



# Foundation for the Future

## URC Contributions to Infrastructure Improvement

A Report from the University Research Corridor



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**A Report Commissioned by the  
University Research Corridor**

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## THE URC'S INFRASTRUCTURE WORK:

- Makes roads last longer and improves their safety
- Develops clean, renewable energy sources
- Brings broadband Internet to unserved communities
- Keeps software and devices safe from hackers
- Protects our water from pollutants
- Is creating the next generation of connected and autonomous vehicles

## HOW DOES THE URC HELP SOLVE INFRASTRUCTURE CHALLENGES?

- Pushes the boundaries of science to develop new technologies
- Trains the next generation of talent
- Partners with communities and industry to solve tough problems
- Brings ideas from the academic laboratory to the private market



# EXECUTIVE SUMMARY

Infrastructure is the foundation of our economy, and it is essential to our health and welfare. Although often out of mind, roads and bridges, the power grid, clean water, and advanced communications are entrenched in our routines and integral to our daily lives. Advanced manufacturing needs a robust transportation system, reliable power, and rapid communications. Clean, pure water supports tourism and agriculture, and attracts skilled workers and their families to Michigan.

We made big investments in infrastructure in the 20th century—the interstate highway system, the power grid, and the Internet, to name a few. But these investments are starting to show their age. Many roads and bridges in Michigan are in poor condition. The Flint water system, Fraser sinkhole, and concerns over electricity reliability in the Upper Peninsula show the need to invest in infrastructure. However, the future of infrastructure is not just about repairing and maintaining past investments. Rapid technological advances present exciting opportunities to make 21st-century investments with the potential to change our lives. We could soon see a future of driverless, alternatively fueled vehicles that pick you up at your door and drop you off at your destination—all while communicating with other vehicles, the roads, and traffic signals to ensure that your ride is safe, comfortable, and speedy. Continued advances in clean renewable energy technologies may fundamentally change the way we generate power. The Internet of Things (IoT) will make our appliances and infrastructure smart and connected.

The technological changes that turn these innovations into reality are the product of talented individuals working together, learning from one another, and contributing to an ever-expanding base of knowledge. In Michigan, the

University Research Corridor (URC) is the source of some of the best work across a broad range of infrastructure categories. The URC is Michigan's research university cluster, consisting of Michigan State University (MSU), the University of Michigan (U-M), and Wayne State University (WSU).

There are few places in the world with the capacity to do the types of research that occur at the URC. This report uses Governor Snyder's 21st Century Infrastructure Commission's framework for defining infrastructure, looking at water, mobility, energy and communications. The URC institutions conducted \$1.64 billion in infrastructure-related research and service from 2012-2016. And the URC institutions have a long history of innovation, including work on the Merit Network, a precursor of the Internet; the nation's first highway materials testing lab; the Ford nuclear reactor; and more. URC researchers are tackling big infrastructure challenges in water, mobility, energy, and communications. They are working to develop automated and connected vehicles, advancing the Internet of Things, and developing renewable energy sources. A preview of many of these technologies can be seen right now on the campuses of the URC institutions. These campuses serve as best practice laboratories, where many recent advances in infrastructure are demonstrating their effectiveness in real-world settings.

The URC institutions are also important talent generators, providing Michigan with the right people to compete with other states and nations. Finally, the technology transfer functions at the universities help turn discoveries into commodities, helping move the ideas from university labs to the marketplace.

# RESEARCH

## Water



As the Great Lakes State, water is central to Michigan's identity and economy. Recognizing how important clean, pure water is to tourism, agriculture, and manufacturing, URC researchers are testing new technologies to keep our water safe and to monitor water quality. For example, researchers at MSU and WSU have developed buoys that provide real-time water quality readings at beaches and in threatened watersheds. The Healthy Urban Waters initiative at WSU is monitoring the impact of environmental stressors on water quality using field stations in the Detroit area.

Monitoring water safety is not enough. Infrastructure needs to protect water quality and prevent flooding. U-M researchers are developing autonomous "smart" technologies for aging stormwater systems to lessen the impacts of flooding—potentially saving lives and preventing billions of dollars in property damage.

And when something does go wrong with water quality, the URC has demonstrated its ability to assist the impacted communities. URC researchers are on the ground in Flint, helping the city and its residents recover from the water crisis by engaging in several initiatives. Researchers at all three universities have been collaborating to determine how long home water filters can be safely used. WSU researchers are investigating the connection between the Legionella outbreak and the water supply, U-M researchers are collaborating with the Genesee County Health Department to collect data on water quality, and MSU researchers have been developing a registry to help keep track of those affected by the crisis.

## Mobility



Home to the automobile industry, Michigan has long been a leader in mobility. This dates to the beginning of the 20th century, when the first mile of concrete highway was built in Wayne County. To maintain our position in the 21st century, Michigan needs to be a leader in connected and automated vehicles (CAVs).<sup>1</sup>

The URC is vital to this leadership, as all three URC institutions are members of the American Center for Mobility (ACM) Academic Consortium, a nonprofit testing and product development facility for CAVs. Additionally, U-M's Mcity Test Facility is the first purpose-built proving ground for testing CAVs and related technologies in simulated urban and suburban driving environments.

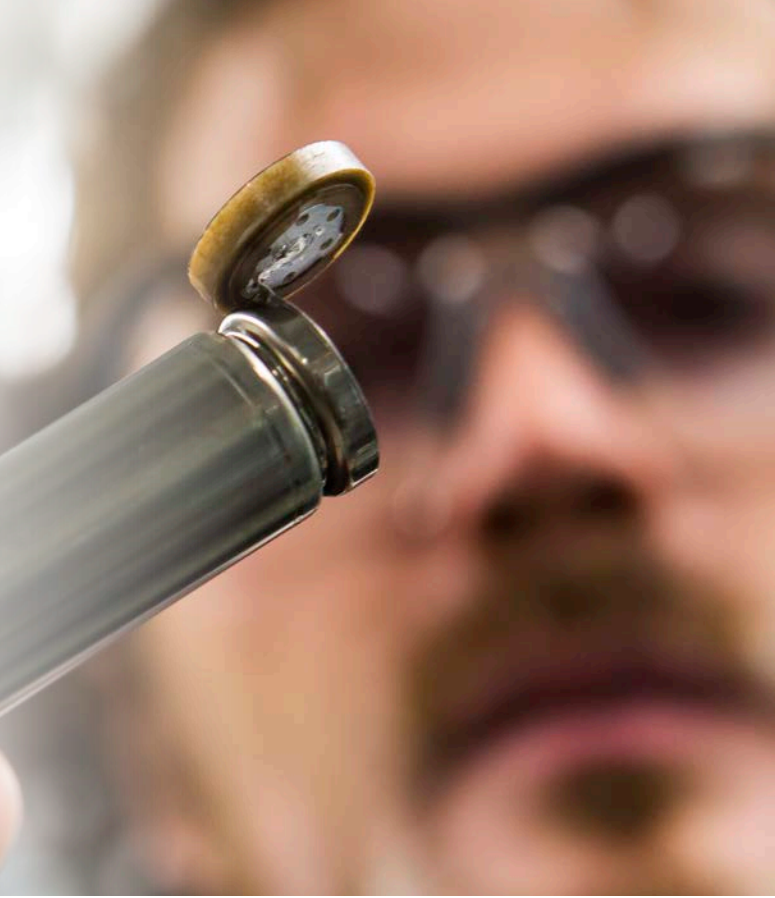
Researchers at MSU's Connected and Autonomous Networked Vehicles for Active Safety (CANVAS) initiative are working on important aspects of CAVs, including sensing, networking, machine learning, communication, security, privacy, traffic modeling, and infrastructure planning.

URC researchers are also working on more traditional mobility issues. U-M researchers are developing a stronger and more durable concrete that comes with a radically reduced cost, while MSU researchers are helping dispose of scrap tires and improve road quality by turning ground-up tires into asphalt. WSU's Transportation Research Group (TRG) is focusing on using technology and large data sets to manage and improve safety and mobility on roadways. Using funding from the Michigan Department of Transportation and the Federal Highway Administration, researchers at WSU are developing and implementing new technologies to improve agency operations. One example is GPS based crowd sourced probed vehicle data which is used to create the Michigan Annual Congestion and Mobility Report. This report is used by planners and engineers to locate congestion issues on Michigan highways and to prioritize road improvement projects.

Mobility also encompasses other modes of moving people and goods, and URC universities are engaged in research in these areas as well. And all three universities have programs in logistics and supply chain. The URC universities are researching innovations in mass transportation and travel by pedestrians, air, rail, and water. With respect to air and water, U-M has engineering programs in aerospace engineering and naval architecture.

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<sup>1</sup> The term automated and autonomous are often used interchangeably. However, autonomous suggests more automation with less human intervention than automated (Levinson 2017). Therefore, automated is the more generic term and is generally used throughout this report except in specific examples where autonomous is more appropriate.



## Energy



Energy infrastructure powers our homes, factories, and our economy. As the nation moves toward renewable sources, biofuels represent a promising opportunity. MSU researchers co-lead the Great Lakes Bioenergy Research Center with the University of Wisconsin-Madison. The Center's researchers are using plants such as switchgrass, poplar trees, and sorghum to create specialty biofuels. U-M and MSU researchers are both working on ways to use algae to develop biofuels. WSU helped establish the National Biofuel Energy Lab in Detroit's Midtown neighborhood.

URC researchers are also working to design better batteries for the widespread adoption of electric and hybrid vehicles. At WSU, researchers are exploring the possibilities of lithium-sulfur batteries, potentially a more powerful and less expensive alternative to lithium-ion batteries. MSU researchers are also looking to improve lithium-ion batteries by making them safer, longer lasting, and less expensive. Most lithium-ion batteries are liquid based, but MSU researchers are trying to determine if a solid material could work better.

Advanced energy storage solutions are also needed to help increase the reliability of wind and solar power. U-M's Battery Lab, which opened in 2015, secures a leadership position for Michigan in the development of energy storage solutions by providing space and tools for researchers to find ways to make batteries lighter, safer, and less costly.

## Communications



The URC institutions have also paved many paths forward in the realm of communications technology. MSU, U-M, and WSU established the Merit Network in 1966, which pioneered many of the forms of communication in use in today's Internet. The URC is continuing to work on advancing high-speed connectivity; its researchers are looking to speed downloads through Internet traffic jams. URC researchers are also developing the low-power communications sensors that will enable the expansion of the IoT. The IoT allows common devices, such as furnaces and refrigerators, to exchange data via the Internet. With IoT sensors, your furnace can tell you it needs a new filter or a repair. This connectivity can work for infrastructure as well; embedded sensors can detect water quality problems in real time, and CAVs can "speak" with each other and communicate with roads, traffic lights, and other infrastructure.

Communications research, the IoT, and other innovations are harnessing the power to connect vast sources of data and make sense of it. The ability to analyze massive data sets and identify patterns and trends leads to innovations in diverse fields. This improves safety and efficiency in utilities, enables medical innovations and healthcare solutions, enhances security of data and systems referred to as cybersecurity, and leads to many other advances.

URC researchers are also bringing advanced broadband technologies to all regions of the state. Communities are finding it increasingly difficult to attract businesses and residents without access to high-speed Internet. URC researchers, including MSU's Quello Center, are connecting these communities, and ensuring that the state's poorest residents are not left out of the rapidly advancing economy. The Merit Network continues its legacy of utility and innovation by expanding access to communications. Its backbone connects hospitals, K-12 schools, universities, libraries, and government institutions.

As more devices connect to the Internet, our lives become more vulnerable to hackers. The URC, however, is a leader in cybersecurity, particularly through MSU's Cyber Security Lab, U-M's Center for Computer Security and Society, and WSU's Cyber Range Hub. WSU's efforts are particularly noteworthy for its community benefits—the hub provides lab space for cybersecurity training, testing, and teaching; individuals in the region can enroll in noncredit-bearing professional development courses; and businesses can use the facility to test software.



# URC CAMPUSES AS BEST PRACTICE LABORATORIES

The URC campuses showcase the infrastructure that is likely to move into widespread use in the near future. MSU's Energy Transition Plan uses infrastructure to improve efficiency and move to alternative energy sources while keeping an eye on the bottom line. MSU's Solar Carport Initiative utilizes space at the university's parking lots to generate solar power. Private companies financed the installation and will maintain the infrastructure in exchange for MSU purchasing the power generated. Energy-efficiency efforts at MSU's Anthony Hall reduce energy use by 34 percent and save \$536,000 per year. While there was an upfront investment, MSU will recoup this investment in just seven to ten years.

WSU is using its campus as a laboratory to define the future of transportation. Researchers are making the campus a testbed for developing new technologies for traffic engineering, performance measurement, network communications, and public safety. This research is being done in partnership with the City of Detroit.

Mcity, a CAV testing facility on U-M's Ann Arbor campus, is testing two driverless shuttles that will transport U-M students, faculty, and staff between research facilities. Mcity and the U-M Transportation Research Institute are deploying 1,500 vehicles that will operate throughout a connected vehicle infrastructure in Ann Arbor.

MSU and U-M are both working to protect the rivers that run through their campuses by reducing stormwater runoff and the volume of synthetic chemicals used in property management.

## TALENT

As infrastructure becomes more technically complex, the need for a skilled workforce to design, install, and maintain it increases. And as mobility infrastructure evolves, Michigan needs this skilled workforce to help ensure that Michigan remains a global leader in vehicle design and production.

Between 2012 and 2016, the URC awarded 34,234 infrastructure-related degrees at the bachelor's level or higher, accounting for half of all such degrees awarded in Michigan. The URC awards 43 percent of Michigan's bachelor's degrees, 63 percent of master's degrees, and 86 percent of PhDs. The URC ranks fourth among the nation's top university clusters in infrastructure degrees awarded. The URC ranks third among the university clusters in bachelor's and master's degrees awarded and sixth in PhDs.

## TECHNOLOGY TRANSFER

Technology transfer represents an important extension of the research process. While research can have an immediate impact by bringing important knowledge to the field, some research needs to be extended. Commercial partners enter at this stage, offering the resources and technical knowhow to bring discoveries to market.

The commercialization process at the URC institutions ensures that inventions are disclosed and evaluated for market potential. Intellectual property is protected with copyrights and patents, and the universities can find potential partners to license the research or provide the financing needed to make it marketable. When appropriate, the universities also can provide the support needed to turn an invention into a successful startup company.

Many infrastructure inventions have the potential to be commercialized, such as MSU's breakthrough with clear solar panels. Because the solar panels are transparent, they can be used in windows and as phone screens. The university has entered into a licensing agreement with Ubiquitous Energy, which has already identified practical uses for the technology, including extending the battery life of mobile devices.

The URC institutions have the facilities that help bridge technological breakthroughs and the marketplace. The ACM and Mcity allow entrepreneurs to test their inventions relating to CAVs. WSU's IoT laboratory will also provide facilities that can aid inventors in testing and perfecting their products.







## CONCLUSION

Aging infrastructure threatens the quality of our water, and rapid advances in mobility technologies threaten our place as a global automotive leader. However, infrastructure is also rich with possibility. Building on a rich history of infrastructure discoveries, the researchers and facilities at the URC institutions have positioned the state to lead the next generation of mobility advances. Advanced sensors combined with infrastructure can help keep our water clean and can make the power grid smarter. URC faculty are working to ensure that advanced broadband reaches all of our communities and residents, and building technologically feasible and scalable models for cleaner, cheaper energy sources.

Michigan's future can be bright, thanks in large part to the innovative work occurring at the URC, which will create the foundation our state needs for a prosperous future.



## OVERVIEW

Infrastructure underlies and supports modern society. Roads and bridges, a reliable and efficient power grid, clean water, and advanced communications technology are the backbone of the economy. Infrastructure investment has driven our state's and nation's greatest economic successes. Now, new investment is needed to increase long-term productivity growth, economic development, public health, and manufacturing competitiveness (Rollins and Datta 2016).

Twentieth-century infrastructure investments have been so successful that infrastructure can seem boring. The nation's power grid, the interstate highway system and supporting roads and bridges, the Internet, and our water system are all tremendous success stories. They just work: the lights come on when you flip the switch, clean water flows when you turn the tap, and safe modern roads allow rapid transit from one end of the country to the other.

Unfortunately, the reliability we so often take for granted is at risk. Michigan's and the nation's infrastructure are showing their age. The Flint water crisis is the most dramatic recent instance of failing infrastructure, but the system faces many challenges beyond Flint. Governor Snyder's *21<sup>st</sup> Century Infrastructure Commission Report* (2016) highlights some of these hurdles. According to the report, 39 percent of Michigan roads are in poor condition and 27 percent of bridges are structurally deficient or obsolete. Since 2008, an average of 5.7 billion gallons of untreated sewage flowed into Michigan waterways each year. Sixty-four rivers—which drain 84 percent of Michigan's Lower Peninsula—recently tested positive for human sewage. Approximately 12 percent of the state's households lack access to advanced broadband. And the Upper Peninsula has recently struggled with balancing electricity reliability and affordability due to planned power plant retirements.

