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THE BIG STORY / JANUARY 2017

# FCVs

## Hydrogen in the Pipeline

AFTER TWO DECADES OF AUTOMOTIVE FUEL-CELL DEVELOPMENT, INDUSTRY INTEREST, DECLINING COSTS AND INCREASING REGULATIONS MAKE THE PROSPECTS FOR A HYDROGEN-FUELED FUTURE BRIGHTER THAN EVER. *– By Bob Gritzinger*

*Cover: Honda Clarity FCX*

More than a decade ago, hydrogen fuel-cell-powered vehicles were seen as the proverbial light at the end of the automotive powertrain tunnel, a remedy for the flaws of the internal-combustion engine, a certain way to meet tough emissions standards and a pathway to a non-fossil-fuel future.

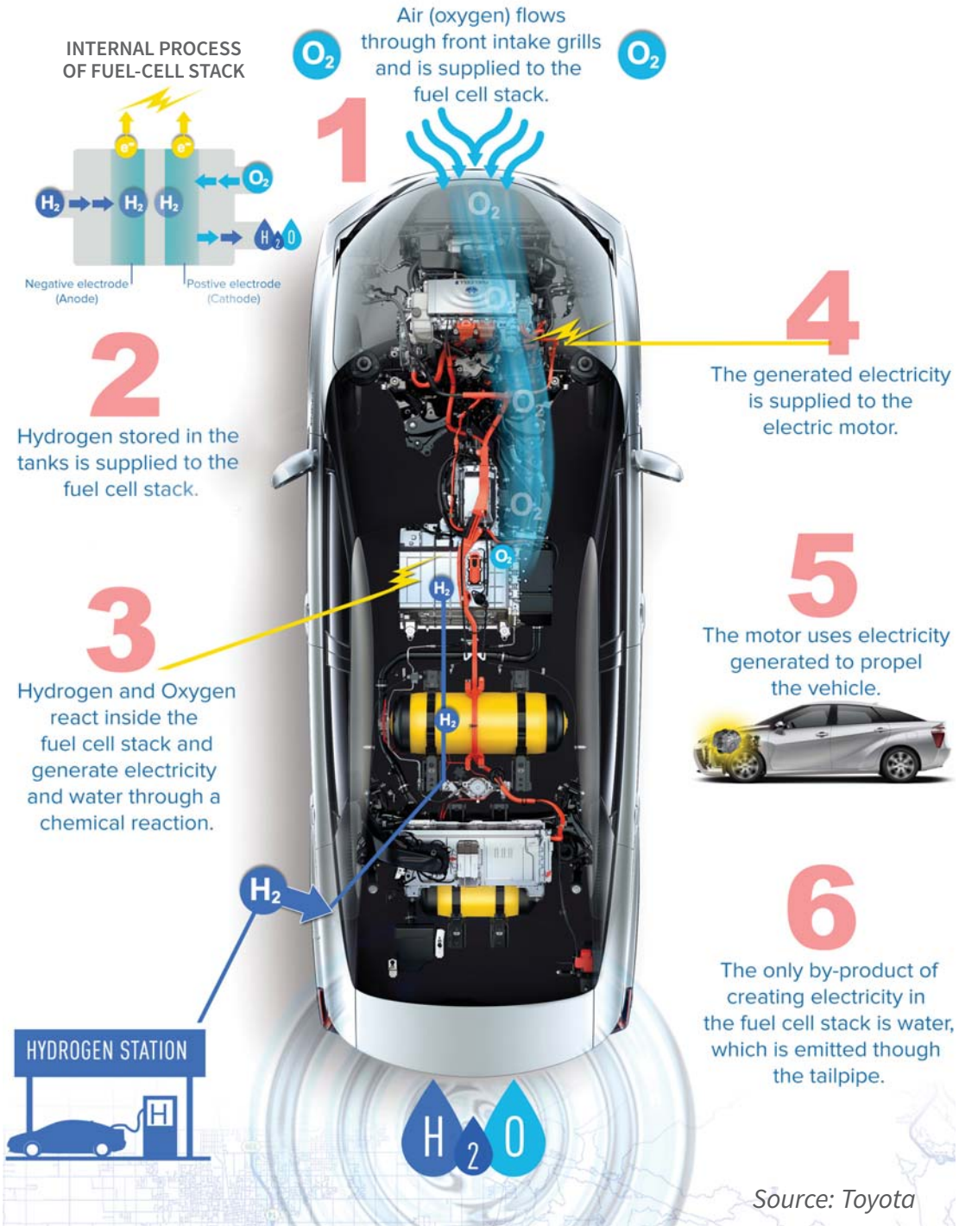
General Motors placed a big bet on the technology, with a campus devoted to fuel-cell development in upstate New York. The lab was a long way from the automaker's technical center in Warren, MI, as was its prototype compared with GM's initial late-1960s lab-on-wheels, fuel-cell-powered Electrovan.

