THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

ANNUAL REPORT

2020

Graphic Design by the College of Engineering

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Mission Statement

The mission of the Center for Automotive Research (CAR) is to provide world-class education for the next generation of automotive industry leaders, through on-campus learning and continuous professional development; serve as a catalyst for innovation in automotive technology through collaborative, interdisciplinary research; and support economic development, regionally and nationally.

A Message from the Director

As we prepare this annual report, we are all facing unusual circumstances. This is an unprecedented time in our history and presents all of us in the academic world and the automotive industry with new challenges.

The automotive industry has embraced the correct way of thinking about these challenges. It is busy supporting our fight against COVID-19 by employing its considerable capabilities to support the health and safety of our citizens. Similarly, our university has dedicated itself, especially at the Wexner Medical Center, to embark upon a series of initiatives in support of medical advances that will assist us in achieving our common goal to return to a healthy, safe and productive environment.

We continue to be grateful for the strong partnership that we have with our industry partners. In spite of the current difficulties, we continue to work with each of you on ongoing projects and we are already talking about the new wave of research projects that we will undertake together in the near future. We are hopeful and positive about the future and we look forward to working together with you.

I'm sure that in the process of reinventing ourselves, we will come up with new ideas, new processes and new forms of collaboration that will make our partnerships even stronger. There will certainly be a new normal and we look forward to reinventing our relationship with you so as to make it as productive as possible for many years to come.

Giorgio Rizzoni

CAR Overview

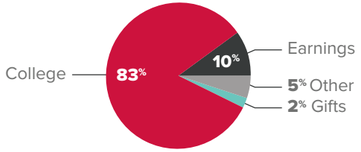
OUR TEAM

57 visiting scholars

43 research and administrative staff

64 CAR-affiliated faculty

OPERATING BUDGET - $1.7M annually



RESEARCH

Total

$11.9M

Industry: $4.8M

Federal: $4.8M

State: $2.3M

STUDENTS

172 students in 2020

Masters: 51
PhD: 69
Undergrads: 52

EXPERIENTIAL LEARNING

7 vehicle project teams

10 on-site labs

45 miles to TRC: North America's largest proving ground

MEMBERSHIP CONSORTIUM

16 consortium members

80 percent of funds invested in exploratory research grants

30 students actively engaged in exploratory research projects

Data for 2019 calendar year

SERVICES

Engineering Services

- Emissions testing
- Battery testing
- Powertrain performance

Distance Education

- 246 professional students enrolled in credit and non-credit courses, representing five companies: GM, FCA, CNHi, Polaris, and Honda

$634,423 in expenditures

Staff Listing

CAR Leadership Team

- Giorgio Rizzoni, Director
- Marcello Canova, Associate Director
- David Cooke, Sr. Associate Director
- Meg Dick, Assistant Director

Business Operations

- Stacy Hillstrom, Program Assistant
- Stacy Wilson, Fiscal Associate
- Jackie Wolfe, Grants Coordinator
- Layla Mohmmad-Ali, Associate Fiscal Officer
- John Kabat, HR Generalist
- Mallory Aliff, HR Consultant
- Marianne Weber, Distance Education Manager

Outreach and Business Development

- David Emerling, Industry Collaborations Director
- Colleen Herr, Marketing and Communications Specialist
- Jennifer Humphrey, Events and Outreach Manager

Research Support

- Dave Brown, Systems Manager
- Jim Riedel, Systems Administrator
- Jim Shively, Lab Technician
- Bill Sparks, Test Technician
- Max Wright, Student Projects Shop Supervisor
- Darrin Orr, Project and Student Teams Coordinator

Research Staff

- CG Cantimer, Research Scientist
- Jeff Chrstos, Research Scientist
- Matilde D'Arpino, Research Scientist
- Ricky Dehner, Research Scientist
- Cam Giang, Research Associate - Engineer
- Yann Guezennec, Faculty Emeritus
- Gary Heydinger, Research Scientist
- Adithya Jayakumar, Lecturer
- Dennis Kibalama, Research Associate - Engineer
- Prashanth Ramesh, Lead Engineer
- Emel Selamet, Research Scientist
- BJ Yurkovich, Research Specialist
- Walt Dudek, Engineering Services Director
- Siyu Jiang, Research Assistant - Engineer
- Jeremy Mak, Research Assistant - Engineer

EDUCATION

Student Performance

MOTORSPORTS

Baja Buckeyes • Buckeye Current • EcoCAR
Venturi Buckeye Bullet • Formula Buckeyes
Supermileage • Underwater Robotics

- Sponsorship: 44%
- TREP: 23%
- Engineering departments: 22%
- University support: 7%
- Other: 4%

UNDERGRADUATES AND GRADUATES

52 undergraduate students

120 graduate students

39 female

18 different countries

INTERNSHIPS

12 CAR students at **9** different partner organizations

TuSimple • FEV • Delphi • Ford • Samsung • Cummins • FCA
Texas Instruments • Guangzhou Automobiles Group

STUDENTS

73 domestic

99 international

86 MS and PhD students have graduated over the past 5 years prepared and ready to enter the workforce

CAMP CAR

Educated 20 high school students about automotive engineering and mobility

CAR INTERNSHIP PROGRAM

Mentored 13 high schools and college students in different areas of automotive engineering

Motorsports

Student Projects

Students at The Ohio State University have the opportunity to participate in Motorsports Student Projects. This program challenges students of all majors, backgrounds, skill levels and degrees of experience to compete on the following teams:

- Baja Buckeye
- Buckeye Current
- Ohio State EcoCAR
- Formula Buckeyes
- Underwater Robotics
- First Alumni and Robotics

COVID-19 cut the season short for the teams, however the hard work and long hours that the students put in this year did not go unnoticed. CAR continues to support these students and looks forward to watching them compete again in 2021.

Baja Buckeyes

The Baja Buckeye team at the 2020 Midnight Mayhem competition

A rendering of the 2020 Baja Buckeye competition vehicle

Buckeye Current

The Buckeye Current team participated in the 2020 Maker X, a public show which celebrates creating with technology

Buckeye Current team member, Tyler Martin working with the capstone team on the data logging system and integration of the DDU donated by Bosch Engineering Group

Ohio State EcoCAR

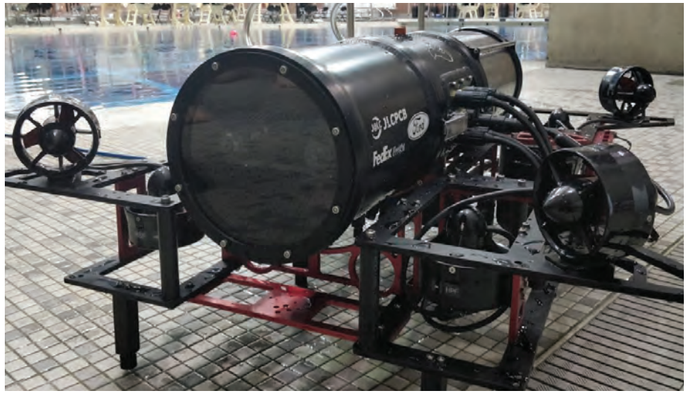
The Ohio State EcoCAR team at the EcoCAR Winter Workshop in Austin, Texas

