2019 TECHNOLOGY STRATEGIES REPORT

FCVs ON THE HORIZON

How, where and when fuel-cell vehicles will take hold in the global market.

- Automaker/Supplier Strategies
- Technology’s Rapid Advancement
- Overcoming Hydrogen Hurdles
- The Market’s Tipping Point

WARDS INTELLIGENCE™

ABOUT THIS REPORT

Fuel-cell vehicles represent a tiny niche in the global automotive market, but their mere existence today as functional, everyday cars marketed by major automakers suggests the technology is on a path to wider proliferation in the coming decade.

While the numbers will remain small compared with vehicles fitted with internal-combustion, battery-electric or hybrid propulsion, automakers and suppliers are planning for substantial growth in the segment as the world's transportation systems slowly transform to a hydrogen-driven future.

This new research report by Wards Intelligence, "FCVs On The Horizon," reveals a number of factors driving that growth: reductions in the cost and size of fuel-cell stacks; improvements in fuel-cell output and durability; public and private efforts to expand the fueling infrastructure and clean sources of hydrogen; improvements in electric motors, energy storage and control systems; and the application of fuel cells to economically power everything from forklifts to Class 8 long-haul trucks.

A Wards Intelligence survey of OEMs and suppliers and projections from our data partner LMC Automotive suggest that fuel-cell demand in light vehicles will pick up momentum by 2025, initially finding the greatest opportunities in fullsize sport/utility vehicles and trucks. Commercial vehicles, buses, heavy-duty trucks and forklifts will provide significant growth opportunities as well.

"It is the first part of the curve, the first 100 to 1,000 units, that is most challenging," says Keith Wipke, laboratory program manager at the U.S. Department of Energy's National Renewable Energy Laboratory. "If an automaker like Toyota is producing 30,000 (FCVs) in 2020, then 100,000 in 2025 is reasonable."

The main impediment is fueling infrastructure. There aren't enough stations and hydrogen is expensive to produce. And depending on the source of hydrogen – if it is produced from coal-fired electric power, for instance – then it is not clean.

Technologically, while on-road operation has been validated and the stack has been downsized sufficiently to be placed in a compact car's engine compartment, system cost is still prohibitive although a pathway can be seen to fill certain niches based on duty cycle and application.

Among the report's key findings:

- The current market leader in FCVs, Toyota, will cede its dominance in the coming decade as Honda and Hyundai grow their FCV portfolios.
- Europe will supplant Asia-Pacific in FCV volume by 2030, joining North America in leading FCV deliveries.
- In the big picture, the numbers still will remain tiny, with about 301,000 annual FCV sales in 2030, well under 1.0% of global volume. However, that number represents a major increase over the infinitesimal 575 FCVs sold in 2015 and signals that FCVs are on a path to wider proliferation in the 2030s and beyond.

"FCVs On The Horizon" draws on Wards Intelligence and LMC Automotive data as well as more than a dozen executive interviews with OEMs and key fuel-cell-system suppliers in the U.S. and Canada, Germany, Japan, South Korea and China, along with input from the Hydrogen Council, NOW, the U.S. Department of Energy, California Energy Commission and Japan's Ministry of Economy, Trade and Industry.

ABOUT THE AUTHOR

Roger Schreffler is a veteran business journalist and WardsAuto correspondent who has covered the Japanese auto industry since the 1970s. He previously authored four reports for Wards Intelligence, including one on batteries and electric cars, one on the emerging 48V electrification technology, one on the recovery of the Japanese automotive supply chain following the devastating 2011 earthquake and tsunami and another on future powertrains.

CONTRIBUTORS:
David E. Zoia, *Research Director*
Bob Gritzinger, *Industry Analyst, Propulsion & Technology*
Erin Sunde, *Industry Analyst, Fuel Economy*
Susan Kozik, *Director, Content Design*

ABOUT WARDS INTELLIGENCE

Wards Intelligence has served the automotive industry's information needs for more than 90 years as a world-leading provider of automotive insights and analysis. Based in metropolitan Detroit, Wards Intelligence provides historical context and forward-looking perspective on all aspects of the automotive business.

Our staff of automotive analysts and industry researchers offers global and regional forecasting, historical data, trend analysis and industry insight through online tools and databases, special content conferences, intelligence reports and consulting services, with a focus on providing clients with reliable, responsive customer service and support.

If you have further requirements, we may be able to help you. Find out more about Wards Intelligence's capabilities.

Visit *wardsintelligence.com*
or contact us directly at *wardsintelligence@informa.com*.

TABLE OF CONTENTS

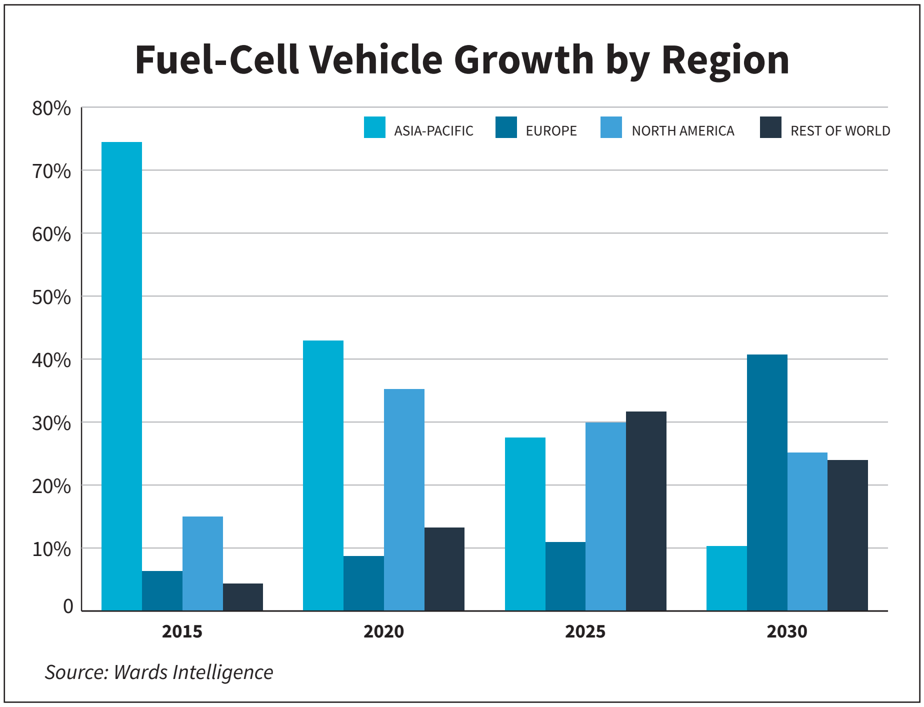
I. OVERVIEW

Much like horseless carriages at the start of the 20th century, today's fuel-cell vehicles represent a mere fly speck among the tens of millions of predominantly gasoline- and diesel-powered cars, trucks, commercial vehicles and buses plying the world's roadways. But similar to those early internal-combustion-powered vehicles vying for lane space and recognition in an age of established horse-and-buggy transportation, proponents contend fuel-cell vehicles represent a harbinger of mobility to come, a proverbial canary in the ICE coal mine.

To be clear, fuel-cell propulsion won't be crowding out ICEs, or even electrified vehicles, any time soon. Global projections put the percentage of FCVs sold in 2030 at about 0.3% of the likely 120 million worldwide deliveries, up from an even more minuscule 0.01% market share in the preceding decade. However, that small number does represent a huge leap in deliveries of FCVs and the likely early stages of a shift from more than a century and a half of fossil-fueled vehicles to a future powered by hydrogen, one of the world's most plentiful elements.

GLOBAL VOLUME AND ADOPTION FORECASTS

Actual numbers are hard to project, but estimates from Wards Intelligence partner LMC Automotive based on manufacturer forecasts put market leaders Hyundai, Toyota and Honda together producing about 130,000 FCVs by the end of the coming decade. The balance of FCV sales totaling 301,000 in 2030 will be driven by Daimler, General Motors and Volkswagen Group, plus a wide range of smaller FCV makers that include Chinese manufacturer Great Wall Motors.

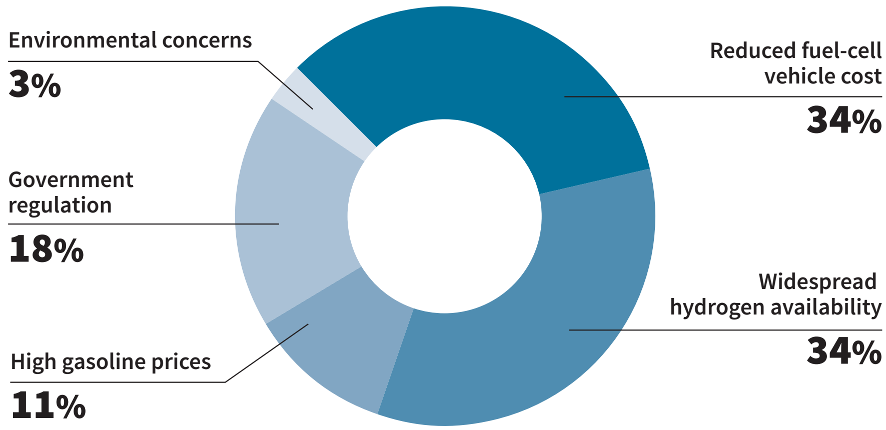


Though the gross figures are small, the global growth rate from 2025 to 2030 is a solid 365%, with the largest percentage gains coming in Europe following a decade in which North America had led the parade. Total sales of FCVs in Europe will surpass 120,000 while North American sales will top 75,000 units in 2030.

Today's market leader, Toyota, will cede dominance in the coming decade as Honda and Hyundai grow their FCV numbers and GM and Daimler increase their shares.

A mid-2018 survey by Wards Intelligence suggests the industry is expecting similar, low-volume trends to take hold in the coming decade. More than one-third of respondents from the OE, supplier and retail sectors

What events do OEMs say will trigger a move to fuel-cell adoption?



Source: Wards Intelligence 2018 Fuel-Cell Vehicle Survey

agree hydrogen availability and fueling infrastructure are the greatest impediments to FCV proliferation, followed closely by technological breakthroughs necessary to improve fuel-cell life and capability.

While this report focuses primarily on light-duty vehicles, survey responses show the industry is keenly aware that buses, local-delivery commercial vehicles and long-haul trucks hold the greatest potential for fuel-cell adoption. Local-delivery vehicles, forklifts and other short-range vehicles used for movement of goods at ports of entry, both air and sea, as well as for warehousing operations, along with short-run buses, are seen as likely fuel-cell opportunities because operators easily could set up hydrogen fueling to support those uses. Likewise, Class 8 over-the-road trucking and long-haul buses could be readily supported by a network of expressway-route hydrogen-fueling depots.

HYDROGEN DEPENDENCY

Until a hydrogen fueling infrastructure and a clean, non-fossil-fuel-dependent source of hydrogen can be developed, any plans for widespread proliferation of FCVs remain tentative at best.

Significant efforts to develop fueling stations are under way in Germany, Japan and in California, with hundreds of fueling stations planned or in place that could make FCV ownership and long-range driving feasible within those geographic areas. California has a target of 200 hydrogen fueling stations by 2025. The bottom line: Adoption of FCVs is dependent on whether additional countries and U.S. states are added to the list.

In China, Great Wall Motors estimates 15 hydrogen fueling stations currently are in operation and another 20 are under construction, with a goal of 100 by 2020. The government has set a target of 300 in 2025 and 1,000 in 2030, although speculation is those numbers will be increased to 1,000 and 3,000.

In South Korea, the government projects a cumulative 200 hydrogen fueling stations will be in operation in 2025. Japan is on target to have 160 stations by 2020 and 320 by 2025.

In Germany, 52 stations are in operation. The number is expected to grow to 100 by the end of 2019.

Creation of a green hydrogen source relies on energy companies developing the technology to harness clean power sources needed to obtain and store hydrogen. The concept suggested by Nikola Motors could serve as a model, wherein solar and wind sources provide the power needed to locally crack hydrogen from natural gas or other sources.

GRADING THE OEMS

The Wards Intelligence review of global automakers reveals a clear divide between those putting a high priority on fuel-cell-vehicle development and marketing and those automakers that have placed FCVs on the back burner, at least for now. The former group includes OEMs taking steps to develop and market a limited range of FCVs, drawing on past work and/or collaborating with other OEMs and suppliers with strength in FCVs.

The latter group includes a handful of automakers that previously delved deeply into the technology but subsequently have reduced that emphasis, usually due to a need to channel scarce resources to the development and near-term deployment of electrified vehicles, including gas-electric hybrids and pure BEVs. This strategy may be wise in that development of EV powertrains, including motors, batteries and control systems readily have the potential to carry over into production of FCVs down the road.

OEMs not listed in this review have little or no history of fuel-cell development and/or no evident plans to embrace the technology in the coming decade.