The 2002 prototype, a Chevrolet S-10 pickup, featured a bed stuffed with batteries and an onboard reformer cracking hydrogen from gasoline to feed its fuel-cell powerplant. Although it pushed the scales at 6,300 lbs. (2,858 kg) and required a 6-minute startup procedure, the S-10 FCV was hailed for its huge advancements compared with GM's earlier fuel-cell projects.

**Former GM executive Larry Burns with the Chevrolet S-10 FCV pickup.**

Larry Burns, GM's vice president-research and development at the time, touted the S-10 as a major milestone toward putting a functional FCV on the road by 2010.

**HOW IT WORKS:** This graphic details the design and operation of a fuel-cell vehicle and internal process of a fuel-cell stack.




*Source: Toyota*

**1966**
General Motors develops world's first fuel-cell-powered vehicle, the **Electrovan.**

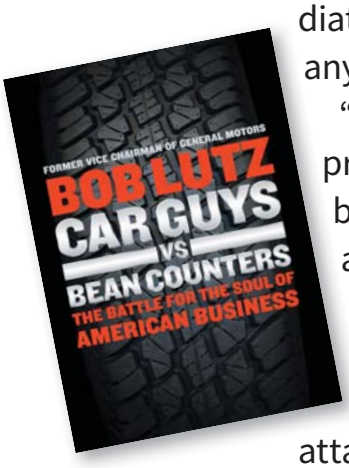

**06.1996**
Mercedes unveils its **NECAR II FCV**, based on its V-Class minivan – top speed is 68 mph and range on full tanks is 155 miles.

**04.1999**
**DaimlerChrysler, Ford, Ballard and three oil companies** link up in a project to put 50 FCVs on U.S. roads between 2000 and 2003.

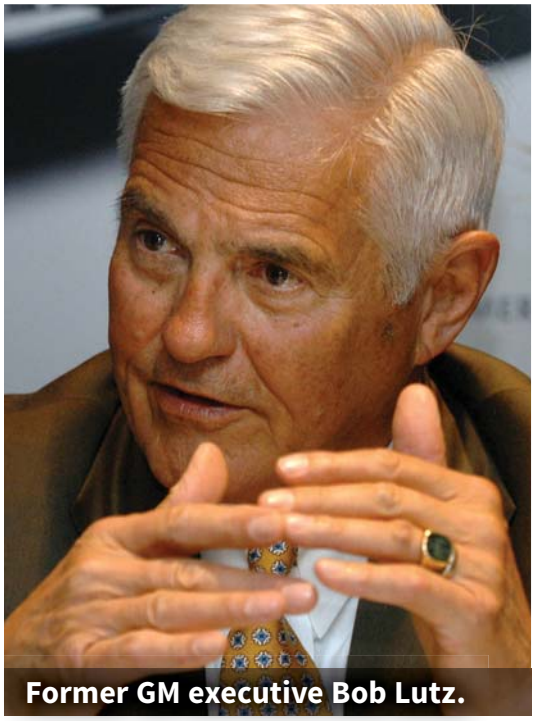
More prototypes and a pilot fleet of Chevy Equinoxes followed to further test the reliability and practicality of FCVs.