Formula Buckeyes

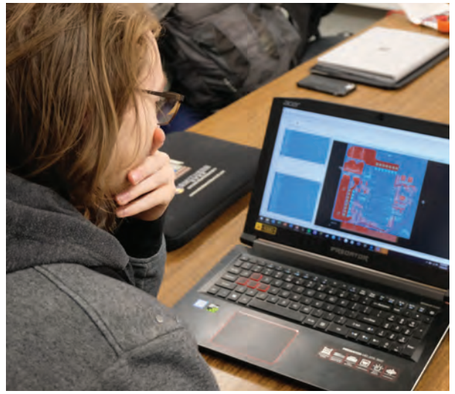
The Formula Buckeyes team participating in the Brake Box Tech Inspection at Michigan International Speedway

Suspension lead, Jacob Buchhop machining aluminum on the shop lathe

Underwater Robotics



The robot making a test run at the diving well at McCorkle Aquatic Pavilion



Electrical team member, Dylan Trainor designing a circuit board in EagleCAD

First Alumni and Robotics

Team members presenting "THE" robot, built in three days at the PAST Foundation to nine local FIRST Robotics competition teams

Distance Education

CAR Delivers In-Person, Customized Courses to Consortia Members

The CAR Distance Education program creates customized packages and course offerings depending on the needs of each partner. Options range from live short courses tailored around one specific subject area, to online credit courses and non-credit seminars, including 1-year certificate programs that focus on specialized areas of study such as advanced propulsion, powertrain modeling and control and noise vibration and harshness.

These programs draw extensively from CAR's research and innovation and are targeted to professionals in the transportation industry.

In December 2019 and January 2020, two customized, live short courses were delivered to 45 staff members at Dana Corporation, an American supplier of axles, driveshafts, transmissions and electrodynamic, thermal, sealing and digital equipment for conventional, hybrid and electric-powered vehicles. These courses focused on vehicle electrification and energy storage and were taught by Associate Professor Marcello Canova, Assistant Professor Jung-Hyun Kim and CAR Director Giorgio Rizzoni.

"This course explored many relevant topics from hybrid vehicle architectures to quantifying benefits from the system in a way that was both rigorous and approachable. Dr. Rizzoni clearly enjoys his work, and he is an excellent communicator, which always makes for a great class," said Andrew Brammer, a lead engineer at Dana.

Rizzoni and Canova also provided a virtual course on electrification to 40 Honda Performance Development team members, the engineering team responsible for working with the Honda racing teams.

The engineers viewed lectures over a month and every other week, the group provided Rizzoni and Canova with a list of questions and topics for discussion in a live consulting session with Rizzoni, Canova and Research Scientist, Matilde D'Arpino.

"This opportunity allows us to use distance learning to educate ourselves and build our skills," said David Salter, technical director at Honda Performance Development. "The information was extremely relevant for our electrification needs going forward and gave a solid knowledge foundation, both practical and theoretical."

Additionally, industry engineers routinely benefit from CAR's preparatory seminars before they enroll in the graduate automotive engineering courses or advanced seminars on specialized topics. These advanced seminars focus on specific and innovative topics with constantly updated material and range from 8 - 20 hours, some including lab sessions. Seminars can be delivered as self-paced online courses, live on-site, or live at CAR.

> *"The information was extremely relevant for our electrification needs going forward and gave a solid knowledge foundation, both practical and theoretical."*

Outreach

While the COVID-19 pandemic required CAR to cancel many of our in-person events, it did not prevent us from staying connected to our students, staff, industry partners and future students.

Defense and candidacy exams were held virtually, allowing fellow students the opportunity to share their support.

CAR staff participated in weekly virtual social gatherings, offering a fun opportunity to stay connected.

Graduates of the class of 2020 received special recognition during a virtual commencement celebration led by CAR faculty and staff.

Camp CAR 2020 Goes Virtual

For the third consecutive year, CAR, with the support of Honda, Ohio State Energy Partners and Engie provided a unique experience for those interested in automotive engineering through Camp CAR. What is typically a week long summer day camp for 20 high school students, this year the camp was held virtually for one afternoon and open to people of all ages who were interested in learning more about CAR.

"Camp is a highlight of our programming year, and while we were disappointed not being able to host an in-person version, our entire CAR team worked hard to create webinar content that was informative, engaging and fun," said Jen Humphrey, CAR outreach and events manager. "Two silver linings of the virtual experience were that we were able to welcome four-times the amount of participants of our in-person camp, as well as welcome participants from ten other US states, Puerto Rico and three international countries."

Campers had the opportunity to hear from CAR faculty and students and attend a virtual tour of the facility. They were also introduced to the Student Motorsports teams and watched videos of the teams during competition.

"Getting young students exposed to CAR and all of the different components of automotive engineering is important for developing the next generation of innovators in our field," said Polina Brodsky, a PhD student in Mechanical Engineering who helped lead the camp. "Our industry is always advancing, and showing students how multi-faceted it is shows them the opportunities they could have in a career in the automotive industry."

Camp CAR participants will be invited to an in-person tour of CAR and Motorsports facilities once campus is open to the public.

Camp CAR is an annual summer program. Applications for the 2021 camp will be available at *car.osu.edu* in the spring of 2021.

Camp CAR participant, Elise Edwards participates from her home in Amanda, Ohio

JAXON WILKERSON

Jaxon Wilkerson, a graduate research assistant working in the Driving Dynamics Lab (DDL) at CAR is helping transform the way the automotive industry tackles vehicle safety testing. Wilkerson began his journey as an undergrad in the Department of Mechanical Engineering at The Ohio State University and is now part of a research group developing a driving simulator to test advanced driver-assisted systems at CAR.

The DDL looks at vehicle dynamics and active-safety work mostly through the use and development of the vehicle dynamics driver-in-the-loop simulator.

During his work in the DDL Jaxon is advised by CAR Director Giorgio Rizzoni and Research Scientist Jeff Chrstos.

"The biggest thing that drew me to CAR in the first place was working with Professor Rizzoni, he's a big name in the field, and then within that the available opportunities that were out there specifically doing something with safety systems. What's relevant right now and becoming more relevant is driving simulators, so when Professor Rizzoni said that was an option here at CAR, that was most in line with my goals," Wilkerson said.

Wilkerson is focusing on the development and testing of active-safety systems through the driving simulator. Active-safety systems help to decrease the chances of accidents before they occur; mirrors, car sensors and brake assist for example. As opposed to passive-safety systems, which mitigate damage after the collision has occurred; air bags, seat belts and the structure of the vehicle.