WARDSAUTO INTELLIGENCE STRATEGIC REPORT CARD — OEMs

FCV MARKET PROSPECTS

AUTOMAKER	COMPETITIVE POSITION
GRADE A: KEY DRIVER OF FCV DEVELOPMENT AND MARKET	
Daimler	Long FCV development history now leading to wide-ranging FCV product line
General Motors	Deep FC and EV knowledge, Honda partnership point to bright future in FCVs
Honda	Strong player with vehicles on market, tie-up with GM on development
Hyundai	Building on 20-year FCV track record, aiming for global FCV leadership
Toyota	Global leader with large portfolio and well-developed FCV supply chain
GRADE B: REASONABLY POSITIONED FOR FCV FUTURE, BUT LACKING IMMEDIACY OR MARKET REACH	
BMW	Peripheral FCV strategy as company develops and markets hybrids and BEVs
Great Wall Motors	Rapid development under way, but still behind top players
Nikola Motors	Strong business case and plan in FCV trucking, but limited in scope
Volkswagen Group	Late arrival but catching up quickly with FCV focus on premium Audi brand
GRADE C: SLOW PACE IN FCV DEVELOPMENT AND DEPLOYMENT	
Ford	Reduced R&D for FCVs amid shift to BEVs, but some product in pipeline
Renault-Nissan-Mitsubishi	Attention to BEVs hinders FCVs, but on-board reformer strategy intriguing

II. TECHNOLOGY

Global OEMs have made huge strides in advancing fuel-cell technology and now are putting emphasis on bringing down cost.

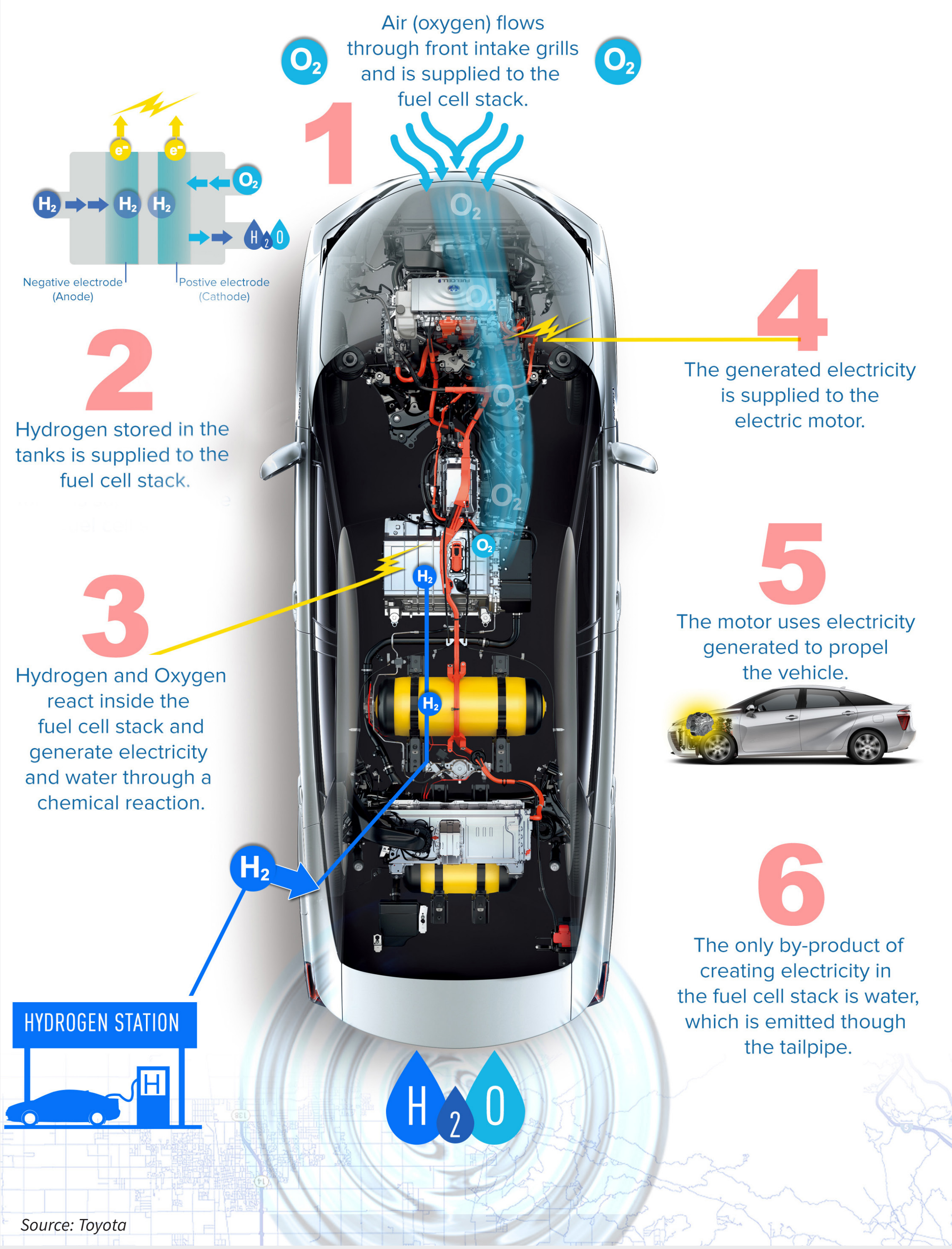
Toyota, Hyundai, Honda and Daimler, the big four, along with fuel-cell suppliers Ballard Power Systems and Plug Power, have overcome most main technical hurdles by putting product on the market.

The focus moving forward will be on improving system performance – getting more power out of the stack at constant or lower cost without sacrificing durability – while steadily increasing production volume.

Keith Wipke, laboratory program manager at the National Renewable Energy Laboratory in Golden, CO, reports the stack, and particularly the membrane electrode assembly and catalyst, continues to be the main obstacle to bringing down cost, thus the main focus of the industry's research activities.

"We need to improve catalyst and membrane performance without sacrificing durability in order advance the technology," Wipke says. "If you can lower the platinum amount or get rid of it completely, you can reduce the cost. But as you go to lower platinum levels, durability and performance can suffer.

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

"All those things need to be done simultaneously: lower cost, better performance, longer durability. There's a balance between the three."

The goal, of course, is to lower the cost of the fuel-cell system to a point it can compete with an internal-combustion engine. Wipke estimates if costs can be cut 30%-40% at high-volume production, then the technology will begin to take hold.

And when might that occur? "It wouldn't be unreasonable for a large automaker to scale from, say, 20,000 units in 2020 to five times that in 2025 based on historical cost reduction and system improvement trends," Wipke says.

"However," he cautions, "fueling infrastructure needs to grow equally rapidly to enlarge existing fuel-cell-vehicle markets and precede FCEV sales in new markets and regions."

Wipke, who managed the technical portion of the Fuel Cell Technologies Office demonstration program from 2004 to 2011, references the U.S. Department of Energy's latest cost and performance targets.

The Fuel Cell Technologies Office, which is responsible for coordinating the R&D activities for the DOE's hydrogen and fuel-cell program, including work done at the National Renewable Energy Laboratory, evaluated the performance of 185 fuel-cell vehicles and 25 hydrogen-fuel stations in its demonstration program.

Program participants included General Motors, Ford, DaimlerChrysler and Hyundai working in conjunction with BP, Chevron Texaco (renamed Chevron) and Shell Oil, a U.S. subsidiary of Royal Dutch Shell.

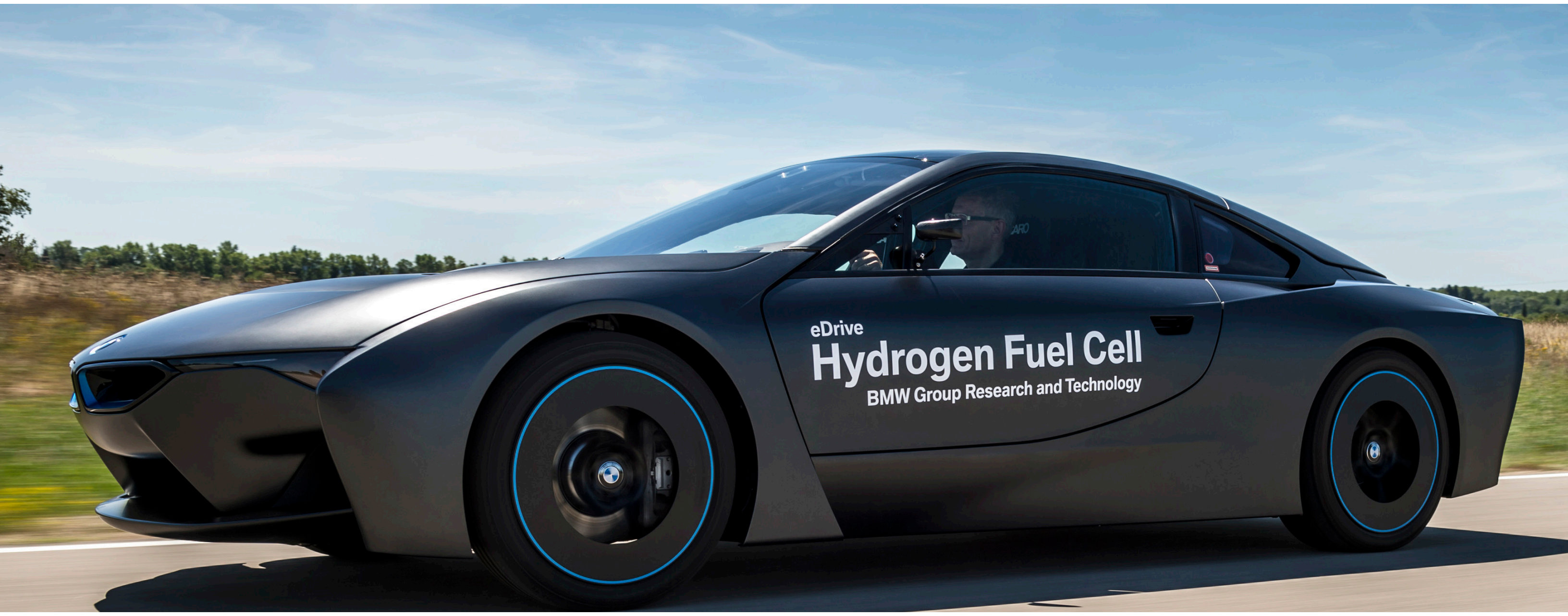
Separately, the DOE noted in its 2017 annual report that durability and driving range have improved significantly over the past 10 years. In addition, steady progress has been made in key metrics such as voltage durability, system gravimetric and volumetric capacity, specific power and power density.

The U.S. DRIVE Partnership, a government-industry collaboration comprising the DOE, major U.S. OEMs, energy companies and utilities, in November 2017 published targets for fuel-cell vehicles and systems.

The 2025 targets assume 500,000-unit combined global annual production. That volume appears optimistic, however, based on Wards/LMC Automotive forecasts showing the global market reaching just over 300,000 FCVs in 2030.

The U.S. DRIVE targets include:

- Fuel-cell systems: peak energy efficiency and specific power of 65% and 900 watts/kg, the latter from around 650 watts/kg at present, and cost of $35/kW, down from $45/kW.
- Stack: Specific power of 2,700 watts/kg and 8,000 cycles, up from 2,000 watts/kg and 4,100 cycles at present, while cost is projected to fall 8% to $17.50/kW.
- Membrane electrode assembly and catalyst: MEA cost of $10/kW and platinum consumption, down from $11.80 and 0.1 gram/kW at present, and durability of 8,000 cycles, double current levels of 4,000.
- Membranes: Maximum operating temperature of 100° C (212° F), already achieved, and cost of $17.50 per square meter, down 10%.
- Bipolar plates: Plate cost and weight of $2/kW and 0.18 kg/kW, down more than 60% and 55% respectively.
- Hydrogen storage (published July 2017): System geometric and volumetric capacity of 1.8 kWh/kg 1.5 kWh/L with storage system cost falling to $9/kWh as automakers shift from specialty-grade to commodity-grade plastics. All fuel tanks, Type IV, will vary from 5,000 psi (35 MPa) to 10,000 psi (70 MPa), depending on the market and application.



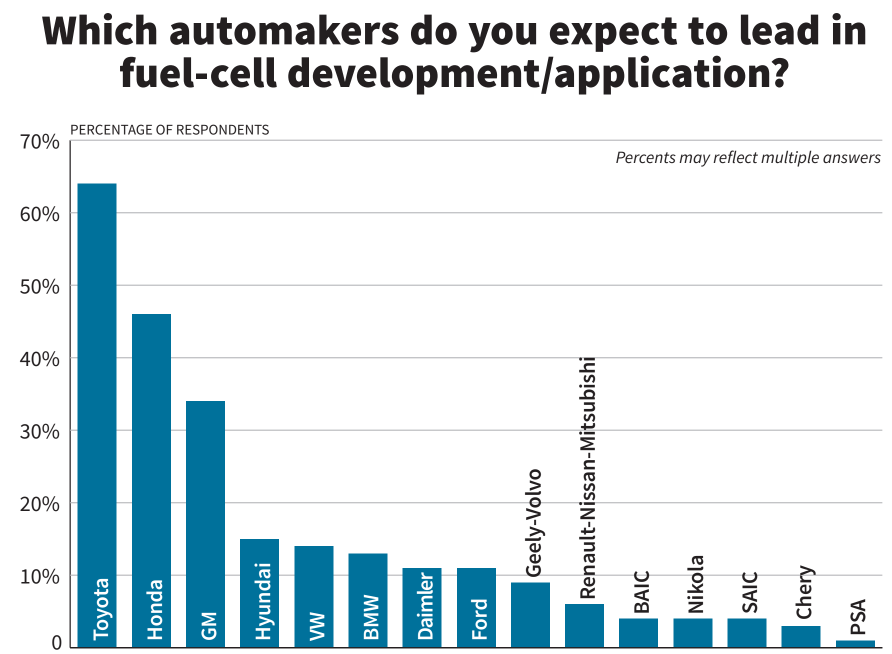
III. MARKET

Fuel-cell vehicles, once viewed as expensive science projects with little real-world application, slowly are gaining momentum in the global marketplace, with some predicting a tipping point toward cost-competitive hydrogen-powered transportation during the coming decade but most assuredly in the 2030s.