Proponents were many, including automakers, suppliers, government agencies and a variety of public-private partnerships touting the notion fuel cells soon would begin to replace ICEs.

Detractors, including then-GM Vice Chairman Bob Lutz, complained the program drained R&D resources away from more immediate needs without producing any substantial positive results.




"The problem with our fuel-cell program was that, despite GM's best efforts, the world saw it as 'vaporware,'" Lutz wrote in his book, "Car Guys vs. Bean Counters." "The fuel-cell program was just too easy to attack: production was too many years away; deadlines for initial production came and went, and it was all too easy for detractors to point to the absence of a distributed hydrogen infrastructure."


Former GM executive Bob Lutz.

"The fact that GM was the absolute world leader in the development of the hydrogen fuel-cell vehicle…failed to resonate with

**05.1999**
**GM and Toyota** form 5-year partnership to develop environmentally friendly vehicles, presumably including FCVs.

**08. 2000**

GM makes its **HydroGen1 FCV** available to media for test drives.

**05.2002**


DaimlerChrysler's **NECAR 5 FCV** completes 3,662-mile (5,892-km) cross-country trip from San Francisco to Washington.

the media or the public," Lutz wrote.

Fuel-cell backers soldiered on anyway, at least until 2009 when Steven Chu, then U.S. Secretary of Energy under President Obama, cut federal funding for FCV research. Chu said fuel-cell-powered transportation would require too many technological "miracles" – easy availability of hydrogen, transportation and compact storage of the gas, a large-scale hydrogen infrastructure and breakthroughs in fuel cells – to be a realistic option.

Automakers faced with recession-level budgets for R&D moved on to more immediate solutions: gasoline-electric hybrids, battery-electric vehicles and increasingly efficient ICEs. Meanwhile, oil as a source of fuel became readily and cheaply available. Fuel cells, once considered crucial to the future of transportation, disappeared from the public eye, even as development work continued through the first decade and a half of the new millennium.

**07.2002**
**Nissan** says it will put an FCV on the market in 2003, two years ahead of its original schedule.

**01.2003**
Fuel-cell company stocks spike after **President Bush** proposes an outlay of $1.2 billion to develop hydrogen-powered vehicles.

**10.2003**
EU launches **European Hydrogen and Fuel Cells Technology Partnership** to coordinate research on hydrogen as a fuel.

## So ... Why Now?

Despite retreating from public view, "we have never completely let down on fuel cells as a major activity," says Andreas Schamel, Ford director of global powertrain research and advanced engineering. "During the downturn, things slowed a bit, but four years ago started ramping back up. We never really slowed down in the fuel-cell activity.

"All the fundamental ingredients are in place," says Schamel. "We won't see volume in this decade, but it's quite realistic to see volume early in the next decade. It's three-digit now, but it will grow into the five-digit sales level in the next decade."

Lower-cost fuel-cells are another driver. What once were multimillion-dollar science projects are now $100,000 vehicles and experts predict we likely will see another 50% cost reduction by the middle of the next decade. Toyota says in the past five years it has reduced by 95% the cost of manufacturing an FCV.

"The cost to put a fuel-cell car on the road a decade ago would have been hundreds of thousands of dollars," says

### RENEWED INTEREST

A combination of factors have returned the FCV to center stage:

- regulatory pressure to build and sell carbon-free vehicles
- improvements in battery-electric vehicle technology
- plentiful and clean sources of hydrogen
- a range of initiatives aimed at growing the hydrogen infrastructure

**04.2004** **DaimlerChrysler, BP and the U.S. DOE** link up on a 5-year program to test FCVs in U.S.

**05.2004** GM sets an FCV distance record with its **HydroGen3** model, a converted Opel Zafira. Distance: 3,400 miles (5,471 km).