Michigan—and the nation—must solve the problems that emerge from outdated and underfunded infrastructure. President Trump has introduced a plan to spend at least \$200 billion in federal funds on infrastructure with the intention of spurring more than \$1 trillion dollars in state, local, and private investment. Closer to home,

Michigan needs to invest to address challenges with aging infrastructure, while looking to the future to champion the advanced infrastructure that will drive the state's economy through the century.

The 21<sup>st</sup> Century Infrastructure Commission laid out a vision for Michigan's future:

*"Michigan will lead the nation in creating 21<sup>st</sup> Century infrastructure systems that will include innovative technology, sustainable funding solutions, sound economic principles, and a collaborative and integrated asset management and investment approach that will enhance Michigan's quality of life and build strong communities for the future."*

The commission outlined 22 recommendations for achieving this vision. These recommendations included maintaining our status as a global leader in intelligent vehicle and other emerging technologies; increasing the share of electricity generated from clean renewable sources; using advanced technologies to design and build a 21<sup>st</sup> century water infrastructure; and finding innovative ways to secure Michigan's digital infrastructure.

As will be seen throughout this report, the URC's research in advancing infrastructure technology in water, mobility, energy, and communications is helping the state devise ways to implement the commission's recommendations for the infrastructure we need today and the infrastructure we plan for tomorrow. Michigan needs world-class infrastructure for its economy to compete with the rest of the nation and world. The URC's work in CAVs is an excellent example of how the URC is helping Michigan compete. Exciting advances in connected and automated vehicles occur in the state every day; however, to remain an innovation leader, Michigan also needs to break ground in infrastructure. Smart and connected roads, advances in sensors and communications technology, and innovations in battery technology are all vital to the future of mobility.

The rapid changes around CAVs present immense opportunities and threats for Michigan. Our state has long led the nation in automobile research and development (R&D) and production; Michigan houses 375 automotive R&D centers and accounts for 76 percent of the nation's business-funded automotive R&D (MICHauto n.d.). Automobile R&D and production create tens of thousands of jobs, billions of dollars in income, and is far and away the state's most important industry. However, there is no guarantee that Michigan will remain an automotive leader. Boston, Pittsburgh, and Silicon Valley are also researching the technologies for vehicles of the future (Arison 2017). Tesla's manufacturing plant in Fremont, California, is just a stone's throw from Silicon Valley, illustrating the increasing

importance of information technology to the development and production of cars and trucks.

Like mobility, water is vital to our daily lives. The Flint water crisis illustrated the risks of a failing water system. Water is vital to the state's economy and intrinsic to the state's identity. It supports jobs in tourism, agriculture, transportation, and manufacturing an estimated one in five Michigan jobs are tied to water (Rosaen, 2014).

Communications are important as well. Communities need access to advanced broadband services to support businesses and attract residents. Manufacturing now requires much more advanced software, connectivity, and a skilled information technology workforce.

Michigan's power production is also in transition. Legal changes, advances in technology, and concerns about greenhouse gases and other pollutants are moving Michigan away from legacy coal power plants and toward more renewable energy sources. These changes will continue as Michigan moves toward wind and solar, and away from greenhouse-generating fuels.

The URC institutions play an essential role in helping Michigan meet its infrastructure challenges. These flagship universities are a vital source of talent, awarding half of the state's degrees and producing a talent base competitive with the top university clusters around the country. As illustrated throughout this report, the URC, its facilities, and its talent model innovation in water, energy, mobility, and energy.



*"Safe and reliable infrastructure is critically important to the health and well-being of the people of Michigan and will help support our growing economy in the future. Our state is poised to be a global leader in emerging technologies as we move forward in the 21<sup>st</sup> century, so it is essential that we have the infrastructure to match our goals."*

— Gov. Rick Snyder, December 5, 2016





# **RESEARCH**

## Overview

As leading research institutions, MSU, U-M, and WSU account for 92 percent of all academic R&D in Michigan (URC 2018). A review of funded infrastructure projects at the URC institutions identified more than 5,900 research projects totaling \$1.64 billion occurring over the past five years.<sup>2</sup> Through these projects, URC researchers are working to solve today's infrastructure problems and innovating for tomorrow.

### URC Infrastructure Research (2012–2016)

#### \$1.64 Billion in Total Infrastructure-related Awards

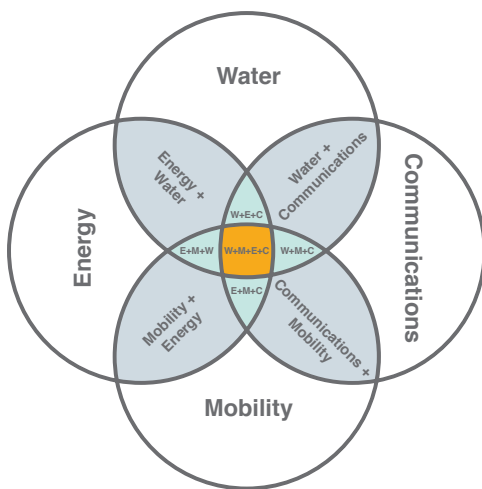
- Water: \$205 million
- Mobility: \$408 million
- Energy: \$695 million
- Communications: \$630 million
- R&D that fits more than one category: \$274 million

This research is not esoteric; rather, it focuses on issues that impact the daily lives of millions of Michiganders. Researchers are studying the effectiveness of Flint water filters. They are testing automated vehicles in real-world conditions. They are looking for ways to bring broadband to unserved communities.

In this section, we provide just a sampling of the important infrastructure research the URC institutions are doing in water, mobility, energy, and communications.

## Water

Water is central to Michigan's identity. It is home to 104,252 square miles of water, the most in the contiguous United States. It has 11,000 inland lakes and 3,400



miles of shoreline (Austin, Good, and Kolluri 2017). Water is vital to Michigan's economy, and is used in farming, manufacturing, mining, and energy production. One in five Michigan jobs is tied to industries closely related to water quality and quantity (Rosaen 2014).

Michigan's water infrastructure helps keep our water clean and pure, and it delivers safe drinking water to millions of state residents. It helps protect streams and lakes from sewage discharge and contaminated stormwater runoff. However, it is a system under stress. There is an estimated \$800 million annual gap in the investment needed to meet Michigan's water infrastructure needs resulting from decades of deferred maintenance (21<sup>st</sup> Century Infrastructure Commission 2016). The challenges with the current system are becoming more obvious; water shutoffs in Detroit, the sinkhole in Fraser, the Flint water crisis, and the billions of gallons of raw sewage that flow into Michigan waters each year point to a system in need of attention.

## Water Quality and Safety

U-M researchers are working to improve aging stormwater systems to lessen the impact of flooding. These researchers outfitted stormwater systems with autonomous sensors and valves that can adjust in real time to improve water quality and reduce flooding, which is the leading cause of fatalities and property damage during major weather events. Torrential rains can often overwhelm stormwater systems, leading to massive flooding, as was seen recently with Hurricane Harvey in Texas. A complete fix would require communities to replace their old infrastructure, an option too expensive for many to even consider. With sensors that allow for real-time adjustments, U-M researchers are helping find ways to improve existing legacy infrastructure to help address flooding (Lynch 2017).

Embedding sensors and communications technology into other types of infrastructure represents an important advance with many applications. Researchers at WSU recently won an award for their research using a combination of nanotechnology-based sensors, microbatteries, and wireless communication. The team is using these technologies to develop buoys with aquatic sensor technology to assess water quality in real time. The device's batteries can be recharged with solar power. The group is using this technology to monitor Lake Erie for phosphorus and other harmful nutrients (WSU College of Engineering 2017).

MSU researchers have also used buoys to improve water safety. Researchers have embedded sensors in buoys that can provide real-time information on water quality at beaches. Previously, water needed to be sent to a lab for testing, which can take 24 to 48 hours. With the buoy

technology in place, it will be much easier to protect beachgoers from contaminated water (Mantha and Oswald 2016).

Researchers at the URC institutions are doing important work to protect the state's watersheds. WSU's Urban Watershed Environmental Research Group (UWERG) focuses on ecological and human health within the St. Clair Watershed (WSU Living Green 2017). One important project of the UWERG is the Healthy Urban Waters (HUW) initiative, which focuses on mitigating environmental degradation due to human activities, such as polluted stormwater runoff and industrial wastewater. The HUW gathers data from three field stations in the Detroit area that help monitor the effects of environmental stressors on water quality, the interface of groundwater and surface water, the impact of invasive species, and other topics important to the watershed (WSU HUW 2017b).

Water systems are vulnerable not just to contaminants from municipal and industrial sources, but also potentially from terrorist activities. Knowing this, researchers at the HUW are collaborating with local public health departments in Wayne, Oakland, and Macomb Counties and with the military to install sensors that can monitor for a variety of potential contaminants to the water supply. These new smart sensors and integrated microsystems provide data in real time and replace tests that take 24 hours to conduct, significantly improving public safety (WSU HUW 2017a).

Water shortages can also threaten the safety of our communities. MSU researchers recently sounded the alarm that groundwater was being withdrawn from one of Ottawa County's major aquifers faster than it could be replenished. This poses a significant risk, since the overuse caused brine at the bottom of the aquifer to be drawn into drinking and irrigation wells. MSU Extension is also part of the study team and will help the community develop potential solutions once enough is known about the problem (Schindler 2012).

The Michigan Sea Grant is a collaborative effort of MSU and U-M and is part of the National Sea Grant College Program. The program increases understanding, conservation, and use of Michigan's coastal resources. Grant funds support research, education, and outreach, including supporting extension educators located in Michigan's coastal communities (Sea Grant Michigan n.d.).

The Water Center at U-M's Graham Sustainability Institute addresses critical and emerging regional and national water issues. The Water Center works collaboratively with natural resource managers, nonprofit and business leaders, and policymakers from all levels of government to develop high-quality, usable, research benefitting the Great Lakes region and the nation (Graham Sustainability Institute Water Center 2017).

*Continued on page 16*





# PRESERVING OUR STATE'S FRESHWATER HERITAGE

Perhaps no resource is as precious or as integral to Michigan's identity as water. Outlined by Lakes Superior, Michigan, Huron and Erie—the shape of Michigan's two peninsulas is unmistakable. In addition to bordering four of the five Great Lakes, Michigan is home to more than 11,000 inland lakes and 36,000 miles of rivers, streams, and wetlands (21<sup>st</sup> Century Infrastructure Commission 2016). Beyond defining the state's boundaries and topography, Michigan's freshwater resources are fundamental to the state's economy, providing countless recreation and economic opportunities. A 2014 study—commissioned by the URC—found that one in five jobs in the state rely on water resources (URC 2014).

While Michigan's abundant freshwater resources provide great economic benefit, they also come with a great deal of responsibility. Michigan's location at in the center of the Great Lakes Basin—home to 90 percent of the nation's freshwater resources—means that the state's role in protecting the health and vitality of the Great Lakes is not just a local or even regional concern but an issue of continental importance.

Problems with Michigan's water infrastructure have gained national attention in recent years. From the Flint water crisis to harmful algal blooms in Lake Erie, Michigan's deteriorating water infrastructure causes significant damage to the state's resources and public health and safety. According to Glen Daigger, professor of engineering practice at U-M, "Aging urban infrastructure is a serious problem facing the nation, and the Flint water crisis is simply one point of proof. As a nation, we must be able to immediately and efficiently provide a solution to, or support for, either the rehabilitation of distressed infrastructure, or replace it with higher-performing systems" (URC 2017).

Recognizing the need for creative solutions to Michigan's water infrastructure needs and the importance of collaboration in addressing these issues, URC institutions have joined forces to form the Infrastructure Network for Water (inH2O). Founded in March 2017, inH2O converts scientific research into practical applications to address water infrastructure needs in Michigan and across the country. The inH2O initiative will draw on expertise from corridor universities as well as national experts from academia, industry, and government to develop new strategies for improving infrastructure and protecting water resources. Carol Miller—codirector of WSU's Healthy

Urban Waters (HUW) program—explained, "It was a logical decision for these three universities to combine expertise in development of a nation-leading water infrastructure network. We expect inH2O to play a leading role in the research, maintenance, and implementation of numerous technologies and innovations relating to Michigan's water resources" (URC 2017).

While the URC inH2O partnership is a recent initiative, URC institutions and researchers have worked on water-related issues for years. Through university programs and centers, faculty engage with urban and rural communities statewide to implement new infrastructure technologies, measure the impact of existing infrastructure on residents' health and well-being, and learn about residents' greatest needs as they continue to innovate the next generation of technologies.

At MSU, researchers connect with communities in every Michigan county through the MSU Extension program. MSU Extension's mission is to provide residents, businesses and communities with the resources and science to improve agricultural practices and sustainably and effectively manage natural resources and water infrastructure. In this work, MSU Extension and researchers help communities with issues related to onsite septic systems. In Michigan, 30 percent of households rely on septic systems to manage wastewater, and it is estimated that at least 10 percent of these systems are failing (21<sup>st</sup> Century Infrastructure Commission 2016).

Until recently, there has been little understanding of the impacts septic systems have on public health and the environment. Even scientists were unsure of the effects until MSU researchers led by Professor Joan Rose—the Homer Nowlin Endowed Chair in Water Research—discovered the connection between the prevalence of septic systems and freshwater contamination in Michigan watersheds. According to Rose, "All along, we have presumed that onsite wastewater disposal systems were working, but in this study, sample after sample, bacterial concentrations were highest where there were higher numbers of septic systems in the watershed area" (Kastl 2015).

For Professor Rose, the work doesn't stop at identifying the problem. She calls for "better methods [to] improve management decisions for locating, constructing, and maintaining onsite wastewater treatment systems" (Kastl 2015). Through the Septic System Education program, MSU Extension uses Professor Rose's research to provide homeowners and communities with educational resources to ensure onsite wastewater management systems are properly installed and maintained. MSU Extension also provides communities with access to expertise for improving planning and developing better policies.

In contrast to MSU's research and outreach that works in communities statewide, the Healthy Urban Waters

program at WSU focuses on water infrastructure needs specific to urban environments. Founded in 2009, HUW works to promote research, provide education, advance new technology, and engage the public (WSU n.d.b.). Through the HUW program, WSU researchers explore a variety of areas related to water infrastructure and quality, including use and management, biology, engineering and design, and policy. HUW focuses on the Lake Huron to Lake Erie corridor in Southeast Michigan, which serves as the drinking water source for more than six million people (Guzmán 2016). The program's efforts to support urban water resources along the Huron-Erie Corridor center around improving research capabilities at field stations located on Lake St. Clair in Macomb County, Belle Isle in the Detroit River, and at the Great Lakes Water Authority Water Works Park.

Expanding water quality monitoring sites near Detroit opens the door to urban water quality research. HUW researchers are particularly concerned about the quality of water at beaches in the Huron-Erie Corridor because communities do not require water quality monitoring at these locations (WSU n.d.a.). In more affluent communities along the Huron-Erie Corridor, water quality is monitored regularly, but in economically disadvantaged areas like Detroit, there are limited resources for monitoring, which means problems can arise that expose the public to potentially harmful bacteria levels. WSU's expanded water monitoring and research capabilities enable significant new research around this issue. HUW's codirector and WSU professor Jeffrey Ram puts these new resources to use. In the Spring of 2017, Professor Ram received funding through HUW to continue his research of contamination levels and the sources of bacteria at beaches throughout the Huron-Erie Corridor (WSU n.d.a.).

At U-M's Graham Sustainability Institute Water Center, protecting the Great Lakes is priority one. Founded in 2012, the Water Center connects U-M research with multidisciplinary and multisector perspectives to improve policies and management decisions impacting water resources. The Water Center focuses on four areas: water quality, water quantity, climate change, and habitat (U-M 2017). From researching the impacts of invasive species on native fish populations in Lake Huron to addressing implications of variable water levels for shoreline communities on Lake Michigan, the Water Center has tackled some of the most challenging issues facing the Great Lakes (Plazza 2015).

Despite past success addressing challenges in the Great Lakes, new problems are emerging. About a decade ago, scientists noticed increased frequency and severity of toxic algal blooms in Lake Erie. The problem gained national attention when the City of Toledo advised residents not to drink the water, as toxic algae overwhelmed water

treatment facilities. Lake Erie's troubles are not new, the lake was unofficially declared dead in the 1960's due to environmental damage, but the lake was reinvigorated following the passage of the Clean Water Act, which cracked down on pollution responsible for the lake's decline.

U-M's Water Center researchers are at the center of the latest fight to revive Lake Erie. According to Don Scavia, Professor Emeritus at U-M, "Toxic algae not only harm your drinking water—excess algae also can reduce the fish population in the Great Lakes. We can no longer cross our fingers and hope for the best. We need to look for ways to reduce nutrient runoff so we can protect the health and vitality of our lakes" (Plazza 2015). Supported by the Water Center, U-M researchers are working on a variety of research projects aimed at curbing the impact of harmful algal blooms by predicting bloom severity before they occur, providing ongoing monitoring of water quality to warn municipal water utilities of pending issues, and identifying strategies to reduce harmful phosphorous and nitrogen runoff that proliferates these toxic events.