Major automakers are developing – and in limited cases, marketing and selling – FCVs while working with supplier partners to increase performance and range, reduce size and cost and improve durability. Partnerships such as the General Motors-Honda and BMW-Toyota pairings, and potentially a Hyundai-Audi tie-up, signal a need to share technology to keep costs down during the nascent development period. Ballard Power Systems capital ties with Chinese partners reflect this same concern.

According to data from Wards Intelligence partner LMC Automotive, light-duty FCV sales in 2018 totaled 6,098 vehicles, just 0.01% of the worldwide market, recorded in sales of the Toyota Mirai, Honda Clarity and Hyundai Tucson/i35 in Japan, South Korea and in the U.S., primarily in Southern California.

Though that volume is minuscule compared with the total global vehicle market, it marks considerable growth in FCV segment since 2015 when

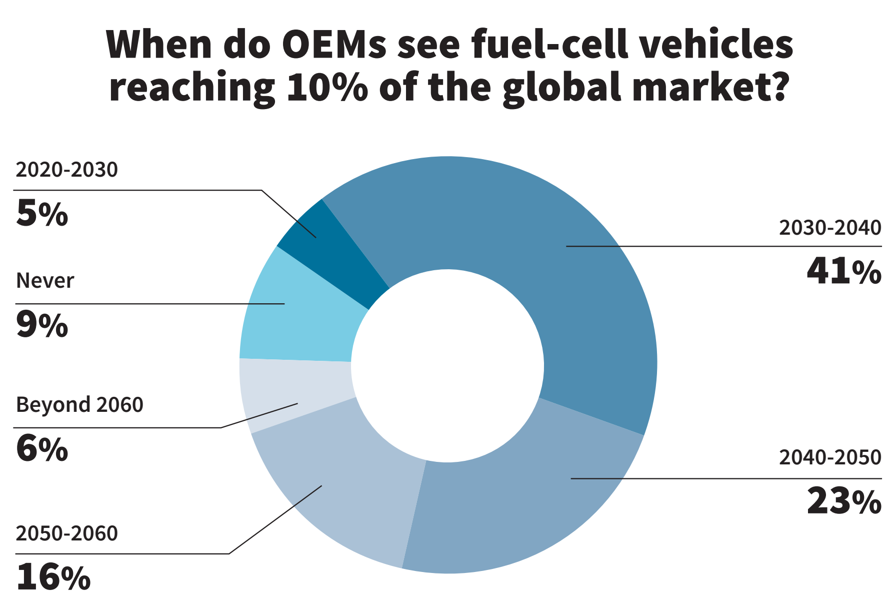


Source: Wards Intelligence 2018 Fuel-Cell Vehicle Survey

only 575 FCVs were delivered worldwide. LMC forecasts FCVs to grow to 0.3% of worldwide vehicles sales by 2030. Although that is a small share of global vehicle sales, it still represents 301,000 units in annual sales and likely indicates the beginnings of a worldwide shift to significantly higher volumes of hydrogen-powered vehicles.

Toyota dominates today's FCV world, selling more than 86% of all FCVs delivered in 2018, but that share will shrink dramatically in the coming decade as Honda and Hyundai grow their FCV sales and other players such as Renault-Nissan-Mitsubishi, Daimler, BMW, GM and Volkswagen Group enter the market, LMC projects. Looking ahead to 2030, more than a quarter of global FCV sales are expected to go to today's smaller players, such as China's Great Wall Motors, as FCV products and markets mature.

By 2030, Europe and North America will lead in volume, marking a significant shift away from today's preponderance of FCV deliveries in the Asia-Pacific region and the U.S. Total sales of FCVs in Europe will surpass 120,000 while North American sales will top 75,000.



Source: Wards Intelligence 2018 Fuel-Cell Vehicle Survey

BEVS LEADING THE CHARGE

Helping pave the way for FCVs is the proliferation of hybrids and battery-electric vehicles, in part due to improvements in motor, battery and controls technology that can be shared with FCVs. The BEV market is expected to grow, both in models and volume, in the coming decade as manufacturers turn to electric propulsion to meet increasingly stringent emissions and fuel-economy regulations.

Manufacturers believe as the EV market matures over the next 10-15 years and as EVs become commonplace, the transition to electrically driven, hydrogen-powered FCVs will be a natural step. BEVs will fill the need for urban use and short-distance driving in smaller vehicles while FCVs will replace internal-combustion power and hybrid powertrains in larger vehicles used for long-distance driving. Fuel cells also are seen as likely for use in local-route delivery vans and commuter buses where battery charging is significantly slower than hydrogen fueling, giving FCVs a utilization-rate advantage.

BEVs are key, but advancements in fuel-cell technology also will be necessary to improve range and output from ever-smaller fuel-cell stacks, respondents say in a survey of Wards Intelligence subscribers. Improvement in on-board hydrogen storage also is seen as a major concern.

Despite those hurdles, the survey shows OEMs and suppliers see a rosy picture for FCVs, with a third of respondents predicting FCVs will claim 10%

of the global market in the 2030s, well in excess of estimates but possibly indicating a tipping point for FCVs will be reached in that time frame.

COMMERCIAL, AUTONOMOUS APPLICATIONS LIKELY

Fuel cells also are likely to find their way into fleet vehicles used in transport in ports, replacing diesel-powered trucks and other material-handling machinery such as forklifts. Fleet use allows many vehicles to use one central hydrogen fueling station, minimizing the infrastructure cost.

Autonomous vehicles also present a golden opportunity for fuel-cell application, allowing for maximum operating time for those vehicles. It eliminates having BEVs sitting idle while recharging and would require a relatively small number of hydrogen stations to support a fleet.

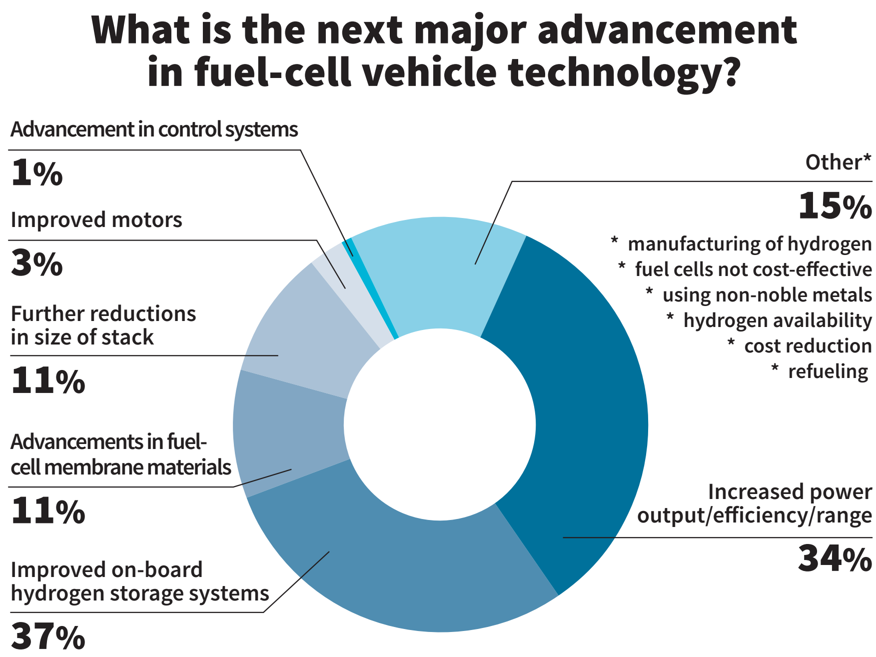
"Last-mile" and EV range-extender fuel-cell applications also show promise. In Europe, Paris-based Symbio FCell supplies fuel-cell kits to La Poste, the French postal service, for a small portion of its Renault Kangoo ZE fleet. StreetScooter, based in Aachen, Germany, reportedly has been contracted to supply 100 Work L fuel-cell vans to Deutsche Post DHL Group.

Finally, the growth of fuel-cell-powered buses in China and South Korea suggests widespread fleet application of the technology, potentially in Japan and Europe, is closer than forecasts might indicate. Hyundai's Nexo FCV, for instance, is fitted with hydrogen tanks and valves scaled for use in the light vehicle, but also easily could be adapted for large, commercial-vehicle applications. Similarly, stacks in Toyota's Mirai and Daimler's B-Class F-Cell FCVs (the latter the generation before the new GLC F-Cell) are scaled for the Toyota Sora and Mercedes-Benz Citaro Fuel Cell buses, respectively. The Mirai's stack also is a fit for fuel-cell forklifts produced by Toyota Industries, one of the world's leading manufacturers of forklifts.

COSTS COMING DOWN, CAPABILITY CLIMBING

Million-dollar science-project costs from decades ago have now given way to FCVs dipping below $100,000, but the expense of fuel-cell stacks, high-pressure tanks and related control systems remains an impediment.

Cutting the cost of FCVs is cited by 35% of those responding to a survey question asking what is needed to trigger a move to widespread FCV



Source: Wards Intelligence 2018 Fuel-Cell Vehicle Survey

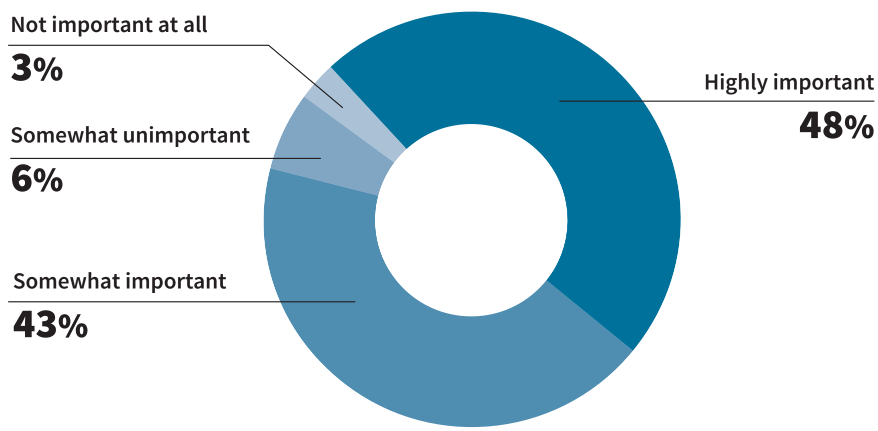
adoption, followed closely by the need for a hydrogen fueling infrastructure. Manufacturers predict the cost of fuel-cell stacks will continue to decrease as stacks become smaller and more efficient, reducing the need for expensive rare-earth metals for stack membranes. Reductions in BEV costs for batteries and motors also aid the FCV balance sheet.

Japan-based market research firm Fuji Keizai Group estimates FCV system costs in 2017 at ¥2.4 million ($21,175) including ¥1.5 million ($13,230) for the stack and ¥900,000 ($7,937) to ¥950,000 ($8,378) for the hydrogen tank. The firm projects those costs to drop by 2025 to ¥300,000 ($2,645) for the stack and ¥650,000 ($5,730) for the tank.

Fuji Keizai expects FC system cost to fall on a kWh basis from an estimated ¥25,000 ($220) in 2017 to ¥10,000 ($88) in 2025.

Toyota, at the 2018 International Hydrogen and Fuel Cell Expo, reported that with increased production volumes in 2020 it expects to lower fuel-cell system costs 50% from 2015 levels. Concurrently, the automaker hopes to reduce stack size 30%, thus requirements for expensive materials that go into the stack by 30%. It also expects to lower costs through improved mass-production processes and the conversion to commodity-grade composites for the hydrogen fuel tanks. GM and Honda predict a similar size and cost reductions in their next-generation system.

How important is the relative price of hydrogen in the proliferation of fuel-cell vehicles?



Source: Wards Intelligence 2018 Fuel-Cell Vehicle Survey

HYDROGEN HOLDS KEY

Regardless of vehicle availability, everyone in the FCV business agrees fuel cells won't be viable without a well-developed hydrogen refueling infrastructure, the cost of which is generated by both the production of hydrogen and the capability to readily deliver it to consumers.

Chris Richter, a research executive at CLSA, declares, "The cost of the fuel cells, the cost of building a hydrogen network and the fact that hydrogen isn't green all raise serious questions. You get hydrogen mostly from reforming natural gas, thus it's an odd decision to spend money for a technology that doesn't really solve the (carbon-dioxide) problem."