**10.2004** **DaimlerChrysler** targets 2015 to debut a mass-market FCV. Cost and durability cited as two problems still to be solved.

> THE ADVANTAGE FCVS HAVE IS THEY DON'T REQUIRE A CHANGE IN CONSUMER BEHAVIOR.

Tony Guglielmin, CFO at Ballard, a Canadian fuel-cell stack developer and manufacturer. "Today it would be under $100,000, so frankly you can put a fuel-cell car on the road probably for the price of a Tesla in modest volumes. That's still expensive, but it has come down significantly. Both the fuel cell and the total cost of the car has come down dramatically."

From a consumer point of view, FCVs promise the emission-free driving of a battery-electric vehicle without any of the associated range anxiety common with even the best of today's electrics capable of traveling more than 200 miles (320 km) on a charge.

FCVs offer range similar to that of an ICE vehicle with the same kind of quick and easy refueling time, and the propulsion system has proved to be extremely low maintenance in long-term durability testing.

Overlooked, but possibly most important, FCVs require no special knowledge of battery capabilities or changes in driving style or patterns – they drive much like typical battery-electric vehicles but with all the operational simplicity of ICE-powered vehicles.

"The advantage FCVs have is they don't require a change in consumer behavior," says Guy McAree, director-investor relations at Ballard. "A fuel-cell car operates the same as a gasoline car in terms of how long it takes to refuel it and how far it can go on a tankful. Battery-electric cars require a change in consumer behavior, and I think that's the biggest obstacle."

Lutz hasn't changed his opinion, contending in a recent interview with *WardsAuto* the latest initia-


**11.2004**

GM and Shell cut the ribbon on a **new hydrogen-fuel pump** in Washington to facilitate FCV test drives by policy makers.

**03.2005**

GM and DaimlerChrysler sign **deals with the U.S. DOE** covering FCV programs to put 140 FCVs on road by year end.

**04.2005**

GM introduces a **fuel-cell Silverado pickup** for a test by the U.S. Army as part of efforts to commercialize FCVs by 2010.

tives by automakers are mere window dressing to meet California's zero-emissions vehicle mandate.

But Chu, seeing progress in hydrogen availability and fuel-cell reliability in buses, reversed his stance by the time he left office in 2013. Chu told reporters the Department of Energy would "continue to support the fuel-cell program," calling it "an important technology."

Today, automakers have a dozen projects in various stages of development, including several vehicle-leasing pilot programs poised to commercialize FCVs as soon as the hydrogen infrastructure is capable of supporting them, if not sooner.


**Toyota Mirai at fuel station.**

"(FCVs) are a number of years away yet from full commercialization, but because of a vast improvement in cost reduction, because of a vast improvement in reliability and durability, all the technical issues largely have been resolved and the product costs have come down now to where there's increasingly a proposition for automotive fuel-cell-powered cars," McAree says.

"The biggest challenges are going to be consumer acceptance and understanding and then the fueling infrastructure. But I think the automotive companies are well on the way."

**09.2006**

GM announces it will put 100 **Equinox FCVs** in a consumer-test program in New York, Los Angeles and Washington.

**09.2007**

Hyundai shows off **i-Blue FCV** to make public debut at Frankfurt auto show later in month.


**09.2007**

**Toyota's FCHV** completes 350-mile (560-km) trip from Osaka to Tokyo on one tank of fuel.

## Hydrogen Hold-up

Yet there remains a huge elephant in the room: the lack of infrastructure to create, store and deliver hydrogen to power a fuel-cell-based transportation system. While California leads the U.S. in hydrogen filling stations, with roughly 40 online today, 51 expected by the end of the year and 100 by 2020, that's a flyspeck compared with the 9,000 gasoline stations in the Golden State.

"I would say today the primary disadvantage is we are waiting for stations to be built," Craig Scott, national manager-advanced technologies, Toyota Motor Sales USA, says. "You're limited to the number that can have access to it today. But once the station network is developed


First Element's True Zero pump.

