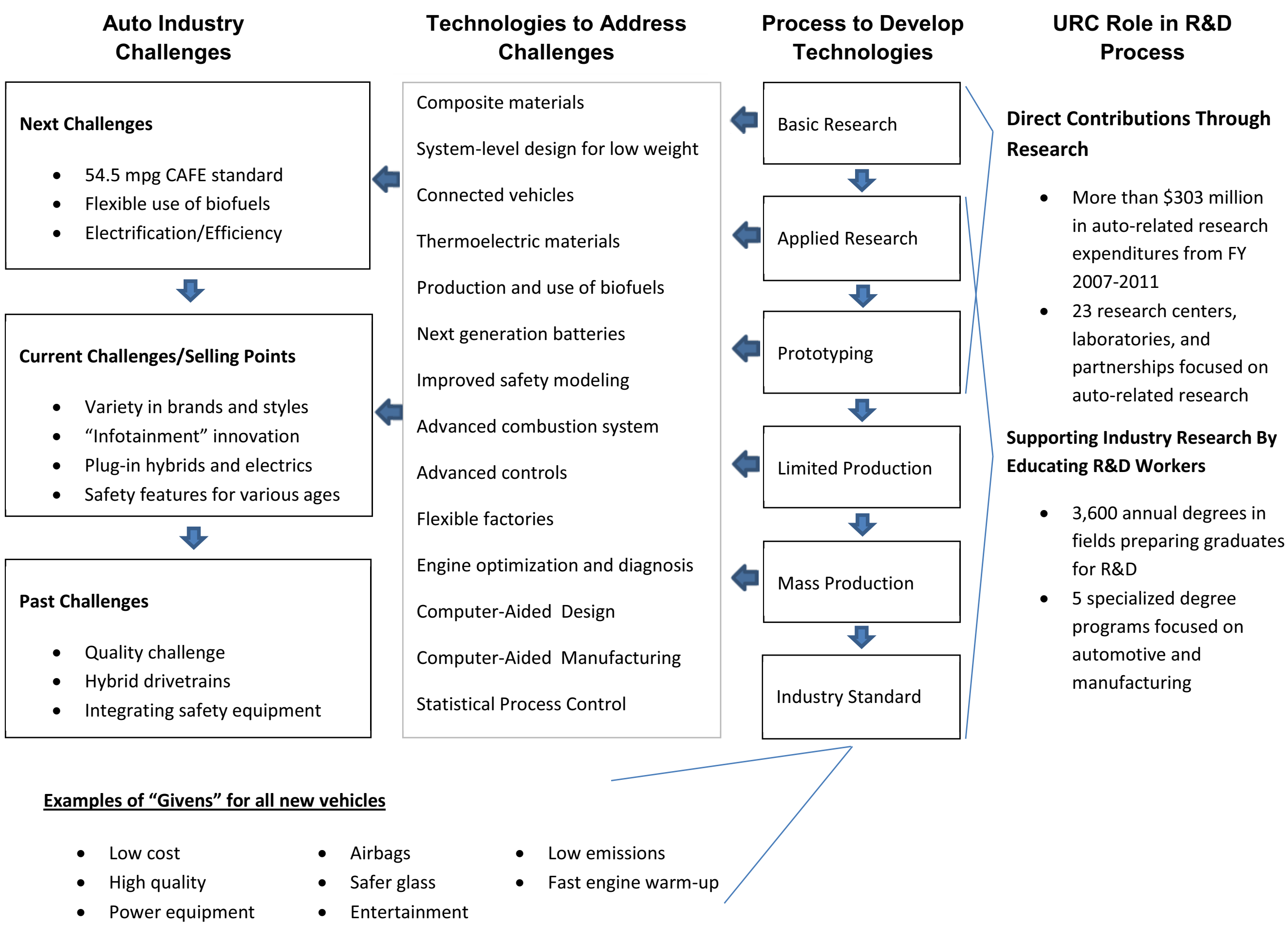
Prototyping and Limited Production. Once a process is understood, the next step may be to produce examples of a redesigned component for testing and optimization. The component may even see use in limited-production vehicles where cost pressures are lower, as is the case with carbon-fiber composite body components used in high-end performance vehicles to reduce weight and maintain or improve strength.

Mass Production. An innovation faces serious limits in use until the industry can implement it on a mass scale economically. Moving from a component that works to a mass-produced component often requires considerable development effort.

WHERE DO UNIVERSITIES FIT IN?

The auto companies themselves usually have the most to gain by developing and implementing new technologies themselves, in-house, in a proprietary setting. The closer a technology is to mass production, the more advantageous it is for the company to have exclusive possession of an innovation—until the rest of the industry catches up. Nevertheless, universities play a direct role in using research to drive innovation at the earlier stages, especially when the federal government, or other research funder, makes development of certain technologies a priority (e.g. recent extensive government funding of battery technology for vehicle applications).

FIGURE 5. University Role in Technology Development of the Auto Industry



Source: Anderson Economic Group, LLC

The URC universities contribute along the entire spectrum of research from basic to development in different ways. More applied and development research is done mostly by companies (with occasional injections of applied research projects where necessary) to meet near-term challenges, with engineers employed in-house leading the way. These engineers, of course, are educated at universities. The URC universities' substantial contribution to providing the state's auto industry with the talent to innovate is described in the next section, "The URC Supplies Talent to the Auto Industry" on page 20.

Basic research is more likely to be done directly at universities rather than at the companies. The URC universities perform a large amount of applied research as well, but often work with industry and government sponsors to do this. The large amount of research (in dollar terms) on auto-related topics performed by the URC universities and their specialized research centers is described in "URC Auto-Related Research Centers and Funding Awards" on page 28. The final section of the report, "URC Research Addressing Auto Industry Challenges" on page 38, provides specific examples of past and current research projects at the URC universities that are helping the auto industry meet the challenges they face through technological development.

IV. The URC Supplies Talent to the Auto Industry

"The Role of the URC in Auto Industry Innovation" on page 16 discussed, in "big picture" terms, the role of the URC universities in acting as an important resource for talent and basic and applied research for the auto industry as it faces challenges requiring innovation. This section provides more detail about the educational contributions made by the URC universities. We first highlight the number of graduates in auto-technology-related fields and then describe the specific auto-related special programs and courses that the schools have developed.

URC DEGREES CONFERRED IN RELATED TECHNICAL AREAS

The most significant contribution the URC universities make to the auto industry is providing a steady stream of educated workers. The education that students receive at URC schools in rigorous scientific methods and practical problem-solving skills enables them to join the global auto workforce upon graduation and contribute to the innovation process.

AEG has identified degrees that prepare graduates for technical careers in the auto industry. We call these "Auto Ready" degrees and they include bachelors and masters in engineering, computer sciences, math, and physical sciences; and PhDs in math and engineering.[9] URC graduates with Auto Ready degrees are likely to become employed in the automotive industry either by the original equipment manufacturers, automotive suppliers, or heavy-duty vehicle manufacturers.

We quantify the number of URC Auto Ready degrees conferred at URC universities below. For our complete methodology see "Auto Related Degrees Conferred" in Appendix A on page A-1.

In 2010, the URC universities produced 3,649 undergraduate and advanced Auto Ready degrees. As shown in Table 2 on page 21, just over one third of Auto Ready degrees completed are advanced degrees (masters, PhDs, and advanced certificates). In the past five years (2006-2010), the URC conferred nearly 12,000 undergraduate and more than 7,000 advanced Auto Ready degrees. During that time, the URC prepared 19,048 graduates for potential employment in R&D within the automotive industry.

9. We also include math and engineering certificates above bachelor level for their particular relevance in the auto industry, although they total fewer than ten per year. See "Auto Related Degrees Conferred" in Appendix A on page A-1 for additional descriptions of degree type inclusions.

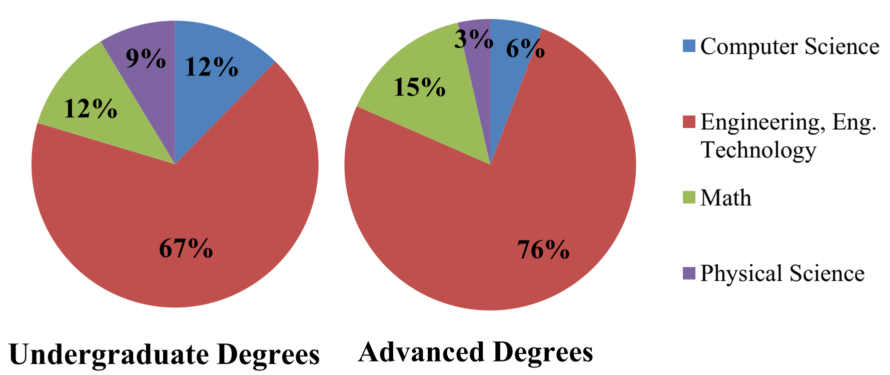
TABLE 2. Number of URC Auto Ready Graduates, 2006-2010

	2006	2007	2008	2009	2010	Total
Undergraduate	2,345	2,261	2,411	2,467	2,303	11,787
Advanced	1,513	1,462	1,530	1,410	1,346	7,261
Total	**3,858**	**3,723**	**3,941**	**3,877**	**3,649**	**19,048**

Source: IPEDS, degree completions
Analysis: Anderson Economic Group, LLC

Auto Ready degrees are in areas of engineering, computer sciences, math, and physical sciences. As shown below in Figure 6, in 2010 in particular, two thirds (67%) of Auto Ready undergraduate degrees and three quarters (76%) of Auto Ready advanced degrees were in engineering and engineering technology. The academic area that makes up the next largest share of Auto Ready degrees is math (12% undergraduate and 15% advanced).

FIGURE 6. URC Auto Ready Graduates by Type of Degree, 2010



See "Auto Related Degrees Conferred" in Appendix A for list of degrees included.
Source: IPEDS, degree completions
Analysis: Anderson Economic Group, LLC

AUTO-CENTERED ACADEMIC PROGRAMS AT URC UNIVERSITIES

While most degrees that prepare graduates for jobs in auto industry innovation are in the broad engineering and physical sciences, the URC universities also offer specialized graduate degrees specifically focused on advanced automotive and manufacturing topics. These degrees are typically designed for professionals working in industry to gain additional technical skills in a specific area from a specialized engineering curriculum, often combined with a leadership- and teamwork-building learning structure and the skills and contacts offered by classes in business schools.