At present, he notes, more than 90% of hydrogen is produced from steam reformation of methane, mainly natural gas, and gasification of coal. Coal still accounts for nearly 70% of electric power generation in China and slightly more than 70% in India, meaning that hybrids can be cleaner in parts of both markets.

"If you want to make hydrogen truly green (through solar energy or electrolysis of water), then it is going to add cost to an already-expensive system," Richter says. "It can be done. It's just harder. Thus while there's a place for fuel cells, I just do not think that place is in small passenger cars. Commercial vehicles including trucks and buses, yes."

Steve Ellis, manager of fuel-cell-vehicle marketing, American Honda, counters: “Every new fuel is the problem. But you don’t not act just because the fuel is a problem. Foundationally, philosophically and operationally, hydrogen fuel-cell vehicles mimic what we do today with gasoline vehicles – three-to-five minutes refueling time and long-range operation. Up to this point, we have not met that same metric with ‘plug-in’ electric vehicles.

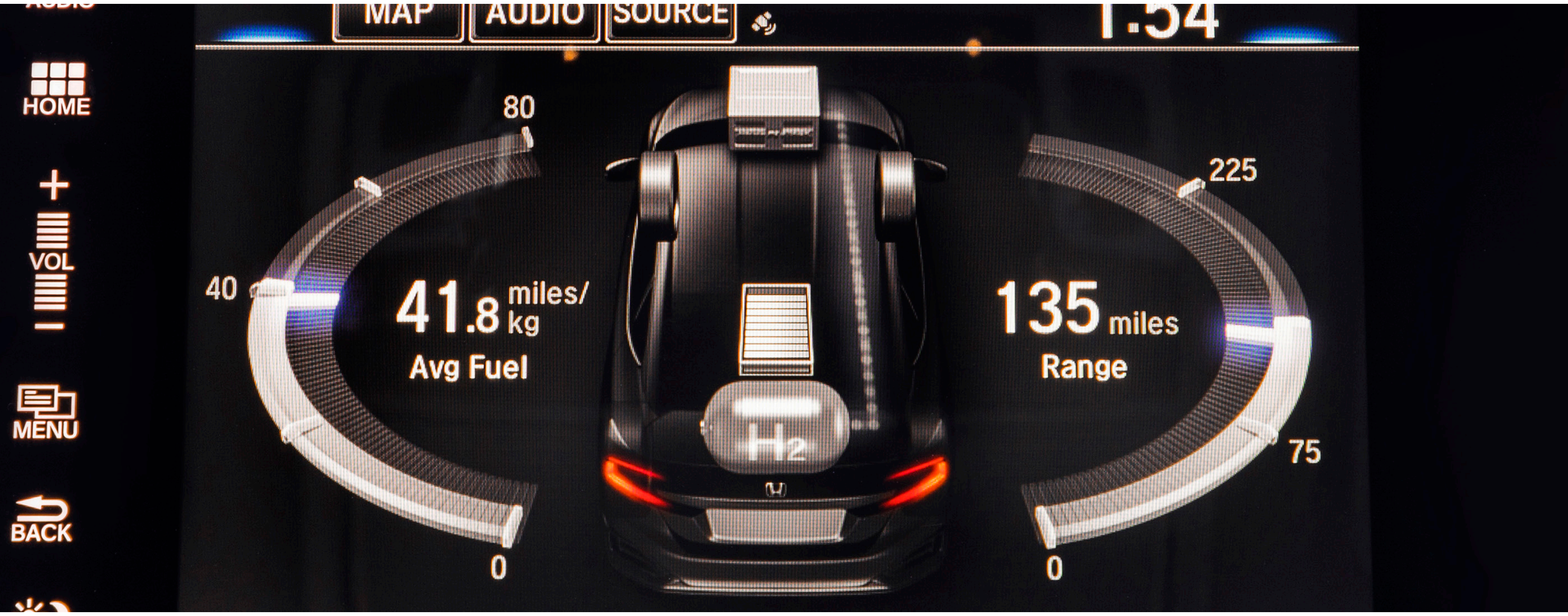
“Hydrogen-fuel-cell technology is scalable across the entire platform of (an automaker’s) vehicles, if society is asking for SUVs, minivans and medium and heavy-duty trucks. That is the value of hydrogen fuel cells,” Ellis says. “The only way to get there, however, is to keep developing the technology, keep advancing it, and then build this infrastructure called hydrogen stations.”

Klaus Bonhoff, managing director of NOW (Germany’s National Organisation for Hydrogen and Fuel Cell Technology), notes: “Talking about hydrogen, we have a very clear focus on making sure that this hydrogen is being produced by renewable fuels. Really, the electrolyzer becomes a key component for the transition of the overall energy system as a whole, providing grid services on one side; on the other side, having a flexible renewable fuel as hydrogen directly or also as a feedstock for further processes to produce synthetic fuel. I think the electrolyzer is a key technology.”

Once hydrogen production is solved, a fueling infrastructure is the next hurdle, and creating one to serve needs such as interstate trucking makes the most sense, Richter says.

“You can imagine having hydrogen fuel stations every couple hundred miles along a highway, so the investment in the fueling network becomes much more manageable,” he says.

Ellis says larger-capacity stations hold the key to creating an economically viable fueling system.



IV. AUTOMAKERS

Global automakers are planting the seeds now for a fuel-cell future that lies just over the horizon, with production vehicles arriving in small numbers in 2030 as the market begins to gain momentum. While some automakers appear to have little or no FCV strategies, others are already producing and delivering functional FCVs in select markets and have long-range plans that include fully integrated supply chains prepared to build thousands of FCVs to meet potential market demand.

This Wards Intelligence review grades automakers on an A-B-C scale based on their current and future FCV strategies, with the top ranking awarded to those OEMs taking steps to develop and market FCVs, typically drawing on past work and/or collaborating with other OEMs and suppliers with strength in FCVs.

Automakers receiving middle grades are taking steps to develop FCVs, but may lack immediate plans or wide market reach. Those on the lower tier include OEMs that previously delved deeply into the technology but subsequently have reduced that emphasis and/or have no evident plans to embrace the technology in the near future. OEMs not listed in this review have little or no history of fuel-cell development and/or no evident plans to embrace the technology.

BMW 5-Series GT Fuel Cell Electric Vehicle developed jointly with Toyota.

BMW

Unlike other global OEMs, BMW initially placed emphasis on using liquid hydrogen as an alternative to gasoline and diesel for its internal-combustion-engine cars.

After experimenting with a series of concepts dating back to the 1980s, the German automaker in 2000 released the hydrogen-powered 750hL luxury sedan and followed up with the limited-production Hydrogen 7 sedan, of which about 100 units were leased between 2005 and 2007. Along the way, a BMW Mini also was converted to run on liquid hydrogen.

Not much became of these efforts other than to demonstrate that liquid hydrogen technology works – that a car like the 750hL could be fitted with a supercooled 37-gallon (140-L) cryogenic fuel tank enabling a 219-mile (352-km) driving range.

Then in 2012, BMW reversed course when it entered into a technical partnership with Toyota to jointly develop electric powertrains and fuel-cell systems and work on lightweighting solutions. The automaker gave an early indication of a possible shift in direction with a fuel-cell test vehicle based on the i8 model unveiled in 2015.

Jointly with Toyota in 2015, it developed a BMW 5-Series GT Fuel Cell Electric Vehicle prototype. Toyota developed the stack and fuel-cell auxiliary system while BMW engineered the fuel-cell housing, hydrogen tank, electric-drive system and hybrid battery. An unspecified number have since been put into trial operation to evaluate performance and durability and to find ways to bring down costs with the aim of having a fuel-cell car road-ready by 2021.

Two years ago, Matthias Klietz, vice president-powertrain research at BMW, told attendees at a technical conference in Tokyo: “Our customers tell us they will only pay an extra 10% for zero-emission technology. On the other hand, they tell us that they want to have similar driving range, interior space and comfort as well as similar refueling time to today’s level with gasoline or diesel powerplants.”

How does the 5-Series GT Hydrogen stand up to that standard so far? It can accelerate to 62 mph (100 km/h) in 8.4 seconds. It can run at speeds of 113 mph (180 km/h). It has a range of 438 miles (700 km), more than 50% higher than the gasoline-powered 5-Series GT. It takes less than five minutes refuel.

BMW has designed the car so that the 180-kW fuel-cell system can be placed in the engine compartment. The car’s 7.1-kg hydrogen fuel tank is mounted in the transmission/driveshaft tunnel in the floor. Hydrogen is stored at 5,000 psi (35 MPa). The power electronics and electric motor, which produce 180 kW, are located behind the rear seats.

Longer term, Kleitz believes fuel cells will find a niche in BMW’s 7-Series and larger models, with plug-in hybrids across the automaker’s 1-Series to 5-Series models and full battery-electrics in the automaker’s more urban-focused Mini lineup. By 2025, BMW expects to have 25 electrified vehicles in its lineup, excluding fuel-cell models, with the share of full-electrics and plug-in hybrids representing 15%-25% of sales, building on the 100,000 electrified vehicles it delivered in 2017.

WARDS INTELLIGENCE REPORT CARD: B

BMW’s tangent into fuel-cell vehicles is peripheral, for now at least, to its push to develop high-performance electrified hybrids and BEVs. Though the automaker has shown an enduring interest in hydrogen as an automotive fuel source, most of that work has centered on burning hydrogen in an internal-combustion engine rather than using it to create electricity in a fuel cell. All that said, BMW’s tie-up with Toyota and the development of the 5-Series GT Hydrogen points to bright potential, with the company expecting to deliver more than 11,000 FCVs annually by 2030.

Cost target for Mercedes-Benz GLC F-Cell is $50,000.

DAIMLER

With the launch of its new GLC F-Cell in late 2018, Daimler moved another step closer to introducing a fuel-cell vehicle into the mass market. The upscale plug-in hybrid SUV, which is sold under the Mercedes-Benz brand, runs off both hydrogen-fuel-cell and battery-electric power depending on trip length – for shorter trips its lithium-ion battery, for longer trips its fuel cell. Daimler opted for a dual powertrain system to address the lack of hydrogen infrastructure.

In developing the GLC F-Cell, Daimler redesigned the stack adopted for the B-Class F-Cell, increasing power output more than 40% and reducing system size by 30%. As a result, the automaker succeeded in fitting the stack in the front compartment of the car where the standard GLC holds its diesel or gasoline engine.

The B-Class F-Cell was released in 2010 as part of a test-marketing program in the U.S. and Germany in which the automaker leased 200 units, each powered by a 100-kW stack and having a range of 250 miles (400 km). The GLC's stack generates 147 kW of power.

In electric mode, the GLC's 13.5-kWh lithium-ion battery allows it to run up to 31 miles (51 km). The model's fuel cell draws hydrogen from two 10,000-psi (70 MPa) tanks built into its floor. The tanks hold a combined 4.4 kg of hydrogen, good for nearly 300 miles (480 km). The GLC F-Cell, like its predecessor, can reach 100 mph (161 km/h).

Christian Mohrdieck, fuel cell director for the Daimler group, reports the automaker chose the GLC because it is one of its best-selling models and because the segment, fullsize SUVs, is well-suited for fuel-cell powertrains.

The standard GLC weighs 4,000 lbs. (1,818 kg) and thus is too heavy for full battery electrification given the still-high costs of lithium-ion batteries. The F-Cell weighs in at 4,250 lbs. (2,055 kg).

Daimler’s cost target for the GLC F-Cell is about $50,000, the current cost of the plug-in hybrid GLC 350e 4MATIC. The automaker hopes to reach that level in 2022, when it substantially increases production to an estimated 20,000 to 60,000 units per year. The current GLC F-Cell, built in Bremen, Germany, leases for €799 ($913) per month.

In developing the vehicle, Daimler collaborated with EDAG Engineering and NuCellSys for drive-system integration and fuel-cell and hydrogen storage development, respectively. NuCellSys is a wholly owned Daimler subsidiary.

The automaker assembles the fuel-cell system at its main powertrain plant in Unterturkheim near downtown Stuttgart. It sources stacks from Mercedes-Benz Fuel Cell, a division of Mercedes-Benz Canada, from a plant in Burnaby, British Columbia, inside Ballard Power Systems.

It is separate from the former Automotive Fuel Cell Cooperation, a joint venture set up in 2008 by Daimler, Ballard and Ford to develop stacks, fuel-cell systems and electric drivetrains. Nissan and Renault joined the venture in 2013, but the collaboration dissolved in July 2018.

Daimler, which has been working on fuel-cell technology since the 1980s, unveiled NECAR 1 in 1994, a converted MB-180 van fitted with a 50-kW Ballard stack. The vehicle had a range of 81 miles (130 km). In 1997, it began collaborating with Ballard and Ford with the aim of developing, manufacturing and selling fuel-cell systems for future automotive applications.

Daimler introduced the battery-electric Mercedes Citaro city bus in July 2018 with the option of adding a range-extender fuel cell. Two B-Class F-Cell fuel cells are placed on the Citaro’s roof, providing additional range of more than 156 miles (250 km). The new bus holds 35 kg of hydrogen in fuel tanks on the roof. Previously, Daimler test-marketed about 60 fuel-cell buses over two generations in Germany.