"Those active safety systems first get developed in a simulator, because part of the developmental phase is going to save a bunch of time and capital once you have the initial simulator investment," Wilkerson said.

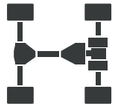
Wilkerson came to CAR to work on these active systems. He focuses on the sensors and automated systems that work in the background which help to prevent vehicle collisions.

"On a simulator all the systems require sensors, so we have what's called high-fidelity vehicle models, so our vehicle reacts like a real vehicle does, not like a game, we're not entertainment we're an engineering tool," Wilkerson said.

After completing his master's at CAR, Wilkerson has set his sights on original equipment manufacturing in the transportation field. He wants to take his experience at the DDL and work for an automotive manufacturer doing developmental design, working in a research group or designing active safety systems.

Core research areas

Propulsion and Systems Control



Electrification

Safety and Security

Autonomous and Connected Vehicles

Smart Mobility

PhD students' experiences impacted by NEXTCAR

For Shreshta Rajakumar Deshpande (top photo) and Shobhit Gupta (bottom photo), working at CAR benefits more than their professional careers. Both are doctoral candidates in Mechanical Engineering at The Ohio State University. Their work on the ARPA-E NEXTCAR project at CAR is shaping their studies, their future careers and the future of connected and automated vehicles.

NEXTCAR (NEXT-Generation Energy Technologies for Connected and Automated On-Road Vehicles) is a three-year project led by the university in collaboration with Delphi Technologies, Tula Technology, Transportation Research Center and Aptiv. The project aims to improve connected vehicle technologies and ultimately boost hybrid electric vehicles' (HEVs) fuel economy by 20 percent.

Gupta and Rajakumar Deshpande develop optimization algorithms that leverage connected and autonomous features like look-ahead route and traffic information to improve energy management and consumption in HEVs. Both PhD students have been impacted by their work on this project and their time at CAR.

Gupta, who has worked at CAR for more than two years and describes it as "a second home," was drawn to the center because of the opportunities it presents.

"One of the fascinating things about CAR is the interdisciplinary research and the opportunity to interact with leaders from both academia and automotive industry while working on cutting-edge research projects," said Gupta.

When Dr. Marcello Canova added Gupta to the NEXTCAR project, he began participating in interdisciplinary research himself.

"Working with the NEXTCAR team, I got the opportunity to not only develop theories and solutions but also to deploy them on a test vehicle at a test track, which is the most satisfying part for a researcher," said Gupta.

His work with NEXTCAR also has inspired his long-term career trajectory.

"After my graduation, I hope to join the e-mobility/CAV-related (connected and autonomous vehicles) research group of an automotive company," Gupta said. "My long-term aspiration is to become an expert in the area of powertrain electrification. I want to apply the knowledge and experience I have gained at CAR to solve real-world problems and contribute in driving the automotive sector toward cleaner, more efficient and smarter vehicles."

Rajakumar Deshpande values his time at CAR for the challenges he has been able to take on.

"The NEXTCAR project is unique in that it calls for not just the development of sophisticated vehicle control strategies in simulation, but also the demonstration of these algorithms in a production vehicle," he said. "The ambitious nature of this three-year program has facilitated my growth as a PhD student, through which I have built a strong background in control and optimization theory, and modeling of dynamic systems. Further, the on-board deployment of our optimization algorithms has helped me appreciate the interaction between complex control systems and helped me grow as a mechanical engineer."

After graduation, Rajakumar Deshpande plans to keep advancing research in connected and autonomous vehicles. His career ambition to work in a transformative and innovative space that pushes the boundaries of the automotive industry began at CAR.

"CAR, and in particular, my advisor Marcello Canova, have given me learning experiences that extend far beyond the confines of research projects and coursework," he said. "They have made me a better thinker, a better engineer and helped me push the boundaries of what I thought I was capable of doing."

Those experiences will endure, even as Rajakumar Deshpande moves forward in his career.

"The friendships at CAR, the collaborative learning and the self-discovery are things that will stay with me, now and always," he said.

Professor returns to Ohio State with lab and research in energy system control and optimization

Stephanie Stockar, assistant professor in the Department of Mechanical and Aerospace Engineering (MAE), brought her lab and research in the optimization and control of energy systems when she recently returned to Ohio State University.

Stockar earned her PhD at Ohio State, and worked as a research associate at CAR before joining Pennsylvania State University as an assistant professor of mechanical engineering in 2016. At the end of the 2018/2019 academic year, Stockar transitioned back to Ohio State.

Upon returning to her alma mater, Stockar brought with her research in the optimization and control of energy systems, which wasn't a major area of focus at her previous institution. In particular, Stockar is interested in how to optimize

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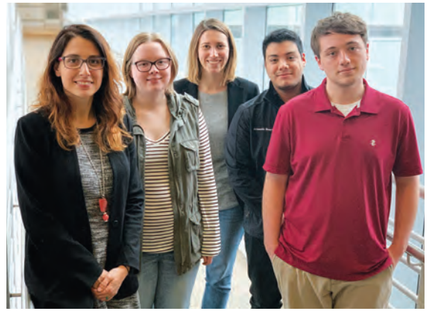
and improve the efficiency of systems that are characterized by energy conversion and storage.

"I first arrived at Ohio State in 2008 as a visiting scholar," she said. "At the time, I was pursuing my master's degree from the Swiss Federal Institute of Technology and my research focused on hybrid vehicle energy management. I was interested in conducting research abroad and my advisor suggested a period at CAR where I could work with Professor (Giorgio) Rizzoni. I truly enjoyed the whole experience: the research, the environment at CAR, the university and Columbus and decided to apply for a PhD at Ohio State."

"The opportunity to work with exceptional undergraduate and graduate students and the amazing colleagues in the department and college was something I was looking forward to coming back to," she said.

One area of Stockar's research revolves around the optimization of district heating networks; a system for distributing heat generated in a centralized location through a series of pipes. These networks typically provide heat to public buildings, so there are many variables that make testing and improving the efficiency of the energy systems difficult.



Stockar and members of her research team (L to R): Stephanie Stockar, Audrey Blizard, Anna Misley, Armando Henriquez and Jacob Paugh

"It's not very easy to test those strategies because it would require us to override what they are doing now," she said. "The other problem is that the repetition of testing is very difficult. You want to rerun the same test multiple times under the same conditions, but with district heating networks we have temperature in the environment changing, and people in the building asking for more or less heat, so you have a lot of variability, hence it's very difficult to understand, evaluate or benchmark your control strategy."

With her laboratory setup, however, Stockar is able to solve the issues that come with trying to test and increase the efficiency of these systems.