Such specialized auto- and manufacturing-centered degrees and classes are offered by both U-M and WSU, whose proximity to the existing workplaces of many auto industry engineers and scientists makes them a convenient choice for evening work on a degree or certificate, or work on a full-time degree that may not require relocation during or after the program.

University of Michigan Programs

The University of Michigan also has four specialized "Master of Engineering" degrees for students seeking a more industry-oriented education than a Master of Science in Engineering. These include:

- **Master of Engineering in Manufacturing.** This professional degree includes 70% engineering courses and 30% courses in the Stephen M. Ross School of Business at the University of Michigan. The degree prepares engineers to improve manufacturing systems' efficiency and quality.
- **Master of Engineering in Automotive Engineering.** This professional degree is designed for engineers seeking to improve their technical skills with an interdisciplinary education in engineering and business. The degree program includes a Capstone Project sponsored by an industry partner that gives the student important contact with and feedback from a business engaged in engineering research and development.
- **Master of Engineering in Global Automotive and Manufacturing Engineering.** This degree is geared toward professionals seeking to build knowledge and capability in important areas of auto industry global operations. It provides a global context for both product development and manufacturing operations in the auto industry, giving perspective across the entire product creation process.
- **Master of Engineering in Energy System Engineering.** This professional degree is focused specifically on the science, engineering, economic, and management knowledge required to create innovative energy systems. Among the concentration areas available are "transportation power" systems, relevant to the auto industry.

At Michigan Engineering, students and faculty are encouraged to work across engineering disciplines and build competencies beyond engineering. Michigan Engineering students design, build prototypes and carry out testing in multidisciplinary teams. The International Center of Automotive Medicine is an example of medical and engineering students learning from one other to prevent injuries and improve outcomes of automotive accidents, which we describe in "Auto Research Institutions at the URC" on page 30.

Wayne State University Programs

Electric-Drive Vehicle Engineering (EVE) Program. Wayne State University has a multidisciplinary master's degree program in electric-drive vehicle engineering that was developed with a 2009 Department of Energy grant for curriculum development and research. This degree program includes courses in the fundamental science and engineering concepts needed to design these systems, simulation tools that designers can use to optimize designs, as well as entrepreneurship and management skills. The program also includes a Capstone Design project in which students work in a team environment to design a simulated electric-drive vehicle with complete analysis of engineering, environmental, safety, and economic impacts of the designs.

Center for Automotive Research (CAR) Courses. Wayne State's Center for Automotive Research coordinates instructional programs for graduate students across several engineering disciplines. Five courses focus on engine combustion and/or emissions. Many students who take these classes are engineers in the auto industry looking to continue their education in automotive areas that are particularly challenging. Students are also exposed to ongoing research at CAR, which we describe in "Auto Research Institutions at the URC" on page 36.

Michigan State University Engineering Program

MSU's engineering curriculum follows a science and mathematical focused path that prepares its students for many job opportunities in the automotive industry. Graduate students specialize in many areas that are focused on auto industry challenges, while the undergraduate population gains all the tools needed to work with their fellow engineers to build a greater automobile industry. The Manufacturing Engineering Concentration, along with concentrations in Biomechanical, Engineering Mechanics, and Global Engineering, allow undergraduates to obtain further knowledge in manufacturing processes, product development, machine tool laboratory, advanced computer aided design, advanced composite materials processing, and advanced composite materials. Students also study calculus-based economics principles and introductions to micro and macro economics.

URC ALUMNI IN THE AUTO INDUSTRY

URC alumni directly contribute to automotive innovation through their expertise in clean combustion, emission controls, hybrid powertrains, lightweight high performance materials, vehicle safety, and more. Below we highlight several alumni who have offered their perspective on how time at their alma mater has contributed to their career in the auto industry.

Kristen Zimmerman. As a mechanical engineer with a pilot's license, Kristin Zimmerman originally had her sights set on working in the space program. Instead, she has worked abroad and in the U.S. on energy and environmental policy issues engaging both internal and external stakeholders to craft General Motors' energy strategy. As manager of advanced technology infrastructure at General Motors, Zimmerman helped craft the automotive company's energy strategy and further contributed her expertise as a member of the team that created the hybrid electric Chevy Volt.

Zimmerman credits her Michigan State education—a bachelor's degree in mechanical engineering and masters and doctoral degrees in engineering mechanics—and her ability to problem solve in any situation with giving her the flexibility to pursue new areas in her field and beyond.

Robert D. Brown. Recently appointed vice president of Sustainability, Environment & Safety at Ford Motor Company, Brown assumes direct responsibility for the company's environmental and safety strategy, policy, and performance.

Since joining Ford as a compliance engineer in 1979, Brown has held a variety of leadership positions including serving as Ford's environmental regulatory manager working in Washington D.C., assistant director in the company's Automotive Safety Office, and director of Vehicle Environmental Engineering.

Brown holds a masters in industrial engineering from WSU and a bachelors degree in electrical engineering from U-M Dearborn.

Julius Reeves. Reeves currently works in Infotainment and OnStar Engineering and GM Global Vehicle Engineering at General Motors Corporation. Since joining GM in 1986 he has held numerous positions with GM including engineer, engineering group manager in their Powertrain Division, strategic business planner, and program manager. Reeves also spearheads numerous WSU/GM collaborations, including numerous student-related initiatives and scholarships.

He graduated from Wayne State with a bachelor's in industrial engineering. He also holds a master's degree in industrial engineering from University of Michigan - Dearborn, and an MBA from University of Chicago.

Susan Pacheco. Currently, the Director of Product and Business Strategy at Ford Motor Company, Pacheco utilizes her mechanical engineering degree from Michigan State University and her MBA from the University of Detroit Mercy. Since joining Ford in 1984 upon graduation from Michigan State University, Pacheco has dedicated her professional life to Ford Motor company, serving as Aerostar Vehicle line director, F-150/250 chief program engineer, vehicle director, Lincoln Mercury, and president of Ford Unlimited Enterprise. In her role as team leader for the technical and business program execution of the F-Series and Expedition vehicle lines, she led 350 people and was responsible for program budgets of approximately $700 million and yearly profit contributions of approximately $3 billion.

Charles (Chuck) Gulash. As a Senior Executive Engineer at Toyota Technical Center (TTC) in their North American R&D division, Gulash directs Toyota's Collaborative Safety Research Center, which we describe in "Auto Research Institutions at the URC" on page 35. He is also involved in advanced research as part of the Toyota Research Institute of North America.

Chuck joined TTC in 1996 as general manager of Vehicle Evaluation at the Arizona Proving Ground and has held a series of leadership roles in vehicle evaluation, performance development, materials development and advanced research. Prior to joining TTC, Chuck held various engineering and management positions at General Motors Corporation, where he was involved with vehicle safety, design engineering and total vehicle development.

Chuck earned a Bachelor of Science degree in Mechanical Engineering and a Masters degree in Business Administration from the University of Michigan. He maintains his connection with U-M by serving on the External Advisory Boards of the U-M Mechanical Engineering Department and Transportation Research Institute, as well as the Visiting Committee at the College of Engineering and Computer Science, U-M Dearborn.

Jon Lauckner. Jon Lauckner was named GM Vice President and Chief Technology Officer (CTO), effective April 1, 2012. In addition to his role as CTO, Jon remains President of GM Ventures and is also responsible for leading GM's Global Research and Development organization. Prior to becoming CTO, Lauckner was responsible for forming General Motors Ventures, LLC, a separate subsidiary started in July of 2010. As president, Jon leads a team that makes equity investments in startup companies that are developing next-generation automotive technology.

Lauckner joined General Motors in 1979 and held a number of positions in product engineering, powertrain engineering and product development, including international assignments in South America and Europe. Lauckner received a Bachelor of Science degree in mechanical engineering from the University of Michigan and then went on to earn a Master of Science degree in management from Stanford Business School and attended the GM-Harvard Senior Executive Program. While at U-M, Jon specialized in automotive-related topics, which gave him a solid foundation for his career in GM. One professor that was instrumental in cultivating his interest while a student was Dave Cole (professor of Mechanical Engineering at the time), who has continued to collaborate with Jon on various initiatives that involve the automotive industry.

Randy Stephens. A twenty-year veteran with Toyota Corporation, Stephens is now one of three North American Chief Engineers with the corporation working on the new Avalon sedan expected in two years. While commenting about the value of American engineers and the work that they do, he said, "Our autonomy has been increasing, in part because of the greater capability we have. I'm in my 19^{th} year at Toyota and I've definitely seen an exponential growth in responsibility for North American operations."

Stephens, a native of Grand Blanc, chose MSU after a campus visit and graduated with a degree in mechanical engineering. "MSU was a very welcoming place," Randy recalls. "It was a perfect preparation for work life," he says. "The courses were very challenging, but also a lot of fun. You come away with technical and social skills that help you in a professional setting. You get to work with a team and learn that collaboration is important in helping to bring about success in the real world."

Mark Chernoby. Head of product portfolio for Fiat/Chrysler and recently appointed Senior Vice President of Engineering at Chrysler Group LLC, Chernoby has responsibility for all systems and component engineering, vehicle line platform programs, international engineering, advance vehicle development and innovation, powertrain product engineering, product technical planning and regulatory affairs. He also oversees vehicle testing, validation and all product development processes in support of a world class product development factory.

Prior to his current role, Chernoby was Head of Vehicle Engineering where he was responsible for all vehicle line platform programs along with vehicle development analysis and validation. Since joining Chrysler Corporation in 1985 as a powertrain engineer, Chernoby has made use of his experience in focused component engineering, advanced vehicle programs and vehicle homologation for Chrysler, Jeep and Dodge products. He earned his bachelor's degree in mechanical engineering at MSU, and his master's in mechanical engineering and an MBA from U-M.