While sustaining the long-term health and vitality of Michigan's water resources is difficult work, corridor institutions and partnerships led by the URC provide innovative solutions to the valuable ecosystems' challenges.



URC researchers have also contributed their expertise to help protect the Great Lakes through service to the International Joint Commissions (IJC). The IJC is a bi-national organization established by the governments of the United States and Canada under the Boundary Waters Treaty of 1909, to protect our shared natural resources. A number of researchers across the URC institutions have shared their expertise with the IJC over the years. Currently Dr. Carol Miller, professor and chair of the Department of Civil and Environmental Engineering at WSU, and David Allen, professor emeritus of the School of Resources and Environment at U-M were appointed and serve as co-chair and member, respectively, on the IJC's Science Advisory Board.

## Flint Water Crisis

The city of Flint continues to struggle with the repercussions of its recent water crisis, so URC students and faculty are engaging in the community in a wide variety of ways. Several studies have shown that there are bacteria risks associated with the use of water filters residents use, so URC researchers are studying the filters' effectiveness and how frequently they need to be changed. These researchers have been able to provide residents with much-needed information on how to safely use water in their homes (Oswald, Moore, and Lockwood 2016).

In response to the environmental contamination of Flint's municipal water system, Drs. Shawn McElmurry and Paul Kilgore of WSU's Center for Urban Responses to Environmental Stressors (CURES), received funding from the National Institutes of Environmental Health Sciences in 2016 to investigate and combat adverse health effects emerging from water contamination and disinfection-by-products in vulnerable persons. WSU created the Flint Area Community Health and Environmental Partnership (FACHEP), a consortium led by WSU that also includes MSU, U-M, Kettering University, Colorado State University, and the Henry Ford Health System. FACHEP conducted an independent study looking at the Legionnaires disease outbreak in Flint and the possible connection to the water system. These researchers analyzed Legionnaires cases in Genesee, Oakland, and Wayne Counties and found that an estimated 80 percent of cases occurring during the 2014–2015 outbreak in Genesee County can be attributed to the change in the city's drinking water supply to the Flint River. The results of this study were published in peer-reviewed journals verifying that the methods and conclusions of the study met rigorous standards for accuracy (Lockwood 2018).

The WSU CURES team also spearheaded a key component of a comprehensive research program entitled Environmental Influences on Child Health Outcomes (ECHO) Pediatric

Cohorts. Funded by the National Institutes of Health in 2016, this \$28 million multi-institutional research program, led by Dr. Nigel Paneth of MSU, engaged investigators and project leaders from MSU, U-M, and WSU, the Michigan Department of Health and Human Services, the Henry Ford Health System, and other regional partners. Together, this group of scientists, clinicians, and educators seeks to understand the child health impact of complex toxic exposures that occur during vulnerable periods of growth and development.

U-M researchers at the School for Public Health have been collaborating with the Genesee County Health Department to collect data on water issues. The data encompasses water quality (taste, smell, appearance), what residents use drinking water for, why they buy bottled water, and any difficulty they have paying their water bills (U-M School of Public Health 2018).

MSU is creating a registry of residents who were exposed to lead-contaminated water during the water crisis. The registry is part of MSU's long-term commitment to the city. The project will link key participant data—including exposure, health and childhood developmental milestones to community intervention services—and will track the information over time to guide future policy recommendations (Kelley, Gleason, and Cantor 2017).

MSU Extension was recently honored by the U.S. Department of Agriculture for its response to Flint's water crisis, which included identifying the highest-risk areas in need of education and outreach, developing nutrition guidebooks and fact sheets, facilitating the donation of milk, and partnering with other organizations to fund and distribute water filters and soil tests (Scarber 2016).

## Water Infrastructure and the Social Sciences

The Flint water crisis demonstrated that while engineering and science are critical to infrastructure issues, social sciences such as public policy and urban planning are just as important. Sociology researchers at MSU showed that people of color pay more for basic water and sewer services than white people, as a result of white residents fleeing urban areas, leaving the remaining minority residents to bear the cost of maintaining aging water and sewer systems (Henion and Gasteyer 2011). This issue was clearly in play in Flint, where despite the poor water quality, residents paid the highest water rates in the nation (Wisely 2016).

MSU researchers have shown that if water rates continue to rise at their projected rates, nearly one-third of U.S. households will be unable to afford water in just five years. Mississippi has the highest concentration of at-risk households and Michigan ranks 12<sup>th</sup> on the list. This



study has provided an early warning that current policies for financing water systems might not be sustainable in the long run (Henion and Lunt 2017).

Getting research knowledge into the field where it can be applied can be challenging. The Center for Urban Responses to Environmental Stressors (CURES) at WSU works to improve communication between researchers and the public on environmental issues, including water issues. CURES researchers recently developed a Detroit Farmers' Water Management Almanac designed to advise on matters of irrigation and water management techniques (WSU CURES 2018).

U-M researchers are also working to bridge research knowledge and community practice. The Urban Collaboratory at U-M draws researchers together to work directly with city stakeholders to address the challenges faced by urban communities. As part of this initiative, U-M researchers are working to improve water service delivery in Benton Harbor by integrating health and asset management techniques. Researchers in the Urban Collaboratory are also helping the city address water quality problems associated with agricultural runoff.

## Mobility

As the modern automobile industry developed here in Michigan, the industry transformed the state and nation—reducing the cost of transporting goods and people, making the economy more efficient, and increasing standards of living for people everywhere. Further, the high-paying manufacturing jobs of Michigan's automobile industry helped create America's middle class.

It is no surprise, then, that Michigan has long been a leader in mobility infrastructure as well. In 1909, the nation's first mile of concrete highway was built in Wayne County. The state also was the first to create a superhighway and complete a border-to-border interstate (Michigan Department of Transportation 2015).

URC institutions have long supported this mobility infrastructure through research. The nation's first highway materials testing laboratory was at U-M. WSU professor Lawrence Patrick supported the development of crash test dummies by using his own body to test the effects of auto crashes. Data from his tests eventually led to the creation of humanoid crash test dummies (WSU 2018).

URC schools helped advance the business side of the auto industry, too. In the early 1960s, leaders of Ford, General Motors (GM), and Chrysler reached out to the MSU Business School for help with professional development for rising executives. Starting in the fall of 1964, 46 executives began meeting two nights a week to earn an MBA in the

newly developed Advanced Management Program. Over the years, this program yielded auto industry leaders like former Ford chairman and CEO Alexander Trotman, former GM chairman and CEO Robert Stempel, and former Chrysler CEO James Holden (MSU Eli Broad College of Business n.d.).

The development of the modern auto industry in the early and middle 20<sup>th</sup> century represented a time of enormous technological innovation. Thanks to CAV technology, this sector is poised to take a technological leap forward once again.

## Connected and Automated Vehicles

Stakeholders across Michigan are working to leverage the state's unparalleled automotive heritage to become the center of CAV technology development. This emerging industry could improve safety and alter the way we get around. It could also drive job creation, talent retention, and economic development, and improve quality of life.

The term "connected and automated vehicle" can refer to a variety of vehicle technologies currently being implemented to improve travel. These technologies may work at the level of the vehicle, the transportation system, or both. Many types of connectivity and automation are feasible, as are many ways to combine them. For example, some vehicles could be connected without being automated, and possibly others could be automated without being connected (though increasingly, vehicles are connected one way or the other, even if only via a 4G LTE device inside the vehicle).

Meanwhile, an automated vehicle could theoretically only rely on information from its sensors (camera, radar, etc.) to perceive the external environment, and human-operated vehicles can have connectivity applications (telematics, GPS, etc.). Further complicating these discussions, both connected and automated systems are often conflated with intelligent transportation systems (ITS). ITS may include CAV systems, but is a much broader concept involving a variety of advanced applications that go beyond vehicle systems. For example, CAV technologies may or may not integrate into ITS, depending on the specific application.

URC researchers are at the forefront of CAV technological advances. All three institutions are members of the ACM Academic Consortium, a nonprofit testing, education, and product development facility "designed to enable safe validation and self-certification of connected and automated vehicle technology and future mobility and to accelerate the development of voluntary standards (ACM 2017)." The ACM is one of just 10 automotive proving grounds that have been approved by the U.S. Department of Transportation.

*Continued on page 20*



# URC PAVES THE WAY FOR NEW MOBILITY

Michigan has long been at the forefront of transportation, revolutionizing the way people and goods move around the world. Today, the state continues to lead this sector, particularly as the automotive industry reaches a crucial moment in the advancement of mobility.

Advanced mobility technologies, such as connected and autonomous vehicles (CAVs), will significantly improve transportation safety, equity, and access. Beyond public health benefits, CAVs present opportunities to expand Michigan's workforce capacities today to capitalize on the industry needs of tomorrow.

The URC and American Center for Mobility (ACM) are advancing transportation training demands for the next generation of talent. The ACM is a nonprofit testing, education, and product development facility for future mobility. The URC and 12 other Michigan universities and colleges have formed an academic consortium with the ACM to help the workforce meet emerging industry needs. Consortium members identify courses and training program needs, as well as recruitment opportunities, internships, co-op and work-study programs.

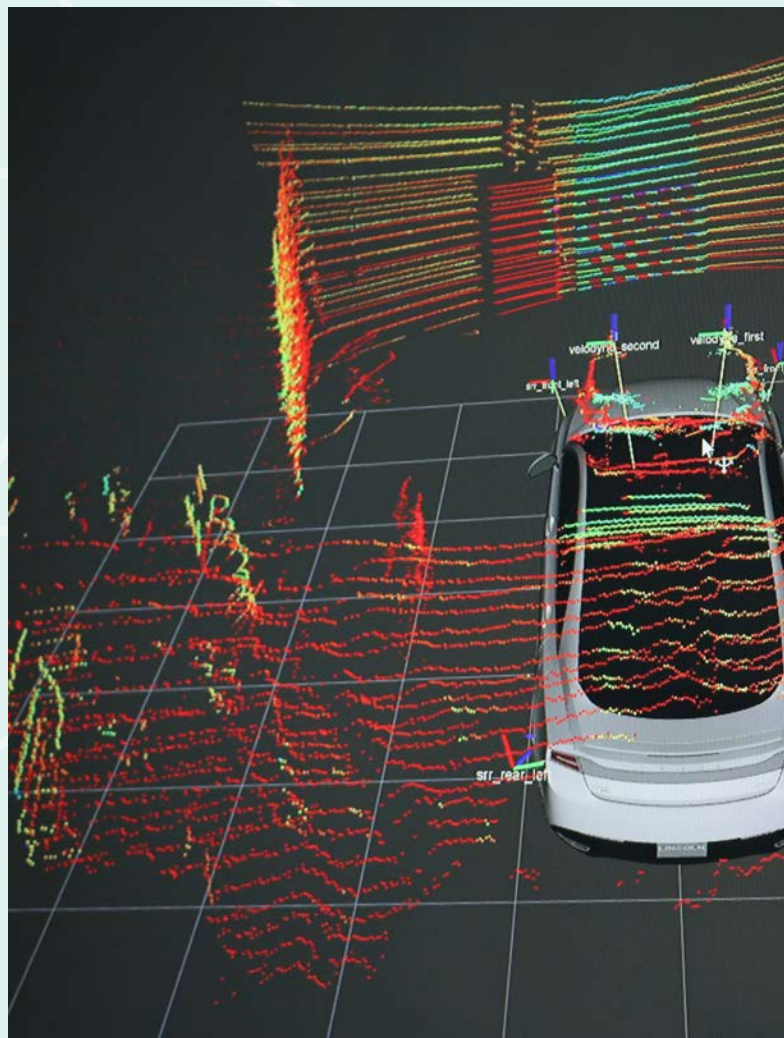
"We are proud to partner with Michigan's world-class academic institutions to ensure we have the top talent needed to lead this automotive and technological innovation," said John Maddox, president and CEO of the ACM. "This first-of-its-kind collaboration will solidify Michigan's place as a global hub for CAV technologies" (Shavers 2017).

Although the consortium's curricula are in early development, programming will cover a diverse range of topics, such as legal training, software development, and vehicle repair. Classes will vary from continuing education to postgraduate courses and will be held at the ACM and consortium schools.

"CAVs will create new regulatory questions, so we will need lawyers trained and aware of future transportation issues," Maddox says. "We will also need people who can service autonomous vehicles because it's not your normal repair work. These vehicles will have software updates on a regular basis" (Schmid Stevenson 2017).

Outside of the consortium's work, the URC is addressing questions related to automotive engineering, law, policy, cybersecurity, business, social sciences, and urban planning—all of which will be impacted by advanced mobility.

U-M formed Mcity, a group of industry, academic, and corporate partners that focuses on research and education

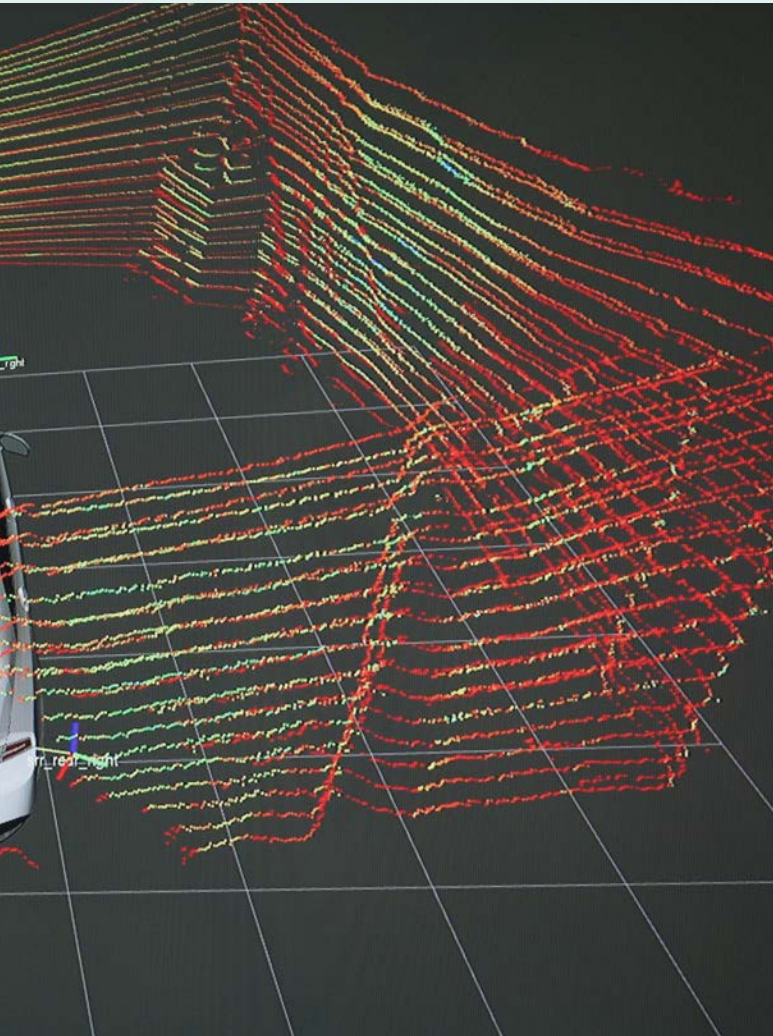


for all areas impacted by CAVs. It is also home to a one-of-a-kind urban CAV-testing facility used for on-road vehicle deployment. Mcity, along with the ACM, will span the range of mobility technology developments—from basic and applied research to product validation and certification.

"By providing a platform for faculty, students, industry partners, and startups to test CAVs, we will break down technology barriers and dramatically speed up innovation," said Carrie Morton, deputy director of Mcity. "We're democratizing access to automated vehicle technology for research and education" (Carney 2016).

WSU is focusing their efforts on controlling CAVs on highways, a critical component of developing smart transportation systems. A research team led by Le Yi Wang, professor of electrical and computer engineering, is





At MSU, researchers are involved in work that will someday make self-driving vehicles commonplace. Through the CANVAS project, or Connected and Autonomous Networked Vehicles for Active Safety, MSU scientists are focusing on the recognition and tracking of objects, such as pedestrians or other vehicles; fusion of data captured by radars and cameras; localization, mapping, and advanced artificial intelligence algorithms that allow autonomous vehicles to maneuver in their environments; and computer software to control vehicles.

“Much of our work focuses on technology that integrates the vehicle with its environment,” said Hayder Radha, a professor of electrical and computer engineering and director of CANVAS. “In particular, MSU is a recognized leader in computer vision, radars and antenna design, high-assurance computing, and related technologies—all areas that are at the core of self-driving vehicles” (MSU n.d.).