**06.2008**
First **Honda FCX Clarity FCV** rolls off line in Japan.

**07.2009**
**Toyota** exec says the price of the automaker's FCV due in 2015 will be "shocking for most of the people in the industry."

**09.2011**
Mercedes-Benz unveils **F125! FCV concept** at Frankfurt auto show, calling it a look ahead to vehicles in the 2025 time frame.

**Steve Center: "To put money in the fueling is really kind of a strange thing for the automaker."**

then there's really very little to no limitations or disadvantages to the customer."

Progress is being made mostly through public-private partnerships or government incentives, but also as a result of automakers joining the effort as they take on a role as both the chicken and the egg – manufacturing fuel-cell cars while also helping build the necessary hydrogen infrastructure to support them.

Automakers are investing in the development of a hydrogen fueling network, but it feels unnatural for the manufacturers.

"I'm a little bit of a historian, but I don't recall automakers really getting involved in the roads, other than I think Henry Ford or Firestone had an image for a transcontinental highway a long time ago," Steve Center, vice president-environmental business development for American Honda, says. "It's usually been other private enterprise or the governments. So to put money in the fueling is really kind of a strange thing for the automaker. Do you want to be selling the car and the fuel and servicing the car?"

Toyota's Scott agrees: "Today we don't build roads for cars and we don't build gasoline stations for them. Quite honestly this is not our core competency and it's also not something I think most car companies are comfortable doing, because it feels so out of the norm. But the reality of it is, at least in Toyota, we finally accepted it wasn't going to happen fast enough. At least it wasn't going to meet our timeframe for what we would call success. It

**2014**
**Hyundai Tucson Fuel Cell** and **Toyota Mirai** *(photo)* introduced as first commercially viable FCVs.

**10.2015**
U.S. Congress designates Oct. 8 **"National Hydrogen and Fuel Cell Day,"** based on hydrogen atomic weight (1.008).

**12.2015**
**Hyundai Tucson FCV** earns *Wards 10 Best Engines* award.

required us then to take a more active role in that, so that's what we've done."

In the U.S., the California Air Resources Board leads the way when it comes to mandates but also in providing funding, investing $20 million annually in 2016-17 to help build the hydrogen future.

The state's ambitious goals include reducing climate-change emissions 40% by 2030, cutting petroleum use up to 50% by 2030 and meeting federal air-quality standards, which CARB recognizes "will require a fundamental transformation of the vehicles and fuels we use today."

CARB estimates the state's FCV fleet will grow to 13,500 by 2019, and to 43,600 by 2022, up from estimates issued by the agency in 2015 that projected 10,500 in 2018 and 34,300 in 2016.

The increase in FCVs on the road will require a substantial hike in the number of fueling stations. The 51 stations online by year's end will provide a daily fueling capacity of 9,400 kg, enough to handle the needs of about 13,500 vehicles, CARB says. But that's assuming the filling stations all are in the right places.

"I'm not sure if having a fueling station within a one-tank range is good enough for general customers," says Ford's Schamel. "To really break through to the mainstream will require a mass refueling infrastructure."

**09.2016**
Toyota drops lease price on **'17 Mirai** to $349 month.

**10.2016**
GM and U.S. Army introduce fuel-cell-powered **Chevrolet Colorado ZH2** test vehicle.

**12.2016**
**Honda Clarity** goes on sale in California; plug-in version due in 2018.

## Filling the Hydrogen Tank

> WITH REAL PRODUCT ON THE STREET, WE'RE SEEING A LOT MORE MOMENTUM.

That's where companies like First Element Fuel come in. Led by former GM and Hyundai marketing executive Joel Ewanick, First Element is working hand-in-hand with automakers and the California Fuel-Cell Partnership (CaFCP) to create a hydrogen refueling grid capable of meeting expected demand, both geographically and in capacity, through its True Zero filling stations.