URC GRADUATES ENGAGING IN AUTOMOTIVE R&D

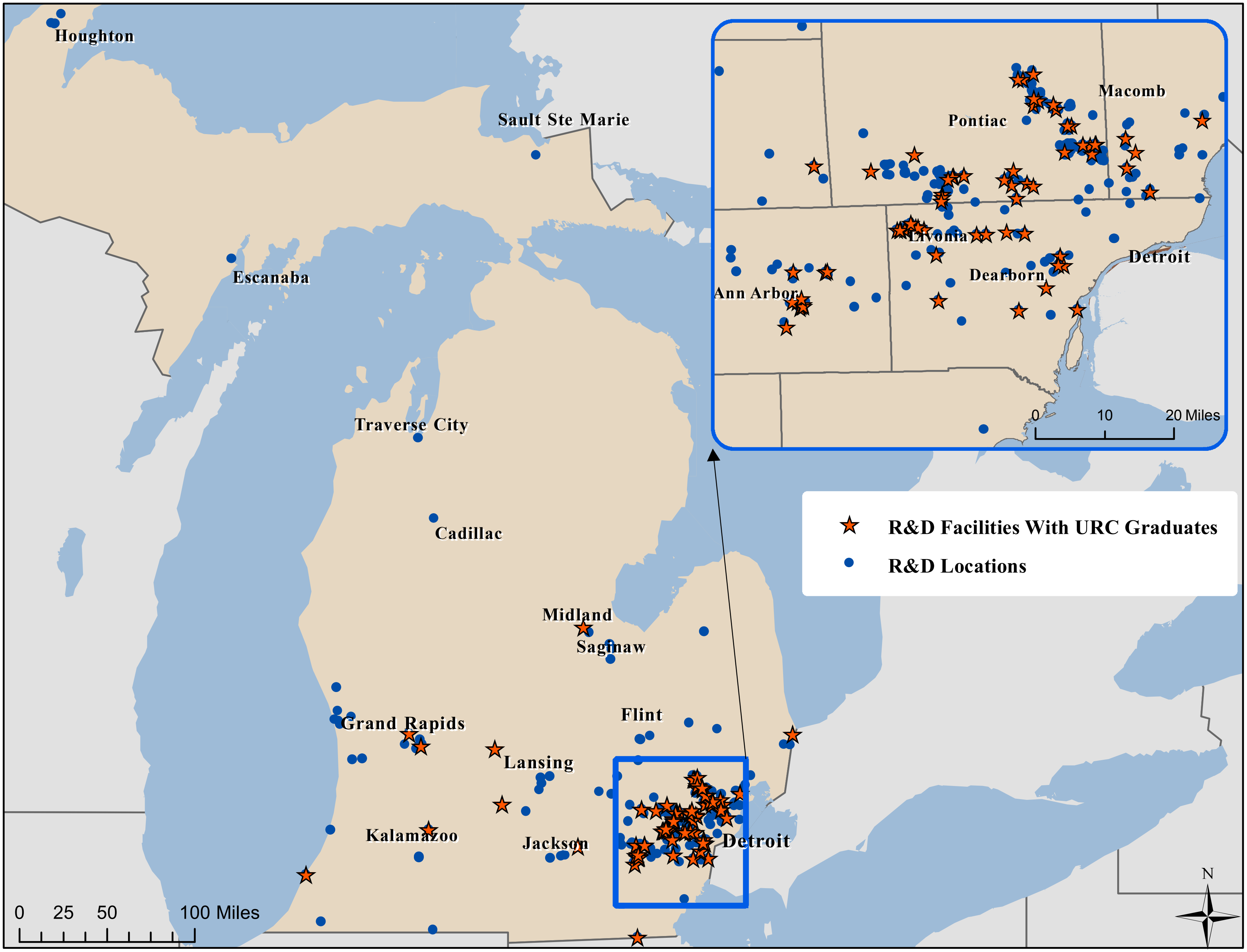
Michigan is home to a significant amount of automotive R&D. Map 1, "Auto Industry R&D Locations with Southeast Michigan Detail," on page 12 shows the prevalence of firms engaging in automotive research and development in Michigan. URC engineering alums work at many of these companies. We show the breadth and location of where URC engineering alums are employed in Map 2, "Auto Industry R&D Locations Where URC Engineering Graduates are Employed with Southeast Michigan Detail," on page 27.

Of the 372 R&D automotive firms we identified in Michigan, we know that at least 84 companies have hired an engineering graduate from a URC university in the past five years (2007 to 2011). The 84 companies is likely an underestimate of the true number of companies URC alumni work at since the data provided by the URC universities was not complete.[10] We specifically focused on where engineering alumni go to work in the automotive industry since the focus of this report is auto innovation.

URC graduates with degrees in fields other than engineering also work in the auto industry. Currently, almost 13,000 URC alums work at Chrysler, Ford, and GM in a variety of occupations.

10. See "Maps Displaying Auto R&D Facilities" in Appendix A on page A-1 for our complete methodology.

Map 2. Auto Industry R&D Locations Where URC Graduates are Employed with Southeast Michigan Detail



*Note: Many companies have mulitple tech centers in the state. We show one location per company on this map due to data we were provided.

Data: Michigan Economic Development Corporation 2007; URC Universities; ESRI Inc.
Analysis: Anderson Economic Group, LLC 2012

V. URC Auto-Related Research Centers and Funding Awards

“The Role of the URC in Auto Industry Innovation” on page 16 identified education and research as the two main ways in which the URC universities contribute to technological advancement in the auto industry. This section is the first of two that highlight the research contributions of the universities. Below we lay out the impressive volume and breadth of research awards won by the URC universities for auto-related research. We then identify the myriad research centers at the URC universities that conduct auto-related research, noting the research focus, size, and funding sources for each.

The next section, “URC Research Addressing Auto Industry Challenges” on page 38, provides specific examples of URC research projects (many conducted at the research centers identified below).

AUTO-RELATED RESEARCH FUNDING AWARDS

The URC universities perform basic and applied research that benefits the auto industry in two important ways. First, the URC universities perform basic research that benefits the entire industry, raising the level of know-how that allows innovation to happen faster. Second, the URC universities work with specific companies to solve existing problems and assist in product development.

Last fiscal year (FY 2011), we estimate that the URC universities spent $65.1 million on auto research. This is approximately 4.6% of all research awards.[11] Between fiscal years 2006 and 2011, the URC universities had more than 1,400 open research projects in auto-related areas. The universities spent (on a prorated basis) $303.1 million on auto research during this five year period.[12]

Most auto research occurs in engineering colleges at these universities. During the five year period we studied, 63.6% of the research was conducted in mechanical, chemical, computer science, and other engineering departments. Another 28.7% occurred in special automotive and transportation research centers. This includes University of Michigan’s Transportation Research Institute and Wayne State University’s Center for Automotive Research (discussed in the next section). Another 2.4% of the auto research was performed in medical

11. The URC universities provided a list of all open awards between 2006 and 2011. The average annual expenditures of these research awards during the five year period is $1.4 billion. This is not the same as research expenditures reported to the National Science Foundation.

12. The URC universities provided data that included a description of the award, the department in which the research was occurring, the award amount, the source of funding, and the dates during which the project was active. We used the award total and dates during which the award was active to calculate an average amount spent each day during the life of the project as if the award was spent evenly during the period. We report this prorated amount.

schools and public health departments. See Table 3 below.

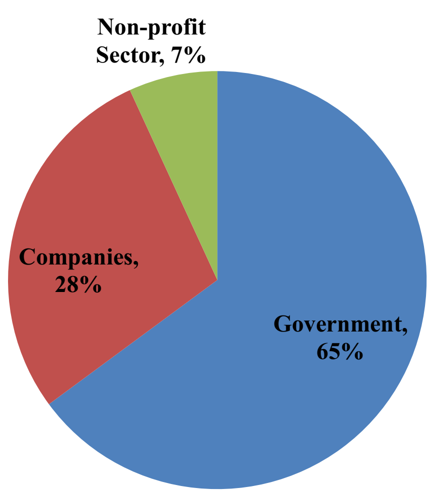
TABLE 3. Auto R&D Expenditures by Department at URC Universities, Open Awards FY 2007-2011

Department	Amount (in millions)	*Percent of Total*
Transportation Research Centers	$86.9	*28.7%*
Engineering	$192.8	*63.6%*
Business	$0.2	*0.1%*
Medicine and Public Health	$7.2	*2.4%*
Agricultural Sciences	$4.5	*1.5%*
Other Departments	$11.5	*3.7%*
Total Research Awards	**$303.1**	***100%***

Source: URC Universities' Administration Offices
Analysis: Anderson Economic Group, LLC

The URC universities received research funding for auto projects from governmental agencies, for-profit companies, and non-profit associations and foundations. We estimate that during the period we studied (FY 2007-2011), 65% of the auto research awards that were active came from federal and state governments and agencies. This includes the Department of Defense, the Environmental Protection Agency, National Laboratories, various State of Michigan departments, and the Michigan Economic Development Corporation. We estimate that 28% came from companies. This is nine times the average share of industry research support for all R&D. Non-profit associations and foundations provided 7% of the funding. See Figure 7 below.

FIGURE 7. Auto Research Awards by Sponsor, Open Awards FY 2007-2011



Source: URC Universities' Administration Offices
Analysis: Anderson Economic Group, LLC

AUTO RESEARCH INSTITUTIONS AT THE URC

Research centers at universities provide wonderful opportunities for students to engage in and become exposed to ongoing research, as well as interact with faculty. The URC universities have over 20 centers that engage in basic and applied research that is relevant to the automotive industry. We highlight some of those research institutions affiliated with the URC in Table 4 and describe them below.