Also in July, the automaker unveiled the Concept Sprinter F-Cell, a modified camper van developed for the purpose of demonstrating that its latest F-Cell technology could be used for other applications.

Meanwhile, the automaker is a shareholder in H2 Mobility, a hydrogen-fueling infrastructure company, along with Shell, Air Liquide, Linde, OMB and Total and associated partners including BMW, Toyota, Honda, Hyundai, Volkswagen and Great Wall Motors. It also is a core member of the Brussels-based Hydrogen Council.

WARDS INTELLIGENCE REPORT CARD: A

From small cars to intercity buses, Daimler is steeped in the real-world deployment of fuel-cell vehicles. With a long history of working with key players in the industry, the German automaker has leveraged its know-how and vehicle-development capability to create functional, practical fuel-cell-based hybrid-electric vehicles that can operate in the real world, whether as personal or commercial vehicles. Its strong relationships with suppliers and its role in helping encourage a hydrogen-fueling infrastructure also play in its favor. Wards Intelligence forecasting partner LMC sees Daimler holding a nearly 5.0% annual share of the 300,000-unit global FCV market by 2030.

Ford's last foray into fuel cell vehicles, the Flexible Series Edge concept.

FORD

Despite its early involvement in fuel-cell technology, Ford will not be among the leaders in introducing fuel-cell vehicles, as it has shifted focus to BEVs and PHEVs.

Ford worked with partners Daimler and Ballard Power Systems on fuel-cell technology, beginning in the mid-1990s with Daimler and then jointly with Daimler and Ballard to develop fuel-cell stacks, fuel-cell systems and electric drivetrains. The trio in 2008 formed the Automotive Fuel Cell Cooperation to develop fuel-cell stacks. Nissan and Renault joined the venture in 2013, but the collaboration dissolved in July 2018.

Against this backdrop, the automaker developed and introduced 30 Ford Focus FCVs in 2001 that were put into trial operation in the U.S., Canada and Germany. The Focus FCV boasted a range of 150-200 miles (240-320 km) at speeds up to 80 mph (128 km/h). Each was fitted with a Ballard stack, producing peak power of 67 kW.

In 2007, Ford unveiled the Flexible Series Edge concept, a fuel-cell hybrid vehicle fitted with an electric motor and battery that was recharged by a small Ballard-supplied fuel-cell stack when its state of charge fell below 40%. Fitted with a 4.5-kg hydrogen tank, the car reportedly achieved a range of 225 miles (360 km). That same year, Ford and Ballard built the Fusion Hydrogen 999, a special test car that set a land-speed record of 207 mph (333 km/h) at the Bonneville Salt Flats in Utah.

Even though Ford has made an $11 billion commitment to introducing 40 electrified vehicles by 2022, including 16 full electrics, the automaker is eyeing only small steps in FCVs as it monitors the market and development of a hydrogen infrastructure.

WARDS INTELLIGENCE REPORT CARD: C

Ford is steeped in fuel-cell development, but so far is showing only small steps toward commercialization of FCVs. The Dearborn, MI, automaker has some Ford-branded FCVs on its drawing board and is projected to ramp up production to more than 11,000 vehicles annually in the coming decade, but for the moment, EVs and PHEVs are its main focus.

The U.S. Army is evaluating military applications for vehicles like the Chevrolet Colorado ZH2.

GENERAL MOTORS

General Motors began developing fuel-cell technology in 1964 and two years later introduced the Electrovan, the world's first fuel-cell vehicle. In the years that followed, GM spent a reported $2.5 billion on the technology while introducing more than 10 prototypes and test models including a fuel-cell-powered Equinox CUV deployed in a major fleet test beginning in 2008. Over a 5-year test period, 119 units were driven more than 3 million miles (5 million km) in New York, California and Washington, D.C.

Main specifications were validated: reliable operation of a 115-kW fuel cell, range of nearly 200 miles (320 km) using a 4.5-kg fuel tank storing hydrogen gas at 10,000-psi (70 MPa) pressure levels, a 50,000-mile (80,000-km) stack life, operation at subfreezing temperatures close to 0° F (-5° C), and a 12-second 0-62-mph (100-km/h) time.

Despite being a pioneer in the field and having committed $85 million to jointly producing fuel-cell stacks and system components with Honda at GM's Brownstown Township, MI, battery plant, the company has not tipped its hand on plans for introducing fuel-cell vehicles into the mass market. Near term, GM is prioritizing battery-electric technology with plans to launch 20 new all-electric models by 2023, nearly half in China.

The Michigan fuel-cell plant will produce a common stack for both automakers based on GM's Gen 2 unit, capable of generating 95 kW while weighing only 230 lbs. (105 kg) and reducing costly platinum use to less than half an ounce (12 g).

Charles Freese, GM's head of global fuel-cell research, says the timetable for starting stack production and bringing a vehicle to market is "after 2020," with applications ranging from cars and commercial vehicles to forklifts and locomotives. LMC global forecasts show GM's first FCVs arriving in small batches in 2020, with a significant increase in volume coming in 2026.

"The Brownstown plant is being set up to build fuel-cell systems, which we can apply to any application and any market we choose," Freese says.

GM is prioritizing battery-electric technology in the near term with plans to launch 20 new all-electric models by 2023, nearly half in China.

Honda reports its Clarity Fuel Cell, currently powered by a Honda stack, is scheduled to complete its production run in 2021. The automaker gave no timetable for the model's next generation, but presumably it will come shortly after, using the jointly developed system.

By being a joint-venture plant, the Brownstown operation also is being set up to generate economies of scale and more efficient use of R&D resources.

"We will be able to share costs," says Freese. "Even an inexpensive component is expensive in low volume."

Other potential applications include off-road and undersea vehicles for the U.S. military, specifically the Chevrolet Colorado ZH2 pickup and the UUV (Unmanned Undersea Vehicle). The UUV being is being tested by the U.S. Navy, while the U.S. Army is evaluating the Colorado ZH2. The Colorado ZH2 reportedly has achieved a range of 400 miles (640 km) in super-quiet operation.

Also in the pipeline: A flexible fuel-cell platform for heavy-duty truck and freight applications called SURUS, for Silent Utility Rover Universal Superstructure. The concept is being considered for both commercial and military customers.

GM holds more than 1,200 patents in fuel-cell technology and now conducts fuel-cell development at its Global Propulsion Center in Pontiac, MI.

WARDS INTELLIGENCE REPORT CARD: A

General Motors is tackling the prospects of a fuel-cell future head-on, drawing on decades of R&D work and a deep bench when it comes to related electrification advancements. Add in the company's partnership with another industry leader, Honda, in the development of fuel-cell stacks and ancillary systems and it is clear the Detroit automaker is preparing to play a role in FCVs across a wide range of applications for many years to come.

Great Wall's C30 EV could be platform for fuel-cell vehicle.

GREAT WALL MOTORS

Great Wall Motors could become China's first automaker to mass-produce a fuel-cell vehicle and, if management sticks to its timetable, the automaker could become one of the global leaders in the segment in the coming decade.

Based in Baoding nearly 100 miles (160 km) southwest of Beijing, Great Wall Motors is China's largest producer of SUVs and pickup trucks, providing a natural segue into fuel cells from its current lineup of gasoline and diesel internal-combustion engines.

The automaker is launching five full-electric cars, three based on its ME or "Mini Electric" platform, along with several plug-in hybrids to help it meet China's 2019 and 2020 New Energy Vehicle mandates. Separately, Great Wall Motors entered into a joint venture in July 2018 with BMW Holding to produce full-electric cars in Jiangsu province.

In fuel cells, the main driver is vehicle weight. The majority of vehicles sold under the Great Wall, Haval and Wey brands weigh upwards of 3,300 lbs. (1,500 kg), thus are not good candidates for full electrification but make sense for fuel-cell power.

The company plans to exhibit a prototype model in spring 2020, then introduce a road-ready vehicle by 2022 to coincide with hosting the Winter Olympics in Beijing. Management believes it can produce at 10,000-unit annual levels by 2025, when it will have two models on the market, raising volumes to 100,000 units before 2030.

"It depends on how quickly and efficiently we can set up production," says Great Wall Motors executive Tobias Brunner.

To advance its fuel-cell program, Great Wall Motors is working with an unnamed foreign technology partner to develop fuel-cell stacks and systems. The automaker is expected to reveal its partner's name in 2020.

Great Wall Motors' Hydrogen Technology R&D Center also will play a pivotal role. Opening in 2018, the center includes extended prototyping capability to enable the automaker to test components and systems including stacks and membrane electrode assemblies. It also has constructed a liquid hydrogen refueling station to test various pressure levels of between 5,000 psi (35 MPa), the Chinese standard for fuel-cell buses, and 10,000 psi (70 MPa).

The automaker's targets:

- For the fuel-cell stack, the company seeks power density of more than 5 kW/L, membrane thickness less than 10 microns, platinum content of 0.3 gram/kW and long-term durability with only 5% degradation after 5,000 hours.
- Great Wall wants power output of 75 kW-150 kW from the overall fuel-cell system, power density greater than 1 kW/kg, more than 7,000-hour durability and an operating temperature of 167°-203° F (75°-95° C.). The automaker plans to switch to a high-speed turbo-compressor from a roots blower compressor.
- The automaker plans to develop three hydrogen tanks with plastic liners, 5,000 psi, 7,250 psi (50 MPa) and 10,000 psi, with respective capacities of 5 kg, 6.5 kg and 7.5 kg.

In a related development, Great Wall has purchased Shanghai Fuel Cell Vehicle Powertrain to provide fuel-cell systems to third parties including truck, bus and forklift manufacturers. The automaker also has taken steps to acquire an equity stake in H2 Mobility Deutschland, a hydrogen fueling operator in Germany.

While the automaker has no plans to produce fuel-cell trucks and buses, currently the main markets in China for fuel-cell powertrain technology, it will supply the segment with fuel-cell powertrains through Shanghai Fuel Cell.

In 2018, an estimated 1,000 fuel-cell trucks were being placed into operation, following an estimated 500 in Shanghai in 2017. An estimated 300 fuel-cell buses also have been deployed to date. The Chinese government hopes to have 5,000 fuel-cell vehicles in operation in 2020 and 50,000 in 2025.

WARDS INTELLIGENCE REPORT CARD: B

Great Wall Motors may be late to the fuel-cell game, but the Chinese automaker is rapidly evening the score. While predictions for any venture in China require a somewhat jaundiced eye given the impact changes in government policy can have on the automotive industry, for now it appears the Asian powerhouse is putting considerable emphasis on electrified and fuel-cell-powered vehicles. If a road-ready vehicle appears in 2022, watch for Great Wall to ramp up significant production of FCVs over the following decade, although the company’s suggestion that it will deliver 100,000 FCVs by 2030 seems like a stretch at this point.

Honda integrates its fuel cell and traction motor under the hood of the Clarity Fuel Cell.

HONDA

Honda began research on fuel-cell vehicles in 1986, and 13 years later in the runup to the 1999 Tokyo Motor Show, the automaker unveiled the FCX-V1 and FCX-V2 prototypes, its first fuel-cell-powered cars. The FCX-V1 ran on hydrogen supplied from a metal hydride storage tank in the car's trunk, while the FCX-V2 had an onboard reformer using methanol as fuel. Ballard Power Systems supplied the stack for the FCX-V1, Honda for the FCX-V2.

Nearly two decades later, in 2016, the automaker launched the Clarity Fuel Cell into the Japanese and U.S. markets. By the end of 2018, Honda will have leased about 1,000 Clarity Fuel Cells globally, in part due to availability being limited to urban areas in Japan and mostly California in the U.S.

Honda currently makes stacks on a small production line at the Haga facility of Honda Engineering in Tochigi, Japan. It assembles the Clarity Fuel Cell, along with the Clarity Electric and Clarity Plug-In Hybrid, the other two models in the Clarity advanced powertrain series, at its Saiyama plant north of Tokyo.

The automaker switched to a Honda-designed stack with the launch of the 2004 FCX and has steadily improved fuel-cell system performance since then. The company test-marketed 35 FCXs in Japan and the U.S. The FCX Clarity, the predecessor to the current model, followed in 2008 with the lease of 72 units, 75% in the U.S.

In the Clarity Fuel Cell, Honda succeeded in downsizing the fuel-cell system to allow it to fit in the engine compartment of the upscale sedan. The previous model featured a center tunnel stack.

The Clarity Fuel Cell's stack produces 103 kW of power. Stack density is more than 3.1 kW/L. Operators can refuel the car's 6-kg, 10,000-psi (70 MPa) fuel tank in three minutes. The car can operate at cold temperatures of -22° F (-30° C). Range has been extended to 469 miles (750 km).

Honda succeeded in putting the fuel cell in the front engine compartment by integrating the stack with a redesigned, low-height traction motor. Other components integrated into the system include the voltage control unit, or VCU, which adopted a silicon-carbide power module, both hydrogen and air supply systems, the electric turbo-compressor and reengineered power control unit joining the drive motor and gear box. Through these modifications, the car's fuel-cell powertrain almost exactly replicates the dimensions of Honda's 3.5L V-6 engine.

