> **DRIVERLESS, FULLY AUTOMATED VEHICLES ARE LIKELY FURTHER AWAY THAN SOME WOULD HAVE YOU BELIEVE—IF THEY EVER ARRIVE AT ALL**
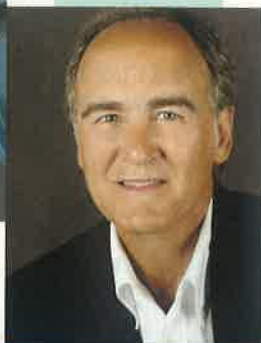
by ARTHUR ST. ANTOINE

Autonomous
STATE

FOR ROUGHLY 130 years humans have been in charge of the steering wheels, throttles, and brakes in our road-going vehicles; it's all been up to us—for better *and* for worse. Today, though, the future envisioned as long ago as the 1939 World's Fair is nearly here. Computers are poised to pilot us wherever we want to go with no human intervention necessary. In fact, in a few select areas they're already doing just that (see sidebar).

The implications are enormous. What does the arrival of connected and automated vehicles (CAVs) mean for the future of transportation? And, crucially for driving enthusiasts like us, will the conventional human-driven automobile survive? The answers are as amazing as they are thought-provoking.

Francisco, over the Oakland Bay Bridge, and all the way to Treasure Island in San Francisco Bay. (The Discovery Channel offices there were considered too far away for most takeout joints.) Levandowski's team added lidar (laser-based radar), radar, and other automated tech to a Toyota Prius and hacked its drive-by-wire system, and in mere weeks "Pribot" successfully completed the mission. The Discovery producers got their North Beach Pizza. Without a delivery driver.

Google co-founder Larry Page—who as a student at the University of Michigan suffered through freezing winters waiting for campus buses to arrive—took notice of the remarkable pizza car. He also realized self-driving vehicles could cure the bus-waiting problem—and much more. As Burns notes in his book, Page told a colleague: "If this business succeeds, it could be bigger than Google. Which means, even if there's just a 10 percent chance of this succeeding, it's worth the investment." Thus was born Google's Chauffeur project, now Waymo.

The Promise. And the Pizza.

"Safety is first and foremost," says Lawrence D. Burns, Ph.D., former chief of R&D at General Motors, and a prime consultant on Google's self-driving-car project (now dubbed Waymo, for "a new way forward in mobility") since 2011. "Traffic-safety experts believe we can reduce 90 percent of crashes using CAVs. Given that 1.3 million people die in autos worldwide every year, that's 1 million people. Divide that by 365 days, and that's 3,000 lives per day. I always say in my stump speeches, 'If we can get to the full safety potential of CAVs one day earlier, we're going to save 3,000 lives.' The biggest risk is not getting to that future as soon as we can."

Burns is arguably the world's leading expert on CAVs. In his riveting new book, *Autonomy: The Quest to Build the Driverless Car*—which reads like a tech thriller—he notes that CAVs were largely spurred into existence after 9/11, when the U.S. government's Defense Advanced Research Projects Agency (DARPA) investigated the feasibility of driverless military vehicles by sponsoring the Grand Challenge, an event held to see if a CAV could complete a 150-mile race in California's Mojave Desert with a million-dollar prize on the line. (None finished the first year; five robots completed the second year's 132-mile event.)

Yet it was an altogether different motivation, Burns says, that inspired the first real-world automated vehicle: hunger. For pizza. In 2008, the Discovery Channel program "Prototype This!" approached self-driving-car engineer Anthony Levandowski (who was working on Google's Street View camera tech at the time) with a challenge: build an automated vehicle that would deliver a pizza from San

"Imagine, I have my own autonomous vehicle," says Burns from his home in bucolic Franklin, Michigan. "I ride to my office in Detroit, where my vehicle drops me off at the door. It's then intelligent enough to go find a place to stage—I call it staging, not parking. Maybe while there it's re-energizing its batteries, or getting some maintenance, or being cleaned. During the day I can even dispatch it to get my kids at school and take them to soccer practice. Then, at the end of the day, my vehicle stops by a Chinese restaurant, picks up my takeout order, then picks me up at my office door and drives me home. Actually, getting the takeout brings up one of the best potential

78% of Americans believe that AVs could make their lives easier

SOURCE: Volvo, 2016

CHESKY / SHUTTERSTOCK.COM

We expect mobility services to grow from 22 million vehicles in 2016 to 130 million by 2030

22M 2016

SOURCE: BofA, Merrill Lynch Global Research Estimate, June, 2017

2030 **130M**

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time-savers when using an AV: It's not that you don't have to pay attention when driving; it's that you don't have to take the trip at all."