TABLE 4. Summary of URC Auto Research Institutions

Research Focus	Name of Institution	Lead Institution	Other Partners
Batteries and Hybrids	Ford Powertrain Laboratory	MSU	Ford
	MSU Power Electronics and Motor Drives Laboratory	MSU	
	U-M/GM Advanced Battery Coalition for Drivetrains	U-M	GM
	Clean Energy Research Center	U-M	
	Electric Drive Vehicle Engineering Labs	WSU	
Biofuels	Biomass Conversion Research Laboratory	MSU	
	Energy and Automotive Research Lab	MSU	
	Great Lakes Bioenergy Research Center	U of Wisconsin	MSU
	National Biofuels Lab	WSU	
Composites and Materials	Composite Materials and Structures Center	MSU	
	Composite Vehicle Research Center	MSU	WSU
	Energy Frontier Research Centers	Multiple[a]	
	U-M/GM Smart Materials and Structures	U-M	GM
Safety	International Center for Automotive Medicine	U-M	
	U of M Transportation Research Institute	U-M	
	Toyota Collaborative Safety Research Center	WSU, U-M	Toyota
	Biomedical Engineering Center	WSU	
Vehicle Manufacturing	Center for Advanced Cutting Tool Technology	MSU	
	U-M/GM Advanced Vehicle Manufacturing	U-M	
	Center for Automotive Research	WSU	GM
Other	Automotive Research Center	U-M	U.S. Army
	Ground Robotics Reliability Center	U-M	MSU, WSU
	U-M/GM Engine Systems	U-M	GM

Source: URC Universities' websites
Analysis: Anderson Economic Group, LLC

a. There are 46 Energy Frontier Research Centers established by the U.S. Department of Energy. U-M and MSU each house one center.

Batteries and Hybrids

Ford Powertrain Laboratory (MSU). Researchers use this facility, equipped with six dynamometers with more than 1,000 kW worth of absorption capability, to study vehicles. The room temperature can be maintained from 70-120F, making it ideally suited for the investigation of hybrid applications, including medium and heavy duty configurations. The working area will accommodate a vehicle three meters in width and up to eight meters in length. Research within the Ford Powertrain Laboratory includes hybrid powertrain testing and provides measurements and optimization of powertrain performance in advanced hybrid vehicles under a broad range of driving conditions. The lab conducts real-time hardware-in-the-loop (HIL) simulations using a dynamometer control system configured to simultaneously and independently control each wheel of up to a six-wheeled vehicle with a real-time HIL vehicle simulator, allowing one to perform experiments on a drive cycle of interest.

MSU Power Electronics and Motor Drives Laboratory (MSU). Michigan State's Research Center for Power Electronics focuses on advanced R&D on power conversion technology and motor control for renewable energy, utility, and transportation applications. The lab conducts a wide range of research, development, and testing of power converters on small to large motor drives.

The lab works with government laboratories, industry, and other universities on many projects in power conversion; targeting cleaner, more efficient, and more affordable energy. The effort includes working extensively with automotive companies and suppliers to develop a new conversion circuit to more efficiently control electric motors. The objective is to optimize efficiency and reduce cost of electric-hybrid vehicles. Advanced electronic circuits and lighter and less expensive battery-based energy storage systems could make hybrid and electric vehicles more affordable and efficient.

Advanced Battery Coalition for Drivetrains (ABCD) Collaborative Research Lab (U-M). This lab is one of four Collaborative Research Laboratories (CRLs) between General Motors and U-M. The first GM satellite research lab was established at U-M in 1998 in order to provide collaborative research opportunities and a new venue for joint research with U-M. Each lab has a different research focus but is part of GM's commitment to cultivating a long-term, strategic relationship with the University of Michigan, linking faculty expertise and educational programs with GM needs.

The Advanced Battery Coalition for Drivetrains (ABCD) was created in 2009, as part of a corporate battery research and development strategy by GM. The research at ABCD spans the gap between vehicle integration and developing the next generation of car batteries. U-M also has a strong partnership with GM's Technical Education Program, which delivers Master of Engineering programs to selected GM employees worldwide. Particularly relevant to the research at ABCD is their Master of Engineering in Energy Systems Engineering.

Clean Energy Research Center (CERC) for Clean Vehicles (U-M). This Department of Energy funded research center is a partnership between Chinese universities and U.S. researchers at universities and national laboratories to address energy efficiency, advanced coal, and clean vehicle technology. The group's research includes energy systems analysis, technology road maps and policies; vehicle-grid interactions; vehicle electrification; advanced batteries and energy conversion; advanced biofuels and clean combustion; and advanced lightweight materials and structures. The focus is on fundamental research that could lead to advances in technology available to the entire industry.

Electric-drive Vehicle Engineering labs (WSU). In 2009, Wayne State University was awarded a competitive Department of Energy grant to develop and put in place a curriculum and research facility in Electric Drive Vehicle Engineering (EVE). The curriculum is described in "Auto-Centered Academic Programs at URC Universities" on page 21. The EVE department has 14 associated engineering faculty and additional graduate student researchers. The research focus of this center is using industry-standard testing and simulation tools to improve the performance of electric and hybrid vehicle systems and their components.

Biofuels

Biomass Conversion Research Laboratory (MSU). The mission of the Biomass Conversion Research Laboratory at Michigan State University is to develop cost effective and environmentally attractive means of generating fuels, chemicals, materials, foods and feeds from renewable plant biomass. A MSU developed patented process called ammonia fiber expansion (AFEX), which makes the breakdown of cellulose more efficient, is a significant technical challenge in producing ethanol. This lab is working towards moving society away from its reliance on petroleum as a source of liquid transportation fuels.

Energy and Automotive Research Labs (MSU). This new $10 million facilities for energy and automotive research at MSU's College of Engineering, houses five engine dynamometer sites, a powertrain test facility, a fundamental combustion lab, a spray laboratory, a controls lab and a thermoelectric generator fabrication facility.

The Energy and Automotive Research Lab's primary focus is to develop bio-derived fuels that do not compete with the food supply and improve the efficiency of the machines that convert these fuels to work. Collaboration across engineering disciplines include Chemical and Mechanical Engineers blending biofuels with petroleum to enhance diesel combustion, as well as Electrical and Mechanical Engineers developing hybrid systems that utilize the kinetic energy otherwise wasted in braking and converting it to stored electrical energy and useful mechanical work.

Great Lakes Bioenergy Research Center (MSU). The Great Lakes Bioenergy Research Center (GLBRC) is a collaborative effort to engage in basic research to generate technology that will convert biomass to ethanol and other advanced biofuels. This effort is led by the University of Wisconsin-Madison, with its major partner being MSU. Additional scientific partners are the Department of Energy's National Laboratories, other universities, and a biotechnology company.

National Biofuels Energy Laboratory (WSU). One of the most viable options for alternative fuel sources is the conversion of biomass into liquid fuel. Funded by the Department of Energy and housed at Next Energy and managed by Wayne State, the National Biofuels Energy Laboratory (NBEL) is working to address the technical barriers for widespread use of biomass-based fuels and evaluate biodiesel blends. Research at NBEL is being done to evaluate the conversion efficiency of biomass to biofuel and understand the relationship between fuel properties and engine performance, which are necessary to develop fuel quality standards. As a renewable resource, biomass could serve as the nation's sustainable source of energy.

Composites and Materials

Composite Materials and Structures Center (MSU). Established in 1986, the CMSC is a multidisciplinary center focused on research into the materials, processing and fabrication of composite materials. The CMSC is a state-of-the-art facility consisting of more that $5 million in analytical, characterization and processing equipment for composite research. Research efforts underway include multifunctional (i.e. mechanical, electrical, thermal barrier, and flammability) fibers, polymers, and composite material production, new and novel nanoreinforcements of graphite and cellulose, as well as advanced energy storage (i.e. batter, fuel cell) materials.

The CMSC also supports graduate and undergraduate education in the science and engineering of composites as well as an active outreach and technology transfer program with industry. Approximately 25 faculty from the College of Engineering participate in the CMSC research and outreach activities.

Composite Vehicle Research Center (MSU). The CVRC engages in research and design of composite structures for safe, durable, and lightweight vehicles for air, ground, and marine transportation. They particularly focus on research in composite vehicles and vehicle components.

Translating new knowledge of materials into industry product development is often a fragmented process. The CVRC aims to unify this process through collaboration with industry and research labs that provide expertise across a spectrum of composite materials, technology and knowledge exchange among researchers, manufacturers, and suppliers. Together fourteen MSU faculty, one professor from WSU, and more than 40 graduate students participate in materials testing and cutting edge characterization research. The research agenda of the CVRC is complementary to another center at MSU, which we next describe.

Energy Frontier Research Centers (EFRCs). In August 2009, the U.S. Department of Energy's established 46 Energy Frontier Research Centers (EFRCs), which involve universities, national laboratories, nonprofit organizations, and for-profit firms. Two of these centers are housed in Michigan:

- **Revolutionary Materials for Solid State Energy Conversion (MSU)**
  This Center investigates the underlying physical and chemical principles of advanced materials for the conversion of heat into electricity. This is particularly relevant to the auto industry due to wasted heat that escapes during the combustion process. MSU is attempting to convert that heat into electrical power for use on board the vehicle.
- **Center for Solar and Thermal Energy Conversion (U-M)**
  This center studies material structures on the nanoscale (the point where properties of a material change) to identify features that could potentially be used to convert solar energy and heat to electricity.

Smart Materials and Structures Collaborative Research Lab (U-M). This Collaborative Research Laboratory is the third of four GM/U-M labs.[13] It was established in 2005 to further accelerate the path from basic research to launching competitive products, focusing particularly on Smart Materials and Structures (SMS). This CRL researches the emerging capabilities of smart materials to support innovative device technologies in vehicles.

Safety

International Center of Automotive Medicine (U-M). This center is a multidisciplinary blending of U-M's medical, engineering, and educational resources to translate research into better treatments, policy, and outcomes related to automotive accidents. The primary focus of the center is researching the causes of injuries in automotive accidents so that they can be better treated and prevented, as well as predicting injury severity following crashes. Another major focus of the center is educating across disciplines; particularly instilling engineers with an awareness of anatomy, medical science, and injury care, in order to improve vehicle design safety.

University of Michigan Transportation Research Institute (UMTRI). In 1965, the University of Michigan founded UMTRI through gift funds to engage in interdisciplinary research to ultimately increase driving safety and further transportation systems knowledge. The approach to research at UMTRI is reflected in the great variety of disciplines represented within the Institute, and

13. We provide greater discussion of the relationship cultivated by GM and U-M through collaborative labs in "Advanced Battery Coalition for Drivetrains (ABCD) Collaborative Research Lab (U-M)" on page 31.

by its involvement with other units of the University including approximately 141researchers, technical and administrative personnel, teaching faculty, and graduate students. UMTRI's research significantly impacts highway transportation practice, in the United States and internationally. Their biggest ongoing project is described in “Connected Vehicles” on page 40.