Honda reports that the Clarity Fuel Cell is scheduled to complete its production run in 2021 at which time, jointly with GM, the automaker will coproduce next-generation fuel-cell systems, including stacks, at a new $85 million plant in Brownstown Township, MI, where GM currently makes battery packs for the Chevrolet Volt and Bolt.

Takashi Moriya, senior chief engineer at Honda R&D, says, "Commercialization requires that we pass beyond a crossover point where lifetime operating costs for an FCEV are less than a vehicle powered by an internal combustion engine or a hybrid." Moriya expects sales to expand and price to become affordable around 2025.

To reach its cost targets, Honda is working to make greater use of common components, shorten production time and reduce the amount of platinum and other precious metals in the fuel-cell stack.

When Honda introduced the FCX and became the first OEM to receive zero-emission vehicle certification from the U.S. EPA and California Air Resources Board, the automaker set a 2020 price target of around ¥4 million ($35,750), the "price of an upper-grade Accord," according to the then-head of its fuel-cell development program. It won't reach that by 2020.

WARDS INTELLIGENCE REPORT CARD: A

Honda has a stylish and capable performer on the road today in the Clarity

Fuel Cell sedan, built on decades of steady investment in the development and improvement of its fuel-cell technology. Today, the company's powerful fuel-cell stack and electric drive motor is compact enough to fit in the engine bay of any of its existing V-6-powered vehicles, opening the door to instant additions to the Clarity lineup as market demand and hydrogen availability increase. Honda's partnership with General Motors is expected to produce an even better and lower-cost system by 2022. LMC predicts Honda will hold more than 11% of the global FCV market by 2030, third behind Hyundai and Toyota in the battle for fuel-cell supremacy.

Hyundai's latest fuel-cell vehicle, Nexo, builds on the Tucson FCEV's 350-mile range.

HYUNDAI

In 2018, 20 years after Hyundai developed its first fuel-cell concept car, the South Korean automaker launched the Nexo, a fuel-cell-powered CUV with a 500-mile (800-km) range.

In the years between, the automaker developed a series of prototypes from the Santa Fe FCV in 2000 to the first-generation Tucson in 2007 and Kia Sportage and Borrego models in 2007 and 2008. Hyundai participated in the U.S. Department of Energy demonstration programs between 2004 and 2009 with a test fleet of 32 Santa Fe SUVs.

The first-generation Tucson, which boasted a range of 200 miles (320 km), would be superseded six years later by the ix35/Tucson FCEV with a 350-mile (560-km) range. Hyundai introduced the ix35/Tucson FCEV in February 2013 and has since placed about 1,000 units into operation, mostly through leases in 20 countries including South Korea and the U.S. Included in the number: more than 50 taxis in Paris.

For smaller and shorter-range vehicles, Hyundai believes battery power is a better alternative than fuel cells. "But if you want heavier duty," says an executive, "battery-electrics are limited because of longer charging time, battery weight and battery cost."

Hyundai launched the Nexo in South Korea in March 2018 with a first-year sales target of 200-300 units. In 2019, it hopes to sell about 3,000 units following the launch of the vehicle in Europe and the U.S.

The Nexo was launched at select dealerships in Germany and Norway in August and in the California market in November.

To meet that volume, Hyundai Mobis has built a large fuel-cell powertrain plant in Chungju, North Chungcheong, where it produces membrane electrode and stack assemblies, fuel-cell systems, propulsion motors and chassis and wiring assemblies, joining them into powertrain modules. The supplier invested $630 million in the facility.

Evaluating the launch, Sae Hoon Kim, vice president of Hyundai's fuel-cell group, said that "The main problem is producing them faster" and bringing down cost.

The Hyundai-designed stack's power output is 95 kW. Total power output (stack plus lithium-polymer battery) is 135 kW. Stack capacity is 3.1 kW/L. The stack can start at temperatures as low as -22° F (-30° C) in 30 seconds or less. Weight has been cut 10% compared to the ix35 system, while output has improved 15%. Fuel-cell efficiency is rated at 60%.

Overall fuel tank capacity is 41.4 gallons (157L). Three 10,000-psi (70 MPa) tanks, each able to hold 13.8 gallons (52L) of hydrogen, are placed on the Nexo's flat floor.

The vehicle's range is 625 miles (756 km) on the New European Driving Cycle. Under real-world or WLTP driving conditions: 416 miles (666 km). The car can accelerate to 62 mph (100 km/h) in 10 seconds.

Hyundai guarantees stack life of 100,000 miles (160,000 km) or 10 years. Hyundai and Kia plan to introduce 38 eco-friendly vehicles by 2025 including hybrids, full battery-electrics and fuel-cell models. In addition to the Nexo, the automakers reportedly will introduce a second fuel-cell vehicle with a 250-mile (400-km) range in 2020. Speculation is that vehicle will be based on a Kia Sorento CUV.

Hyundai in 2018 announced a collaboration with Volkswagen premium brand Audi to explore opportunities in joint production of components and cross-licensing of technology with the primary aim of reducing costs. Audi is working with Ballard Power Systems to develop a fuel-cell system for a future car.

Meanwhile, Hyundai announced at the 2018 IAA Commercial Vehicles exhibition in Hanover that it would launch a fuel-cell truck in 2019. In a separate announcement, the automaker revealed plans to deliver 1,000 hydrogen-powered trucks to H2 Energy of Switzerland between 2019 and 2021.

Hyundai also is looking at the bus market. In 2012, it deployed a pair of fuel-cell buses (each with 200-kW stacks) at Incheon International airport, followed by public demonstrations in the cities of Ulsan and Gwangju. Unconfirmed plans have the company beginning FC bus production in 2020.

Like Toyota and Honda in Japan and Daimler in Germany, the automaker is supported by a government that is friendly to hydrogen and which has aggressive plans to build a nationwide network of fueling stations: 100 by 2020, 250 by 2025 and 520 by 2030. Critics feel the Korean government's targets are too ambitious.

For the most part, the automaker has relied on homegrown technology. Early on, it worked with UTC Power, now owned by ClearEdge Power.

WARDS INTELLIGENCE REPORT CARD: A

Hyundai has a track record of fuel-cell development and commercialization and shows no sign of relinquishing what is becoming a global leadership position on fuel-cell vehicles. Aided by government support of a hydrogen infrastructure in South Korea, the automaker is pushing ahead in numerous directions – cars, CUVs, commercial vehicles and buses – to expand its fleet of FCVs. Look for Hyundai's partnership with Audi to help cut costs as the automaker ramps up toward a projected 50,000-vehicle scale by 2030.

Nikola's long-haul fuel-cell trucks aim to supplant Class 8 diesels.

NIKOLA MOTOR

Although it is targeting a niche market, Nikola Motor's decision to focus on Class 8 trucks serving dedicated routes is intuitively the right way to proceed as it solves two major problems: fueling infrastructure and cost.

Founded in 2014, the Salt Lake City, UT-based startup plans to open a $1 billion fuel-cell truck plant in a suburb of Phoenix, AZ, in 2021. Plans call for producing 50,000 semi-truck cabs annually by late 2027 when the plant reaches capacity.

Prior to the opening of the plant, Nikola will consign production of the first 5,000 units to an assembler in Tennessee.

Nikola founder and CEO Trevor Milton reports its fuel-cell trucks can operate 20% less expensively than Class 8 diesel trucks on a cost-per-mile basis. Milton does not break out costs other than to say that Nikola's truck – two prototypes are in trial operation – is only "slightly" more expensive than a Class 8 diesel.

The business model, Milton says, is that Nikola will lease fleets of trucks for 10 years or 1 million miles (1.6 million km) to be deployed on dedicated long-haul routes. To support the vehicles, Nikola plans a network of hydrogen fueling stations on those routes at 1,000-mile (1,600-km) intervals. Those stations will produce hydrogen onsite via electrolysis. Nikola has factored the hydrogen costs into the lease.

Among Nikola's early customers is Anheuser-Busch, which in May announced plans to lease as many as 800 Nikola trucks and convert its entire long-haul fleet from diesel to hydrogen by 2025. Through October 2018, Nikola has received more than $11 billion in pre-order sales, including an order from U.S. Xpress Enterprises.

In June 2018, Nikola signed a $1 billion contract with Norway-based NEL ASA for 448 electrolyzers and associated fueling equipment to be deployed beginning in 2020. NEL is a global supplier of hydrogen production equipment and technology. Under the current plan, a station would be equipped with as many as eight electrolyzers, each producing 1 ton of hydrogen per day. Each ton of hydrogen converts into 2.2 MW of power.

The first two stations, both for demonstration purposes, will be located at the Nikola truck plant site in Arizona and a still-to-be-named location in California. They will be followed by 28 stations on routes for Anheuser-Busch.

Separately, Nikola has named PowerCell as its stack supplier and Robert Bosch to design the powertrain system. The stack is designed to produce 300 kW of continuous power.

Milton reports that one-fourth of Class 8 trucks in operation in the U.S. – about 1 million vehicles – run on dedicated routes. Annual replacement demand is about 100,000 units, and that's the market Nikola plans to target.

WARDS INTELLIGENCE REPORT CARD: B

Nikola has chosen a key niche in the fuel-cell market – Class 8 trucks – and is laser-focused on developing a fuel-cell system, vehicle and hydrogen infrastructure to support its goal of replacing diesel-burning long-haul trucks with zero-emission fuel-cell Class 8 semis. The company not only is demonstrating the possibilities but also has contracts for trucks and orders in for electrolyzers to support its carefully calculated plan to build an interstate highway refueling system.

Nissan last exhibited a fuel-cell vehicle, the TeRRA concept, in 2012.

RENAULT-NISSAN-MITSUBISHI

Nissan began researching fuel cells in the early 1990s and put a small number of fuel-cell vehicles into trial operation in 1999, placing it among the early leaders. The automaker continues to develop the technology, but not as a priority, and unlike most other global OEMs, Nissan's focus is on onboard reforming of ethanol.

In 2016, the automaker announced it was developing a solid-oxide fuel-cell-powered system in which the fuel cell acts as a power generator, converting ethanol or an ethanol-water blend to either charge the vehicle's 24-kWh EV battery or provide power to its electric drive. The "e-Bio Fuel Cell" is installed in and operates as a range extender in an e-NV200 electric passenger van.

Nissan says ethanol is reformed into hydrogen on board and is then converted into electricity in the fuel-cell stack, no different from a conventional fuel cell. Small amounts of carbon dioxide are generated during the ethanol-reforming process, but Nissan considers the system to be carbon-neutral insofar as ethanol is derived from plants which in turn convert CO_2 into oxygen.

Nissan believes the technology has excellent potential in countries such as Brazil and Thailand, both of which have made a commitment to developing biofuels. The automaker set no timeframe for commercializing the technology, although it expressed a desire for an early 2020s public demonstration.

Nissan claims operating costs of the e-Bio model are similar to a full-electric car at about $0.40/mile vs. $0.43/mile.

Nissan's 1999 demonstration model, which was based on a R'nessa SUV, used a Ballard fuel cell and like the new e-Bio model, the R'nessa FCEV was equipped with an onboard reformer fueled by methanol.

In 2000, Nissan joined the California Fuel Cell Partnership and began public road testing with an Xterra FCEV followed by similar road tests in Japan. Cruising range was 219 miles (350 km).

In 2003, the automaker developed a prototype X-Trail FCV incorporating a fuel-cell stack from UTC Power. In 2005, it fitted the vehicle with a Nissan stack and, when employing a 10,000-psi (70 MPa) fuel tank (doubling the previous model's 35-MPa unit), increased cruising range to more than 312 miles (500 km).

Nissan and alliance partner Renault developed a fuel-cell-powered Scenic ZEV H2 in 2008. Renault used Nissan's 90-kW stack, the same unit in the X-Trail. In 2012, Nissan exhibited the TeRRA fuel-cell concept at the Paris Motor Show.

In 2013, Nissan and Renault agreed to collaborate with Daimler and Ford to develop a common fuel-cell system for deployment as early as 2017. But with the global push toward full electrics, the agreement was dissolved in July 2018. Of the four OEMs, only Daimler is aggressively pursuing fuel-cell development.

WARDS INTELLIGENCE REPORT CARD: C

For a global automaker with a deep base of knowledge in fuel-cell vehicles and what appeared to be a game plan to act on that R&D, the global Renault-Nissan-Mitsubishi consortium is stepping away from FCVs at a time when others are stepping up. While pursuing a BEV-focused strategy might make short-term sense, in the long run the company's minuscule presence in what could be the propulsion system for years to come seems shortsighted. On the other hand, Nissan's biofuel FCV with an onboard hydrogen reformer designed to take advantage of fuel stocks in specific regions might be one of the industry's smartest moves.

Toyota's Mirai is the most successful fuel-cell vehicle on the market.

TOYOTA

Toyota is far and away the market leader in the fuel-cell vehicle field, having leased and sold an estimated 8,500 Mirai FCVs since launching the car in late 2014. Less than a year after launching the Mirai, Toyota revealed plans to sell 30,000 fuel-cell vehicles in 2020, including some 12,000 in Japan. Separately, the automaker committed to delivering more than 100 fuel-cell buses in the runup to the 2020 Tokyo Olympics.

