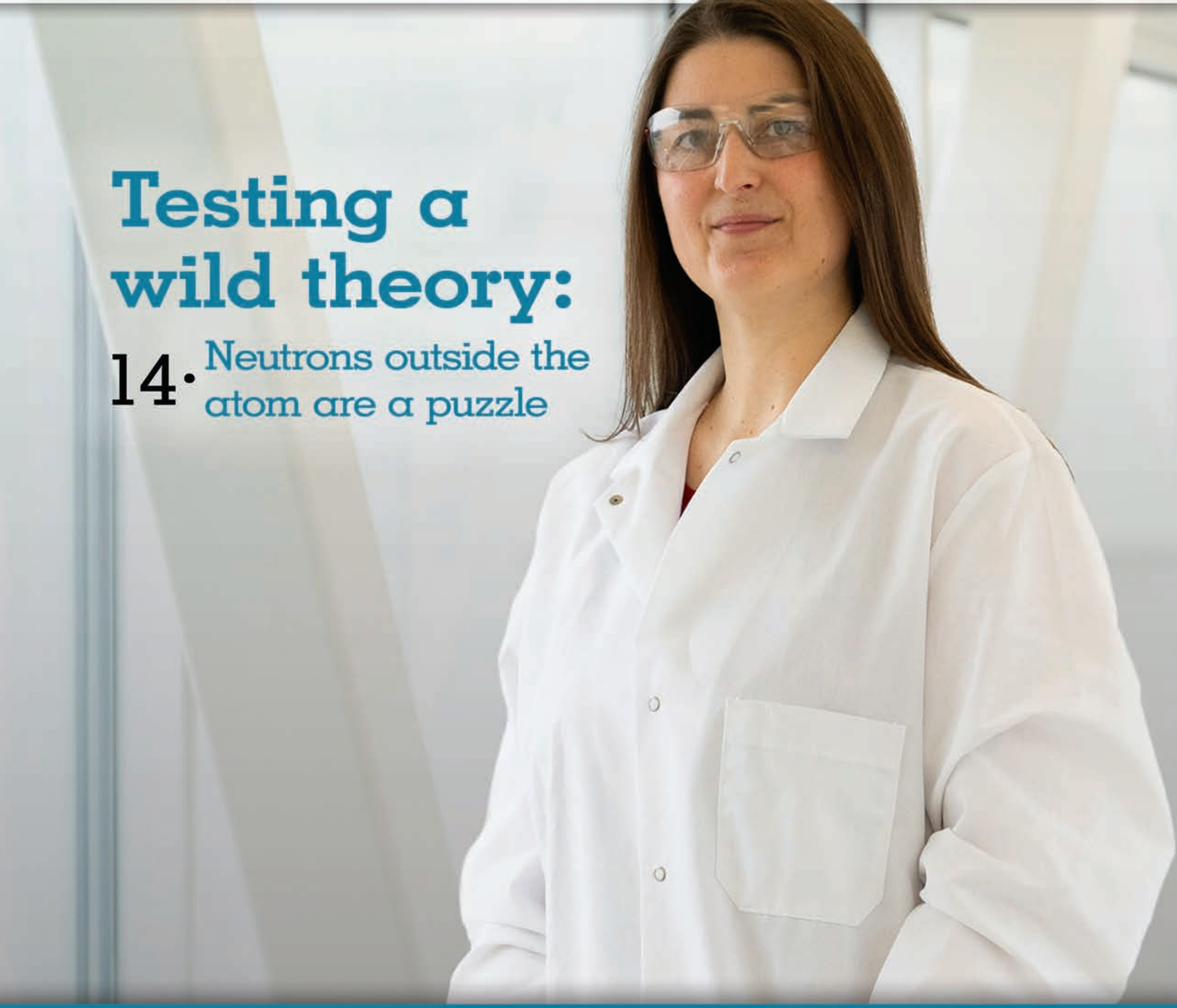
OAK RIDGE NATIONAL LABORATORY

Review



Testing a wild theory:

OAK RIDGE National Laboratory

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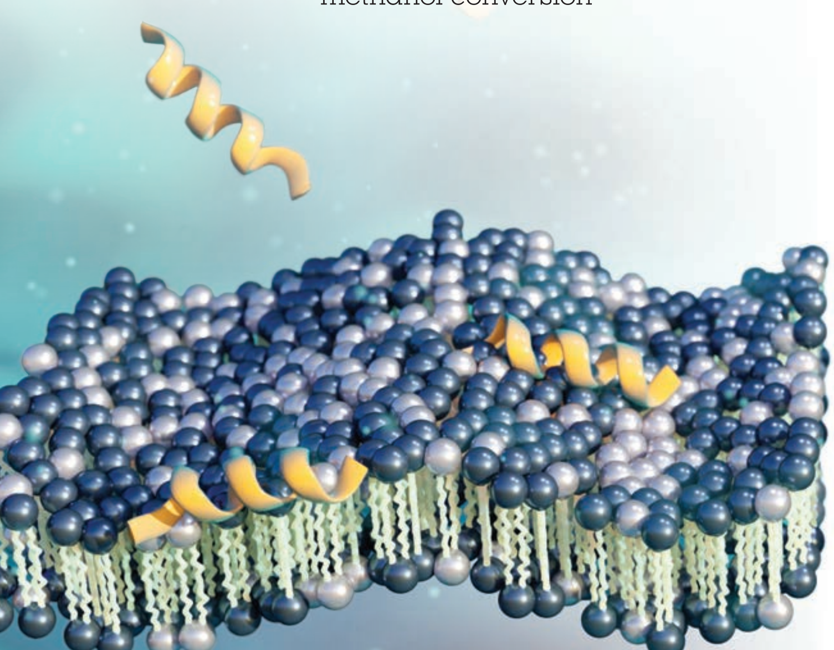

On the Cover

ORNL physicist Leah Broussard and colleagues explore the neutron lifetime puzzle. Image credit: Carlos Jones, ORNL personal residences). Figure 15 shows the m-UGA (left panel) and a snapshot of its measurement output (right panel).

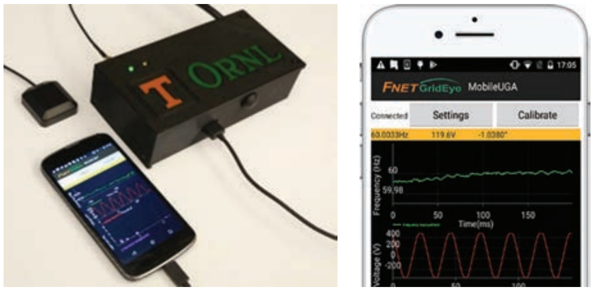

Figure 15. Mobile UGA. (Credit: ORNL, UTK)

CONCLUSIONS

The GridEye system offers wide-ranging capabilities to support the decarbonization of the US power grid with high-renewable resources. Some important applications include real-time visualization, inertia estimation and alert, real-time oscillation detection and location, islanding detection, event location, power system dynamic model validation, and measurement-adaptive oscillation damping control. The latest advancements to the GridEye sensor design, including an e-UGA, ultrahigh-speed and fault-tolerant grid measurements, and a mobile grid analyzer, will further extend GridEye's award-winning capabilities to novel power grid monitoring methodologies.

IMPACT

GridEye is a low-cost, quickly deployable GPS-synchronized wide-area measurement network for power grids. As a unique nationwide power grid monitoring system, over the past 15 years, GridEye and its related applications, GridDamper and m-UGA, have won three R&D 100 Awards. Since its introduction in 2004, the GridEye system has provided nationwide situational awareness to system operators, utilities, industry, and academia. With the hardware and measurement algorithm advancements made in recent years to GridEye sensors, and by applying machine learning and big data techonlogies in GridEye applications, the GridEye system will continue to play a vital role in facilitating the decarbonization of US power grids.

COLLABORATE WITH ME

Lingwei Zhan, (865) 574-7535, zhanl@ornl.gov

Yilu Liu, (865) 241-2314, liu@utk.edu

Thomas King, (865) 241-5756, kingtjjr@ornl.gov

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From Signal Processing to Signaling Traffic: Using Digital Twins to Improve Traffic and Reduce Our Carbon Footprint

J. Brogan,[1] A. Berres[2]

[1]Electrification and Energy Infrastructures Division, [2]Computational Sciences and Engineering Division

broganjr@ornl.gov

INTRODUCTION

Traffic backups and long commutes are an unfortunate reality we all deal with these days. Beyond costing us valuable time, traffic wastes fuel and contributes substantially to our global carbon footprint. If we could design a dynamic, adaptive system to actively coordinate and time lights, choose routes, and even recommend certain lanes, we could greatly alleviate congested traffic and the myriad problems that come with it. Unfortunately, developing such a dynamic system that coordinates traffic across an entire region is easier said than done! Traffic and transit systems are complex, and the testing of new light sequences or traffic patterns in real life can be cost-prohibitive, dangerous, or both. It is for these reasons that the use of digital twins is such an exciting prospect.