Toyota’s Collaborative Safety Research Center (WSU and U-M). In early 2011 Toyota announced the formation of the Collaborative Safety Research Center (CSRC), a partnership between the company and several universities. The center’s mission, to which Toyota has pledged approximately $50 million over five years, is to support non-proprietary (i.e. openly published) research that improves the safety performance of the entire auto industry.

Two of the center’s research targets have lead to partnerships with URC universities. Toyota has partnered with Wayne State faculty to research improvements in the industry’s performance with vulnerable populations, including children and seniors. The company has also engaged the University of Michigan’s UMTRI for research in active safety and the effect on safety of vehicle seating position of seniors.

Biomedical Engineering Center (WSU). The graduate program in Biomedical Engineering at Wayne State was initiated in 1998 and became a department in 2002. In 2010, a new biomedical undergraduate degree was created. The Bioengineering Center, established in 1965, is a leader in human trauma research and modeling, in order to reduce fatalities and major injuries. The center is known for its research contributions to the overall development of many automobile safety designs, including the high penetration resistant windshield, seat belt, air bags, the collapsible steering column, and the Indianapolis 500 soft wall.

Vehicle Manufacturing

Center for Advanced Cutting Tool Technology (MSU). Currently, MSU is working to establish a cooperative research center between the university and industry. It will focus on advancing tool material systems, machines, and cutting process technologies to address the arising challenges facing machining industries, such as productivity-based predictive modeling, new tool alloys and micro machining systems.

Advanced Vehicle Manufacturing Collaborative Research Lab (U-M). This lab is an extension of GM/U-M’s original CRL.[14] The Advanced Vehicle Manufacturing Collaborative Research Lab carries out research and development activities in areas that are of critical importance to GM's vehicle manufacturing operations, with particular emphasis on automotive body manufacturing pro-

14. We first describe the relationship cultivated by GM and U-M through collaborative labs in “Advanced Battery Coalition for Drivetrains (ABCD) Collaborative Research Lab (U-M)” on page 31. The other two GM/U-M CRLs are discussed on page 34 and page 36.

cesses and systems. The lab focuses on four areas of manufacturing: forming, joining, assembly, and manufacturing systems.

U-M's strong partnership with GM Technical Education Program, which delivers Master of Engineering programs to selected GM employees worldwide offers particularly relevant Master of Engineering degrees in Manufacturing and Global Automotive and Manufacturing Engineering.

Center for Automotive Research (WSU). CAR represents the WSU's College of Engineering long-standing role in the development of advanced automotive technology. The Center conducts research and coordinates instructional programs focused on enhancing all aspects of automotive engineering and production, ranging from engine optimization, including gas and diesel engines, to cabin noise reduction. At CAR, graduate students and faculty continue to develop a close-working relationship with the major players in the automotive industry.

Other Centers

Automotive Research Center (U-M). The Automotive Research Center (ARC) is a U.S. Army Center of Excellence housed at U-M Ann Arbor. Research focuses on high fidelity simulation of military and civilian ground vehicles. ARC is the basic research partner of the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) in Warren, Michigan. Since its establishment in 1994, ARC has acquired partners including Wayne State and other universities to meet the research needs of its Army sponsors.

Ground Robotics Reliability Center (U-M). Launched in 2008, Ground Robotics Reliability Center (GRRC) conducts research in autonomous ground vehicles and mobile robots. It is housed at U-M Ann Arbor and has academic partners including Wayne State, MSU, U-M Dearborn and others. Research projects conducted by the GRRC are primarily funded by the U.S. Army's Tank Automotive Research Development and Engineering Center (TARDEC). It is working to help establish Southeastern Michigan as a center of activity for these emerging new technologies through supporting programs in research and education.

Engine Systems Collaborative Research Lab (U-M). This Collaborative Research Laboratory is the second of four GM/U-M labs.[15] Building on the success of the original CRL, GM added an Engine Systems lab in 2002. This CRL was formed to carry out research and development activities in areas that are of

15. We provide greater discussion of the relationship cultivated by GM and U-M through collaborative labs in "Advanced Battery Coalition for Drivetrains (ABCD) Collaborative Research Lab (U-M)" on page 31.

critical importance to General Motors (GM) for internal combustion engine and aftertreatment systems. They are working to address key engine issues including diagnostics, the understanding of thermal conditions in direct-injection engines, and optimizing diesel engine combustion.

VI. URC Research Addressing Auto Industry Challenges

The previous section discussed, in "big picture" terms, the role of the URC universities in acting as an important resource for basic and applied research for the auto industry as it faces challenges requiring innovation. This section expands on this, providing specific examples of research projects at the URC universities that helped the auto industry face challenges with innovation.

This section focuses on several of the biggest innovation areas the auto industry confronts today, including: reducing fossil fuel use and improving quality, safety, and engine performance and efficiency. Below in Figure 8 we include a list of examples of URC research that contribute to addressing industry challenges.

FIGURE 8. URC Research Examples Addressing Challenges in New Auto

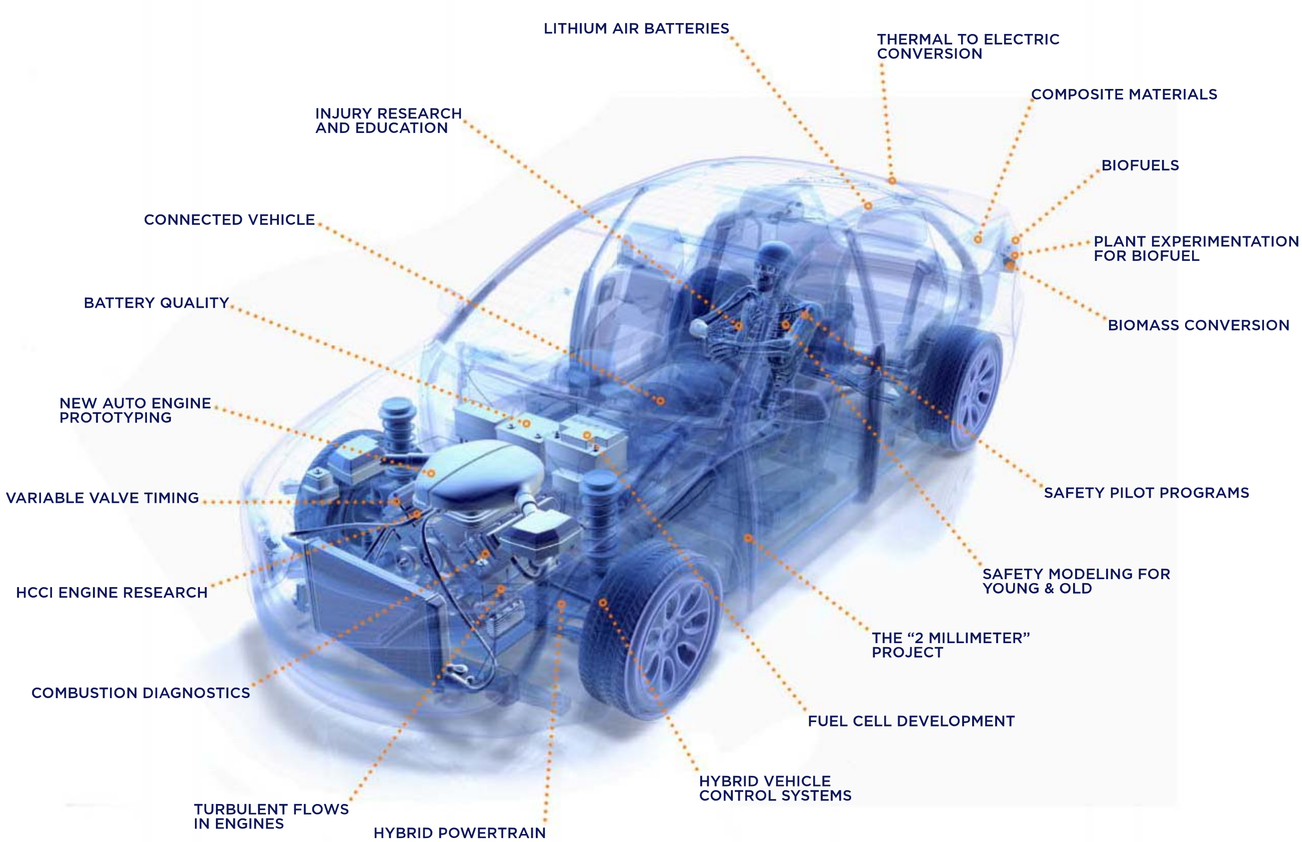


Image created by Michigan State University
Analysis: Anderson Economic Group, LLC of research examples provided by URC universities

STEPS FORWARD IN VEHICLE SAFETY

The auto industry has made great strides in improving vehicle safety throughout its history in response to customer demands, competition from innovative members looking to differentiate their products, and government regulations. Vehicle components have been redesigned to absorb more energy and do less damage to the human body in crashes, vehicles have been designed to make loss of control less likely, and new proactive features such as sensors that have been created to reduce the likelihood of crashes. Below are several examples of URC research that is helping the auto industry further improve safety performance in all of these areas.

Focus on Vulnerable Populations

Auto companies continue to seek ways to build on existing successes in reducing the incidence of injuries and fatalities in auto accidents. One line of research on this front is to evaluate current and future safety measures for a wider variety of body types, extending beyond what reducing the impacts on an "average adult" sized crash dummy.

Toyota Research on Modeling Safety for Young and Old (WSU). In January 2011 Toyota announced the creation of its Collaborative Safety Research Center, committing $50 million over five years for industry/academic cooperation to improve the entire industry's safety performance. In one key project in this initiative, Toyota is working with researchers at Wayne State University's College of Engineering on reducing injuries in children and seniors. The team will develop computerized human body finite element models for children and seniors so that engineers can account for differences in their body characteristics when designing vehicle safety systems. The study aims to close the gap between current safety testing and the actual injuries sustained by these two vulnerable populations, ultimately reducing injuries to all occupants regardless of age.