"We developed a scaled down experiment, which was representative of a district heating network," she said. "Since it's in a lab room and it's much smaller, it operates faster and we can use that facility to understand whether our modeling approach for doing control design is appropriate and accurate. We can use a lab setup to implement and prototype control strategies and verify the optimality of our control strategies empirically."

Another project Stockar is undertaking is the optimization of the air conditioning of a passenger vehicle by controlling different activators in the system.

"We need to develop a good understanding of how the system and coupling behaves so that we can minimize the energy usage and the fuel associated with the operation of the air conditioning," Stockar said.

Stockar's research is a valuable contribution in understanding the way energy systems can be optimized and controlled, and this could lead to the increased efficiency of a wide variety of energy systems.

"Ohio State and Columbus have been the center of several university and community scale initiatives that line up with my research interests," Stockar said. "As such, Ohio State provides a unique environment to collaborate across multiple disciplines, as well as Industry, National (Laboratories) and external organizations such as Smart Columbus. In addition to the research opportunities provided by such collaborations, these initiatives have been crucial for attracting outstanding students to the MAE graduate program."

Assistant professor aims to build better batteries for electric vehicles

We use batteries in our cars, phones, computers and in countless other common household objects. But the simple battery is a complex feat of chemistry and engineering, a feat that Jung-Hyun Kim, assistant professor in the Department of Mechanical and Aerospace Engineering, and his team at the Energy Innovation Lab perform every day.

Today, the leading type of battery is a lithium-ion battery. The three main parts of these batteries are a cathode, an anode and an electrolyte that sits between them. Lithium-ion batteries are low-maintenance and provide high-energy capacity, but even higher energy is needed to extend the driving distance of current electric vehicles (EVs). Also, their reduced performance at high and low temperatures, high price, limited fast-charging capability and abuse tolerance make them less reliable in EVs. As more people seek out electric transportation options, Kim is searching for a battery that can address those problems.

The Energy Innovation Lab is a collaborative research lab from CAR, the Institute for Materials Research (IMR) and Nanotech West. Researchers at the lab synthesize and characterize materials, build batteries and test those batteries' longevity, capacity, and stability – all in pursuit of a better battery.

The process begins with design and material synthesis. Kim and his team design and synthesize cathode, anode and electrolyte materials using various chemical or solid-state synthesis methods. The synthesized materials are analyzed by microscopies, spectroscopies and diffractometers to examine if the team obtained the target materials. The materials are used to create experimental battery elements that can then be combined with industry-standard materials to build battery cells.

The cells often are constructed in moistureless glove boxes to maintain the integrity of the materials. Battery cells are very sensitive to moisture, so researchers fabricate them in a glove box filled with argon gas. Once cells are fabricated and sealed in the boxes, they move on to testing, the final step in the experimental process.

Small coin-type cells are tested first, and if they pass the performance criteria, a bigger pouch-type cell is fabricated and tested. Cells are tested at different temperatures and under different testing protocols, battery cyclers and temperature-controlled environmental chambers. Because testing is automated, the battery cells are quickly and accurately assessed for success according to the Energy Innovation Lab's goals.

"Our mission is to make a battery cell that lasts longer, for driving longer at high power and high energies," said Kim. As the automotive industry moves toward electrification, better batteries are becoming more important to ensure reliable vehicles. The Energy Innovation Lab is up to the challenge.

Battery cells often are constructed in moistureless glove boxes to maintain the integrity of the materials.

CAR researchers tackle extreme fast charging of electric vehicles

An exploratory research program at CAR aims to evaluate the feasibility of "Extreme Fast Charging" (XFC) which would allow electric vehicles to be recharged as fast as conventional vehicles are refueled. XFC promises to accelerate the adoption of battery electric vehicles (BEVs) by designing high-performance, cost-effective, safe and affordable energy-storage systems.

CAR Research Scientist Matilde D'Arpino and Associate Professor Marcello Canova are heading the project, which is contributing to the understanding of the technological barriers and potential solutions to achieve XFC. Zachary Salyer is the graduate research assistant working on the project while earning a master's degree in Mechanical Engineering.

"It's really working toward reducing the charging time, which is a huge concern for electric vehicle consumers," Salyer said. "That's one of the big challenges that the industry is facing."

Starting from work done by the U.S. Department of Energy's National Laboratories, the CAR XFC research program is mapping the key technological barriers in charging infrastructure, battery pack design and electrical and thermal battery management, which currently limit the maximum charging "C-rate" per cell. The C-rating shows how fast batteries can charge and discharge energy. In this case, the research could allow for up to a C-rate of 6, which is a 10-minute charge time.

"Teslas can charge from 20% to 80% state of charge in about 20 to 30 minutes," Salyer said. "That would correspond to about a 1.5C rate, so getting that to 6C is a huge challenge because the increased charging rate is going to cause a lot of heating, and the cells are not necessarily able to withstand that high charging rate because of increased degradation."

Several technical challenges need to be addressed at multiple levels, particularly in critical areas such as the understanding of the aging mechanism, thermal control and safety to enable XFC systems that would allow for maximum charging current per cell up to the 6C rate.

The researchers aim to produce a behavioral model of a Li-ion battery that they can use to predict the main factors that may pose constraints to fast charging, including cell degradation and heat generation.

"The ideal goal is that once we have a degradation model finalized and calibrated, we will be able to use the model to derive optimal charging strategies for specific cell chemistries and pack specifications," D'Arpino said. "Moreover, we will be able to estimate the degradation that the cells will see using that specific profile and doing benchmarks between different cell technologies to understand their capabilities to withstand XFC."

The researchers will conduct a simulation study aimed at exploring electro-thermal control optimization solutions that could mitigate potential degradation and thermal issues when performing fast charging. The study will explore how to dynamically charge a cell in order to optimize simultaneously for charge time, heat generation and cell cycle life. This would produce an algorithm that could be used to explore the impact of pack design parameters on the ability of the pack to tolerate fast charging at higher rates.

This research could be a valuable contribution in the knowledge of batteries and how small choices in cell design can impact the overall performance of a battery. The impact of the research could prove to be more resourceful than in the realm of just electric vehicles.

"It's really a matter of focusing on reducing those charging times, and better understanding what's happening within the cell, that can help you design better charging methods and extend the life of the batteries as well," Salyer said.

Electric vehicle charging stations are located outside the Center for Automotive Research

Flow, engine, acoustics and turbocharger research laboratories

For more than three decades, the focus of the Flow, Engine, Acoustics and Turbocharger Research Laboratories at CAR, under the direction of Ahmet Selamet, professor in the Department of Mechanical and Aerospace Engineering, has been on the development and validation of simulation tools to:

- Predict the engine performance by integrating wave dynamics, combustion and heat transfer;
- Predict the airborne noise generation and attenuation in the breathing system of engines, including the linear and nonlinear acoustic behavior of silencers;
- Understand the noise generated by flow and flow-acoustic coupling, encompassing a wide frequency range, including whoosh, whistle, chirp, hoot and ring; and
- Investigate the pollutant emissions and their control.