To that end, in May 2018 the automaker announced plans to construct an eight-story production facility at its Honsha plant in Aichi Prefecture to make fuel-cell stacks. The company also is building a dedicated line to make high-pressure hydrogen tanks inside its Shimoyama components plant in nearby Miyoshi. Both facilities are scheduled to come onstream in 2020.

The automaker plans to increase monthly capacity to 2,500 stacks and 5,000 tanks, from current levels estimated at 250 and 500. Annually, it will have capacity to produce 30,000 stacks and 60,000 tanks.

Toyota began its fuel-cell development activities in 1992 and exhibited its first fuel-cell vehicle, the FCEV, in 1996. Over the next 17 years it would test-market a total of eight models, mostly SUVs, and lease an estimated 100 units.

In addition to the Mirai, the Honsha plant supplies an unspecified number of stacks and hydrogen tanks to Hino Motors, Toyota's truck and bus-making subsidiary, for the Sora fuel-cell bus as well as to Toyota Industries for fuel-cell-powered forklifts under development.

For the Sora, which went on sale in March 2018, the plant supplies 10 hydrogen tanks and two stacks per bus. The Sora has a cruising range of 125 miles (200 km), which compares to 312 miles (500 km) for the Mirai.

Against this backdrop, Toyota reported at the International Hydrogen and Fuel Cell Expo in March 2018 that with increased production volumes in 2020 it expected to lower fuel-cell system costs 50% from 2015 levels. Concurrently, the automaker hopes to reduce stack size 30% along with a similar reduction in expensive materials that go into the stack. It also expects to lower costs through improved mass-production processes and the conversion to commodity-grade composites for the hydrogen fuel tanks.

In December 2017, Toyota sharpened the focus of its fuel-cell-vehicle development program, saying it would place greater emphasis on buses, trucks and other commercial vehicles. The automaker's official position is that hydrogen has great potential "for larger vehicles and longer-distance mobility. Energy efficiency per unit weight is substantially greater for hydrogen than for batteries."

The automaker is collaborating with Kenworth Truck as part of an $82 million project to develop Class 8 fuel-cell-powered trucks to handle cargo inside the ports of Los Angeles and Long Beach and in the Los Angeles basin. Meanwhile, in Japan it has entered into an agreement with 7-Eleven to begin pilot testing of fuel-cell trucks in 2019.

The Toyota-Kenworth announcement follows Toyota's unveiling of a second-generation fuel-cell-powered Class 8 truck in July 2018. The new model boasts a 300-mile (480-km) range, nearly 50% more than its predecessor that the automaker says logged 10,000 test miles (16,000 km).

Toyota engineers increased the range of the new model – dubbed "Beta" as the successor to the previous model "Alpha" – by reconfiguring wire harnesses and electronics. Horsepower and torque of the 80,000-lb. (36,364-kg) truck remained unchanged.

The automaker's objective: to bring the concept closer to commercial viability. And the business rationale: to replace more than 16,000 pollution-emitting, mostly diesel, trucks operating inside the ports of Long Beach and Los Angeles and more than 43,000 nationwide. That number is projected to double by 2030.

Among Toyota's strengths is its highly regarded supplier group including the Aisin Group, Denso, JTEKT, Primearth EV Energy, Toyota Boshoku and Toyota Industries.

Excluding the Mirai's stack and fuel tank, both produced in-house by Toyota, the automaker's suppliers deliver such key fuel-cell systems as the Mirai's air-valve module (Aisin); cooling systemtemperature sensor, hydrogen fueling control unit and intelligent power module (Denso); high-pressure gas valves (JTEKT); nickel-metal hydride battery pack (Primearth); separators and stack manifolds (Toyota Boshoku) and air compressor and hydrogen circulation pump (Toyota Industries).

Separately, Toyota Industries, the world's leading manufacturer of forklifts, has introduced a fuel-cell-powered unit that is being tested at several key locations in Japan, including the Kansai Airport in Osaka. Through March 2018, Toyota Industries had delivered 80 fuel-cell forklifts. Toyota Industries assembles the stack, a smaller version of the Mirai stack.

WARDS INTELLIGENCE REPORT CARD: A

Toyota leads all OEMs in development and delivery of FCVs across a wide range of applications – cars, buses, trucks – while developing a manufacturing base that mixes Toyota expertise with key suppliers to create a cost-effective system for building FCVs. Look for the Japanese automaker to hold a leadership position in the FCV market until late in the next decade when it is surpassed by Hyundai. Even then, the automaker will command about 15% of the global market for FCVs, a share that could grow depending on the expansion of a hydrogen fueling infrastructure. The company is perfectly positioned to pivot its fuel-cell efforts into whatever direction the market dictates.

Audi plans to produce a car based on the A7 Sportback h-tron quattro concept.

VOLKSWAGEN

The Volkswagen Group entered into a fuel-cell development program with Ballard Power Systems in 2013 to advance the automaker's "HyMotion" (for Hydrogen Motion) technology.

In 2016, Audi assumed the lead role in the effort, which is now scheduled to continue until summer 2022. At that time, Audi hopes to begin limited production of a car likely based on the h-tron quattro SUV concept. The h-tron quattro, Audi's fifth-generation hydrogen car, was revealed at the 2016 North American International Auto Show in Detroit.

Ballard is developing the fuel-cell module and assisting Audi with integrating the module into the car. Prototype cars adopting Ballard's fuel-cell stack and system technology in the Volkswagen Group include the Audi h-tron quattro and A7 Sportback h-tron quattro and the VW Golf SportWagen HyMotion and Passat HyMotion.

Jurgen Jablonski, director of fuel-cell development at Audi, told a technical conference in Tokyo in 2018 that the h-tron quattro is fitted with three CFRP/GFRP fuel tanks able to store a combined 13.2 lbs. (6 kg) of hydrogen at 10,000-psi (70 MPa) pressure levels.

Jablonski says the h-tron quattro technology will be applied to everything in the group's lineup from small cars to long-haul trucks and for brands from Audi and Porsche to VW and Scania. Jablonski notes that fuel cells offer advantages for larger and heavier vehicles.

In June 2018, Audi and Hyundai announced a plan to cross-license patents and grant access to noncompetitive components. In September, VW announced its involvement in joint research with Stanford University to develop a new platinum coating process that has potential to substantially reduce the cost of catalysts while improving performance.

Audi represents the Volkswagen group in the Brussels-based Hydrogen Council.

WARDS INTELLIGENCE REPORT CARD: B

Although relatively late to the party, the Volkswagen Group is making substantial progress catching up with the leaders, with the prospect of building to a nearly 8.0% share of the global FCV market by 2030, according to LMC projections. Focusing its efforts on the luxury Audi brand makes sense in terms of vehicle cost in the early going, while participation in joint research projects and pairing with FCV powerhouse Hyundai should produce rapid results.

V. SUPPLIERS

It is still too soon to draw a clear roadmap of the future fuel-cell system supply chain, but the early signs indicate most components – including compressors, pumps, humidifiers, heat exchangers and valves but excluding the stack – eventually will be sourced from the traditional supply base.

The key will be for production to reach volumes that justify suppliers making an investment in facilities. Based on our current demand forecast, that will not happen until 2025 at the earliest, the main exception being Toyota, whose *keiretsu* supplier group has a history of co-developing new technologies with the automaker.

In Asia, we expect Denso, Aisin Seiki and Toyota Boshoku to collaborate with Toyota, Keihin with Honda, and Hyundai Mobis, Hyundai KEFICO and Hyundai Wia with Hyundai-Kia.

In North America and Europe, BorgWarner and Magna, BASF, Mahle, Bosch and Valeo likely will be players. Freudenberg Sealing Technologies and Garrett Motion (formerly Honeywell Transportation Systems) already are actively involved in fuel-cell development, as well.

Two independent stack manufacturers, Ballard Power Systems and Plug Power, and Freudenberg Sealing Technologies, the leading supplier of seals to the industry, all have made moves to expand their presence in the market. Freudenberg also is committed to producing stacks.

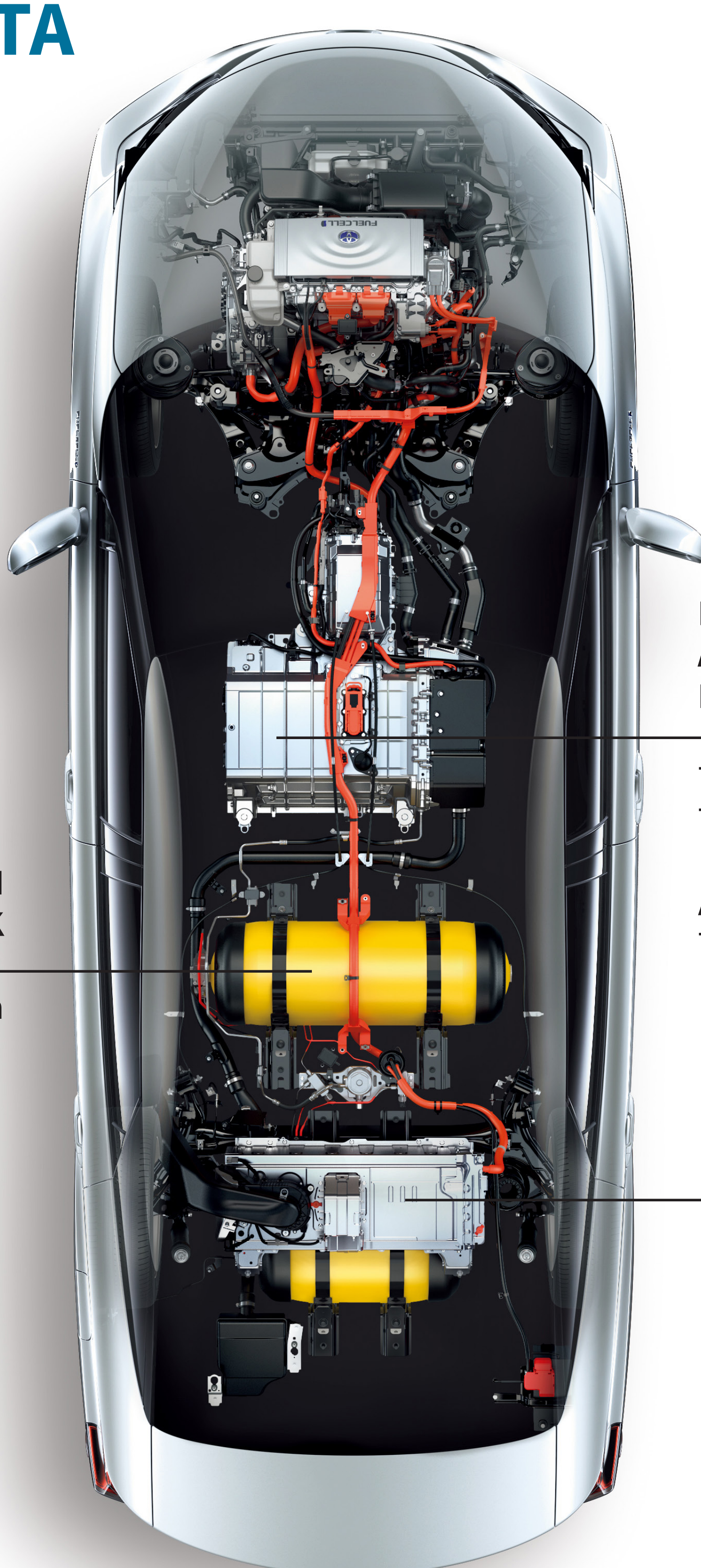
Toyota is the furthest along with plans to produce as many as 30,000 fuel-cell vehicles in 2020. The company will manufacture stacks at a new plant inside its Honsha production site in Aichi prefecture. It will produce high-pressure hydrogen tanks on a new dedicated line inside its Shimoyama components plant in nearby Miyoshi.

Hyundai has consigned production of fuel-cell systems to an affiliated supplier, Hyundai Mobis, at a new $620 million plant in Chungju, North Chungcheong Province.