Connected Vehicles

Recent safety innovations use sensors to detect pedestrians, other vehicles, and the edges of the driving lane. This line of innovation in using sensors to help the car make drivers safer could be extended through "connected vehicles." The concept of connected vehicles is based on a wireless technology that enables vehicles to "talk" to each other. This would move beyond limited sensing of physical objects to providing information about what is further ahead, and what the "intentions" of another vehicle are. Vehicles could negotiate whose turn it is at an intersection themselves, allowing faster traffic flow, for example. These technologies are what the U.S. government and vehicle manufacturers hope will be the next big advance in road safety. Below we describe some of the research being done at URC universities.

Connected Vehicle Research (WSU). Computer scientists at WSU are investigating basic questions of having vehicles communicate with each other. Topics include several approaches for how to handle the less-than-perfect reliability of real-world communication networks if cars were to use wireless communications technologies.

Safety Pilot Program (U-M). The Safety Pilot Model Deployment, a series of 'driver clinics' under way across five states, is essentially a large-scale test of "Connected Vehicle" technologies in a real-world setting. U-M's Transportation Research Institute was awarded a contract by the U.S. Department of Transportation for $22 million. U-M is providing a setting to test the deployment of vehicle-to-vehicle and vehicle-to-infrastructure safety applications in Ann Arbor, which provides an all season test environment, a mix of roadway types, and proximity to the auto industry. The goal of the program is to determine the effectiveness of connected vehicle safety applications at reducing accidents, as well as determine the viability of the technology.

IMPROVING ENGINE PERFORMANCE AND EFFICIENCY

Advancements in engine performance and efficiency have steadily accumulated throughout the history of the auto industry, as engines wring more power out of the same sized engine, and out of a given amount of fuel. For example, many of the examples below discuss improving control of engine combustion, the explosion of mixed fuel and air that occurs inside each piston during each turn of the engine. Due to improvements in engine technology, a given size engine can now produce more power and use less fuel than in the past. On average, each class of vehicle now achieves better fuel economy and better performance than in the past. Many consumers have chosen to take advantage of the extra power output of engines to drive larger vehicles than in the past. This section outlines some of the contributions that URC research has made in laying the foundation for engine advancement.

Research on Variable Valve Timing (U-M). The precise timing of when air is allowed to move in and out of a piston (controlled by the opening and closing of valves) has a major impact on the power output and efficiency of an engine. One challenge facing engine designers is how to "tune" the engine's valve timing. When the engine is set to operate very efficiently in some circumstances (say, accelerating quickly up to highway speed), it may operate less efficiently in others (driving at steady highway speeds or at slow speeds in a neighborhood). One way the industry addressed this challenge is with *variable* valve timing—changing the valve timing in different operating conditions, allowing the engine to be "tuned" closer to optimally in many different circumstances. This allows engines to, for example, operate efficiently at steady highway speeds while still performing well during acceleration. While working to maximize the variable valve timing's ability to reduce fuel consumption and improve emissions, researchers must avoid adversely affecting a vehicle's driveability.

Researchers at the University of Michigan were among the leaders in helping the auto industry lay the groundwork and perform early applied tests of variable valve timing concepts. Work has included:

- Work at the Electrical Engineering Systems Laboratory with Ford in the early 1990's to develop low cost dual-equal variable camshaft actuators.

- Continued development of automatic control algorithms that adapt the fully flexible valve train's valve profiles and timings to any driving condition in real time (as of 2004).
- The development of models, control algorithms, and patents at the W.E. Lay Automotive Laboratory.
- Many master's and PhD students who have studied and advanced variable valve timing technology. These students have gone on to work in the industry and continued in academia developing the science of engine performance.

Variable valve timing technology was being demonstrated in computer models and in research laboratories in the late 1980's and early 1990's, and is now used nearly every gasoline engine sold in the world.

Prototype of New Auto Engine (MSU). Michigan State researchers have built a prototype of a new gasoline engine for hybrids that lack a transmission, crankshaft, pistons, valves, fuel compression, cooling systems, and fluids found in conventional internal combustion engines. The Wave Disk Generator uses shock waves to more efficiently compress fuel and transmit energy. According to MSU, this generator would use about 60% of fuel for propulsion, which would be a dramatic improvement over typical car engines that typically use only 15% of fuel for forward movement. This engine could also greatly decrease the weight of vehicles, potentially significantly decrease auto emissions, and improve the overall efficiency of gas-electric hybrid automobiles.

Research on Turbulent Flows in Engines (MSU). Michigan State researchers are addressing a major difficulty in the understanding of flows of fuel and air inside engine cylinders when the flow is turbulent. (Turbulent flow is a messy, chaotic mode of fluid flow that characterizes rapids in a river, for example.) Through these studies, which are based on in-cylinder flow measurements, researchers have developed a new technique for identifying the turbulence based on a statistical technique called "stochastic estimation theory." Having a better understanding of the conditions under which turbulent flow occurs in the cylinder will help improve engine designs to improve the controllability of the engine.

HCCI Engine Research (U-M, MSU). University of Michigan researchers are researching Homogeneous Charge Compression Ignition (HCCI) engine technology. This new mode of engine operation is a "lean" (i.e. low fuel-to-air ratio) combustion regime that reduces both fuel consumption and emissions simultaneously, removing the need for expensive after-treatment devices. The U-M team is part of a DOE sponsored consortium of universities and industry for advancing certain control systems that would allow the use of the HCCI combustion mode in "transient" conditions (i.e. while changing the load on the engine, as when the driver presses the gas pedal to accelerate). The overall goal of this consortium is to demonstrate fuel savings of up to 50% on a vehicle by 2014.

One of the roadblocks hindering the implementation of HCCI in production engines is the transition between HCCI operation and normal engine operation. MSU, in collaboration with Chrysler, has been developing the control algorithms for a smooth transition under a DOE grant that will make these transitions seamless.

Research Using Optical Engines (MSU). Understanding engine air flow and fuel-air mixing is a major factor in improving engine combustion. MSU has been a leader in optical engine development and the diagnostics (using sensors similar to video cameras) to research combustion using unique diagnostic techniques, such as “molecular tagging velocimetry” (MTV). MTV allows one to quantify the airflow details that are responsible for fuel-air mixing and control the subsequent combustion process. The MTV technique was a collaborative development between the MSU Colleges of Natural Science and Engineering during a ten year National Science Foundation sponsored “Center for Sensor Materials.”

Research on Combustion Diagnostics (WSU). Both engine performance and emissions can be improved with a more detailed understanding of the combustion that happens inside the engine. Researchers at WSU’s Center for Automotive Research have developed sensors that use high-speed visual signals (essentially specialized high-speed video) to gather important information such as temperature profiles within the piston of a running engine. This sensor technology has attracted the interest of automakers, who may license the technology. The sensor could be used to measure the performance of prototype engines and validate computer simulations used in the design process. Ultimately, advances in the understanding of combustion behavior could improve engine efficiency and reduce emissions in engines.

Model-Based Closed-Loop Control (MSU). One important way that engines can be made more powerful and efficient is through better control of engine combustion, which is the conversion fuel and air to products (mostly CO2 and water). This occurs inside each piston's combustion chamber during the part of a cycle termed the dynamic stage of combustion. The engine combustion process can be optimized through accurate control of the mixture motion, fuel injection and spark timing and other aspects of the engine’s function. Mechanical engineering researchers at MSU are optimizing the combustion process using detailed combustion models implemented in an engine's control systems to manage in-cylinder pressures and temperatures for optimum performance. The use of MSU's “closed loop” control methods enable advances in power output and efficiency, including reliable HCCI (homogeneous charge compression ignition) capable engines. (Other HCCI-enabling URC research is discussed on page 41.)

IMPROVING QUALITY

Product quality and reliability is a feature that customers always value. Nevertheless, it wasn't until the 1980's and 90's that quality took center stage in the auto industry, with Japanese automakers challenging American brands (including many models designed and built in Michigan) in the marketplace on the basis of quality. Several URC projects have helped Michigan's auto industry push forward its own extensive and continuing efforts to meet customer demands.

The "2 millimeter" project (U-M). A consortium of auto manufacturers, equipment suppliers, and universities, called the Auto Body Consortium, ran a project from 1992-1995 to advance the industry's performance on product quality. The industry-university consortium was funded by the NIST Advanced Technology Program and industry, led by researchers from the University of Michigan, but also included participation from Wayne State University as a subcontractor in the project. The goal was to limit and control the car to car variation in auto body assembly to 2mm (six-sigma) variation. Such low level of variation will lead to reduced water leaks, wind noise, and squeaks and rattles in the vehicle. At the time, only Japanese auto manufacturers consistently achieved this level of performance, with European and American manufacturers producing greater variation. The "2 mm project" increased the US auto companies' understanding of state-of-the-art scientific approaches to reducing variability in their components and assembly. Such approaches included using real-time data from production lines to diagnose and correct problems in the manufacturing process that can result in variability in component dimensions. As a result of the project, both GM and Chrysler implemented new procedures for identifying opportunities to reduce variation. This project was just one visible effort in an industry-wide process of continuing advances in product quality, resulting in better quality from the entire industry. Methods developed through the program are still in us by the auto manufacturers today.

Chevrolet Volt Battery Quality Project (U-M). The collaborative work of U-M's College of Engineering and General Motors is helping to guarantee that the battery assemblies used in the Chevrolet Volt meets exceptional quality standards. Using complex technology to monitor welding quality in assembling multiple battery cells, engineers were able to create a sustainable manufacturing process, allowing Chevrolet to deliver high quality batteries to their customers. The system allows team members manufacturing the battery packs at GM's Brownstown battery plant to monitor the weld quality and integrity, thus ensuring high-quality battery performance on the road.

REDUCING FOSSIL FUEL USE

Reducing the amount of petroleum-based fuels used by our nation's passenger vehicle fleet is a goal that addresses a wide variety of concerns in our society, from national security and economic security concerns to environmental priorities. This section describes URC research that is contributing to this goal on many fronts, from tried and true principles such as vehicle weight reduction to possible next steps that the industry could adopt if first proven in the laboratory, as well as and initial moves into the marketplace like electrification and use of biofuels.

Vehicle Weight Reduction

Reducing the weight of a vehicle without compromising performance is one of the most effective ways to reduce fuel consumption. This is because each time the vehicle accelerates, the engine has to work to bring every ounce of the vehicle up to the new speed. As a result, a lighter vehicle gets from zero to 60 mph using less fuel. While some degree of weight reduction can be achieved by reducing performance (for example, by supplying a smaller, less peppy engine, or providing a spare tire that is not full sized), reducing weight while maintaining performance is more appealing to customers. URC researchers are pursuing basic and applied research in advanced materials that could improve the auto industry's ability to reduce vehicle weight.