While self-driving vehicles once seemed like a distant utopia, their workplace and technological impacts could be seen in the near future. The comprehensive research, collaboration, and behind-the-scenes brainpower from the URC and ACM will ensure that Michigan, and the world, is prepared for their deployment.

examining some of the challenges associated with vehicles traveling in controlled, close formations—also known as longitudinal platoons. According to Wang, the primary challenges of platoon control include variations in road conditions, reliability under sensor and communication errors and interruptions, safety and smooth operation when vehicles merge into and depart from a platoon, and highway resource usage and fuel economy.

“Platoon formation has been identified as one promising strategy for enhanced safety, improved highway utility, increased fuel economy, and reduced emission toward autonomous or semiautonomous vehicle control,” said Wang. “The goal of longitudinal platoon control is to ensure that all the vehicles move in the same lane at the same speed with desired intervehicle distances” (WSU n.d.c.).



The academic consortium is training the next generation of high-tech talent who will develop and manufacture CAVs (Larcom 2017). This talent base will be essential to ensuring that Michigan remains the center of transportation innovation and production.

WSU is one of 16 North American universities selected to compete in EcoCAR 3, a U.S. Department of Energy competition challenging researchers to redesign a 2016 Chevrolet Camaro by demonstrating emerging technologies. The Hybrid Warriors team is a WSU student organization comprised of 29 members across the engineering, communications, and business disciplines at the undergraduate and graduate levels (U.S. Department of Energy EcoCAR 3 n.d.). The team's current system configuration includes two cameras, three radar sensors, a driver drowsiness detection system, and two driver interaction displays. The system will be demonstrated in May 2018 with all the autonomous driving systems functioning, showing some advanced-level object detection and classification, such as identifying pedestrians compared to vehicles.

U-M's Mcity is leading the transition to a new world of CAVs, as university researchers, collaborators, and partners consider all aspects of the future of transportation and mobility, such as the impact on business, infrastructure, and society. Working with the Michigan Department of Transportation, U-M designed the Mcity Test Facility, which simulates the broad range of complexities vehicles encounter in urban and suburban environments. Mcity sits on a 32-acre site on U-M's North Campus with about 16 acres of roads and traffic infrastructure. The grounds include approximately five lane-miles of roads with intersections, traffic signs and signals, simulated buildings, streetlights, and obstacles such as construction barriers (Mcity 2018).

U-M also has research vehicles that serve as open testbeds for academic and industry researchers to rapidly test self-driving and connected vehicle technologies at a world-class proving ground. These open CAVs, based at Mcity, are equipped with sensors including radar, LiDAR and cameras, among other features. They are able to link to a robot operating system. While a handful of other institutions may offer similar research vehicles, U-M is the only one that also operates a high-tech, real-world testing facility. By providing a platform for faculty, students, industry partners, and startups to test this technology, open CAVs will break down technology barriers and dramatically speed up innovation (Carney and Moore 2016).

Between Mcity and the ACM, URC researchers have access to world-class facilities to pursue cutting-edge CAV technologies, including work on vehicles and the technologies embedded in the infrastructure that will

support these vehicles. One possible way to implement CAVs is with vehicle platoons. Platoons are a grouping of vehicles aimed at reducing the distance between cars and trucks using electronic coupling. Platooning is a means of increasing the capacity of roads. WSU researchers recently won the best paper award from the *Journal of Systems Science and Complexity* for their work on vehicle platoon control. WSU's research used unique algorithms to establish a vehicle pattern and achieve global coordination of the platoon (WSU January 19, 2017).

Competition is an effective way to spur innovation. GM recently selected MSU faculty and students to compete in an autonomous vehicle competition. GM is providing each team with a Chevrolet Bolt EV as the vehicle platform. Researchers will need to navigate the fully automated vehicle through an urban driving course (Mroczek and Henion April 2017).

MSU's CANVAS initiative is primed for success in this competition. Through this initiative, researchers are developing technologies in sensing, networking, machine learning, communication, security, privacy, traffic modeling, and infrastructure planning. Through CANVAS, a clearer picture of how these systems connect and work with one another, and how they affect passengers, vehicles, and the entire transportation system, can emerge. CANVAS research is also developing things like multimodal sensing using technologies like radar and LiDAR to develop a 3-D map of where a vehicle is driving; sensor and data fusion to enable communication between vehicles, infrastructure, and people; deep learning to support object recognition and to help develop the algorithms that enable a vehicle to maneuver in its environment; and internal sensing, including biometrics, to help improve human vehicle interactions and improve safety (MSU CANVAS n.d.).

## Other Mobility Research

While URC researchers are working on the mobility technologies of the future, they are also improving the infrastructure we use every day. Research from WSU is helping transportation departments and highway design experts to create safer ways to access the freeway. New freeway interchanges, called double crossover diamonds, prioritize safer left turns onto the highways. The designs are the results of a research team's analysis of seven test interchanges, 28 years of cumulative preinstallation data, and 19 years of post-installation data. When WSU graduate students analyzed 3,000 crash reports, the findings showed a 33 percent reduction in collisions and a 40 percent reduction in traffic injuries compared to a standard diamond. Michigan just opened its first diverging diamond at I-75 and University Drive in Auburn Hills (Moran 2015).

The WSU Transportation Research Group (TRG) is working with GPS based crowd sourced probe vehicle data to create the Michigan Annual Congestion and Mobility Report. This report is used by planners and engineers to locate congestion issues on Michigan roadways and prioritize roadway improvement projects.

The TRG is implementing the first automated traffic signal performance measurement system on two Michigan arterial roadways. This system utilizes high resolution data logging signal controllers to collect data at signalized intersections. These data are then processed and aggregated into performance measures to monitor and maintain proper signal timings on corridors.

The TRG recently completed a study demonstrating the effectiveness of highway rumble strips in improving traffic safety. The study showed that rumble strips reduce several categories of crashes, including head-on, sideswipe, and run-off-the road crashes. In the categories examined, the study showed that rumble strips reduced total crashes by 47 percent and fatal crashes by 51 percent (WSU College of Engineering June 2015). As many as 40,000 people die in highway crashes each year, so the findings from this study can potentially save thousands of lives each year (Korosec 2017).

Rumble strips are just one way to improve roads. U-M researchers are working on a stronger and more durable concrete that could make potholes a thing of the past. Regular concrete has a strength of 4,000 pounds per square inch, but this concrete's strength is 22,000 pounds per square inch. This concrete is also much better at handling the freeze thaw cycle that creates the potholes that Michigan drivers dread. This concrete, currently being produced by a private company, is expensive—up to 27 times the cost of traditional concrete, at close to \$2,700 a cubic yard. But U-M is working with the Michigan Department of Transportation to develop a more cost-effective alternative. These researchers have already reduced the cost to \$880 per cubic yard, a third of the price of the private supplier. While the cost is still high, it can still be a bargain when considering that a bridge deck made from this concrete could last 200 years (Jesse 2017).

MSU is the first university to have a University Transportation Center (UTC) for Highway Preservation. Created in 2003 by MSU and the National Center for Pavement Preservation to conduct research and serve as a clearing house to practitioners across the U.S., MSU's Center for Highway Pavement Preservation (CHPP) was designated in 2013 by the U.S. Department of Transportation as a Tier 1 UTC (Mroczek, 2015). MSU is looking to improve roads while also addressing the disposal of scrap tires, a major environmental challenge. The technique mixes asphalt with rubber from

ground up scrap tires. Building two miles of roads can use up to 4,000 tires, and these roads better resist cracks, have a longer life, and are quieter. MSU researchers are working with Michigan's Department of Environmental Quality to find the optimal mixture. The mixtures are first studied in a laboratory to find the most promising blends and are then deployed on stretches of road to see how well they perform in the field (MSU Department of Civil and Environmental Engineering 2016).

Of course, mobility includes more than just cars and roads. Mobility includes transporting people and goods by rail, sea, and air. The URC institutions do world-class research in all of these areas, and produce the mechanical, aerospace, and other engineers that design and improve a wide range of transportation vehicles, such as passenger jets, freight and commuter trains, naval vessels, and even space vehicles.

U-M's Naval Architecture and Marine Engineering (NAME) Department is an example of URC work in marine engineering. NAME dates back to the late 1900s when Congress authorized the U.S. Navy to assign a few officers to engineering colleges. Over 100 years later, NAME is still going strong. Current research includes autonomous naval systems, a good complement to the URC work with CAVs (U-M NAME n.d.).

URC graduates do not just design these vehicles, but pilot them as well. In fact, alumni from all three institutions have gone on to become astronauts, including the crew of Apollo 15, which consisted exclusively of U-M graduates.

## Energy

Electricity powers Michigan's manufacturing plants; it lights our homes and helps to cool them in the summer. Energy is used to heat Michigan homes during the state's long, cold winters. Michigan's energy infrastructure is extremely reliable. Most people seldom think about energy and where it comes from until an ice storm or some other event creates a rare power outage.

Changes are afoot in the energy industry, though. In 2009, Michigan had 17 megawatts (MW) of renewable energy capacity. By 2017, that capacity had grown to 1,715 MW, primarily through the dramatic increase in wind power generation (Talberg, Saari, and Eubanks 2017). Growth in renewable energy production will continue, driven by advances in technology, the shuttering of legacy coal plants, and a desire to reduce greenhouse gas emissions. There is also great interest in producing and using energy more efficiently. Smart meters will help consumers better manage energy usage, and hybrid and alternatively fueled vehicles will reduce the consumption of motor fuels.

*Continued on page 24*





# SENSORS: DEVELOPING SMARTER INFRASTRUCTURE

Michigan's infrastructure includes complex networks of roadways, bridges, water delivery systems, and communication technology. Maintaining these infrastructure assets is a near-constant job that requires a great deal of monitoring and testing—and funding. The Michigan Department of Transportation (MDOT) projects that it will spend more than \$1.4 billion annually to repair the state's roads and bridges over the next five years (MDOT 2017). In spite of these costs, we rely on these networks to maintain our way of life; failure to maintain them threatens public safety and impedes economic growth.

One of the challenges of keeping our infrastructure in good shape is identifying vulnerabilities and prioritizing investments. Technology is helping address this challenge, thanks in large part to URC researchers, who are developing cutting-edge sensor technologies that will expand our abilities to monitor infrastructure, improve wireless networks, and enhance water quality.

At MSU, researchers—in collaboration with Washington University in St. Louis, and the University of Southern California—have received funding from the Federal Highway Administration and the National Science Foundation to demonstrate the potential of new sensor technology to monitor and report on the integrity of the Mackinac Bridge. This technology could change how we monitor our infrastructure, because unlike traditional technology, these sensors do not require batteries or wired electricity. Instead, they self-generate power, much like a self-winding watch, from the vibrations caused by normal traffic. These sensors report data wirelessly, allowing them to be embedded in previously inaccessible spots in bridges, highways, and buildings. Researchers can access the information simply by driving over the bridge with a laptop.

The project team—led by MSU's Nizar Lajnef, associate professor of civil and environmental engineering—identified the Mackinac Bridge as an ideal location to test the accuracy and performance of the sensors. “We could test this innovative technology on any number of bridges, but what location could be better than an engineering icon like the Mackinac Bridge?” he said to Gaslight Media in 2016. In September 2016, Lajnef and his project partners installed their sensor technology on the Mackinac Bridge. The team will monitor the sensors over a three-year period;



*Photo credit: MDOT*

if the sensors perform as intended they will be brought to other locations.

The Mackinac Bridge demonstration has created a virtual, cloud-based structure for the sensors, allowing project engineers to connect wirelessly to access information quickly in case of an emergency, such as an earthquake, flood or terror attack. This cloud-based network also enhances ongoing maintenance efforts by continuously monitoring the bridge's structural integrity. Historically, bridge inspections have been conducted by workers visually, but the research team expects that these sensors will provide a digital picture of the bridge over time, helping identify issues as they occur instead of after they are problems. If something goes wrong, sensors can report that data to the cloud, and engineers can quickly determine

whether a certain part of the bridge experiences abnormal levels of strain and target an emergency response.

"There is huge potential and benefit for sensors like these on structures beyond the Mackinac Bridge, and we're excited these prototypes are being tested here," said Bob Sweeney, executive secretary of the Mackinac Bridge Authority. "We meticulously maintain and inspect the bridge each year, and sensors like these will complement our efforts, giving us even more information on the bridge's condition to help keep it well maintained and safe for many years to come" (Gaslight Media 2016).

Professor Lajnef and his team hope the Mackinac Bridge demonstration will allow the technology to be further refined and eventually lead to widespread implementation. This technology could have far-reaching benefits—making people's lives safer and reducing the cost of bridge maintenance.

In addition to attaching sensors to infrastructure that span bodies of water, URC researchers are also using sensor technology to monitor what is in the water we drink. Ensuring drinking water quality is a key infrastructure challenge that if not handled correctly poses real health risks to the public, as exemplified by the recent Flint water crisis. Standard testing kits require users to run their water for several minutes, causing the test to miss any lead that leaches into the water from the home's own pipes. To combat this issue, a team of professors at U-M headed by Mark Burns, the T.C. Chang professor of chemical engineering, have designed a potentially low-cost, electronic lead sensor that could monitor water supplies and alert residents and officials to the presence of lead within days. Researchers envision that these sensors could be placed at key points in a municipality's water system as well as in homes to map lead levels across the system. While the technology is still in early development, U-M researchers are seeking partners to bring the technology to market.

On a scale even broader than these two projects is an innovative research project taking place at WSU that involves the coordination of thousands of sensors deployed over wide geographic areas. Professor Abusayeed Saifullah is leading an effort to create a highly scalable wireless sensor network that can be used over wide areas to monitor large civil infrastructure, oil fields, and national borders. The project, funded by the National Science Foundation, is still in the early stages of development, but has the potential to provide greater monitoring power and accuracy for large-scale, potentially vulnerable sites.

As showcased by the research being conducted at URC institutions, sensor technology has broad applications throughout our society. It can help identify structural defects in bridges, identify contaminants in our drinking water, and provide a large-scale wireless network to improve homeland security efforts. Beyond these applications, sensors have the potential to create "smarter" civil engineering and infrastructure that can improve public safety, protect public health, and help our economy run more efficiently.



*Photo credit: MDOT*



## Renewable Energy

Despite advances in the share of energy produced by renewable sources, the U.S. still generates 81 percent of its energy from nonrenewable sources (U.S. Energy Information Administration 2017). Recent advances in oil and natural gas discovery and extraction techniques have increased production and dramatically reduced the price of fossil fuels. Still, fossil fuels are in finite supply, and at some point, they will become increasingly difficult to locate and extract. Therefore, it is imperative to the country's energy and economic future that more progress be made in developing renewable energy sources.

URC researchers are working hard to meet this need. WSU researchers have been working to develop biofuels at the National Biofuel Energy Lab. WSU has partnered with NextEnergy Inc., Michigan's nonprofit business accelerator for alternative energy sources, to develop the research lab in Detroit's Midtown neighborhood. The lab is part of NextEnergy's Biodiesel Value Chain Initiative, which is researching and developing biodiesel use (WSU College of Engineering 2006).

MSU, along with the University of Wisconsin-Madison, leads the Great Lakes Bioenergy Research Center (GLBRC), one of three bioenergy research centers established by the U.S. Department of Energy in 2007. Among other projects, the GLBRC is developing sustainable fuel sources and chemicals from plants such as switchgrass, poplar trees, and sorghum (GLBRC 2017). These crops will be grown on marginal, or nonagricultural land, so they will not displace traditional agriculture. Over the GLBRC's ten-year history, it has built academic and industrial partnerships that have yielded more than 1,000 scientific publications, 160 patent applications, 80 licenses or options, and five startup companies (Eastman and Cameron 2017).

MSU researchers are also working to develop algae-based biofuels. Partnering with ExxonMobil, these researchers are taking advantage of a suite of new technologies that allow for rapid, high-throughput testing of photosynthetic efficiency of algae lines under simulated growth conditions (Cameron, Kramer, and Flathman 2015).

Biofuels will not solve all of our energy problems, though. U-M research has shown that while these fuels have benefits, including renewability and the potential to reduce greenhouse gas emissions, there are also potential downsides, such as the high cropland requirement and increasing food prices (U-M Center for Sustainable Systems 2017). A researcher at U-M's Energy Institute sparked a national conversation as to whether biofuels actually reduce CO<sub>2</sub> emissions, arguing that in some cases biofuels may have worse emissions than gasoline (U-M Energy Institute September 16, 2016).

This debate is not surprising. With 81 percent of U.S. energy consumption coming from fossil fuels, developing alternatives represents a massive undertaking with extreme importance to the nation's economy and to the health of the planet. There is no easy solution, and URC researchers are working on this problem from multiple angles, recognizing that technologies that may solve one problem may create others. Biofuels are renewable, but burning them does release greenhouse gases. Of course, biofuels research represents just one part of a long chain of URC research aimed at trying to find promising fossil fuels alternatives.