Research also explores innovative concepts to simultaneously (a) improve the engine performance, including fuel efficiency, (b) suppress the flow-generated and/or airborne noise, and (c) minimize the pollutant emissions.

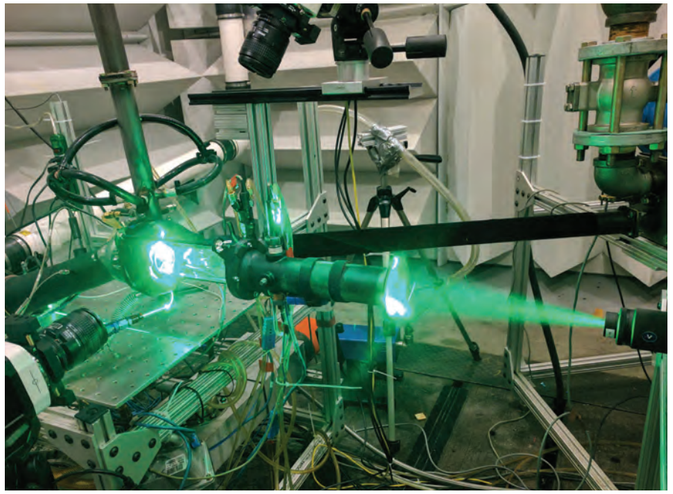
"While the primary emphasis of studies has been the development of fundamental understanding and validation of the resulting models, the in-depth knowledge gained in the process also is used to produce design guidelines and novel bench techniques," said Selamet.

The rise of turbochargers as implemented recently in downsized and boosted spark ignition engines to improve fuel efficiency and reduce emissions has led to meticulous efforts during the last decade through a unique bench-top turbocharger research laboratory supported by a Particle Image Velocimetry system in addition to the other advanced time-resolved measurement capabilities and nonlinear flow simulations. Key objectives of these critical turbocharger inquiries have been to:

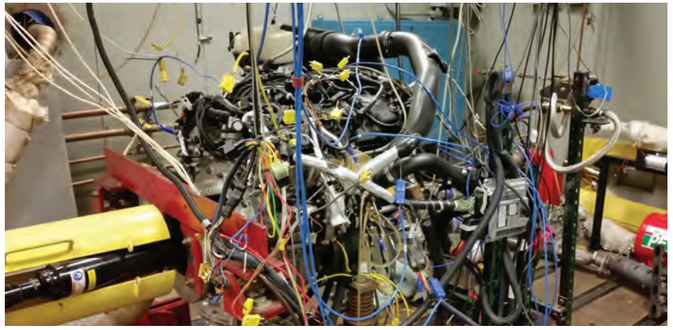
- Characterize the performance of both the compressor and turbine of turbochargers, capable of extending beyond the conventional knowledge, including reverse flow;
- Capture the unsteady pressure and velocity fields resulting from flow instabilities (due to surge) in centrifugal compressors at low flow rates both experimentally and computationally;
- Examine the broadband noise associated with flow separation within compressors and discrete tones due to surge and/or blade passing;
- Understand the inherent steady and unsteady physics better, particularly within the compression system, leading to the development of improved predictive tools, including for surge;
- Incorporate design changes to attenuate or delay surge.

The impact of contemporary research in these laboratories has been extraordinary throughout the decades, particularly in the following areas:

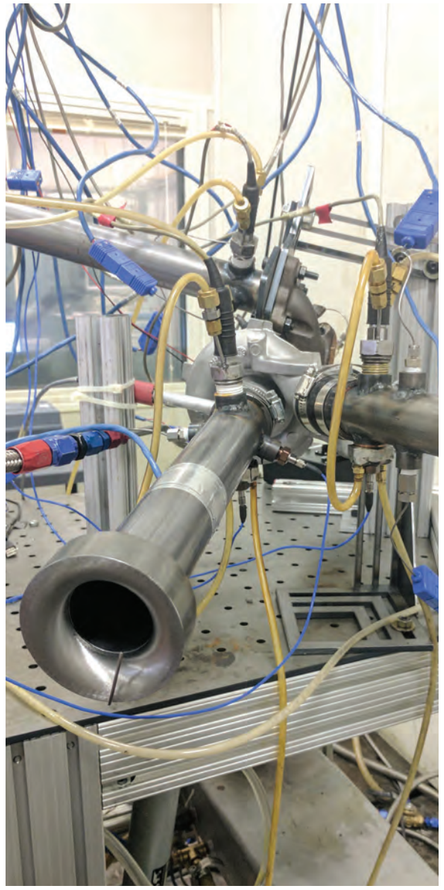
- developing reliable models for engine simulations as validated by experiments;
- identifying and isolating pertinent physics from engines and duplicating these scientific puzzles on a bench-top environment for a more in-depth examination, leading to original knowledge creation and dissemination;
- promoting a learning environment for engineers that always couples laboratory measurements and computational predictions, while striving to shrink the gap between the two approaches, thereby making the predictions ultimately powerful design tools;
- building an exemplary collaborative relationship with the automotive industry; and finally, yet perhaps most importantly,
- successfully educating the great young minds to contribute to the future of mobility and society.



Turbocharger Lab



Ford 3.5L 4V TiVCT GTDI V6 Twin-Turbo Ecoboost Engine



Automotive Turbocharger Instrumented for Performance and Acoustic Measurements

CyberCAR research to promote safety and security in modern vehicles

Research Associate Professor of Mechanical and Aerospace Engineering Qadeer Ahmed has secured funding for a new research venture in coordination with faculty from CAR, the Institute for Cybersecurity and Data Trust and the College of Engineering. The project will use a retrofitted minivan, called a CyberCAR, to research cybersecurity and mobility and promote safety and security in the next generation of vehicles.

This diverse research team combines backgrounds in mechanical engineering, electrical and computer engineering and computer science engineering to better understand the scope of challenges facing cybersecurity and mobility. Recently, the team secured two grants to fund the project: one from Third Frontier will fund the human resources while an Ohio Department of Higher Education RAPIDS (Regionally Aligned Priorities in Delivering Skills) grant will provide half of the cost of the minivan. The other half of the vehicle funding will come from Electrical and Computer Engineering (ECE) and Computer Science and Engineering (CSE) Chaired Professor Ness Schroff, ECE Assistant Professor Abhishek Gupta and CSE Associate Professor Zhiqiang Lin.

The CyberCAR will be an off-the-shelf minivan retrofitted with an advance sensor package and a drive-by-wire kit, which, Ahmed said, allows him to " essentially accelerate, decelerate or have the control on the steering."

Researchers will use this minivan to understand and address vulnerabilities in modern vehicles so and determine how vehicles can become safer and more secure. CyberCAR also will be a learning opportunity for students.