Composite Material Research (MSU). MSU's federal-government-funded Composite Vehicle Research Center is pursuing advanced research into vehicle-based applications of composites (materials that are made using more than one material combined in a way that improves performance).[16] The center is pursuing a variety of research topics, including basic research into material properties, applied research into material durability, manufacturability, and electromagnetic properties. Applications being investigated currently include integrating electronics into structural components (having components with electronics built in rather than run through separate wires), electromagnetic shielding (to prevent electronic components from interfering with each other's signals). The center is also creating software tools and developing know-how to advance thinking about the use of composites in design at the level of whole subsystems (e.g. chassis, seating, steering, braking) or even the whole vehicle. This approach would involve moving beyond simply replacing metal components with lighter-weight or stronger composites to take advantage of larger opportunities presented by radically improved performance-to-weight ratios of materials.

Electrification of the Car

Electric drivetrains in vehicles could completely eliminate fossil fuel use from the automotive picture if combined with renewable sources of electricity or hydrogen. Even when connected to a non-renewable power grid, driving vehicles with electric motors offers a key advantage in reducing fossil fuel use over petroleum-fueled engines: reducing the wasted energy inherent in burning fuel

16. One naturally-occurring "composite" material that most readers are familiar with is wood, which is made of both strong cellulose fibers (the "grain" of the wood) and a lignin matrix (the material in which the grains are situated). The resulting combination of high strength and relatively low weight accounts for its use as a building material throughout human history.

on board the vehicle, which includes the 70-80 percent of the energy in fuels that is lost to heat and friction. Nevertheless, electric drive vehicles face many challenges before they can compete on a mass scale with the performance and reliability of the petroleum fuel engine technology, which has a century of intensive development behind it. These challenges include increasing the range of vehicles powered by battery-driven electric cars, and improving the cost and reliability of both hydrogen fuel cells and batteries.

Research in Hybrids Trucks and Multi-wheeled Military Vehicles (MSU). The MSU Powertrain Research Facility, under contract with the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC), is developing a hybrid truck vehicle using powertrain control strategies for vehicles with both an electric drivetrain and diesel engine. MSU recently conducted studies on an Army vehicle called the Autonomous Platform Demonstrator, a six-wheel drive unmanned ground vehicle that can conduct missions while controlled by armed services members located away from danger.

Research on Lithium Air Batteries (U-M). Material scientists at the University of Michigan have several current projects exploring lithium-air batteries, a technology that, if proven, could represent a leap forward in battery performance from the current lithium ion batteries. Project objectives include simulating materials at the atomic scale, examining compounds that form when batteries discharge, the electrical properties of Lithium Peroxide, and other properties of materials that affect performance and speed. One DOE-funded project at the Clean Energy Research Center for Clean Vehicles has U-M researchers collaborating with others at industrial partners, national laboratories, and other universities in the USA and China to explore the basic material properties, electronics, and other basic research necessary to lay the groundwork for advancement. Other projects include internally-funded and industry-funded projects. This research typifies the basic and applied research that is often done by or in industrial partnerships with university researchers that can later be extended and commercialized if successful.

Research on Thermal to Electric Energy Conversion (MSU). Materials science researchers at MSU are pursuing advances in thermoelectric energy conversion. Mechanical Engineers that are part of the University's automotive research group are conducting research to recover waste heat from diesel engines. This extracted energy is then used to help power the vehicle. The goal is to improve fuel economy of large trucks by 2-3 percent in the next few years. Automobile companies are turning to MSU's hybrid vehicles team for applications to auto components that will help maximize the efficiency and affordability of hybrid models. MSU's collaborative automotive and fuels research holds promise for reducing automobile emissions.

MSU is one of the few places in the world where one can conduct all of the steps needed to build a demonstration thermoelectric generator in the range of 100 to 1,000 watts. Uniquely, this allows the evaluation of new materials as they are developed in devices that have commercially-viable applications. Research projects on this topic include efforts to collaborate with other academic researchers (including other URC universities) at the Energy Frontier Research Center, and with companies in Michigan developing thermoelectric components, such as Amerigon in Northville and Tellurex in Traverse City.

Research on Fuel Cell Development (U-M). University of Michigan researchers at the Power Control Laboratory are studying statistical patterns in the performance of hydrogen fuel cells to get a handle on the conditions under which performance is degraded and equipment life is reduced. Phenomena such as nitrogen or water accumulation within the cell can interfere with the performance of the fuel cell's power output. Once these performance and degradation conditions are better understood, fuel cell manufacturers could potentially improve design and manufacturing processes that affect performance.

Hybrid Systems

"Hybrid" systems combine more than one method of powering vehicles. Most commonly, electric motors are integrated with gasoline powered engines to take advantage of the strengths of both modes. Electric motors operate more efficiently during acceleration and can rely in part on energy captured when the driver hits the brakes. Gasoline engines allow significantly greater range (since a car's gasoline tank can store much more energy more economically than current-generation batteries) and can operate quite efficiently at steady speeds (having been assisted during acceleration by the electric motor). The development and improved performance of hybrid powertrains is currently the most widely-deployed new technology for reducing fossil fuel use.

Hybrid Powertrain Research (U-M). The University of Michigan has pursued many projects advancing the field of hybrid powertrains in vehicles going back to the early 2000's, working with industry and pursuing traditional academic research. For example, the Automotive Research Center at U-M worked with auto supplier Eaton Corporation in 2003 on computer simulations of hybrid-electric powertrains, demonstrating that a 45% improvement in the fuel economy of a commercial truck was possible. The modeling technology was shared with Eaton, which stated to U-M researchers that the technology from the study has been used in mor than 1,000 hybrid-electric powertrain units in city busses in Beijing. Furthermore, one of the graduate students on the project subsequently joined Eaton after graduation.

A more recent study developed an approach for managing the implementation of power grid systems supporting the widespread use of plug-in hybrid electric vehicles (such as the Chevy Volt), which use energy from both the power grid and fuel carried on board. This type of research, thinking through the interaction between new vehicle technologies and other parts of our infrastructure, exemplifies the role that research universities such as the URC universities can lay the groundwork for widespread deployment of new technologies developed by the industry.

Hybrid Vehicle Control System Research (MSU). MSU researchers have been working on hybrid powertrain control systems on two fronts. First, researchers are investigating the use of "fault detection" (using sensors to identify when a component failure has occurred and pinpointing its type and location) to improve the reliability of hybrid vehicles. Research areas include detecting the type and location of a fault, predicting the time to component failure, and creating fault-tolerant systems that can continue to function properly despite the presence of certain defects. Work on this topic has been funded over the past decade by Ford, Delphi, GM, the State of Michigan, as well as the U.S. Department of Energy and U.S. Department of Defense.

Second, researchers are working on "closed loop" control technology (discussed on page 42 as applied to engine combustion) for the optimization and control of the hybrid powertrains. This requires the coordination of many subsystems, such as internal combustion engines, electrical machines, and transmission. The goal is to develop real-time control strategies for the best fuel economy within a given level of emissions.

Biofuels

As oil prices rise, researchers and refiners are working to advance non-food feedstocks and refining technologies. Congress has also passed a mandate requiring the use of one billion gallons of biomass-based diesel, which by government standards must reduce greenhouse gas emissions by 50 percent over petroleum diesel.

Plant Experimentation for Biofuel (MSU). In 2011, Power Alternative, an idled biodiesel refinery in Warren, Michigan, along with local organizations, and MSU began working together to explore the possibilities of using pennycress, a common weed, as biofuel feedstock. At the time Michigan had four commercial biodiesel refineries, but none were producing fuel because of the price of soy oil (the feedstock of choice). Pennycress is particularly attractive to Detroit because as the weed grows, it naturally absorbs heavy metals from soil. As Detroit was once home to several lead smelters, which are now vacant contaminated land, growing pennycress for biodiesel could cleanup these sites over time, while providing a less expensive low grade feedstock.

Biofuels Research at The National Biofuels Energy Laboratory (WSU). Not all diesel fuels are the same: the name "diesel fuel" can apply to a wide variety of mixed chemical compounds that can "work" in a diesel engine. Nevertheless, many specific attributes of this mix must be specified and followed for the fuel and engine to work together in a way that produces the long engine life and emissions standards we have come to expect from the auto industry. This presents a challenge to the auto industry with increased interest by consumers (and the military) in using more bio-based diesel fuels, such as those produced from soybean oil. Fuel producers and engine manufacturers needed to coordinate their actions with a standard on what type of fuels would be produced and how the engines would be made to consume these fuels. In 2010, WSU researchers began working through the National Biofuels Energy Laboratory (NBEL) at Next Energy (which works with partners in private industry and the federal government to develop biofuel technology) with a consortium of private companies to address this problem. They helped to develop an ASTM standard for a diesel fuel called B-20, which consists of 80 percent conventional petroleum-based diesel fuel blended with 20 percent diesel fuel from bio-based sources. Such standards are crucial for coordinating the investment and product development actions of fuel refiners and engine manufacturers.

Research at the laboratory has also led in recent years to the development of catalysts that can could expand the set of substances ("feedstocks" in industry parlance) that can be converted into biofuels economically. One opportunity is to create "green diesel," which is chemically similar to petroleum-derived diesel fuel but originates with oils and greases in industrial waste. Another opportunity to expand the feedstock base has lead to the spin-off of a company, NextCAT of Detroit, which is working to commercialize a proven catalyst technology developed at WSU that allows the conversion into biofuels of feedstocks that are cheaper than the soybean oil and other feedstocks that are most widely used currently.