CAVs also offer the promise of dramatically reducing transportation costs. "Today, cars cost about $1.50 per mile to operate, including depreciation, fuel, financing, parking, and human time," Burns says. "I think we're going to see a future where that drops to 25 cents a mile or less. Your payment will only be how much time you had the vehicle, and how many miles."

Indeed, the potential economic benefits to society as a whole are staggering. "Instead of driving, it will be Transportation as a Service," Burns says. "We'll be selling trips and experiences instead of vehicles and gas and insurance. As Uber and Lyft are doing with ride-sharing, you'll hail a CAV when you need it, or perhaps you'll subscribe to a service that provides you with your own vehicle but handles all maintenance, refueling, and parking. If we get to that 25-cents-per-mile cost, and given that Americans drive 3 trillion miles per year, that's a potential savings of $4 trillion—about the annual budget of the U.S. government. Think if consumers spent that money on something else besides their cars."

Dave Cole, former director of the UM's Office for the Study of Automotive Transportation (OSAT) and one of the founders of Auto Harvest, an intellectual property portal

91

for the auto industry, notes the many secondary benefits to CAVs. "Obviously, when [crashes decrease], you'll see a huge reduction in insurance costs," he says. "Instead of owning a car you use only 20 to 40 minutes a day, you'll buy access to a car that gets used 20 hours a day by multiple people, so that's big savings. You'll also see a vast reduction in the complexity of hospital ER cases because the crashes won't occur. And of course sustainability—climate change, air pollution, land use, all those are going to benefit. Systems thinking is really important when looking at autonomous vehicles."

Burns says Wall Street is beginning to see the "profound opportunities" of CAVs. "Right now, most automakers make between $1,500 and $5,000 per vehicle. Now, if you take a CAV with a 300,000-mile life, then you make 10 cents a mile on it, that's $30,000 profit. I really think companies are going to want to go in this direction once it's proven."

Obstacles of Course

The inertia ingrained into the auto industry is massive. "When I'd mention self-driving cars to Detroit auto executives," Burns says, "they'd say, 'It's never going to happen. People *like* driving.' And I'd say, 'Yeah. But there were also people who liked to ride horses.'" Burns has a warning for the non-believers: "Companies that stick to the 130-year-old paradigm of conventional roadway vehicles are going to be punished pretty aggressively by Wall Street."

The technology behind CAVs doesn't appear to be a show-stopper, but there are sticking points. "Don't be fooled by some of the hype that the tech is ready," says Richard Wallace, director of transportation systems analysis for the Center for Automotive Research. "Not all of the hurdles still to be overcome are related to artificial intelligence-related driving. There's cyber-security. It would be crazy to have drivers take a nap in the back seat without that figured out. And the AI has to be far better than drivers today. Right now humans have one fatal crash every 100 million miles. That's 99.99 percent safe, but that's not good enough. For CAVs, we need 99.999999999 percent, a *lot* of digits. Near-perfection."

The Mcity research park (below and opposite) employs 50 University of Michigan faculty members and more than 100 students in an environment studying some 1,500 connected test vehicles, the world's largest CAV program.