BACKGROUND

Chattanooga Digital Twin. Digital twins are virtual reproductions of complex real-world systems. They "offer an effective way to mitigate risks and improve performance without significant loss of time or money" [1].

In 2019, the Chattanooga Digital Twin project, or CTwin, sought to develop a complete transit-level digital twin of the Chattanooga area that could act as a virtual test bed for smart traffic routing. As a low-cost yet accurate-to-real-life traffic environment, the CTwin system allowed researchers to observe virtual traffic patterns and problems and optimize a region-wide virtual controller system that could leverage virtual sensors and cameras to dynamically adapt traffic patterns [2]. A good example of this multimodal sensing-and-control loop can be seen in Figure 1.

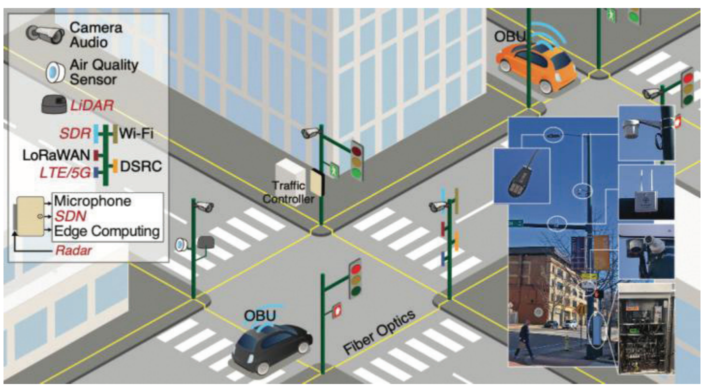

Figure 1. Visualization of how city-level traffic is modeled and controlled in the original CTwin system, which models a virtual version of Chattanooga. (Credit: University of Tennessee–Chattanooga Center for Urban Informatics and Progress)

CTwin2.0 Project. CTwin's successor, CTwin2.0, takes the optimal techniques learned from the virtual CTwin world and applies them to the real Chattanooga, scaling the solution across the entire Chattanooga area. CTWin2.0 brings to life a region-wide, complex traffic controller that coordinates inputs from many sensors as feedback to dynamically change traffic patterns on global and local scales. The idea of adaptive traffic control systems (ATCSs) is not entirely new—there have been versions of ATCSs in use since the 1980s. This is the first controller, however, to both be designed using digital twin technology and specifically optimize for fuel efficiency and emission reduction [3]. The project is a collaborative effort of Oak Ridge National Laboratory's (ORNL's) Computational Sciences and Engineering Division (CSED), Electrification and Energy Infrastructures Division (EEID), and National Transportation Research Center (NTRC); the National Renewable Energy Laboratory (NREL); and the Tennessee Department of Transportation (TDOT). One of the main and most straightforward avenues for realizing this control loop is through the implementation of a next-generation smart fleet routing system for highway freight, helping alleviate traffic congestion on busy highways and city streets.

Fleet Routing Problem. The Fleet Routing Problem (FRP) boils down to optimizing the multistop routes of many vehicles in a fleet to ensure all required stops are made with maximal overall efficiency. FRP has many parameters, both physical and temporal, that must be considered in the optimization process. More concretely, a standard FRP task is planning transport schedules and routes around peak traffic times and locations while still servicing all of the required destinations on a set of customer manifests. When done well, fleet routing can markedly reduce the carbon footprint of freight traffic across entire regions or even the country.

IMPLEMENTATION

Realizing complex sensor systems. While current FRP systems optimize routes and schedules based on historical data in a more static manner, CTwin2.0 aims to go further. Using foundational observations from the CTwin traffic control system in the virtual world, the project aggregates streaming data from a set of distributed multimodal sensors operated and maintained by TDOT. CTwin2.0 utilizes this large set of streaming data to detect incidents and provide a dynamic, situationally aware FRP solution that continuously adapts and updates freight trucking routes and strategies in real time.

Detecting anomalies. CTwin2.0 leverages streaming data from hundreds of Radio Data System (RDS) sensors. These sensors produce lane-level information on vehicle counts, occupancy counts, and average speeds of vehicles aggregated over 20–30 seconds. RDS sensors can be used to quickly detect local anomalies and incidents along TDOT TN SmartWay highways that require immediate attention within the FRP controller. The sensor network is shown in Figure 2.