"This will give an opportunity to students, either in the form of thesis projects or in the form of internships, that will help them to learn and get to know what's the latest in the automotive systems," Ahmed said.

Ahmed identifies a specific topic that excites many students and industry professionals: vehicle hacking.

"In the past, we've had some workshops on vehicle hacking. When you start this workshop, you start with simulation tools," he said. "But eventually, if there is a vehicle ... students and people attending the workshop (could) do some hands-on vehicle hacking."

While widespread vehicle hacking may seem far-off, researchers learn to hack in order to learn how to make vehicles more secure.

"Although these topics may not seem realistic now, the intent is that they don't seem realistic in the future also. If you are able to address them well in time, you can come up with some solutions that can help the vehicles to be more safe and secure," Ahmed said. "It's not just to exploit the thing, it's to understand the weaknesses and how to address them."

In the future, Ahmed plans for the project to expand to mobility infrastructure and additional vehicles.

"More than one vehicle is necessary, because in the coming time, we'll have vehicle-to-vehicle activities also," he said. "As vehicles become increasingly connected and autonomous, researchers will work hard to ensure that mobility will be as safe and secure as possible."

System diagnostics for smarter, safer vehicles

When the "check engine" light illuminates, drivers take their cars to a repair shop and a repair technician fixes the problem. But how did the vehicle recognize a fault? Through system diagnostics.

"Diagnosis is more or less about recognizing differences between expected behavior and anomalies," said CAR Director Giorgio Rizzoni. "You would like to be able to detect anomalies in the behavior of a system before they result in a problem."

Rizzoni has been conducting research in system diagnostics since the late 1980s when the topic was first recognized as an important component of engine and emissions control systems.

"The government announced that they were going to require onboard diagnostics (OBD) systems for every vehicle that was going to go into production," he said. "In 1994, the second generation, OBD-II, went into effect. So, why are on-board diagnostics important in that 1980s-1990s generation of vehicles?"

In 1994, California implemented a set of regulations known as OBD-II, which were adopted nationwide by 1996. They required automakers to implement sophisticated onboard diagnostics to verify that all components related to the exhaust emission control system were continuously diagnosed.

Today, system diagnosis is an integral element of all of a vehicle's electronic control systems. There are two main classes of diagnostic systems: those that are government-regulated (mostly related to environmental protection) and those that are linked to vehicle safety. Reliable diagnostic systems also provide quick identification of malfunctions and therefore faster and more reliable service and maintenance procedures.

As electronic control systems become more common through the use of hybrid-electric powertrains and connected and automated vehicles (CAV), the need for accurate diagnosis is steadily increasing. Diagnosing systems traditionally has used mathematics- and physics-based models, which predict behavior and anticipate malfunctions. But using these methods to diagnose increasingly complex systems leads to extremely complicated models.

"What if I had 20 sensors in my car that measure what I need to know to automate the driving of my vehicle? Can I really create a model that links and ties all of these things in such a way that I can use it for real-time diagnosis?" Rizzoni asked. "Yes, I probably can. But then I need the Ohio Supercomputer Center to run the model. I can't do it onboard the vehicle."

CAR-affiliated researchers are tackling system diagnosis through a combination of physics-based models, machine learning and artificial intelligence methods, and cloud computing to comply with ever-changing technologies and regulations. Their work produces safer, more cost-effective vehicles on the cutting edge of modern transportation.

Ruochen Yang, who recently earned a PhD in Electrical and Computer Engineering, is working to improve evaporative emissions control systems by improving the detection of small leaks

Diagnosing leaks and reducing emissions

Automotive system diagnostics has expanded beyond its roots in exhaust emissions systems, but that original system still is challenging researchers. Dr. Ruochen Yang, who recently earned a PhD in Electrical and Computer Engineering, is working to refine evaporative emissions control systems (EVAP) by improving the detection of small leaks.

"The regulations of the Environmental Protection Agency and the California Air Resource Board require detections of any hardware or component that may malfunction and affect the emissions performance in the system," said Yang. "One of the most challenging faults to be detected – and that is required by the regulations – is small leaks."

How small? Leaks as small as 0.020 inches in diameter must be detected and repaired.

"Auto companies tend to be very conservative about detecting them," Yang said. "So sometimes a good system without leaks may be considered as a small leak."

Those false alarms often are unable to be reproduced by a mechanic, leaving customers dissatisfied. Yang is attempting to reduce false alarms while still detecting true leaks, so that customers are satisfied and vehicles comply with ever-stricter regulations.

"Diagnosis will be an area that requires a lot of advancement in the industry to comply with the standards while remaining cost-effective," Yang predicts.

But as the transportation industry moves toward electric vehicles, gasoline emissions may become a smaller concern.

Building safer energy storage systems

CAR Senior Design Engineer Prashanth Ramesh knows the pain of trying to drive a car with an unexpectedly drained battery. A research project to predict when batteries would fail to start a car allowed him to improve user experience and solve a day-to-day problem. Solving tangible issues is what Ramesh enjoys about system diagnostics.

As the transportation industry moves toward electric vehicles, Ramesh is racing to provide reliable diagnostics for their essential energy storage systems.

"Companies are constantly adding more and more batteries to the different applications, like vehicles," he said. As the usage of batteries grows, so does the need to understand when things could go wrong in order to set warranties and ensure the safety of passengers.

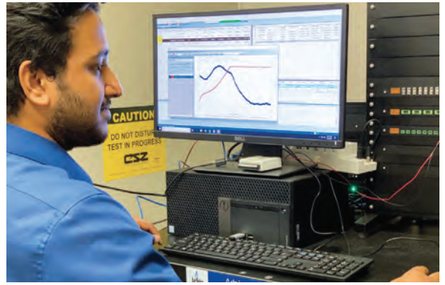
Diagnosing potential faults in batteries is tricky, because batteries are surprisingly delicate and faults can be dramatic.

"A battery is very sensitive to temperature and how you use it," Ramesh said. "So, they need to be able to make sure that it works really (well) in a hot place like Arizona or Florida, but also works pretty well in a really cold place where it's snowing. Temperature has very adverse effects on batteries. So, if it gets too hot things could lead to where the battery explodes, catches fire. But, it could also just fail to function."

Batteries are not only environmentally sensitive, they're also meant to last for years. So, how can researchers test them in an efficient way? Ramesh and his team begin in the lab, performing experiments in carefully controlled environments. Based on that data, a model can be created to predict a battery's behavior.

"Once we generate a model, we can run simulations and try to understand if the model can predict failures," said Ramesh. Using the models allows researchers to predict 10 or more years of usage in a few weeks.

But battery technology is evolving even as Ramesh works on existing systems. New batteries are being produced and existing technologies are being integrated at a deeper level.



As the transportation industry moves toward electric vehicles, Prashanth Ramesh is racing to provide reliable diagnostics for their essential energy storage systems

"It's not just being looked at as trying to solve problems on a battery but more from trying to make sure the system works," Ramesh said. Soon, he predicts, every system on a car will be powered by energy storage systems.