Mcity, a 32-acre research park in Ann Arbor, serves as a hub where industry, government, and academia work together on future mobility systems. Huei Peng, a professor of mechanical engineering at the University of Michigan and director of Mcity, says the technology will get where it needs to be, but there's a lot to consider before that happens. "When you're talking about a Level 4 vehicle, fully autonomous within defined areas and conditions, selling to John Doe right now is not a good idea," he says. "You need to keep the vehicle's cameras clean, the lidar functional, calibrate the systems. It's much better to operate a shared, managed vehicle that's geofenced into a certain

DRIVERLESS CARS:
Where They Stand Now

LEVEL 4 FULLY automated (in certain conditions) driverless vehicles are already here. In Phoenix, residents can apply for Waymo's Early Rider program, which allows them to take taxilike rides around the metro area in the company's automated Chrysler Pacificas and hybrid minivans—no driver necessary. "It makes sense," Huei Peng says. "Phoenix has no snow, very little rain. It's easier to keep the camera lenses and lidar clear without degrading operation."

Peng's Ann Arbor-based Mcity operates two automated shuttles students can ride around the University of Michigan campus. "I call it Level 4-minus," Peng says. "Because our shuttles are fixed-route only, it's hugely different, a much simpler environment. We only need to be perfect on this one route. A driver isn't necessary, but for now we do have a safety conductor on board at all times. We choose to operate the shuttles as Level 3 vehicles so the community and riders feel more comfortable."

Level 2 partially automated vehicles are sold by GM (Cadillac Super Cruise), Nissan (ProPilot), Tesla (Autopilot), and Mercedes-Benz (Distronic Plus), among others. The first commercially available Level 3 vehicle, which can take full control under constant driver supervision, is expected to be Audi's 2019 A8. (As we go to press, Traffic Jam Pilot has yet to be approved for the U.S. market.) Interestingly, in 2012 Google built a Level 3 vehicle for testing by its employees, who could ride from Mountain View, California, to Lake Tahoe. "After looking at the data from onboard cameras, they stopped the program," Larry Burns says. "People were falling asleep, eating, reading—they were doing things that made it impossible to re-engage the driver. That's

why Waymo is aiming to take the driver out of the loop entirely."

How far off are Level 4 or Level 5 vehicles? "I think we'll reach the tipping point," Burns says, "when it's clear that the value of the system exceeds its price. I think we're in a five-year window where that could happen. But I don't think Level 5 is ever gonna happen. I don't think it has to happen. Level 4 vehicles, even restricted to certain areas and conditions, will get us where we want to be. Do we really want a Level 5 vehicle driving in a snowstorm on Colorado's Loveland Pass at night? I don't think *any* vehicle should be doing that."

Richard Wallace of the Center for Auto Research says an industry survey suggests Level 5 vehicles might appear around 2030. But he agrees with

Burns: "I think [artificial intelligence] alone isn't the answer. If it fails, there's nobody there. So maybe it's AI working with humans."

Naturally, the advent of computer-driven vehicles has spawned book after book of new government regulations. Since 2012, 41 states and Washington, D.C. have put forward proposals for automated cars; 29 (and D.C.) have enacted legislation. On a federal level, the National Highway Traffic Safety Administration in 2016 issued a Federal Automated Vehicle Policy designed for safety assurance and enabling CAV innovations. In 2017, following public comments and congressional hearings, the agency released "A Vision for Safety 2.0," incorporating safety-related voluntary measures for CAVs. As we go to press, the Department of Transportation and NHTSA are at work on version 3.0.

"We don't know what's going to be in the federal safety standards that are going to govern Level 4 or 5 vehicles," Wallace says. "I'm not sure NHTSA wants to become a software-testing company. Do they outsource this to AI experts, cyber experts? Do

they bring them in house? Will they be competing with GM and Google for talent? NHTSA is going to have to figure out a lot to certify these new vehicles."

John Maddox, formerly of ACM, notes we have a century of experience with today's system. "We know how to validate a vehicle, but take the human out of the loop, and you can't apply the same 100-year methodology," he says. "That's the key tech hurdle. The technology is moving so fast that no one company knows how to do it all. Companies have learned bits and pieces—so a little sharing could go a long way. We need to work across companies, across countries. That way, we have a chance of creating a harmonized standard. At the ACM, we're reaching out to help create that standard."