Nuclear energy represents another solution explored by the URC with promising upsides and worrisome downsides. The URC has a rich history of exploring the possibilities of atomic energy. Michigan's Memorial Phoenix Project was launched in 1948 to engage in research and other activities to support the peaceful uses of atomic energy. Through this project emerged the Ford Nuclear Reactor on U-M's campus, which operated from 1957 until 2003 (U-M Energy Institute 2016). MSU has also long been a leader in advanced nuclear research and particle physics, first with the National Superconducting Cyclotron Laboratory, and now with the Facility for Rare Isotope Beams (FRIB). The U.S. Department of Energy located the FRIB at MSU in part because it is home to the top-ranked U.S. nuclear physics graduate program. The FRIB is a one-of-a-kind research facility that will allow researchers to answer fundamental questions about the nature of the universe and develop practical applications for society, including medicine, homeland security, and industry (FRIB at MSU n.d.).

While nuclear power helps reduce CO<sub>2</sub> emissions, the radiation from waste products must be contained. So Nuclear Engineering and Radiological Sciences (NERS) researchers at U-M are exploring new materials that can safely hold radioactive waste for hundreds of thousands of years without degrading. These researchers are also working on the difficult goal of nuclear fusion through theoretical studies and experiments with plasma. The U.S. has not constructed a new commercial nuclear reactor in 30 years, and NERS researchers are figuring out how to responsibly extend the life of older reactors, in part by looking at how materials age in reactors after prolonged exposure to high radiation, temperature, and pressure (U-M NERS n.d.).

Wind and solar power represent two of the most promising areas in renewable energy development. Although both technologies have obvious limitations, they are emission free, and the costs of wind and solar power have fallen dramatically in recent years. The cost of generating electricity from solar power is down 62 percent since 2009, and in some places, generating electricity from solar is

less expensive than the cost of generating power with coal (Shankleman and Martin 2017). Wind power has become one of the lowest-cost electricity generation technologies available, with some long-term power purchasing agreements for wind energy coming in at half the cost of power from a natural gas-fired plant (Fares 2017).

MSU researchers recently made a huge breakthrough in solar power generation with their transparent luminescent solar concentrator, a clear solar panel that can be placed on a window without disrupting the view. The thin material can be used in buildings, vehicles, cell phones—anything with a clear surface. Covering the glass surfaces of buildings with clear solar panels has tremendous potential. There is an estimated 5 billion to 7 billion square meters of glass surface in the United States. The researchers estimate this technology has the potential to meet 40 percent of the energy demand in the U.S. (Henion and Lunt 2017).

The National Science Foundation recently granted funds to WSU to support new ways to harvest solar energy. This work includes trying to identify ways solar power could create a chemical fuel, a particularly challenging problem (O'Connor August 2017). U-M researchers have developed a “magic alloy” that could spur the next generation of solar cells called “concentrator photovoltaics.” These cells are on track to achieve efficiency rates of over 50 percent, compared to traditional cells which have efficiency rates in the mid 20 percent range. U-M’s new design is less costly and easier to design than previous iterations. The lower price range for manufacturing is a big step toward moving this technology into mass production (Cherry 2017).

The other prominent nonpolluting renewable energy source is wind power, and wind power generation in Michigan has grown quickly. In 1999, Michigan had 0.6 MW of installed capacity. By 2017, this amount had grown to 1,760.0 MW of installed capacity (Office of Energy Efficiency and Renewable Energy 2017).

Public Act 295 of 2008 required Michigan utilities to have 10 percent of their electricity come from renewable sources by 2015 (Carrasco et al. 2009). Michigan utilities responded to this requirement by expanding wind production. MSU researchers recently compiled the lessons learned after nine years of wind development in Michigan. This work looked at the social impact and controversy of wind energy (Balaskovitz 2017). The placement of windmills can be controversial since they are large and can create a background hum, impact bird populations, and affect landscape views. MSU Extension has been using the knowledge gained through this experience to support the development of wind power by providing training and resources on a number of important community issues, including wind farm siting, community zoning, the impact of

wind farms on residential property values, and the potential health impacts of wind turbines (MSU Extension 2017).

## Batteries

The transition to greener energy sources is increasing the importance of energy storage devices like batteries. Battery technology is the key to hybrid and electric vehicles. To help spur the advancement of our mobility technology, we need batteries that can support an extended range for electric vehicles and lower the cost for electric and hybrid vehicles.

One shortcoming of both wind and solar power is that they cannot support continuous energy production. The wind needs to be blowing or the sun needs to be shining for these technologies to produce electricity, so these technologies often require backup power sources that burn fossil fuels. Advances in energy storage technology can help reduce reliance on these greenhouse gas generating power sources.

WSU’s Avara Research Group is working on a new configuration for a lithium-sulfur battery that is a more powerful and less expensive alternative to commercially available lithium-ion batteries. This technology will potentially allow for up to five times more energy than a lithium-ion battery, a technological leap that could power tomorrow’s phones, laptops, and cars (WSU College of Engineering March 2015).

Another way to make batteries last longer is to use them more efficiently. WSU researchers are working on software-controlled battery management systems to help enable more energy-efficient, long-lasting and secure battery-driven systems. The research team is developing a simulated electrical vehicle that will interact with an actual battery system, which will illustrate the effectiveness of the battery management system in a realistic setting (O'Connor September 2017).

A team of researchers at MSU is looking to improve upon the lithium ion battery, the rechargeable battery used in many hybrid and plug-in vehicles. These researchers are working on a three-fold problem—how to make the battery last longer, less expensive, and safer. Most lithium ion batteries use a liquid, but MSU researchers are trying to determine if a solid material could work better, using a class of materials referred to as a superionic conductor. The hope is to develop a battery that stores more energy but can be produced at a fraction of today’s cost (Oswald and Sakamoto 2013).

U-M’s Energy Institute opened the Battery Fabrication and Characterization User Facility, or Battery Lab in 2015. The facility was created in partnership with the Michigan

*Continued on page 28*



## GENERATING IDEAS TO POWER OUR WORLD

Harnessing the power of moving water is one of civilization's oldest forms of energy production, but only in the last 140 years has society been able to use that power to generate electricity. Michigan was home to one of the very first hydroelectric facilities in the world—which provided electric lighting for the city of Grand Rapids starting in 1880. Once again, the state is at the forefront of hydroelectric innovation. Inspired by the movement of fish through water, researchers at U-M's Marine Renewable Energy Lab are pioneering a new technology that would unlock boundless potential for clean energy production without disrupting aquatic ecosystems or generating harmful emissions.

Led by Michael Bernitsas, the Mortimer E. Cooley collegiate professor of naval architecture and marine engineering at U-M, researchers are reinventing the way hydroelectric power is produced by taking advantage of naturally occurring currents. Instead of capturing hydroelectric flows by damming rivers and sending water through a turbine, their invention would generate electricity, by harnessing vortex-induced vibrations from water's natural currents.

The technology, named VIVACE (pronounced vi-VAH-chē) for Vortex Induced Vibrations for Aquatic Clean Energy, has the potential to unlock untold clean energy production. Conventional hydroelectric facilities typically require water to flow at speeds of six to eight miles per hour, but VIVACE can function at speeds as low as one mile per hour, making it possible to produce energy from previously untapped rivers, streams, lakes or oceans. The added advantage of VIVACE is that it doesn't require expensive or environmentally perilous dams because it can be placed unobtrusively on the bottoms of waterbodies.

The technology is currently being tested beneath the waters of the St. Clair River near Port Huron, Michigan, fittingly within sight of the train depot where a young Thomas Edison once worked. The technology is not yet commercially viable, but the team remains dedicated to their mission to unlock the next breakthrough in advanced clean energy.

"We have a good device, but taking principles from schools of fish and turning them into mechanical devices takes time," Bernitsas said. "It's a long process, but for us, it's also very exciting" (Cherry 2016b).

URC researchers are not stopping at producing energy from beneath the waves; they are also reinventing how we capture the sun's energy. Professor Richard Lunt,



the Johansen Crosby endowed associate professor of chemical engineering and materials science at MSU, and his team have invented a transparent luminescent solar concentrator. This technology could fundamentally change the solar industry by enabling windows or virtually any clear surface to act as a solar panel.

Until now, traditional solar photovoltaic technology involved mounting specialized panels on rooftops or as standalone fixtures. Limits to how much rooftop space or developable land is available, especially in urban settings where space is at a premium, present a significant drawback to expanding solar energy generation with traditional opaque panels.





Beyond finding new ways to capture energy, researchers at WSU are coming up with ways to better store energy. Lead researcher Leela Arava, assistant professor of mechanical engineering, is experimenting with advanced battery storage technology that has the potential to be more powerful, better for the environment, and less expensive than today's technology. The potential for high-energy lithium-sulfur (Li/S) batteries is great. They can store up to five times more energy than current lithium-ion batteries. But to date their development has been limited, due to challenges in overcoming their short life-cycle and efficiency. Professor Arava and his team are working on a new configuration to stabilize and extend Li/S battery performance. Their work could lead to the development of, as he notes, "electric vehicles that match the power, range and cost of combustion engines" (WSU 2016).

With new transparent solar technology, the applications and potential for solar energy are seemingly endless—imagine every window in a skyscraper doubling as a solar panel or cell phones charging just by being left in the sun.

According to Professor Lunt, "this technology offers a promising route to inexpensive, widespread solar adoption on small and large surfaces that were previously inaccessible" (Henion and Lunt 2017).

As for how widespread this technology could be, researchers have estimated that transparent solar technology could one day supply around 40 percent of the U.S.'s energy demand.



Economic Development Corporation and Ford. The lab provides integral infrastructure for the development and testing of next generation energy storage and devices (Mast 2015). The lab also serves as base for U-M R&D efforts as a partner in the Joint Center for Energy Storage Research. The center, a public-private partnership, seeks to create clean energy storage technologies for transportation and the energy grid.

U-M researchers are also working to address the challenges associated with intermittent wind and solar energy production. An interdisciplinary team of sustainability experts and engineers developed 12 principles for green energy storage in grid applications. These principles provide researchers, designers, and industry professionals clear guidance on what to consider when designing energy storage devices and systems (Mast 2016). Researchers are also working on large-scale grid energy storage applications; one solution they are developing is the implementation of “redox flow batteries,” which charge via renewable energy sources and then are stored separately (U-M Energy Institute n.d.).

### Smart Grid

The “grid” describes the system of electric transmission lines, substations, and transformers that deliver electricity to the end user. Advances in communications technology are enabling the “smart grid,” which has sensors, automation, and new technologies and equipment that allow the electric grid to respond more quickly to changes in demand (U.S. Department of Energy n.d.). The smart grid allows for more efficient transmission of energy, improved restoration of power after outages, increased integration of renewables, and better security. It also helps manage demand during peak periods, ultimately leading to lower rates.

U-M is supporting the development of the smart grid through computer modeling. Researchers are creating a model of a year in the life of a power grid to create the most detailed and adaptable power grid simulation ever made. Using real data from a French power grid, their model of the grid allows other researchers to test software and algorithms (Cherry 2016a).

A key component of the smart grid is the interface between electric power and the devices in the home. Smart home devices can be controlled remotely. However, for smart grid technology to work well, the interface to home devices must be secure. MSU's Cyber Security Lab is working on the Secure Access Gateway (SAG) between the home and the grid. By developing login authentication schemes for SAGs, using their own cryptographic algorithms, they make the gateway secure from hackers (Ren n.d.).

## Communications

### Overview

Communications infrastructure connects people, but it also connects machines to one another and machines to people, improving productivity in a wide range of industries. This connectivity is moving beyond computers and phones to a wide range of devices including cars, thermostats, industrial equipment, and even lightbulbs. By 2020, an estimated 50 billion things will be connected to the Internet, enabled by the underlying communications infrastructure (21<sup>st</sup> Century Infrastructure Commission 2016).

The importance of communications infrastructure will continue to grow, and make other infrastructure “smart” by embedding sensors and Internet-connected devices in a wide range of systems, such as roads and bridges, water treatment plants, and the power grid. It will also enable increasingly intelligent vehicles, including automated cars and trucks. As communications infrastructure continues to evolve, it will support the collection of more and more data, and this big data combined with artificial intelligence and machine learning will transform many sectors of the economy, including manufacturing, healthcare, and energy.

The ever-growing prevalence of interconnectedness makes it increasingly important that every person and community has access to the infrastructure that makes high-speed communication possible. Connectivity will be necessary for individuals looking for jobs, communities trying to attract businesses, and schools seeking to access online learning tools.

As we rely more on the Internet, cybersecurity will become increasingly important. With water systems, the power grid, and even the military relying on Internet-connected devices, cybersecurity will be essential to both economic growth and national security. Individuals will see more of their financial, health, education, and other data flowing through communications infrastructure and it is vital that these data are protected.

### High-Speed Communications

URC institutions may not have invented the Internet, but they certainly played a key role in its creation. In 1966, MSU, U-M, and WSU founded the Michigan Educational Research Information Triad, or Merit Network, which pioneered many of the technologies used in today's Internet (Merit 2016). By 1976, Merit was connected to Telenet, an early spinoff or ARPANET, the precursor of the Internet. This connection provided Merit users dial-in access from locations around the United States, connectivity that was rare at the time.



Today, the Merit Network is still expanding the number of people with access to high-speed communications. Its backbone connects universities, K–12 schools, libraries, healthcare, and government institutions. In 2010, the Merit Network received grants to build the fiber-optic infrastructure needed to bring broadband to rural areas of Michigan, including the Upper Peninsula (Merit 2016).

Regarding connectivity, U-M's Computer Science and Engineering (CSE) faculty are researching networking and operating systems and distributed systems to improve performance and user experiences as well as the reliability and robustness of communications infrastructure (U-M CSE 2018). An example of this is GapSense, software developed at U-M to help communications flow smoothly. The proliferation of wireless devices, including WiFi-enabled laptops and tablets and Bluetooth communications devices, is creating traffic jams on the digital highway, and GapSense helps direct this traffic. Researchers found that GapSense could reduce traffic by 88 percent on some networks (Casal Moore 2013). Changing the underlying architecture can speed performance as well. New software called Vroom cuts the median load time in half for 100 popular sports and new websites (Casal Moore 2017). Vroom was developed by a team of researchers at U-M and the Massachusetts Institute of Technology.

WSU's Dependable Networking and Computing Research Group in the Department of Computer Science, has built a foundation for several wireless networking systems, including the emulation system and software-defined innovation platforms for sensing and control networks of CAVs (WSU 2006). MSU's Network Embedded and Wireless Systems Laboratory (NeEWS) researches a wide range of issues, including low-power wireless sensors, which help enable the IoT (MSU NeEWS 2014).

### Access to High-speed Internet

In 2016, 81 percent of Michigan households had access to high-speed Internet, ranking 30<sup>th</sup> best among the states (American FactFinder 2017). Despite the high penetration of broadband, many low-income families and families living in rural areas still do not have access. Working in collaboration with WSU, MSU's Quello Center is working to address this issue through its Broadband to the Neighborhood project. The research team looked at three Detroit neighborhoods with limited Internet access to determine the barriers to access and what could be done to increase digital equity and digital inclusion. The project, which is still in progress, includes surveys, focus groups, and informal interviews (Quello Center 2017a).

The Center's Wireless Innovation for Last Mile Access (WILMA) project has been examining wireless solutions to

help connect those who do not yet have access to high-speed Internet. The research includes case-level analysis of strategies for using wireless technology to extend networks into underserved communities, as well as analysis of wireless spectrum policy and regulation (Quello Center 2017b). A key finding of this work is that although wireless cannot provide the same capacity as fiber networks, it may be the only economically feasible strategy for expanding broadband into certain parts of the country (Shapiro, Murphy, Yankelevich, and Dutton 2016).

MSU recently used grant funds to expand access to the Internet in underserved communities. This project focused on libraries in communities where residents have limited Internet access. The grants helped these communities add 500 new workstations that serve roughly 13,000 patrons per week. The new public computer centers are located in Chippewa, Clare, Gladwin, Gogebic, Grand Traverse, Huron, Leelanau, Marquette, Menominee, Oakland, Oscoda, Otsego, Sanilac, Tuscola, and Van Buren Counties (Oswald, Khire, and DeMaagd 2010).

### Internet of Things

The IoT may be the next big advance in technology. It represents a vast array of physical devices such as cars, refrigerators, and thermostats embedded with technology that enables these objects to communicate with each other and with the Internet. This technology helps make “dumb” objects smarter. For example, a sensor embedded in a furnace could send a message to a homeowner's smartphone saying that the filter needs to be changed or that the furnace is in need of repair.

The opportunities presented by the IoT are virtually limitless—but they do rely on low-cost sensors that use little power. WSU researchers are developing an energy-efficient wireless microsensor based on all-graphene radio frequency and bioelectronics. The practical application of this sensor is that it can be integrated into soft contact lenses to detect targeted pathogen bacteria, infectious agents, diseases, or metabolic changes of interest, and wirelessly transmit data without any power source of sophisticated circuitry.