CaFCP, a joint venture created in 1999 by CARB and the California Energy Commission along with six companies (Ballard Power Systems, the then-DaimlerChrysler, Ford, BP, Shell Hydrogen and ChevronTexaco), is committed to a plan to strategically locate 100 hydrogen stations across the state so the majority of residents would be within a 10-minute drive from a station.

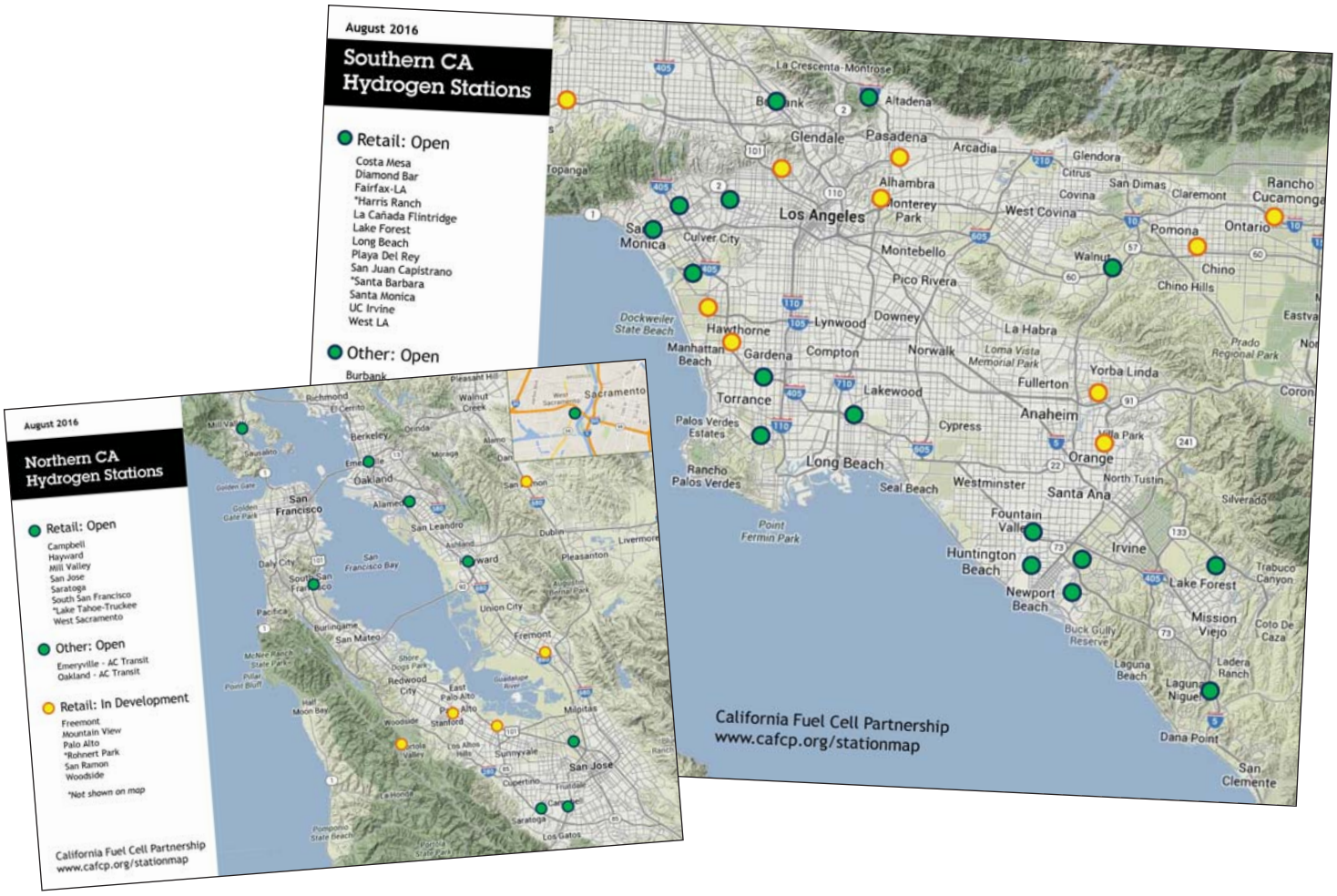
"The California commitment changed the discussion," Bill Elrick, executive director-CaFCP, says during a panel discussion at the Advanced Automotive Battery Conference in Detroit in June 2016. "With real product on the street, we're seeing a lot more momentum."