Bottom line: For now, the world of automated vehicles is the Wild West. So buckle up. It's gonna be a helluva ride.—**A.S.**

93

area, certain weather conditions, and certain speeds than to shoot for Level 5, which is fully autonomous anywhere, anytime. Level 5 may never happen. You'd have to have a vehicle as comfortable with kangaroos in Australia as sandstorms in Saudi Arabia."

Wallace notes other bumps in the automated road. "We certainly don't have a comprehensive regulatory and legislative approach at this time," he says (see sidebar). "Then there's public acceptance. Half to two-thirds of people say they're interested in driverless cars, but then you have the self-driving Uber fatality in Arizona, and the acceptance—particularly among young people—goes way down. Also, though people are curious, they really don't want to give up their steering wheels. Everyone thinks the other guy is the bad driver."

Peng sees two final major challenges. "Reliability has to be automotive-grade," he says. "Ten years, 100,000 miles. That's the target. Right now, CAVs fail too frequently. And then there's the talent issue. Do we have the workforce to get everything done? We're going to need thousands of engineers who know robotics, cyber security, computer programming. If we don't have enough new students in those fields, progress will be held back."

Grounds for Improvement

"This isn't your grandfather's proving grounds," says John Maddox, former president and CEO of the American Center for Mobility (ACM), a 500-acre CAV-testing facility opened in December 2017 at Willow Run Airport in Ypsilanti, Michigan—site of the former bomber plant Henry Ford built during World War II to produce such aircraft as the B-24 Liberator. Created in partnership with the state of Michigan, automakers, and other private entities, the ACM is available for lease to companies by the day, the month, or even at the same time a rival is testing on another area of the track.

"[The ACM] works side by side with OEMs and other industries from all over the world," Maddox says. "But unlike conventional proving grounds, which are really built for accelerated wear or testing fuel economy, the ACM is designed to look like the real world. Otherwise, you wouldn't be able to test decision-making or other tech features reliably and repeatedly."

In fact, the ACM convinced the state of Michigan to allow the facility to swallow up portions of several nearby, lightly used public roads—including two of the first triple-decker bridges ever built in the U.S. Still, much of the ACM lies unfinished as of last summer; garages, roadways, intersections are all under construction. "We may always be building," Maddox says with a laugh. "Right now we're building what testers need, but they learn something new

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Waymo's Level 4 Early Rider Chrysler Pacificas are already performing taxi duties in Phoenix. Since 2009, its test fleet has accumulated more than 10 million driving miles in cities from Kirkland, Washington, to Atlanta.

every day, and they come to us and ask, 'What if we just had a yada yada yada?' And we can reconfigure or build new track as we go along."

Collaboration is a huge part of the ACM, Maddox adds. "Maybe an OEM wants to work with a cellphone maker, a traffic-control company like Siemens, and a sim company. They can have the place to themselves, all four companies working together. The thing is, an automaker like, say, Ford, would never have AT&T onto its own facility, which would compromise the confidentiality of their products. At the ACM they don't have to worry about that."

AMERICAN CENTER FOR MOBILITY

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Test facilities at the American Center for Mobility (above and opposite) mimic real-world driving conditions—and are constantly being reimagined to meet the demands of rapidly evolving CAV technologies.