The Intel Corporation recently awarded WSU a grant to create the Intel Internet of Things Innovators Lab, making WSU the home of the third such lab in the nation. WSU will have 12 teams, comprising two to three members each, that will use IoT equipment donated by Intel to identify data needed by Detroit policymakers and create applications for the technology. To support longer-term efforts related to this endeavor, WSU professor Weisong Shi is helping to create an infrastructure called DISCO (Detroit Data Infrastructure for Smart and Connected Communities),

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# MERIT NETWORK— EMPOWERING MICHIGAN RESIDENTS BY EXPANDING INTERNET ACCESS

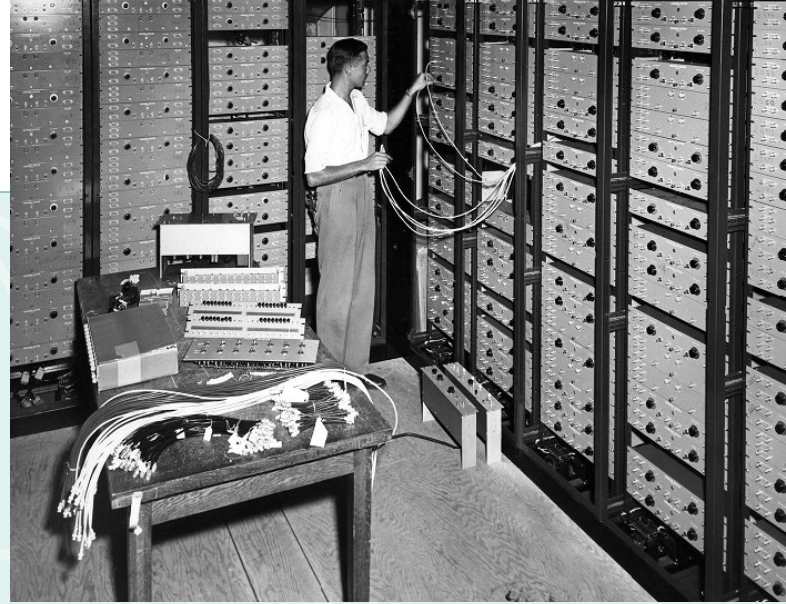
The Internet is one of modern society's most essential infrastructure assets. It enables commerce and communication to take place across the world in mere seconds. For most undergraduate students at URC institutions today, a world without the Internet would be unimaginable. It might surprise these students to learn that their very universities pioneered the technology that foretold the modern Internet.

Founded in 1966, the Michigan Educational Research Information Triad (Merit) Network, began as a partnership between the state's three largest public institutions—MSU, U-M, and WSU—to connect researchers and share data by creating a network that could connect mainframe computers across college campuses.

For over 50 years, the Merit Network has generated innovations in communications technology, not just for Michigan but the world. This visionary effort has empowered Michigan's residents with access to social connectivity, entertainment, information, economic benefits, and a host of other services available through the Internet. Today the Merit Network provides improved Internet access across all public universities in Michigan through the expansion of fiberoptics, promoting cutting-edge network services and protecting data through cybersecurity training.

Prior to the Merit Network, it was impossible for universities' computer systems to communicate or share resources with each other. Shortly after the creation of Merit, the three founding universities were officially linked by a network, which represented a major achievement for Merit and served as a prototype for future computer networks.

As communications technology continued to advance, the Merit Network connected Michigan's system to supercomputing centers as far away as San Diego, Pittsburgh, and the National Science Foundation Network (NSFNET), the forerunner of today's Internet. In 1987, a Merit-led consortium (including organizations like IBM, MCI, and the Michigan Strategic Fund) won a grant from the National Science Foundation to re-engineer and



manage the NSFNET. This new network service connected supercomputing centers around the country at speeds 24 times faster than previously possible and grew to link scientists and educators on university campuses nationwide and around the world.

Through its MichNet services, Merit began rapid expansion of its statewide network offering direct connect and dial-in services. By 2001, there were 10,733 shared dial-in lines in more than 200 Michigan cities. Merit continued to advance along with technology, and in the early 2000s began building out its newer, faster fiberoptic network.

The next major phase of expansion began in 2010, when Merit received over \$100 million in federal funding to fund their Rural, Education, Anchor, Community, and Healthcare—Michigan Middle Mile Collaborative (REACH-3MC) project. Completed in 2014, the REACH-3MC project installed 2,287 miles of fiberoptic infrastructure and connected more than 200 community institutions and organizations in rural and underserved communities in Michigan's Lower Peninsula, Upper Peninsula, Minnesota, and Wisconsin. The new fiberoptic connections increased network speeds providing broadband speeds to previously unserved or underserved parts of Michigan.

The Merit Network now covers a wide range of exciting services beyond network connectivity, including:

- Internet and networking services: Internet services, Internet2 access, and a private fiber network that supports high-speed Internet access
- Cloud and communications: Discounted software licensing, video and media streaming, Internet phone services, and a higher education collaboration portal
- Professional services: Network engineering, security, and consulting to optimize performance
- Michigan Cyber Range: Courses to train IT professionals to be better prepared for cyberattacks
- Professional development: Seminars, workshops, classes, conferences, and meetings

Since its early role in connecting network computers between universities, Merit has drastically expanded the state's Internet access in Michigan and pioneered the technology that makes today's Internet possible. "Merit has grown over the past 50 years to serve as the primary networking organization for the state of Michigan higher education community," said Daren Hubbard, CIO and associate vice president of computing and information technology at Wayne State University and chair of Merit's Board of Directors.

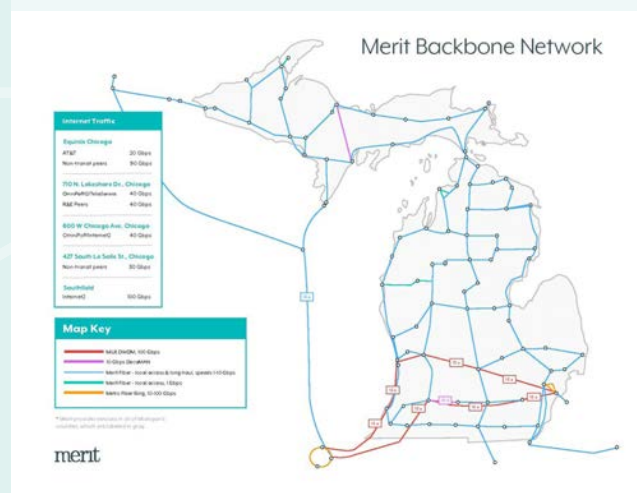
Merit's history of innovation has fostered a wide range of cutting-edge services and tools that have helped Michigan

educational institutions achieve success. Merit has partnered with other organizations, such as Internet2, to expand access and is on the cutting edge of issues such as cybersecurity. In partnership with URC institutions, Merit has led the way in building the network infrastructure that provides Internet access across the state and provides services that ensure network access is safe, efficient, and valuable for Michigan families.

As Hubbard put it, "We appreciate Merit's technological vision that has shaped our present and look to its leadership to shape the future."

### The Merit Network:

- Operates the longest running regional computer network in the United States
- Was formed in 1966 by URC universities
- Was initially funded by the National Science Foundation and the State of Michigan
- Provides computer networking, IT, and cybersecurity services
- Serves clients in the higher education, K-12 education, library, government, healthcare, and nonprofit sectors
- Operates primarily in Michigan



### The Merit Network:

- 1966** – Merit is formed by the three URC universities
- 1969** – Merit receives \$400,000 needed to launch the network
- 1972** – All three universities are officially connected to the network
- 1976** – Merit interconnects with Telenet to provide Merit users dial-in access in locations across the U.S.
- 1983** – Merit connects with Advanced Research Projects Agency Network (ARPANET)
- 1987** – Merit-led consortium receives \$39 million to re-engineer and manage the NSFNET; this leads directly to growth of commercial Internet
- 1998** – All Michigan public universities are officially members
- 2000** – Merit spins off two for-profit companies
- 2003** – Merit selected as primary Internet service provider for State of Michigan
- 2012** – Merit deploys first Cyber Range site
- 2014** – Merit completes fiberoptic project constructing over 2,000 miles of infrastructure

Source: Merit Network n.d.



which will help with the real-time data collection of IoT data. Initial efforts will focus on Detroit health and public safety projects but will eventually include environmental data and traffic management (WSU College of Engineering 2016).

U-M's Wireless Integrated Circuits and Systems (WICS) Group is developing ultra-low power radios for sensors without batteries targeting IoT applications (U-M WICS Group 2017). One example of the work being done at WICS is the development of tiny computers, about the size of a kernel of corn, that can be pumped into oil wells and travel through machinery without damaging equipment. When inside the wells, the sensors on the computers measure and log temperatures and pressures that help oil companies monitor production conditions (U-M Electrical and Computer Engineering 2017).

There are many exciting applications for low-power sensors in healthcare. Health sensor research combines communications expertise with skills across of a variety of disciplines. U-M is working with universities across the country to develop innovative tools to gather, analyze, and interpret health data generated by mobile and wearable sensors. The Mobile Sensor Data-to-Knowledge team combines the expertise of computer scientists, engineers, statisticians, and biomedical researchers to take data collected from wearable sensors and turn it into actionable information (U-M Institute for Social Research 2014).

As discussed throughout this report, the IoT is enabling monumental advances across infrastructure types. Water quality sensors can send alerts about contamination. Smart meters and thermostats can optimize power usage, saving energy and reducing greenhouse emissions. Sensors embedded in roads can connect with automated vehicles to help optimize traffic flow and improve overall safety.

As IoT combines with big data and artificial intelligence continues to advance, the things around us will get smarter. Your car may tell your house when you are coming home, causing your furnace to increase the temperature. Sensors in vehicles can alert traffic lights to congestion, triggering them to change their patterns to alleviate the problem. A CAV can get an alert when an office worker is leaving the building, allowing it to be out front waiting when the worker walks out the door. Researchers at the URC are working on all aspects of these new and exciting technologies to ultimately make our infrastructure cheaper and smarter, and to improve the quality of life for all Michiganders.

## Cybersecurity

The more items that connect to the Internet, the more important cybersecurity will become. People will not use potentially life-improving innovations unless they can be confident that they are secure. In 2015, hackers took

control of a Jeep Cherokee through its entertainment system and brought it to a halt—demonstrating the alarming vulnerabilities posed by increasingly advanced and Internet-connected technology (Greenberg 2015). Fortunately, researchers at the URC institutions are on the case, finding and correcting security vulnerabilities in existing technologies, and designing the products and software to keep future developing technologies secure as well.

The Cyber Security Lab at MSU works “to design cryptographic algorithms and network security protocols for the next generation Internet, ad-hoc and sensor networks where power efficiency and security are of major concerns” (MSU Cyber Security Lab n.d.). U-M's Center for Computer Security and Society (C2S2) investigates emerging threats to critical embedded systems and networks, and on the impact of cybersecurity attacks on crucial infrastructure, governments, and sensitive data (U-M C2S2 2017). WSU's Cyber Range Hub provides lab space for cybersecurity training, testing, and teaching. Students use the hub for classes in cybersecurity, while businesses can use the facility to test software. Individuals can also enroll in noncredit-bearing professional development classes. The Cyber Range Hub prepares cybersecurity professionals to detect, prevent, and mitigate cyber-attacks in a real-world setting; it is also an important source of cybersecurity talent for Southeast Michigan (WSU January 25, 2017).

Getting cybersecurity right is essential to the success of CAVs. If automated cars and trucks cannot be secured, they cannot be trusted, and they will not be widely adopted. In response to this problem, the U-M Transportation Research Institute (UMTRI) is working to make security commercially feasible. U-M researchers working at the Mcity Test Facility created a tool to determine the vulnerability of self-driving cars to hackers, an important step in improving cybersecurity (Laing 2018).

German automaker ZF is working with MSU researchers to increase the security of automated vehicles. MSU researchers are leveraging their experience with design patterns for autonomic systems, real-time embedded systems, and security for enterprise systems (Mroczek and Henion October 2017).

Smart phones are one of the most common ways people connect to the Internet, and MSU researchers recently discovered a vulnerability in the fingerprint security used by many of these phones (Research@MSU 2017). Identifying security shortfalls like this helps manufacturers address issues before hackers can exploit them. Similarly, U-M researchers are working to increase the security of medical devices, helping hospitals assess the risks of their medical device inventory on clinical networks (U-M CSE 2017).





# CYBERSECURITY: PROTECTING MICHIGAN'S INFRASTRUCTURE FROM ATTACK

As computer networks integrate further with the state's critical infrastructure, Michigan becomes more vulnerable to cyberattack. A successful cyberattack on the power grid could black out a city or cause fatalities through interference with life-saving medical devices. In a worst-case scenario, nuclear power plant security mechanisms lie open to attacks that could release harmful radiation into the environment. The potential for these events clearly illustrates the ever-increasing importance of strong cybersecurity.

Cybersecurity is the practice of ensuring the integrity, confidentiality, and availability of digital information. To protect Michigan's infrastructure, researchers from MSU, U-M, and WSU study how cyberattacks work, provide innovative training to professionals, and design systems with greater immunity to cyberattacks. These universities, in partnership with the Merit Network and the State of Michigan, are growing a pool of highly skilled professionals with the knowledge and experience to execute strong cybersecurity strategies for large, complex organizations.

Known as the Michigan Cyber Range (MCR), this training effort brings together URC universities and other institutions to teach cybersecurity professionals how to detect, prevent, and mitigate cyberattacks in real-world situations, increasing our understanding of how these attacks might work. Funded by the Department of Defense Office of Economic Adjustment with matching funding from state and regional partners through the Advance Michigan Defense Collaborative (AMDC), the MCR partnership uses a unique hub strategy to provide training, during which users conduct simulations to test their decision-making and reaction skills and timing. The hub strategy offers cutting-edge cybersecurity training, meeting local communities' growing demand via publicly accessible locations.

WSU is helping to lead the way and opened a Cyber Range Hub in 2017 at their Advanced Technology Education Center in Macomb County. "This Cyber Range Hub is an exciting collaboration among public institutions, the government, and private industry," said Wayne State provost Keith Whitfield. "Working with partners at the Michigan Economic Development Corporation, the AMDC, and the Merit Network, we've created a cybersecurity lab to



bring together educators and industry for the betterment of southeastern Michigan" (Reynolds 2017).

Courses on the WSU Cyber Range Hub have been designed to allow remote participation, so students across the state can enroll in these courses and interact with instructors in real-time during lectures. "The installation of a Cisco Endpoint in our Cyber Range Hub enables students to have a remote in-class experience, allowing us to scale up the training to meet the growing cybersecurity needs of the state," said Loren Schwiebert, Chair of the Department of Computer Science at WSU.

Like all Cyber Range Hubs, WSU's contains computing and networking infrastructure, and provides training exercises, secure software testing, and certification courses for over 20 cybersecurity disciplines for corporate partners. At the hub, IT professionals can acquire valuable hands-on experience and test their skills within the MCR's reactive, cloud-based training environment, Alphaville. Organizations can also lease space within the Merit Secure Sandbox, a digital environment in which users can experiment with cybersecurity exercises and software testing. According to Ahmad Ezzeddine, associate vice president for educational





outreach and international programs at WSU, “This hub will allow us to expand our offerings in cybersecurity to students, as well as professional development training clients and secure software testing for our corporate partners. We look forward to developing graduate, undergraduate, and nondegree programs focused on cybersecurity, and preparing our students to be leaders in this growing industry” (Merit Network n.d.).

This regional hub, along with the hub at Pinckney Community High School, allows for technological innovation and cybersecurity resources to be embedded in Southeast Michigan communities. This placement provides a place where local communities and the public can learn innovative ways to protect their data and promote the free exchange of ideas and services. These hubs can help meet the growing needs of individuals, businesses, and community organizations better understand and respond to the threat of cyberattacks.

In mid-Michigan, MSU professor of computer science and engineering Richard Enbody, author of one of the most complete texts on targeted cyberattacks, leads the charge toward better understanding of these unique threats.

Enbody’s research in ransomware and other cyberassaults explores attackers’ methodologies and uses this information to identify system weaknesses. He shares lessons learned with private and public organizations to help them mount more effective defenses against cyberattacks.

At the University of Michigan, researchers, with funding support from the Defense Advanced Research Projects Agency, are developing an unhackable super computer called MORPHEUS, which integrates cybersecurity solutions into hardware. Unlike current defensive methods of cybersecurity, MORPHEUS outlines a new way to design hardware that prevents attackers from grabbing the critical information they need to construct a successful attack in the first place. Under MORPHEUS, the location of a weakness in a computer’s system constantly changes, and secondary defenses, such as encryption and domain enforcement, construct additional roadblocks. The vulnerability still exists, but the attackers lack the time and resources to exploit it. As this technology is developed, researchers hope to expand its protection to a wider set of users.

Reactive, experimental environments like WSU’s Cyber Range Hub and novel technologies like U-M’s unhackable super computers are just two of URC researchers’ many exciting projects. Corridor institutions are training the cybersecurity workforce of the future and designing solutions so that we can enjoy the benefits of smart infrastructure with fewer vulnerabilities, keeping our digital data safe and moving Michigan forward in innovative cyberengineering.