Modeling faults in steering systems and tire degradation

While earning his PhD in Mechanical and Aerospace Engineering, Tianpei Li researched system diagnosis of electrified power train and vehicle chassis systems. Li, a CAR research associate, uses the classic method of physics-based models to improve the diagnostics of new vehicles, especially electrified and automated vehicles.

"People have used (models) for a long time, but we apply different methodology and different objectives," Li said. "Overall, it still works well."

Li currently works on a project modeling vehicle steering, suspensions and tires. Using experimental data, he creates models to predict the behavior and collaborates with the Driving Dynamics Lab at CAR to improve them using their driver-in-the-loop simulator.

"Once we design the diagnostic strategy and algorithms, we can do simulation in the loop using that simulator by providing real human driver input," Li said. "So, we can simulate more realistic driving scenarios to validate all the diagnostics design."

But no model is perfect. "Models always have uncertainty and inaccuracy," Li said. "There's always modeling error. Making sure the modeling error is within control when you actually use it to apply diagnostic designs … that's a big challenge."

The other main challenge in Li's work is the reliance on onboard vehicle sensors to perform system diagnostics in the real world. Because those sensors are limited in their ability and external noise affects their performance, designing the diagnostic system becomes more complicated.

Despite the challenges, Li is improving the ability to identify and predict system degradation and failure, which in turn improves the safety of the vehicle and saves on maintenance costs, making consumers and auto makers more satisfied with their vehicles.

Facing the future of safety and security

Research Associate Professor Qadeer Ahmed leads the Cybersecurity@CAR Lab, where a diverse team of researchers diagnose new vehicle systems in an effort to keep them safe and secure. Since OBD II was mandated, diagnosis has been happening within the vehicle. With the addition of Advanced Driver Assistance Systems like lane keep assist and adaptive cruise control and in-vehicle connectivity via WiFi and cellular connection, onboard diagnostics systems must become smart enough to diagnose these new systems.

These new features increase a vehicle's connectivity to the world around it, but they also make vehicles more susceptible to outside influence.

"Let's say (a hacker) can spoof your GPS signal. Your lane keep assist is working on your GPS signal; that signal is being changed or influenced. This will affect your lane keep assist. Now, how do we identify that and make sure that lane keep assist module is still behaving the way it should?" asked Ahmed. "These are the types of problems we are looking at in cyber security."

Those problems span multiple disciplines and require varied viewpoints, so Ahmed is building as diverse a team as possible.

"If you don't have the diverse team, we may be addressing part of the solution, which may not fit into the bigger picture," he said.

As new technology evolves, the challenge grows. Vehicles may connect to other vehicles and transportation infrastructure, making the possibilities for system faults nearly limitless.

But there are advantages to technology that continues to change. System diagnostics researchers are able to understand how these technologies are evolving and even influence them, so that vehicles remain as safe and secure as possible.

Alums turn academic experience into real-world careers

When you drive down U.S. Route 33 in East Liberty, Ohio, you might not be aware that you are passing the Transportation Research Center Inc. (TRC), the most comprehensive vehicle testing facility and proving grounds in the United States.

TRC recently opened its SMARTCenter, which is dedicated to testing technology for automated and connected vehicles. It is comprised of 540 acres (roughly two-thirds the size of Central Park), a 10,000-square-foot control center and a 14-person team of researchers, technicians, project managers and engineers. Eight of those team members are Ohio State alumni.

The TRC – Ohio State connection dates back to 1979 when the university assumed management of TRC. Ever since, the two have worked together to provide research and testing services to the automotive industry.

"The overall goal of the SMARTCenter is to help researchers and technologists build their devices with technology in house before they take it out on public roads," said Tim Seitz, a senior research and development engineer at the SMARTCenter and two-time Ohio State College of Engineering alum. "TRC and Ohio State are constantly collaborating on projects, grants and research proposals including the ARPA-E NEXTCAR project. As an alum, I'm fortunate to have connections at Ohio State that can help facilitate these projects and continue the TRC – Ohio State relationship."

College of Engineering alumni Tim Seitz, left, and Mohit Mandokhot in the SMARTCenter control center.

The SMARTCenter is set up for different types of testing to accommodate customers' needs. There is the possibility to recreate a real-world scenario that has already happened but unique scenarios can also be designed to see how a vehicle reacts. This differentiates TRC from others who are in the vehicle testing space.

"The kind of industry projects I worked on as a student at CAR gave me an understanding of what the industry needs in this line of research and how to conduct it in a professional setting," said Mohit Mandokhot, a research and development engineer at TRC and alum of the Department of Mechanical and Aerospace Engineering. "Respecting the confidentially, time, budget and goals of what the industry wants has been a good foundation to help me transition into this role."

Neither Seitz nor Mandokhot interacted with TRC much as students, but were excited to learn about the facility and its Ohio State connection late in their academic careers.

"Having the opportunity to be involved in this line of work at TRC is basically my dream job," said Seitz.

Scholar-entrepreneur tapped to direct Ohio State's Smart Mobility Program

Christopher Atkinson will integrate mobility-related research and education across the university

A technology-based small-business owner with higher education and federal agency experience has been recruited to The Ohio State University to direct its Smart Mobility Program.

Christopher Atkinson, also a professor of mechanical and aerospace engineering, will lead and collaborate with faculty, students and staff to integrate mobility-related research and education across academic units. The Smart Mobility Program is housed in the Office of Research.

"We have created a position that will think broadly enough to be able to integrate all of the mobility-related research and development activities on the Ohio State campus with the city, the region, the state and nationally to create opportunities for large research programs," said Giorgio Rizzoni, the Ford Motor Co. chair in Electromechanical Systems and director of the Center for Automotive Research.

"Chris, as an outgoing director of a federal agency, is incredibly well connected in Washington, D.C., in the national labs and industry," he said. "His prior experience in academe and in the private sector make him the ideal candidate for this role. He will be able to lead initiatives that will bring large research programs to Ohio State and also continue the effort to bring the campus together with a more unified approach to how we understand mobility."

Atkinson will work to enhance Ohio State's existing research centers and institutes in the mobility sciences, including the Center for Automotive Research and Transportation Research Center, the Center for Urban and Regional Analysis, the Campus Transit Lab and other mobility-related initiatives, and will collaborate with industry partners to increase corporate, foundation, state and federal partnerships.

"There's a very coherent transportation and mobility focus at Ohio State that permeates from the university to the city to the county to the state," Atkinson said. "Ohio is very strong in all things automotive from an economy and industry and economic development point of view.

"It's unique, and I use that word correctly," he said. "It is one of a kind."