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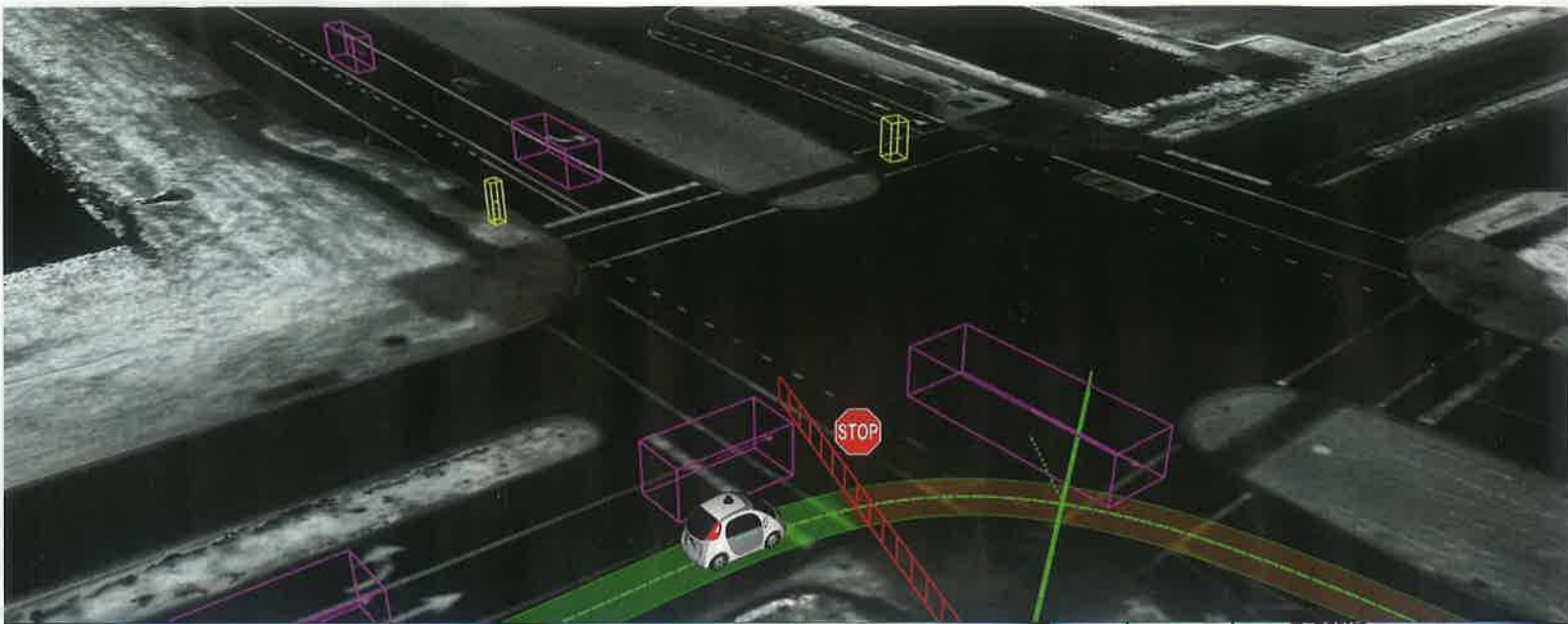
Above: A visualization of what is simultaneously "seen" by Waymo's automated vehicle and its human passenger when encountering a stopped school bus.
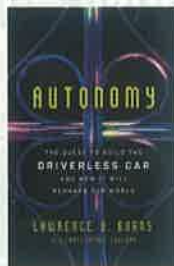

Pick up Burns' book at amazon.com, $16.96 hardcover, or used starting at $2.94, plus shipping and handling.

Bot Wheels

Are computers eventually going to push humans out of the driver's seat? "I've got a bunch of classic muscle cars and trucks, and I'm never giving those up," Maddox says. "In my and my kids' and my grandkids' lifetimes, I believe we'll have human-driven vehicles."

Burns agrees. "When the car became popular, horses didn't go away," he observes. "Enthusiasts will always pursue their hobbies. But most of the time, we're just talking about transportation. The drive from Detroit to Chicago on I-94—that's not fun. I'd much rather have my car do that."

Wallace has a different take. "You look at Waymo, and they're not working on human assistance," he says. "They're trying to jump all the way to Level 4 or Level 5, no human interaction at all. But I'm perplexed there isn't more attention given to making people better drivers with reinforcing technology instead of taking the human out of the loop. Maybe we don't *need* Level 4 or 5—maybe collaborative driving is a better solution. Also, in rural areas there's no benefit to a ride-sharing automated vehicle. There's nobody else out there. In 50 years … maybe. Then our [race] tracks will be the horse farms of the future where you can still take your human-driven car out to play."

Peng thinks we could wind up with the best of both worlds. "When I'm tired or if I drink, then the car can drive," he says. "Other times I want to enjoy driving myself. Maybe even Ferrari will one day make an automated vehicle. You know they will tune it to be fast." **AM**