## URC CAMPUSES AS BEST PRACTICE LABORATORIES

As might be expected given the URC institution's roles in infrastructure research and talent development, the campuses of MSU, U-M, and WSU serve as best practice laboratories for developing and implementing advanced infrastructure. The URC campuses showcase how infrastructure will look in the future and how innovative approaches to infrastructure planning and development can make our air and water cleaner, our transportation safer, and our economy stronger through benefits like reduced energy costs.

### Water

MSU has a Storm Water Management Program to protect the Red Cedar River and connecting water affected by campus activities. MSU manages shared water resources by implementing campus-based best management practices and collaborative activities with communities throughout the Red Cedar River watershed. Part of this work includes implementing stormwater best management practices, such as porous pavement, rain gardens and bioretention areas, green roofs, and the utilization of stormwater treatment devices (MSU Water n.d.).

Similarly, U-M is working to protect the Huron River in Ann Arbor. U-M's initiatives include reducing the volume of synthetic land management chemicals in use on campus by 40 percent, and reducing the runoff relating to impervious surfaces (U-M Office of Campus Sustainability 2016).

Changing industrial landscapes can lead to unique socioeconomic challenges in an



urban environment. For example, aging infrastructure and a decline in manufacturing activity can leave cities with abandoned industrial sites. WSU is training students to work on urban sustainability issues. Transformative Research in Urban Sustainability Training (T-RUST), an innovative graduate training program at WSU, trains students to address complex urban sustainability challenges. The research component of the WSU program features three complementary concentrations: urban ecological systems, urban redevelopment and the blue economy, and sustainable urban water infrastructure. Students will learn how to apply systems analysis tools to evaluate natural and engineered urban environmental systems while evaluating and communicating policy and management options. T-RUST will provide training to 15 National Science Foundation trainees, seven graduate students, and 100 undergraduate students (WSU July 2017).

## Mobility

URC institutions are at the forefront of tremendous changes in how we move people and goods. All three URC universities are living laboratories in their own unique way for the emerging mobility industry. WSU is using its campus as a laboratory to define the future of transportation. WSU professor Stephen Remias is leading a project called ITSWayne, which is collecting the data needed for intelligent transportation systems. His vision is to create a testbed on campus to help develop new technologies for traffic engineering, performance measurement, network communications, and public safety. Potential components of this project include developing and testing new detection products, wireless networks for automated transportation and communication between vehicles and pedestrians, and a 4D vision system for smart transportation and public safety systems. The research team is partnering with the City of Detroit, and the project is beginning at the corner of Warren Avenue and Anthony Wayne Drive (WSU College of Engineering Fall/Winter 2017).

In its urban setting, WSU has partnered for two of the biggest advancements in how people get around Detroit: the QLINE streetcar and the MoGo public bike share system. Both projects launched in May 2017, and represent major advancements in transportation in Detroit, a city that has struggled to move people through means beyond the automobile.

The QLINE streetcar travels a 6.6-mile loop along Woodward Avenue, and has two stops adjacent to the WSU campus, providing important connections from campus to downtown Detroit, and to Detroit's New Center district. The QLINE streetcars are the first to traverse the streets of Detroit since 1956.

The WSU Office of Economic Development led a feasibility study in 2012 for Detroit's MoGo public bike share project. The MoGo system includes over 400 bicycles that can be rented at and returned to any of the 43 bike share stations across the city, including several stations on campus. WSU faculty, staff, and students have discounted access to the bicycle fleet, helping ensure a nonmotorized options for getting around (WSU Newsroom 2017).

As outlined in previous sections, URC institutions are also at the forefront of advances in CAV technology. However, this work isn't limited to research alone. URC campuses are living laboratories for CAV implementation. The Mcity Test Facility at U-M is an example of this—in addition to conducting cutting-edge transportation infrastructure research, Mcity, in partnership with the Transportation Research Institute, has a deployment underway with 1,500 vehicles operating throughout a connected infrastructure in Ann Arbor, and plans to expand to more than 2,000 vehicles—the largest connected vehicle deployment in the United States.

This work includes studying the impact of connected technologies on congestion and pedestrian safety. Mcity is working with its partners to define and develop an advanced system of CAVs that will culminate in the launch of an on-demand mobility service in Ann Arbor by 2021.

## Energy

One of the most noticeable ways the URC campuses lead in advanced infrastructure is in energy. The URC institutions are transitioning to cleaner, more renewable sources of energy to power their facilities in creative, innovative ways. Guided by its Energy Transition Plan (ETP), MSU is making a gradual but profound shift to cleaner, more renewable energy sources and integrating leading sustainability practices into facility operations. First developed in 2009 and updated on a regular basis, the ETP includes ambitious goals to move MSU toward more renewable energy and to sharply reduce greenhouse gas emissions, and university officials have aggressively utilized infrastructure projects to make those goals a reality. Energy savings are not identified in a vacuum. MSU is acutely aware of fiscal constraints and is very careful to limit any impact of the sustainability efforts on tuition; therefore, seeks projects that provide the university with both energy and financial savings.

In line with the recommendations outlined in the ETP, in 2016 MSU stopped burning coal at the campus's T.B. Simon Power Plant, a move that has reduced annual CO<sub>2</sub> emissions by 575 million pounds (MSU IFP). This transition away from coal is a major success, aligned with other energy-saving practices and projects that contribute to energy sustainability and produce renewable energy.



One of those projects is the Solar Carport Initiative, which has utilized the airspace over existing MSU parking lots reserved for commuter students and faculty to build five large solar carports that generate electricity through solar power. In addition to energy generation through renewable sources, the Solar Carport Initiative saved land that can otherwise be used for food production or research purposes, a valuable commodity at this land grant university, by utilizing the campus's parking lots. In 2017, construction began on 40,000 solar panels above 5,000 parking spots. In total, the project covers 45 acres, and will produce over 15,000 MWh per year of solar energy (MSU Energy Townhall 2017). University officials project that, at peak demand, this solar installation will generate about 5 percent of the electricity used on MSU campus each year. And the new solar arrays offer an opportunity for students to conduct research—student teams from the College of Engineering are collaborating with faculty and infrastructure employees to research new power inverter technology and other topics.

An objective within WSU's Sustainability Strategic Plan calls for the institution's campus to be used as a learning laboratory which supports research and enhances the learning environment. In this spirit, WSU implemented a research project utilizing clean, renewable energy on its university campus. This research project enhances understanding of energy storage while also reducing greenhouse gas emissions.

The clean energy research project features a wind turbine and solar array that powers a computer lab as part of a combined renewable energy system on the roof of the Engineering Technology Building. The system charges a battery pack inside the Engineering Technology Building. An inverter converts the direct current (DC) electricity from the battery pack into alternating current (AC) electricity. This powers a computer lab in the building and can be switched to a lab in the Industrial and Manufacturing Engineering building. The hybrid system takes the grid power as a backup, making it one of the most reliable systems on campus. The computer lab normally runs on the renewable system but switches to the grid if there is a problem.

U-M's North Campus has a solar array consisting of 25 rows of panels and seven trackers that rotate the panels with the sun during the day. The installation is part of DTE Energy's SolarCurrents program, which supports DTE's goal of generating 10 percent of its electricity through renewable sources. U-M receives rental payments from DTE for the land (Budzaj Elger 2013).

## Communications

In 2008, U-M opened the Michigan Academic Computing Center (MACC). The project is a partnership between the university, Internet2, MAV Development, Merit Network, and the Michigan Information Technology Center Foundation. The facility allocated 8,500 square feet for hosting university data and 1,500 square feet for other partners (U-M Information and Technology Services 2017). The facility utilizes best practices, such as state-of-the-art climate control to improve energy efficiency and reduce costs.

MSU's new 25,000-square-foot data center will consolidate legacy infrastructure and deliver modern information technology services to its students, faculty, and staff. Savings of \$600,000 is estimated through consolidation of three university enterprise data centers. It also has capacity to spur growth by providing opportunities to collaborate with other university and business partners. Aside from their aforementioned Intel grant-funded work, WSU staff is also constructing a new data center to support teaching, learning, and the research computing needs of the future.

The URC universities also have created communications infrastructure to support data sharing and research across institutions. The Multi-Institutional Open Storage Research Infrastructure (MI-OSIRIS) is a collaboration of MSU, U-M, WSU and Indiana University to enable cross-institutional collaboration to meet data-intensive challenges within the research community. Funded by the National Science Foundation (NSF), MI-OSIRIS provides transparent, high-performance access to the same storage infrastructure from well-connected locations on any of the member campuses. The NSF also funds the ATLAS Great Lakes Tier 2 computing center, which is a collaboration between U-M and MSU to provide greater storage for physics computing.





## TALENT

### Overview

Building and maintaining infrastructure takes thousands of skilled workers. As new technologies integrate more into infrastructure, the skill levels needed to support that infrastructure will continue to grow. Degrees associated with infrastructure include engineering, computer programming, chemistry, architecture, construction trades, and regional planning. In total, we identified 174 individual degrees important to infrastructure, and grouped these degrees by field of study and level. The URC institutions produce thousands of graduates in these fields.

### Top University Clusters

The URC frequently benchmarks its performance against clusters consisting of the best public and private universities from around the nation. An economic cluster is a region with a high density of economically related organizations. Southeast Michigan is known for its automotive cluster. The URC represents a cluster of high-power research universities. The URC has identified the nation's top seven university clusters for comparison purposes: Northern California, Southern California, Illinois, Massachusetts, North Carolina, Pennsylvania, and Texas (see Exhibit 1).

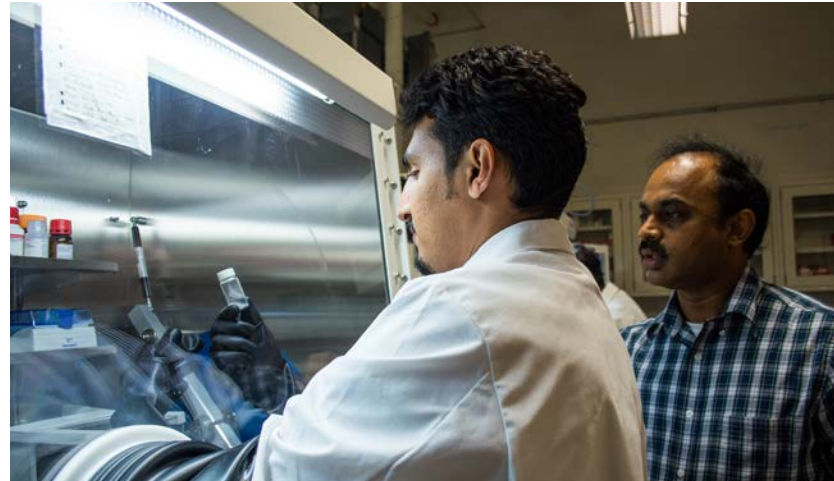


**Exhibit 1. University Clusters**

Cluster	Universities
University Research Corridor	Michigan State University University of Michigan, Ann Arbor, Dearborn and Flint Campuses Wayne State University
Northern California	Stanford University University of California, Berkeley University of California, San Francisco
Southern California	University of California, Los Angeles University of California, San Diego University of Southern California
Illinois	University of Chicago University of Illinois, Urbana-Champaign Northwestern University
Massachusetts	Boston University Harvard University Massachusetts Institute of Technology
North Carolina	Duke University North Carolina State University University of North Carolina, Chapel Hill
Pennsylvania	Carnegie Mellon University Pennsylvania State University University of Pittsburgh
Texas	Rice University Texas A&M, College Station and Commerce University of Texas, Austin

Source: Rosaen and Taylor 2017.

From 2012 to 2016, the URC awarded 34,324 degrees in infrastructure fields, ranking fourth out of the eight clusters (see Exhibit 2). The URC also ranks well with several major field groups. The URC awards the second highest number of degrees at the bachelor's level or higher in architecture, construction, and related management fields. It ranks third in the engineering and engineering technologies fields; fourth in computer, communications, and information sciences; and fifth in physical, agricultural and natural resource sciences and technologies (see Exhibit 3).



**Exhibit 2. Total Infrastructure Bachelor's and Higher Level Degrees Awarded by Research Cluster, 2012–2016**

Degrees Awarded		
Cluster	Number	Rank
Texas	45,557	1
Pennsylvania	37,939	2
Southern California	36,439	3
URC	34,324	4
Northern California	26,349	5
Illinois	25,147	6
North Carolina	22,122	7
Massachusetts	20,329	8

Source: PSC analysis using data from National Center for Education Statistics, Integrated Postsecondary Education Data System for school years ending 2012 through 2016. Only first majors are included. Accessed January 18, 2018. <https://nces.ed.gov/ipeds/datacenter/login.aspx?gotoReportId=7>

**Exhibit 3. Research Cluster Infrastructure Degrees by Level of Degree, 2012–2016**

	<b>Architecture, Construction, and Related Management</b>		<b>Computer, Communications, and Information Sciences</b>		<b>Engineering and Engineering Technologies</b>		<b>Physical, Agricultural, and Natural Resource Sciences and Technologies</b>	
<b>Cluster</b>	<b>Graduates</b>	<b>Rank</b>	<b>Graduates</b>	<b>Rank</b>	<b>Degrees</b>	<b>Rank</b>	<b>Degrees</b>	<b>Rank</b>
Texas	3,732	1	5,176	3	22,023	1	14,626	1
URC	3,655	2	4,768	4	19,809	3	6,092	5
Southern California	2,816	3	6,778	2	19,458	4	7,387	2
Massachusetts	2,520	4	4,595	5	9,334	8	3,880	8
Illinois	1,618	5	3,451	8	14,797	5	5,281	7
Northern California	1,503	6	3,714	7	14,481	6	6,651	4
Pennsylvania	928	7	10,201	1	19,932	2	6,878	3
North Carolina	809	8	4,014	6	11,561	7	5,738	6

Source: PSC analysis using data from National Center for Education Statistics, Integrated Postsecondary Education Data System for school years ending 2012 through 2016. Only first majors are included. Accessed January 18, 2018. <https://nces.ed.gov/ipeds/datacenter/login.aspx?gotoReportId=7>

The URC is slightly above average among leading university clusters for the number of bachelor's and master's degrees conferred, ranking third in both measures (see Exhibit 4). From 2012 to 2016, the URC awarded 19,652 bachelor's degrees in infrastructure and 11,808 master's degrees. The URC ranks sixth in the number of PhDs awarded, with 2,864.

**Exhibit 4. Research Cluster Infrastructure Degrees by Level of Degree, 2012–2016**

	<b>Bachelor's degree</b>		<b>Master's degree</b>		<b>PhD</b>	
<b>Cluster</b>	<b>Graduates</b>	<b>Rank</b>	<b>Graduates</b>	<b>Rank</b>	<b>Degrees</b>	<b>Rank</b>
Texas	31,394	1	10,342	4	3,821	1
Pennsylvania	22,466	2	12,430	2	3,043	5
URC	19,652	3	11,808	3	2,864	6
Southern California	16,975	4	16,344	1	3,120	4
Illinois	14,447	5	7,898	8	2,802	7
Northern California	13,366	6	9,305	6	3,678	2
North Carolina	11,511	7	8,474	7	2,137	8
Massachusetts	7,154	8	10,005	5	3,170	3

Source: PSC analysis using data from National Center for Education Statistics, Integrated Postsecondary Education Data System for school years ending 2012 through 2016. Only first majors are included. Accessed January 18, 2018. <https://nces.ed.gov/ipeds/datacenter/login.aspx?gotoReportId=7>

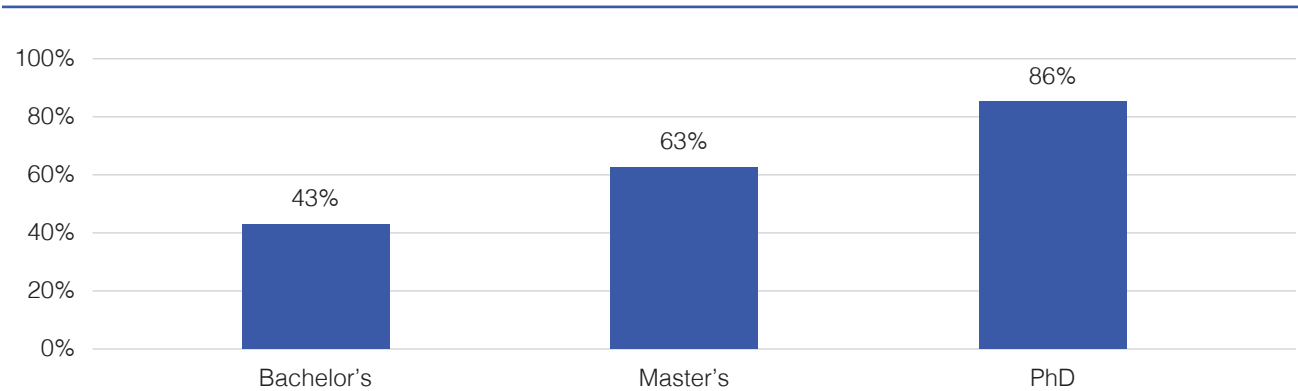
## In Michigan

Having the right talent is critical to meeting Michigan's infrastructure need. Governor Snyder recently highlighted Michigan's challenges in meeting the demand for highly skilled workers, noting that Michigan will have more than 811,000 jobs to fill through 2024 in fields that are facing a talent shortage (Office of Governor Rick Snyder 2018). To compete across the world and to do cutting-edge work in water, energy, communications, and transportation, Michigan needs workers with advanced degrees, from the bachelor's level through PhD.

