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Meet the Companies Building Self-Driving Cars for Google and Tesla (And Maybe Apple)

SCIENCE

A week ago, the CEO of the world's most valuable company telegraphed the next market in its sights.

"It would seem like there will be massive change in that industry, massive change. You may not agree with that. That's what I think," **Apple's Tim Cook said** at last week's WSJDLive conference.

He was talking cars.

In the future, Cook continued, "autonomous driving becomes much more important." The comments stoked the fervor around **Apple's heavily shrouded car plans**. Many in the industry assume that Apple is developing electric vehicles that will drive themselves, pitting the company against Google, Tesla, Uber and the bulk of automakers that have autonomous cars on the road or are scrambling to get them there.

If Apple gets into the self-driving race, it's unlikely to build cars alone. Who will it turn to?

Apple's imminent entrance also casts a light on the nascent cottage industry for manufacturing the next generation of cars — one soon to undergo a seismic change. With mobile devices, Apple accelerated the birth of a formidable supply network,

singlehandedly uplifting entire businesses and decimating others. A similar dynamic is coming to cars. Traditional automakers and suppliers are increasingly facing off with a wave of newcomers to find footholds in this industry upheaval.

"Everyone sees it as an opportunity to expand their business model," said Bobby Hambrick, CEO of AutonomouStuff, an Illinois-based company that sources autonomous computing parts for several industries, including aerospace. Automotive has quickly expanded, and now accounts for a third of its business. "Autonomous driving in general is very disruptive for the automotive business model," Hambrick added. "They're all in a race."

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The shared belief — in Silicon Valley, Detroit, Germany and Japan — is that self-driving cars are inevitable. When they arrive en masse, they will transform transportation and industries attached to the car. Morgan Stanley estimated that by 2022 they will save $488 billion in accident avoidance per year, and add $507 billion in "productivity gains" — think of all we can do (or watch) in cars when we aren't driving.

They will also upend the massive, multinational industry built around building cars. Some faces here are familiar. Tesla has touted its **recent advancements in autonomous driving**, as have big carmakers such as Daimler, Audi and BMW. The less-familiar companies are the ones behind the scenes — the manufacturers, suppliers and startups building the hardware and software that equip vehicles with autonomous features, or that build self-driving cars from scratch.

And that's where Apple might look.

Several of these companies provide parts to the big carmakers, Google and Tesla. Several are working with Apple on its CarPlay in-car dashboard. However, none of the companies would comment on any conversations they have had with the Cupertino giant about their own cars. None of them flat-out denied those conversations, either. Google, Tesla and Apple all declined to comment.

The list below is not exhaustive. Yet after conversations with nearly a dozen manufacturers, industry experts and tech companies involved in the world of self-driving cars, **Re/code** assembled a portrait of the leading, innovative companies and critical dynamics in the autonomous industry.

You know the iPhone teardown. Welcome to the self-driving car industry teardown:

The Body

Our best glimpse of the future of driverless cars comes from Google. Its homemade two-seaters — called, for now, **"the prototype"** — hint at what tech sees on the horizon for cars: Packed with smart sensors and radars, and eventually stripped of the interior parts (i.e., a rearview mirror) rendered anachronistic by driverless tech. A computer on wheels.

Google doesn't make that computer alone. In August 2014, four years after first unveiling its self-driving car project, the company finally released the names of some partners. Roush, a boutique automotive supplier based in Michigan, assembled the car's exterior. LG Chemical, a subsidiary of the Korean manufacturer, made the batteries. A handful of German specialists — Continental, Bosch, Frimo and ZFLS — were behind components like powertrain, brakes and steering wheels.

These companies are not new to the automotive world. Continental and Bosch are multibillion-dollar businesses, supplying traditional and autonomous parts to a range of car companies. When it comes to self-driving, the German companies echo the carmakers: Autonomy is a process, starting with driver assistance features — like automatic lane braking and parking — and, as consumers adapt, progressing to full self-driving.