The Smart Mobility Program will identify existing and create new initiatives that position Ohio State to address and transform the mobility industry. Atkinson will build business relationships with essential local, state and federal partners as well as strategic national and international industries to understand their future and emerging needs and to identify opportunities to collaborate on mobility-related research-based initiatives.

"My attraction to Ohio State is the fact that it has a very strong underpinning in transportation, a very strong commitment to smart mobility and a very close integration with the city, the county, the state and beyond," he said.

Atkinson joins Ohio State from the Advanced Research Projects Agency-Energy in the U.S. Department of Energy. He served as program director, developing programs to fund high-risk, high-reward innovative energy technologies for generation, storage, distribution and usage. He is the founder of Atkinson LLC, a company specializing in engine control and calibration, fuel efficiency optimization and emissions reduction.

Before he joined the Department of Energy, Atkinson was a professor in the Department of Mechanical and Aerospace Engineering at West Virginia University and director of the Center for Alternative Fuels, Engines and Emissions.

He holds a BS degree in chemical engineering from the University of Natal, South Africa, an MS degree in mechanical engineering from West Virginia University and an ScD degree in mechanical engineering from Massachusetts Institute of Technology.

CAR Membership Consortium

The CAR Membership Consortium provides a unique opportunity for industry to engage in original, highly leveraged precompetitive research in automotive and transportation systems with a focus on advanced propulsion systems; fuel economy; vehicle safety, connectivity and autonomy; and advanced driver assistance systems.

The Consortium provides members with:

- The opportunity to participate in leveraged, precompetitive research
- The opportunity to engage graduate students in preparation for future careers in the automotive industry
- An outlet to reach undergraduate students through capstone design and other project activities
- The opportunity to host focused recruitment events

Current members:

Gold Level	Platinum Level
BOSCH, Cummins, DANA, DELPHI, DENSO Crafting the Core, EATON, GENERAL MOTORS, SCHAEFFLER, TE connectivity	COTA, equimobility, FCA, Ford, GROUPE RENAULT, HONDA, TRC

Data from 2019 calendar year

For more information contact David Cooke at cooke.76@osu.edu or David Emerling at emerling.4@osu.edu or visit *car.osu.edu*.

Member Benefits	Silver $10K	Gold $30K	Platinum $50K
Showcase/feature members in CAR marketing materials	X	X	X
Invitation to Bi-Annual Executive Advisory Board Meetings	X	X	X
Membership sponsored exploratory reporting meetings and access to results and presentations		X	X
Distance education benefits (Pre-recorded seminar library)		$5K limit	$10K limit
Opportunity to present technical seminars at CAR	X	X	X
Opportunity to recruit CAR students through resume access, information sessions and meet and greet events	X	X	X
Corporate mentorship for graduate students		X	X
Input on project selection for exploratory research projects		X	
Direct project selection for exploratory research projects			X
Consultant time with faculty and senior research staff		X	X
10% discount on testing services		$5K limit	$10K limit

Ohio State designated federal Bus Testing Center

The Ohio State Center for Automotive Research was selected in 2017 by the U.S. Federal Transit Authority (FTA) as the program manager and official test site for the FTA Low and No Emissions Component Assessment Program. A year later, The Ohio State University was designated an FTA Bus Testing Center.

LoNo programs support the introduction of low- and no-emissions transit buses into transit system fleets. Ohio State will perform full vehicle life-cycle evaluations, system level and individual component testing. The results will provide unbiased public assessments of low- or no-emission vehicles, systems and components, documenting their real-world maintainability, reliability, performance, structural integrity and efficiency.

Ohio State's new on-campus Heavy-Duty Test Center has entered its final technical design phase. Ohio State is designing the new facility in consultation with the FTA and industry partners. The goal is to create a new facility capable of meeting industry's development and testing needs, both today and into the future.

Planned capabilities include full chassis testing, battery pack evaluation and emulation, full vehicle evaluation and durability and autonomous test and standards development – all supporting the transit and heavy-duty industries. To date, Ohio State has been awarded $7 million in capital funding to develop and support the new on-campus Bus Testing Center.

Giorgio Rizzoni

CAR Director appointed to COMVEC executive council

CAR Director, Giorgio Rizzoni has been appointed to the Society of Automotive Engineers (SAE) COMVEC™ Executive Council.

The Executive Council advises and guides SAE in the planning and organization of COMVEC™ including selecting keynote speakers and panelists and organizing panel discussions and technical sessions. The council is composed primarily of commercial vehicle industry executives. The Ohio State University is one of only two universities on the council, the other being Virginia Tech.

Rizzoni Celebrates Platinum Anniversary

CAR Director Giorgio Rizzoni celebrated his platinum anniversary as CAR Director on October 4, 2019.

This milestone anniversary was celebrated with a surprise reception following CAR's External Advisory Board meeting.

Rizzoni Presented 2019 Buckendale Lecture

CAR Director, Giorgio Rizzoni was awarded the L. Ray Buckendale Award and Lecture by the Society of Automotive Engineers (SAE).

Established in 1953, this award provides for an annual lecture that deals with ground vehicles for either on- or off-road operation in either commercial or military service.

Rizzoni's paper and the associated lecture, Transformational Technologies Reshaping Transportation - An Academia Perspective, presents an overview of technology trends and of market and business opportunities created by technology, as well as of the challenges posed by environmental and economic considerations.

Giorgio and his wife Kathy with a plaque presented to him at the anniversary celebration.

Canova and Serrani received Lumley Interdisciplinary Research Award

Marcello Canova

Andrea Serrani

Marcello Canova, associate professor in the Department of Mechanical and Aerospace Engineering, as well as Andrea Serrani, professor in the Department of Electrical and Computer Engineering were awarded the College of Engineering's Lumley Interdisciplinary Research Award.

This award is presented annually to faculty and/or research scientists within the College of Engineering who have demonstrated significant research collaboration that cuts across departmental or discipline boundaries.

"This team is well recognized nationally and internationally, and has made a significant contribution to the advancement of feedback control technology and its applications to advanced powertrain systems," said Hesham El Gamal, professor and chair of the Department of Electrical and Computer Engineering.

Because of the interdisciplinary nature of their work and its balance between methodological depth and industrial relevance, Canova and Serrani have received significant research funding from the National Science Foundation (NSF) as well as Ford Motor Company.

"This award is first and foremost a recognition of the great work of our PhD students, Junqiang Zhou and Cristian Rostiti, whom Marcello and I have co-advised," said Serrani. "Also, it shows appreciation from the College leadership for the value of cross-collaboration across different disciplines, which is a difficult yet exciting endeavor."

D'Arpino promoted to senior researcher

Matilde D'Arpino has been promoted to research scientist at CAR. Her research focuses on the design of high-performance electric vehicles, power converters and energy management for multisource power systems (e.g. microgrids, hybrid vehicles, hybrid aircrafts), testing, modeling, design and control of energy storage for automotive, aerospace and grid-connected systems.

Matilde D'Arpino

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