Figure 2. Map view of the Chattanooga I-75 corridor with RDS sensors utilized by CTwin2.0 shown as green dots. (Credit: A. Berres; J. Brogan, ORNL)

Using cameras as sensors. CTwin2.0 also utilizes cameras from the TDOT TN SmartWay system to supplement the RDS sensor network. CTwin researchers developed lightweight computer vision and machine learning algorithms designed to detect, classify, and track different types of vehicles as they drive by different cameras along major thoroughfares (Figure 3). The output of this algorithm provides traffic counts, relative speed estimates, and throughput metrics that can be utilized as supplemental sensor data for the CTwin controller. To provide real-time data across many incoming video streams, these state-of-the-art computer vision algorithms are deployed using an ORNL-developed computer vision framework called FaRO [4] in NREL's high-performance computing environment, Eagle.

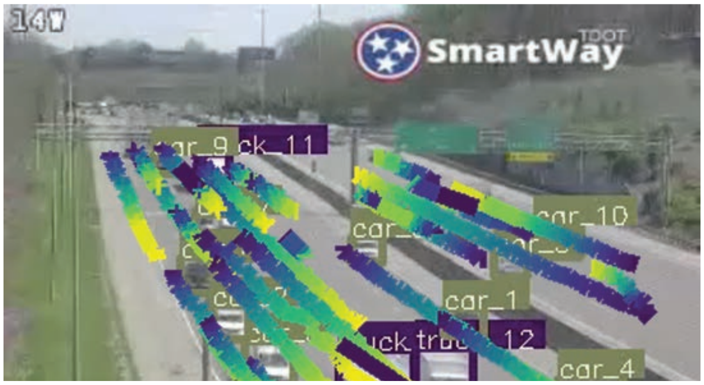

Figure 3. Visualization of what the CTwin2.0 Traffic Vision System sees in an image captured by a TN SmartWay camera. Colored squares represent cars and trucks, while lines represent persistent tracks of each vehicle. (Credit: J. Brogan, ORNL)

Computer vision algorithms summarize real-time traffic flow statistics across hundreds of cameras and coordinate with proprietary roadway sensors to detect traffic incidents and anomalies in real time. Commercial partners will be able to use the system to design daily freight truck routes and update them adaptively throughout the day based on current traffic events and contexts. Research is focused on leveraging this multimodal sensor data to optimize traffic on every level, from traffic light timing to adaptive route avoidance for freight trucks.

Partnering with regional freight. While suggesting route modifications to freight fleets in the CTwin2.0 virtual traffic world is relatively easy, reflecting those modifications in the physical world is much trickier. From a logistics perspective, ORNL and NREL needed to partner with many collaborating entities to realize a physical analog of this dynamic rerouting system. The project focuses on offering integration with industrial and commercial freight fleet operations to provide this unified routing service to as many partners as possible. Currently, two regional fleets are successfully integrated into this work: Chattanooga Public Works Solid Waste and Recycling, whose vehicles visit every city street once a week, and Covenant Transport Group, which runs interstate freighting operations along long-haul lines.

While these initial collaborations provide a good starting point to test the CTwin2.0 controller system, a major portion of the project is focused on building relationships and affiliations with additional public and private institutions to scale up the program to realize its full potential. While there is broad interest across the freighting industry to integrate with CTwin2.0 technology, taking the leap from interest to integration requires a significant amount of technical and logistical coordination. While this effort does take time, we expect to continue expanding CTwin2.0 control system deployment with additional partners over the next project year. In this growing phase, the Technology Readiness Level of CTwin2.0 remains at research levels, meaning ORNL and its collaborating entities will continue to perform maintenance and support for partners integrating with the platform. As the technology matures, further deployment and scaling likely will be handed off to industrial or private partners via technology transfers or cooperative research and development agreements.

RESULTS

The CTwin project has shown breakthroughs in incident detection capabilities, providing early warning of traffic buildups up to 7 min before Waze hazard reports appear and 18 min before official authorities are notified. An example of this capability can be seen in Figure 4, in which RDS sensors and traffic cameras fitted with CTwin2.0 technology show anomalous behavior long before other methods of reporting. This early warning can provide the CTwin FRP controller valuable room to find solutions for rerouting traffic, even before a major traffic jam has formed.