Sales of Bosch's Mobility Solutions unit, which sells smart-car features, grew at twice the industry pace last year, according to the company. (A month after Google announced its partners, Bosch **acquired ZFLS**.) By 2017, Continental projects that it will net $1.3 billion in revenue from systems that build autonomy into brakes,

acceleration and steering. Enno Pigge, a Continental rep, said the company is providing some parts to Tesla, but would not say which ones. Frimo and Roush, Google's other partners, declined to comment.

Another force in the field is Magna International, a Canadian manufacturer. It's a supplier, selling a range of semi-autonomous features to carmakers, but it also runs a vehicle-assembly subsidiary. That gives it an edge. Morgan Stanley wrote that Magna could do what "**Foxconn does today for Apple**," for Google, Uber and the growing list of tech companies looking to build self-driving cars. Swamy Kotagiri, Magna's chief technology officer, deflected the moniker, but said the company sees itself in a good market position. "The one differentiating factor is the breadth of automotive expertise," he said. "We look at it more as a holistic view."

The Eyes

More critical than having smart components inside, a self-driving car needs to see. There's some dispute about how to do it best. The best option may be Lidar, a remote sensing technology that uses lasers to map out surroundings — in addition to cars, the tech is deployed in agriculture, geology and military defense. But Lidar is not cheap.

Velodyne, a 32-year-old company that started in subwoofer technology, branched out into Lidar a decade ago and has become a market leader. It builds three different products: A powerful $80,000 sensor (used by some trucking companies); a $32,000 model; and, released last year, its palm-sized "Puck," which costs $8,000.

As autonomous tech spreads in the coming years, the company expects a surge in demand from carmakers for the cheaper two products, said Wolfgang Juchmann, sales director for Velodyne's Lidar division. Google, which makes its owns Lidar, also buys from Velodyne, shelling out for the priciest model. (Velodyne would not comment on Apple, but its equipment **has been spotted on Apple's mapping vans**.)

Quanergy, a newcomer building Lidar, claims it will bring down the prize to $100 by 2018.

For now, a thriftier alternative to Lidar are high-tech cameras. Mobileye, an Israel-based company with a market cap of around $10 billion, is emerging as the dominant supplier here. More than 90 percent of carmakers have partnered with Mobileye, the company said. Tesla buys its cameras, which are laced with Mobileye's advanced software and chips. Earlier this month, GM said it was working with Mobileye to test self-driving features on the hybrid Chevy Volt.

Mobileye's full hardware and software package, which includes a 360-degree view around cars, can cost less than $1,000 for car companies, said chief communication officer and SVP Yonah Lloyd. "For the car industry, cost is a major consideration," he added. Here is its perception system picking out pedestrians:

Cameras are not only cheaper, but they often have better resolution, and can see certain elements on the roadways — lane markers, traffic lights — that Lidar misses. A few startups, like **Nauto** and Cruise, are deploying cameras coupled with smart computer-vision algorithms to retrofit cars with driver-assistance technology that set the stage for full autonomy.

The Brains

Once a car has the parts to drive alone and see, it still needs an obscene amount of processing power. Enter the chipmakers. Some familiar titans from the mobile world, like Qualcomm and Samsung, are moving into the car industry, providing the graphical interfaces behind the advanced vision systems requisite for autonomous driving.

The company ahead of the curve, however, is Nvidia, which is primarily known for producing chips behind video games. It has shifted its attention to cars, starting in 2007 when its systems powered the integration of Google Earth inside an Audi. Nvidia said its automotive unit posted 85 percent annual growth in sales for the last

fiscal year. Several luxury carmakers use its supercomputers, which can take the reams of data coming from up to 12 cameras on a car, plus any Lidar and ultrasonic sensors, and make sense of it.

"An automaker will come to us because they have really hard problems, and they can't do it themselves," said Danny Shapiro, director of Nvidia's automotive unit. "This notion of being able to build a brain for a self-driving car has really accelerated the demand for our technology."

Tesla and Google purchase from Nvidia, as does Delphi, a global auto supplier that has its own autonomous vehicles on public roads. Nvidia would not comment about Apple.

Being the "brains" of self-driving cars leans on a form of artificial intelligence called deep learning, which trains computers to process reams of visual data. This month, **as Re/code reported**, Nvidia's director of deep learning went to work for Apple.

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