While 100 fueling stations may seem low compared to the easy availability of gasoline pumps, CaFCP believes the gasoline infrastructure is overbuilt. The agency notes just 119 pumps provide fuel for more than half of the state's 650,000 diesel cars.

California is making progress and the Northeast is following suit, where Air Liquide in partnership with Toyota and Honda

is developing a hydrogen infrastructure with the first four of 12 planned stations slated to open early next year in Hartford, CT; Braintree, MA; Mansfield, MA; and Bronx, NY. The stations should cover the New York-to-Boston corridor with additional hydrogen filling locations coming to other Northeast states, including New Jersey, Rhode Island and Vermont. Finally, the public-private partnership H2USA is mapping plans for a national hydrogen infrastructure roughly patterned on the California model.

Building the infrastructure won't be cheap. H2USA estimates capital costs will range from $900,000 to $2 million per station; First Element's strategy of adding hydrogen pumps to existing fuel stations would help contain costs.



## Plotting Global Progress

Globally, fuel-cell programs are picking up steam in Asia and Europe, with Germany's Clean Energy Partnership leading the way. The German Ministry of Transport, along with partners Air Liquide, Air Products, Daimler, Linde and Total Germany, have 50 fueling stations in place and expect to have as many as 400 online by 2023. The Scandinavian Hydrogen Highway Partnership boasts 17 stations across Sweden, Norway and Denmark with another 12 slated to go online by 2018. The U.K. government is investing in a dozen hydrogen stations to enable FCV adoption.

Japan's aggressive "Strategic Road Map" calls for rapidly expanding the hydrogen fueling infrastructure to 160 stations by 2020 and 320 by 2025 to support as many as 200,000 FCVs on the road. In Korea, the government is deploying 1,000 FCVs serviced by 10 stations and hopes to grow the number of FCVs on the road to nearly 10,000 by 2020. India's government also is embracing FCVs, releasing a detailed plan in June to invest in and develop fuel-cell technology by 2022. China, meanwhile, lumps FCVs in with all alternative-fuel vehicles it hopes to promote.

One automaker is leapfrogging the infrastructure roadblock by developing its own on-board hydrogen source. Nissan in August revealed a prototype vehicle powered by a solid-oxide fuel cell capable of extracting hydrogen via a reformer from ethanol or ethanol blended with water.

Critics argue the system emits water and carbon dioxide, unlike a traditional fuel cell that emits only water. Nissan contends the vehicle is carbon-neutral because plants from which the ethanol is derived absorb CO2, offsetting the emissions.

Nissan says it plans to have the solid-oxide FCV in fleets by 2020, aiming at markets such as Brazil where ethanol is widely available.

## Bright Fuel-Cell Future, Eventually

With all the activity surrounding hydrogen FCVs, one might logically conclude full-scale production is just around the corner. But as has been the case since well before Lutz raised his objections, hurdles must be cleared before we can begin to envision an FCV in every garage.

*WardsAuto* forecasts annual production rising from current-year 2,840 vehicles to just fewer than 5,500 globally in 2023, representing a miniscule 0.005% share of the 106.7 million vehicles expected to be produced worldwide that year. Even the rosiest prognostications put annual FCV production at about 70,000 vehicles globally by the middle of the next decade, representing just 0.1% of the total vehicle market.