Biofuels Production and Characterization (MSU). Researchers in MSU's Energy and Automotive Laboratories develop new biofuel formulations through research in new catalytic reaction pathways from biomass (such as plant material) to final products; new processing approaches such as reactive separations and multi-phase reactors; and computer simulations and modeling. The Biofuels Production and Characterization Laboratories have two key capabilities needed in developing next-generation biofuels. One is the ability to develop a sufficiently-detailed description of a new fuel's chemical and physical properties that you can be sure the next batch you make will behave the same way when used in an engine. This process, called "characterization" of the fuel, ensures blending compatibility with existing fuels, sufficient energy content, and consistent behavior at different temperatures. The second capability is the ability to produce enough of a new fuel formulation to allow extended engine tests. For this purpose the laboratory has pilot-scale equipment that facilitates biofuel production in up to one hundred gallon quantities.

Appendix A. Data and Methodology

AUTO RELATED DEGREES CONFERRED

We determined the degrees used in "URC Degrees Conferred in Related Technical Areas" on page 20 using the National Center for Education Statistics' Classification of Instructional Programs (CIP) codes that are used in their Integrated Postsecondary Education Data System (IPEDS). In IPEDS there are no groupings of degrees that are specific to any particular industry. To estimate the number of degrees granted by the URC that gave students the background and experience to enter into R&D related occupations in the auto industry, we used the following methodology:

1. We began by thinking about the types of backgrounds that employees engaging in automotive research and development would have. We used professional judgement of our team, which included a member with a mechanical engineering background.
2. We identified degrees in which students are prepared for jobs in the auto industry as Auto Ready. Graduates earning Auto Ready degrees both prepare students and make it likely that they would be able to become employed by the auto industry. Given the background they will absorb and their proximity to the auto industry, we think a good number of graduates with these types of degree will actually become employed in the auto industry.
3. We determined that Auto Ready degrees include bachelor's and master's degrees in engineering, computer sciences, math, and physical sciences; and PhDs and advanced certificates in engineering and math. Note that for engineering degrees awarded, we included "engineering" and "engineering technologies/technicians," because the IPEDS database presents highly related concentrations under each and they likely signal similar skill sets in the entry level job market.

We show the complete list of all degrees included in Table A-1 on page A-4.

RESEARCH AWARDS ANALYSIS

The URC universities provided research awards data (i.e. funding) that included a description of the award, the department in which the research was occurring, the award amount, the source of funding, and the dates during which the project was active. We used the award total and dates during which the award was active to calculate an average amount spent each day during the life of the project as if the award was spent evenly during the period. We report this prorated amount. We also classified the source of the funding as "government," "industry," and "nonprofit" based on the description of the award source.

MAPS DISPLAYING AUTO R&D FACILITIES

In order to create Map 1, "Auto Industry R&D Locations with Southeast Michigan Detail," on page 12, we began by using a list of locations created by the Michigan Economic Development Corporation (MEDC) in 2007. The MEDC identified and collected the addresses of more than 330 auto tech centers in Michigan. We then chose one location per company to represent their R&D presence in the state.

We realize that auto tech centers may have closed and new ones may have opened since the compilation of this list in 2007. Ensuring that each of these auto tech centers was still in operation was outside of the scope of this project. Rather, we wanted to show the reader the presence of auto tech centers in Michigan over the last five years. This matches with our other purpose of displaying which of these centers draw on talent from the URC, which we show in Map 2, "Auto Industry R&D Locations Where URC Engineering Graduates are Employed with Southeast Michigan Detail," on page 27.

To create Map 2, we needed to collect data on URC alumni. Using career services and alumni relations at the URC, AEG compiled a list of employers of engineering graduates from the URC from 2007-2011.[1] We received this data specifically from:

- **MSU Center for Spartan Engineering.** The list of companies provided was pulled from the Destination Survey that MSU completes each year. They particularly included the results from the Spring semester of 2007 and ending in the Fall semester of 2011. The list was narrowed down to companies in the auto industry and located in Michigan.
- **U-M Engineering Career Resource Center.** The list of companies included were based on a survey taken by student graduates of engineering from December 2006 through August 2011. This survey was taken on a voluntary basis and had a rather low response rate, so it is by no means a comprehensive list of the hires that have taken place.
- **WSU Career Services.** As the alumni database was insufficient to capture the employers of recent engineering graduates, we spoke with career services. They provided us with a list of auto R&D companies in Michigan that actively recruit at Wayne State. By active, we mean that these companies have a standing relationship with career services and offer internships for WSU students. AEG made the assumption that these companies have hired one WSU graduate in the last five years as each has an existing relationship with career services. Additionally, given the nature of the work done at these firms we assume that they are hiring engineers.

AEG and the universities were careful to respect the privacy of alumni by not including the number of URC alumni that went to these firms nor the names of the alumni being hired. We also did not identify from which university alumni graduated from, nor any names of companies in our maps, just locations.

Based on the data availability from each university, AEG tried to match the list of firms to the list provided by the MEDC. MSU and U-M were both able to provide the cities that these firms were located in, which helped us to better match the firms. For WSU, AEG used professional judgement to match firms and erred on the side of not identifying a firm rather than including it as a

1. To better ensure that URC graduates were engaged in research and innovation at these tech centers, we chose to only include centers employing engineering graduates, which would likely be doing work of this type.

employer. Note that in some cases we identified a firm as an employer even if cities did not match because we only included one location per firm.

Adding to the original list of locations. In some cases we found that there were firms listed by a university that were not on the MEDC list. AEG decided to add 36 firms to both Map 1 and Map 2. We were careful to only add firms that were engaged in R&D within the auto industry and located in Michigan. We were also careful only to include one location per company. The end list of firms engaging in automotive R&D in Michigan totalled nearly 370.

Table A-1: List of all Degrees Included in Auto Ready Category

Computer Science	**Bachelors**	
		Computer Technology/Computer Systems Technology
		Computer Programming
		Computer Science
		Computer and Information Sciences General
	Masters	
		Computer and Information Sciences General
		Computer Programming
Engineering	**Bachelors**	
		Engineering Science
		Manufacturing Engineering
		Industrial Production Technologies/Technicians
		Mechanical Engineering Related Technologies/Technicians
		Industrial Engineering
		Mechanical Engineering
		Electromechanical Instrumentation and Maintenance Technologies/Technicians
		Engineering Physics
		Materials Science
		Electrical Engineering Technologies/Technicians
		Materials Engineering
		Naval Architecture and Marine Engineering
		Engineering General
		Aerospace Aeronautical and Astronautical Engineering
		Computer Engineering General
		Chemical Engineering
		Electrical Electronics and Communications Engineering
	Masters	
		Mechanical Engineering
		Industrial Engineering
		Engineering/Industrial Management
		Manufacturing Engineering
		Engineering Mechanics
		Electrical Electronics and Communications Engineering
		Engineering Other
		Computer Engineering General
		Engineering General
		Aerospace Aeronautical and Astronautical Engineering
		Materials Science
		Engineering Technology General
		Systems Engineering
		Materials Engineering
	PhDs	
		Engineering General
		Engineering Other
		Manufacturing Engineering

Engineering	**PhDs**
	Industrial Engineering
	Materials Science
	Materials Engineering
	Mechanical Engineering
	Certificates Above Baccalaureate
	Polymer/Plastics Engineering Certificates
	Engineering Other Certificates
Math	**Bachelors**
	Applied Mathematics
	Statistics
	Mathematics
	Masters
	Applied Mathematics
	Statistics
	Mathematics
	PhDs
	Mathematics
	Applied Mathematics
	Statistics
	Certificates Above Baccalaureate
	Statistics
Physical Sciences	**Bachelors**
	Physics
	Chemistry
	Masters
	Physics

Note: All degrees listed above are IPEDs category of degrees

Source: Anderson Economic Group, LLC

Appendix B. About the Authors

ANDERSON ECONOMIC GROUP

Anderson Economic Group, LLC is research and consulting firm specializing in economics, public policy, finance and business valuation, and market and industry analysis. The firm has offices in Chicago, Illinois and East Lansing, Michigan. AEG has conducted economic and fiscal impact studies for private, public, and non-profit clients across the United States. For more information please visit www.AndersonEconomicGroup.com.

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Ms. Sallee's recent work includes preparing the report *Dollars and Sense*, a 2011 citizen's guide to Michigan's financial health released by Governor Rick Snyder. Ms. Sallee also completes an annual economic impact assessment for Michigan's University Research Corridor (Michigan State University, University of Michigan, and Wayne State University), and has done work for a number of other universities including the University of Chicago. She is also the lead author of the firm's annual 50-state business tax burden study.

Prior to joining Anderson Economic Group, Ms. Sallee worked for the U.S. Government Accountability Office (GAO) as a member of the Education, Workforce and Income Security team. She has also worked as a market analyst for Hábitus, a market research firm in Quito, Ecuador and as a legislative assistant for two U.S. Representatives.

Ms. Sallee holds a Master of Public Policy degree from the Gerald R. Ford School of Public Policy at the University of Michigan and a Bachelor of Arts degree in economics and history from Augustana College.

Alex L. Rosaen. Mr. Rosaen is a Consultant at Anderson Economic Group, working in the Public Policy and Economic Analysis practice areas. Mr. Rosaen's background is in applied economics and public finance.

Mr. Rosaen's recent work includes several economic and fiscal impact analyses, including of proposed real estate developments, power plants, and infrastructure projects; analysis of tax incentives; an analysis of the impact of federal tax incentives on the freight rail industry; and an analysis of the economic contribution that research universities make in the State of Michigan.

Prior to joining Anderson Economic Group, Mr. Rosaen worked for the Office of Retirement Services (part of the Michigan Department of Management and Budget) for the Benefit Plan Design group. He has also worked as a mechanical engineer for Williams International in Walled Lake, Michigan.

Mr. Rosaen holds a Masters in Public Policy from the Gerald R. Ford School of Public Policy at the University of Michigan. He also has a Masters of Science and a Bachelors of Science in mechanical engineering from the University of Michigan.

Erin A. Grover. Ms. Grover is a Senior Analyst at Anderson Economic Group, working in the Public Policy and Economic Analysis practice area. Ms. Grover's recent work consists of several economic and fiscal impact analyses of counties and business ventures throughout the U.S.; evaluating policy changes and potential public funding mechanisms; as well as an analysis of the economic contribution research universities make in Michigan. She is also currently contributing to the book, *Economics of Business Valuation*, a forthcoming publication of Stanford Press.

Ms. Grover holds a Masters degree in Economics from George Mason University and a Bachelors of Science degree in Political Economy from Hillsdale College.