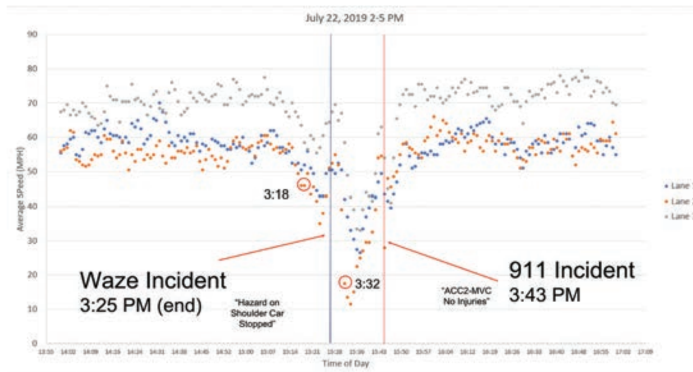

Figure 4. Average speed readings from RDS and camera sensors providing early detection of a traffic jam. Y-axis shows speed readings; x-axis shows time of day. (Credit: A. Berres, ORNL)

Using the CTwin plaftorm to perform fleet routing and dynamically time traffic lights at local levels, a simulated estimate of energy savings shows up to an 18% reduction in energy use and carbon emissions at traffic signals when the dynamic CTwin2.0 FRP controller is utilized. When tested operationally on live traffic signals, a 16% reduction in energy has been realized in real-world controller deployment (Figure 5).

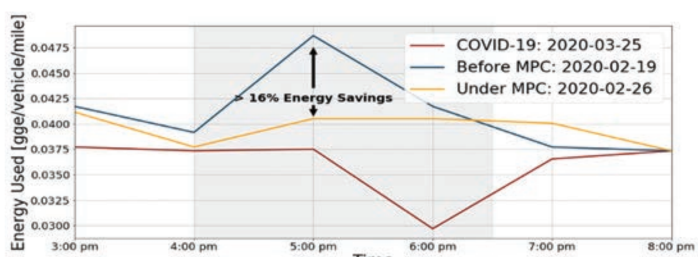

Figure 5. Energy use estimates per vehicle before and after deployment of the CTwin controller, as compared with the 2020 COVID shutdown [5]. (Credit: Wang et al.)

CONCLUSIONS AND IMPACT

Reducing our carbon footprint is one of the highest priorities in today's modern world. Meeting that goal will require a disparate stack of many systems working in tandem, all focused on tackling different problem areas of carbon production. Systems such as CTwin2.0 can help achieve that goal and improve traffic, with the promise of doing so in subtle ways most civilians may not even notice. As our cities continue to grow and become increasingly connected through smart infrastructures, systems like CTwin2.0 will become more instrumental in coordinating the well-oiled transit apparatuses that keep us moving.

To that end, the CTwin2.0 has seen both successes and obstacles while porting digital twin–based traffic solutions to the real-world Chattanooga area. Its deployment will provide measurable benefits to the drivers it serves, yet more work still must be done. As we move forward with further improvements, CTwin2.0 will benefit greatly from wider-reaching freight partnerships that can help implement vehicle-by-vehicle freight control. More sophisticated machine learning algorithms are being explored to better understand the firehose of real-time camera and RDS data streaming in from TDOT TN SmartWay sensors. As self-driving cars inch closer to reality, their sensor and communication networks could greatly benefit the CTwin controller and systems like it, and research in this area is ongoing.

ACKNOWLEDGMENTS

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ORNL's FuelEconomy.gov delivers consumer savings, reduced vehicle emissions

FuelEconomy.gov, a joint US Department of Energy (DOE) and US Environmental Protection Agency website, provides information that helps consumers make informed fuel economy choices when purchasing a vehicle or achieve the best fuel economy possible from the cars they own—topping $1 billion in savings and reducing transportation sector greenhouse gas emissions (GHGs). The website includes fuel economy tips and information on clean vehicle tax credits and advanced vehicle technologies. The Find a Car tool provides fuel economy, fuel cost, and environmental and safety information for vehicle models back to 1984. Other helpful tools include:

- Fuel savings calculator
- Trip cost calculator
- GHG emissions calculator for plug-in hybrid electric vehicles and all-electric vehicles
- Plug-in hybrid electric vehicle cost calculator
- My MPG, which allows consumers to track and share their fuel economy for conventional and all-electric vehicles
- Web services that provide fuel economy data to other public and private entities

Since its launch in 1999, FuelEconomy.gov has hosted more than 500 million users, saved consumers more than $1 billion in fuel costs, and reduced petroleum use and vehicle-related GHGs.

Image credit: Colby Earles, ORNL

Oak Ridge National Laboratory (ORNL) maintains FuelEconony.gov for DOE and supports the website's collection of fuel-saving tips through fuel economy–related research activities. ORNL staff have conducted numerous studies and published peer-reviewed papers on topics such as aggressive driving, speeding, hauling cargo, idling, air conditioner use, and fuel stability.—*Stacy Davis, Buildings and Transportation Science Division, ORNL*


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