The URC supplies much of Michigan's infrastructure talent, awarding 40 percent of the state's degrees related to infrastructure, and approximately half of degrees at the bachelor's level or higher. The URC is especially important with

respect to advanced degrees—the URC awarded 43 percent of bachelor’s degrees, 63 percent of master’s degrees, and 86 percent of the PhDs earned in Michigan in infrastructure-related fields from 2012 to 2016 (see Exhibit 5).

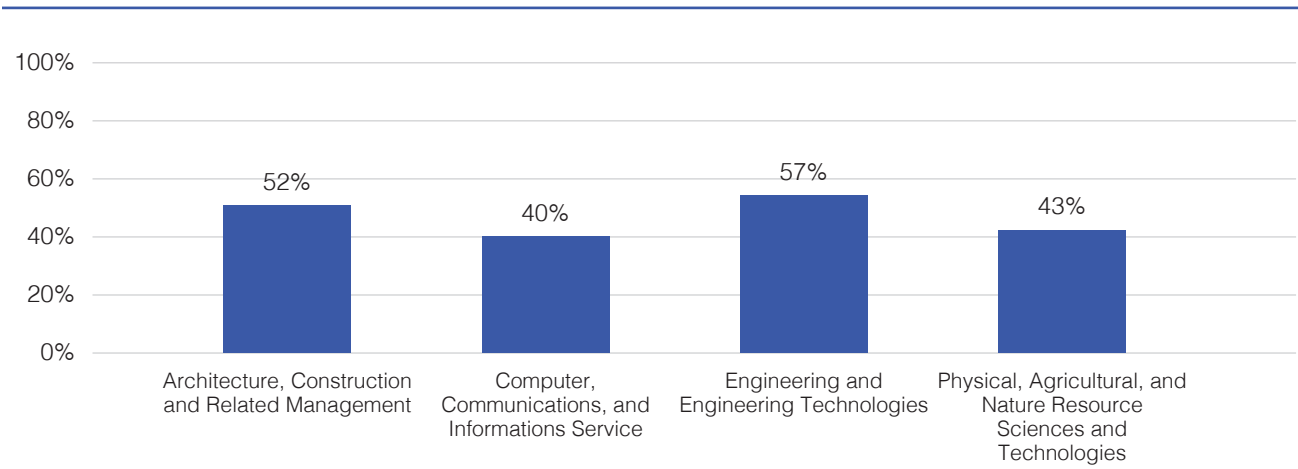
**Exhibit 5. Percent of Michigan Degrees Related to Infrastructure Awarded by the URC, 2012–2016**



Source: PSC analysis using data from National Center for Education Statistics, Integrated Postsecondary Education Data System for school years ending 2012 through 2016. Only first majors are included. Accessed January 18, 2018. <https://nces.ed.gov/ipeds/datacenter/login.aspx?gotoReportId=7>

For bachelor’s degrees and higher, the URC awarded 51 percent of all degrees in infrastructure-related fields. With respect to subfields, the URC awarded 52 percent of the state’s degrees in architecture, construction, and related management; 40 percent in the computer, communications, and information sciences; 57 percent of the state’s bachelor’s degrees and higher in the engineering and engineering technologies; and 43 percent in the physical agricultural and natural resource sciences and technologies (see Exhibit 6).

**Exhibit 6. Percent of Michigan Degrees Related to Infrastructure Awarded by the URC by Subfield, 2012–2016**



Source: PSC analysis using data from National Center for Education Statistics, Integrated Postsecondary Education Data System for school years ending 2012 through 2016. Only first majors are included. Accessed January 18, 2018. <https://nces.ed.gov/ipeds/datacenter/login.aspx?gotoReportId=7>

The importance of the URC’s talent production should not be underestimated. The URC serves as a pipeline for the advanced talent Michigan needs for economically competitive infrastructure. With eight in ten PhDs in Michigan awarded by URC institutions, the URC’s talent development is essential to the state’s ability to do cutting-edge research.





## TECHNOLOGY TRANSFER

Technology commercialization can be an important outcome of the research process. Some research can immediately impact infrastructure by providing essential knowledge to people in the field. Other research needs commercialization to realize its full impact. Corporate partners can provide the resources needed to extend research and ensure that important discoveries make it to the market.

Discoveries that are successfully brought into the marketplace can bring universities licensing fees and can lead to the formation of new companies. These companies create jobs and income, and universities can use licensing fees to support further research and technology commercialization.

The commercialization process works similarly at each of the URC institutions, with functions that can be divided into technology commercialization, business formation, and corporate engagement. During technology commercialization, the universities work with their researchers to ensure that inventions are disclosed and evaluated for market potential. Copyrights and patents protect this intellectual property, and the universities identify potential partners. Partners can license the technology or provide the funding needed to extend the research, since, in some cases, expensive additional research is needed before a product can be brought to market. The universities can connect their researchers with the partners who have the knowledge and capacity to guide the research through the next steps.

The universities also assist in business formation. Where appropriate, the universities can provide the education and financial support needed to turn inventions and discoveries into successful startup businesses. Corporate engagement offices provide an access point for corporations seeking university resources, such as inventions, researchers, and laboratories. These connections help ensure the successful commercialization of university discoveries.

Energy Emissions Intelligence, or E2I, is a good example of a successful startup arising from university technology. E2I is the commercial application of Locational Emissions Estimation Methodology (LEEM), a big-data, emissions-estimating product developed by researchers at WSU. With LEEM, power producers can proactively track, manage, reduce and report their facilities emissions. LEEM allows the user to track emissions for carbon, sulfur oxides, nitrous oxides, lead, and mercury. LEEM has already been incorporated into a number of real-world applications. The technology was extended to an application called Home Energy Read Out (HERO) that allows home users to track their output (WSU College of Engineering 2018).

A key technology enabling the IoT is integrating sensors into all types of everyday products. IoT can go much further when the sensors are not dependent on a plug-in power source or batteries that need to be regularly changed. U-M researchers partnering with the University of Virginia have created a new startup company called PsiKick that has helped eliminate the need for sensors to have an external power source. These researchers have also developed an ultra-low power receiver that consumes 500 times less power than other state-of-the-art devices. In 2012, the research team applied this technology to create a wireless electrocardiogram monitor that used about 1,000 times less power than the commercial systems were using. The power needs of this device are so low that it can be powered using the difference in temperature between the user's skin and the surrounding room temperature. This technology is not limited to medical devices and will find a home in a broad range of practical applications (U-M Electrical and Computer Engineering 2013).

U-M researchers also figured out how to generate power using sound. U-M startup Vesper developed a microphone that generates power from the sound it receives. This technology will allow digital home assistants like Amazon's Alexa to be free from requirements to connect to electrical outlets. It also has potential to embed microphones in wearable products. Vesper recently received \$15 million from investors recognizing the potential for this technology (U-M Tech Transfer n.d.).

Dr. Guangzhao Mao, chair and professor of chemical engineering in the College of Engineering at WSU, is working to improve gas sensing for chemical and environmental monitoring, food safety, and antiterrorism capabilities. With funding from the NSF I-Corps, Department of Defense Small Business Technology Transfer, and Michigan Translational Research and Commercialization programs, Dr. Mao and her team are developing a gas sensor manufacturing technology that could reduce the cost and complexity of manufacturing nanowire sensors. Nanowire

sensors make up an underutilized subset of the \$20 billion global gas sensor market because of current limitations in manufacturing techniques. Dr. Mao's innovation could expand the nanosensors market (O'Connor January 2017).

Technology transfer efforts are not limited to faculty. A team of MSU students developed a phone application called Carbon Cash that allows users to track their carbon footprint and utility bills and then receive rewards for using less energy. This application was originally an entry in a college student entrepreneurial contest, and it is now an application available for smartphones (Barhorst 2014).

MSU's breakthrough technology with clear solar panels was mentioned earlier in this report. Investors quickly recognized the potential for this technology. MSU has entered into a commercialization agreement with Ubiquitous Energy, a Silicon Valley technology company. Ubiquitous Energy will use this technology to continue its work toward eliminating the battery life limitations of mobile devices and putting in place solar panels as windows for buildings (MSU Technologies 2016). The potential upside for this technology is virtually unlimited.

Infrastructure represents a growing opportunity for technology transfer and commercialization. Mcity and the ACM offer students and researchers opportunities to help develop technologies that will bring CAVs into common use. As the IoT becomes more widespread, there will be more and more opportunities for students and faculty to use engineering and computing know-how to make the devices we use in our everyday lives "smarter." The automobile industry is located in Michigan because the state was a center of manufacturing innovation at the start of the 20<sup>th</sup> century, analogous to Silicon Valley's role in software development today. Current advances in infrastructure technology and innovation represent this same type of opportunity for Michigan in the 21<sup>st</sup> century.



## CONCLUSION

Infrastructure is broad, but within this broad framework, there is a vast array of amazing discoveries that will change how we interact with our environment, our communities, and even our bodies. These discoveries have the potential to not only solve some of today's most vexing infrastructure challenges, but to also improve the productivity, security, health, and connectedness of society. Infrastructure is the backbone of our economy and of modern society, but it often works so well that we take it for granted. However, we are now at an inflection point. Legacy infrastructure investments are aging and, in some cases, failing.

At the same time, technological advances are making new forms of infrastructure possible. Smart infrastructure is enabled by the advent of low-cost, low-power sensors. CAVs have the potential to fundamentally change how we move. Concerns over greenhouse gas emissions and the depletion of fossil fuel sources motivate us to change how we generate power.

Michigan needs to be at the forefront of these changes. We need infrastructure that allows our economy to compete with other states and nations. We need to lead in the realm of mobility infrastructure to ensure that the next generation of vehicles are developed and produced here.

Fortunately, the URC institutions are helping Michigan to stay at the forefront of innovation. These campuses are models—living laboratories—for the future of infrastructure. Cutting-edge URC research, talent, and facilities will help to ensure that Michigan creates CAVs, our water supply is safe, renewable energy sources are being discovered and adopted, and advanced broadband service expands to all communities.

Michigan faces big infrastructure challenges, but we are up to the task thanks to the diverse perspectives and expertise at the URC institutions. Whether individually, collectively, or through partnerships with private companies, the faculty and students at the URC schools are working to move Michigan forward.





# APPENDIX A: RESEARCH AWARD METHODOLOGY

To quantify the level of infrastructure-related research and service conducted by the URC institutions between 2012 and 2016, the team reviewed research awards data from the URC universities (including all U-M campuses) for projects active during this period.

The team's operational definition for "infrastructure-related" included any research, outreach, or service activity that focused on any activity that had an impact on one of the four infrastructure areas addressed in this report—water, mobility, energy, and communications. To determine if a project was infrastructure-related, the team investigated the nature of the project as described by available materials, such as dedicated Web pages, press releases, grant applications, project abstracts, and published journal articles. Using this information in combination with professional judgment, the team coded the data to classify infrastructure awards, in general and for the specific categories into which the awards fit. Some awards applied to more than one category.

The search method was based on the model used in previously published URC industry reports (see Appendix B for a list of reports), and it included a multitiered search process conducted by several independent researchers. The first tier of the search process included analysis of recognized search terms, such as "automotive," "naval," "water filtration," "sewer," "energy," and "cybersecurity." The next tier reviewed the titles of awards receiving funding from organizations known to support research infrastructure research (e.g., U.S. Departments of Energy and Transportation). All awards of researchers and funders that had at least one project were coded as infrastructure-related.

Reconciliation of independent researchers' coding of awards was conducted through discussion and review, resulting in a codified list of awards.

The estimate of award spending active during the period of 2012 through 2016 includes projects that started before 2012 and others that were active after 2016. To allocate the award funding for awards commencing before 2012 or lasting beyond 2016 to this period, the total award amount was multiplied by the total number of days the project was active between 2012 and 2016, divided by the total number of days the project was active.

This methodology is limited, in that it does not account for any systematic variation in spending of research award amounts, such as a tendency to spend down awards more heavily toward the beginning or end of the projects.

# APPENDIX B: URC SECTOR REPORTS

Over the past eight years, Michigan's URC—an alliance between MSU, U-M, and WSU—has commissioned a series of reports examining the contributions of the URC to key sectors of Michigan's economy. Key findings include:

## **Leading Discovery: URC Contributions to the Life, Medical, and Health Sciences (2017)**

- URC institutions conducted over \$1.2 billion in academic research and development in the life, medical, and health sciences in 2015, accounting for 95 percent of the state total.
- Operating throughout the state, URC institutions have more than three million patient care visits each year and perform tens of thousands of surgeries.
- The URC ranks first among peer university clusters in talent production in the life, medical, and health sciences. The URC produces 44 percent of the state's degrees in these fields.
- URC institutions have been averaging a new startup company every other month in the life, medical, and health sciences over the past five years.

## **Engaging Detroit: URC's Contribution to Resurgence in the Motor City (2016)**

- The URC's economic impact in Detroit was \$958 million in fiscal year (FY) 2014.
- The URC accounts for one in 20 jobs in Detroit.
- The URC engages in more than 340 programs, projects, activities and events in Detroit focused on community building, economic revitalization, public education, and public health.

## **Talent for the Global Economy (2015)**

- Among top research university clusters, the URC ranks first in medical degrees, total degrees awarded and enrollment, and second in advanced degrees in high-tech fields, such as engineering and sciences.
- Of the 32,000 URC graduates each year, more than a third earn degrees in high-demand fields, such as medicine and engineering.
- Ann Arbor, East Lansing, and Midtown Detroit residents 25 and older are three times more likely to have a degree compared to other Michigan communities.

## **Blue Economy (2014)**

- From 2009 to 2013, URC universities received 2,100 awards totaling nearly \$300 million and supporting 341 researchers from dozens of departments for water-related research and outreach.
- Each year, URC universities produce more than 3,400 graduates prepared to analyze and find solutions to water-related issues in academia, government, and the private sector.
- One in five Michigan jobs (718,700) is associated with water-enabled or water-related industries.

## **Alumni Entrepreneurship (2013)**

- A 2013 survey of URC alumni found 19.1 percent of respondents had founded or cofounded a business.
- Nearly half of the businesses started by URC alumni entrepreneurs began in Michigan.
- URC alumni-started firms were nearly 1.5 times more likely to stay in business versus the national average.
- URC alumni entrepreneurs started or acquired businesses at double the national average rate among college graduates between 1996 and 2012, and many of these companies were in fields outside their major area of study.
- URC alumni entrepreneurs have started businesses in every U.S. state and more than 100 countries.

## **Automotive Innovation (2012)**

- The URC universities confer more than 3,600 degrees annually in auto-ready disciplines, supplying the industry with talent.
- Between FY 2007 and 2011, the URC universities spent \$300 million on more than 1,400 auto projects. More than 28 percent of the research was funded by private industry—nine times the average share of industry funding for all university R&D at these institutions.



- URC researchers have helped automakers improve vehicle quality and safety, improve engine efficiency and performance, and reduce fossil fuel use.

#### **Information and Communication Technology (2011)**

- URC universities spent nearly \$74 million on research projects with a strong IT focus in FY 2010.
- Nearly 40 percent of the approximately 150 URC-assisted startups between 2001 to 2011 had an information and communication technology component.
- Information technology employs about 3.5 percent of the state's workforce (135,000 workers)—a significant standalone sector and the underpinning for much of the major industry activity and growth represented in previous sector reports.

#### **Advanced Manufacturing (2010)**

- URC universities spent \$101 million on advanced manufacturing R&D in 2009.
- URC universities are educating more than 14,000 students in engineering.
- In 2007, Michigan's advanced manufacturing industry employed 381,351 workers, accounting for 10.3 percent of all employment. One-third of the Midwest's advanced manufacturing jobs were in Michigan, paying an average wage of \$64,122.

#### **Life Sciences (2009)**

- In 2008, URC universities spent \$887 million on life sciences R&D.
- R&D expenditures grew 69 percent since the founding of the Life Sciences Corridor in 1999.
- Michigan's life sciences industry employed more than 79,000 workers, (2.1 percent of all employment in 2006).
- Between 1999 and 2006, life sciences industry employment grew by 10.7 percent while manufacturing employment dropped by 24 percent.
- Life sciences wages averaged \$83,494 in 2006.

#### **Alternative Energy R&D (2008)**

- Michigan has a comparative advantage in biomass and wind compared to the energy potential in the other 49 states.
- URC universities spent more than \$79.5 million on R&D related to alternative energy in 2007.
- More than half of all alternative energy R&D supported the auto industry.

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