Annual production may remain low, but the total FCV fleet globally is expected to reach 20 million by 2032, according to a report issued by Information Trends, a Washington-based think tank. CARB, as noted earlier, projects 43,600 FCVs on the road in California alone by the end of 2021. Toyota, which put 270 Mirai FCVs on the road last year, predicts global sales of 30,000 FCVs annually by 2021, following a growth trend similar to hybrid sales.

"This is the technology for Toyota for the next 100 years," Scott says.

Naqi Jaffery, lead author of the Information Trends report, calls FCVs the future of the automobile and predicts they will represent the fastest-growing automotive segment by 2050.

Emissions and fuel-economy regulations play a significant role in how the strategy plays out, but ultimately zero emissions will be the rule, not the exception, and at that point FCVs and their battery-electric vehicle brethren will hold the keys. In the near term, automakers know 10 states (California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont) have adopted a rule requiring 16% of new-vehicle sales in 2025 be ZEVs. And

the nationwide federal CAFE standard of 54.5 mpg (4.3 L/100 km) in 2025 is unlikely to change in the government's midterm review, industry analysts agree.

Ever-evolving battery and electric-vehicle technology is a boon to FCVs in that many advancements in BEVs translate directly into improvements in FCVs. While some argue one technology will win out, most experts see a multi-powered future where FCVs, BEVs and ICEs in various configurations provide multiple powertrain options going forward.

Cost, especially for expensive platinum needed for the fuel-cell membrane, remains an issue, but automakers say they've reduced by 90% the amount of the precious metal needed while increasing the efficiency of the cell.

Nikola One FCV truck offers up to 1,200-mile range.

The first wave of fuel-cell adoption will come in fleets, in delivery vehicles, buses and work equipment such as forklifts, many of which already are in service or on the near-term drawing board. Fleet use, buses and ride-sharing services hold immediate promise for FCVs because the vehicles can be used within a limited range and returned to a central refueling depot, avoiding the problems of limited hydrogen infrastructure.

Ballard is making headway in this area, inking multimillion-dollar deals to provide its partners in China with fuel cells for more than 300 buses. China also wants fuel cells for light trains and cars.

Utah-based Nikola Motor introduced the Nikola One, a Class 8 heavy-duty truck powered by an 800V fuel cell capable of traveling 1,200 miles (1,931 km) between fillups. The company says a fully loaded truck will achieve the equivalent of nearly 20 mpg (11.8 L/100 km) with zero emissions. Nikola plans to produce hydrogen via electrolysis powered by solar energy, pumping the hydrogen

into its trucks via a nationwide network of more than 50 fueling stations.

In 2013, GM confirmed plans to work with Honda on fuel-cell development and to collaborate with the U.S. Army Tank Automotive Research, Development & Engineering Center to develop an FCV for the military. In October, GM and the Army unveiled a hydrogen fuel-cell Chevrolet Colorado midsize pickup that the Army plans to field-test this year.

The Army likes fuel-cell technology for its silent operation, on-demand torque and the potential for FCVs to produce water for soldiers in dry locations. The vehicles also could serve as mobile power stations.

"Hydrogen fuel cells as a power source have the potential to bring to the force incredibly valuable capabilities," says TARDEC Director Paul Rogers. "We expect the vehicle to be quiet in operation and ready to provide electricity generation for needs away from the vehicle. With fuel-cell technology advancing, it's an ideal time to investigate its viability in extreme military-use conditions."

Says Charlie Freese, executive director-GM Global Fuel Cell Activities: "This project is another example of how fuel-cell propulsion can play a role in nontraditional applications. We need to continue pursuing these opportunities along with our plans for production of a commercial fuel-cell system in the 2020 time frame.

"We believe hydrogen fuel-cell technology holds tremendous potential to one day help reduce our dependence on petroleum. "The resilience of our test fleet and new research partnerships are helping us reach this goal." **WA**

*This story was written by Associate Editor Bob Gritzinger with contributions from the WardsAuto staff. Gritzinger is a longtime journalist and industry observer who covers automotive product, technology and business news.*