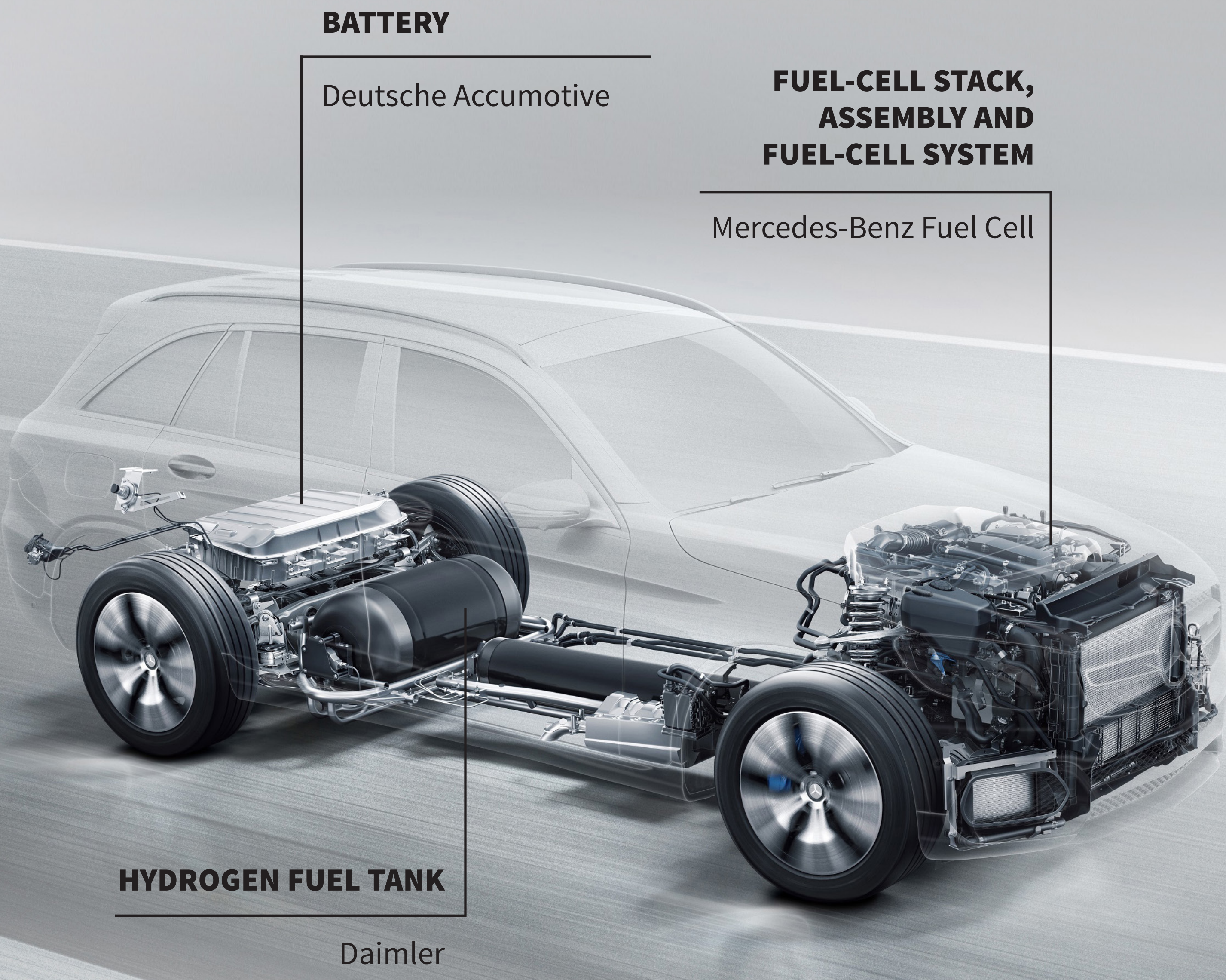
Honda subsidiary Honda Engineering produces stacks for the Japanese automaker. To bring down component costs, Honda and General Motors will produce fuel-cell stack and system components jointly at a new $85 million plant in Brownstown Township, MI, starting early next decade.

In Germany, Daimler assembles the GLC F-Cell's fuel cell module at its Unterturkheim plant. It outsources the stack to its Canadian subsidiary, Mercedes-Benz Fuel Cell.

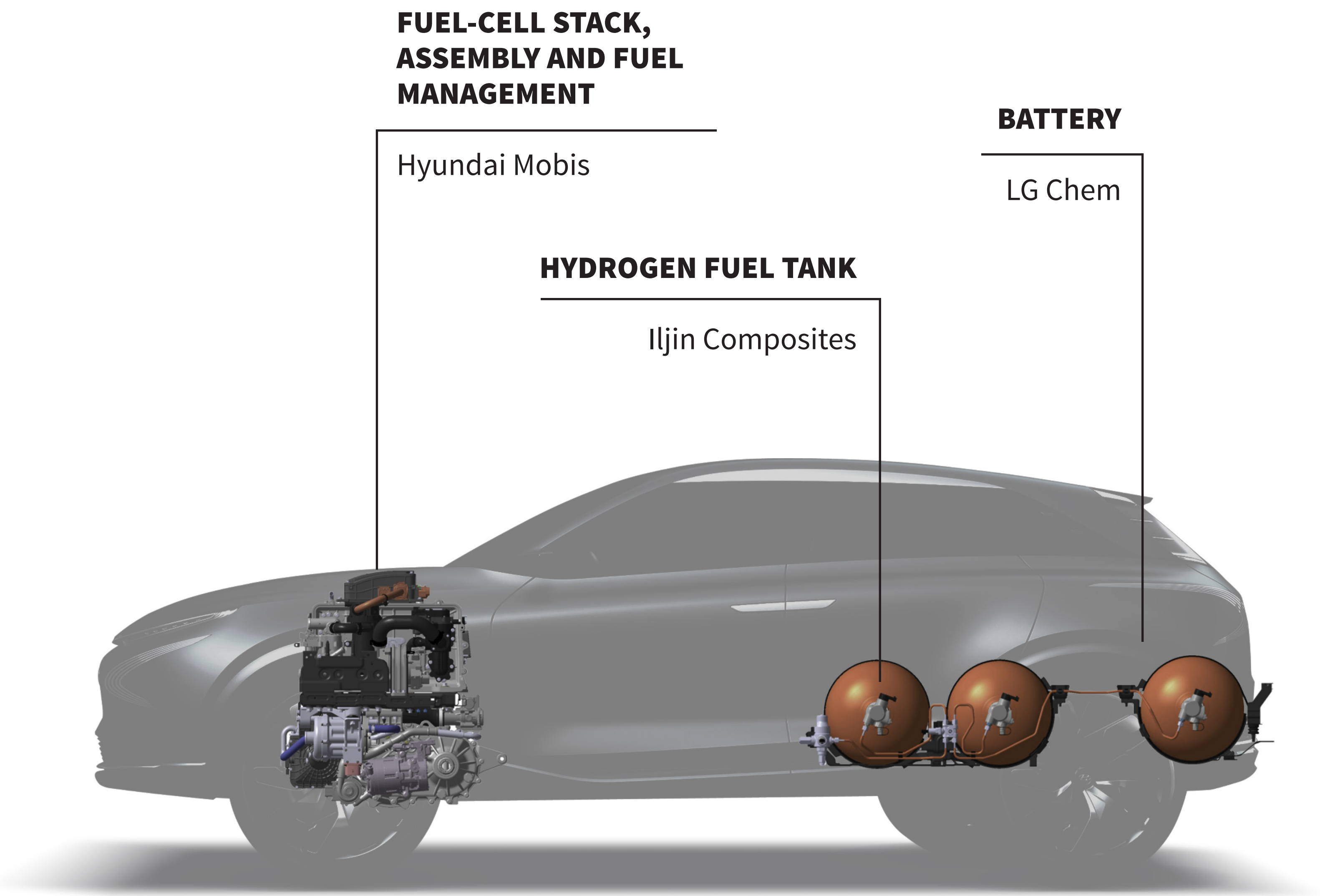
TOYOTA MIRAI



MERCEDES-BENZ GLC F-CELL



HYUNDAI NEXO



HONDA CLARITY FUEL CELL

FUEL-CELL STACK, ASSEMBLY AND FUEL MANAGEMENT

Honda Engineering
Garrett Motion
Keihin

HYDROGEN FUEL TANK

Teijin

BATTERY

Blue Energy

BALLARD POWER SYSTEMS

Ballard Power Systems began fuel-cell development in 1989, and in over two decades-plus it has supplied fuel-cell systems to global automakers such as Honda, Ford, Volkswagen and Daimler. It is now working with Audi, representing the Volkswagen Group, and several unnamed OEMs.

Ballard is supplying fuel-cell modules to Chinese truck and bus makers from its Burnaby plant in British Columbia, Canada. In 2017, Ballard manufactured nearly 1,000 modules at its Canadian facility, most of which were shipped to customers in China.

In August 2018, Ballard and Chinese diesel-engine producer Weichai Power announced a strategic collaboration whereby Weichai is investing $163 million to acquire a 19.9% ownership stake in Ballard.

Weichai and Ballard will establish a joint venture to manufacture Ballard's next-generation liquid-cooled fuel-cell stack and power module for buses, trucks and forklifts at a still-to-be-named location in China. Weichai will pay Ballard $90 million for the technology and plans to manufacture at least 2,000 fuel-cell modules by 2021.

Zhongshan Broad-Ocean Motor also holds a 9.9% stake in Ballard. Broad-Ocean assembles fuel-cell modules under license using Ballard's current generation technology at a plant in Shanghai.

"China has been a big engine of growth in recent years," says Guy McAree, Ballard director of investor relations, adding, "The market for buses in China is larger than anywhere in the world."

Annually, China produces an estimated 180,000 buses.

More generally, McAree reports Ballard has seen significant growth in applications in the heavy-duty segment, including not only buses but trucks, trains and trams and even marine transport. It also has seen growth in material-handling applications such as forklifts.

Ballard and Audi signed a three-and-a-half-year extension of the automaker's "HyMotion" fuel-cell powertrain program in June 2018. The program will run until August 2022, when Audi plans limited production of its fuel-cell h-tron quattro.

Outside of the auto industry, it is working with ABB Group in Sweden on a megawatt-level system for passenger ships and is collaborating with Siemens in Germany in the train market. It also is supplying 40 bus modules to the Dutch firm Van Hool as part of the Joint Initiative for

Hydrogen Vehicles in the Netherlands.

In the U.S., Ballard is working with Kenworth Truck and UPS to supply Class 8 trucks and Class 6 delivery vans in California.

In 2017, Ballard revealed plans to more than double inhouse production capacity of membrane-electrode assemblies, the core component of each fuel cell, to 2.1 million in 2021, from 900,000. The company's July 2018 acquisition of unspecified assets from Automotive Fuel Cell Corp. (AFCC), a joint venture between Daimler and Ford that dissolved in 2018, significantly increased Ballard's membrane-electrode assembly production capacity.

Meanwhile, Ballard has an ongoing "technology solutions" program with Nisshinbo Automotive Manufacturing to integrate Nisshinbo's non-precious metal catalyst technology into Ballard's liquid-cooled and air-cooled stacks. The aim of this program is to eliminate the need for platinum, thus lowering stack costs.

Ballard reports its seventh-generation power module represents a 35% cost reduction from its sixth-generation unit. McAree says its liquid-cooled module will be less expensive, 40% smaller and 30% lighter, while using 50% fewer components. The new module is expected to double the operating life of its predecessor.

Ballard estimates with cost reductions – module, coach, electric-drive system and hydrogen fuel – fuel-cell buses will come down to levels of battery-electric and CNG buses from a total cost of ownership perspective.

FREUDENBERG SEALING TECHNOLOGIES

Freudenberg Sealing Technologies, the industry's largest supplier of sealing products, put a down payment on its future with two big investments in 2018. In January, the supplier acquired Elcore, a Munich-based fuel-cell manufacturer, and in February, it bought a more than 30% stake in XALT Energy, a U.S. lithium-battery maker based in Midland, MI.

Freudenberg calculates a substantial portion of its traditional automotive business, estimated at $1.7 billion annually, will "collapse" with the rise of BEVs and FCVs.

"It doesn't matter whether the tipping point is 2035 or 2040 or even 2045," says Freudenberg CEO Claus Moehlenkamp. "We have to do something to mitigate the worst case of a drop of around $1 billion in sales."

Freudenberg and its Japanese partner NOK began fuel-cell research in the mid-1990s and claim to supply sealing-related products to all major fuel-cell vehicles on the market. Meanwhile, Freudenberg has supplied more than 800 cell seals and manifold gaskets on each of 13 fuel-cell buses operating in Oakland, CA.

With the acquisition of Elcore, the supplier plans to make every stack component in-house, including the catalytic membrane and gas diffusion layers. The supplier has set a late-2019 target to have a scalable fuel-cell stack ready for the market, with meaningful returns coming in 2023 or 2024.

For both its lithium battery and fuel-cell technologies, Freudenberg believes heavy-duty trucks and buses have excellent potential.

PLUG POWER

A U.S. company – not Japanese, South Korean, German or even Chinese – is the leader in fuel-cell applications for logistics and materials-handling. Plug Power, since going public in 2002, has placed more than 23,000 fuel cells into operation, the majority in the materials-handling industry for forklifts. It is now setting its sights on the auto industry.

Through a U.S. Department of Energy grant, the Latham, NY-based supplier is field testing 20 fuel-cell “hybrid” electric delivery vans with FedEx, the U.S. parcel-delivery carrier. Plug Power’s “ProGen” fuel cell is being used to extend the range of a battery-electric van.

Plug Power’s 20-kW fuel-cell module, which is placed in the engine compartment of a converted Workhorse EGEN van, extends the range of the vehicle’s 80-kWh lithium-ion battery from 60 miles (96 km) to more than 160 miles (272 km). Hydrogen is stored in six high-pressure tanks located in the rear of the vehicle with a total capacity of 25.5 lbs. (11.6 kg).

Plug Power hopes to complete phase one of the project in early 2019, at which time it expects FedEx to approve deploying another 19 vehicles. The supplier says the hybrid fuel-cell/BEV could reduce FedEx’s diesel-fuel consumption by 2,600 gallons (9,842 L) per vehicle per year.

Separately, FedEx and Plug Power are testing 1,300 fuel-cell hybrid airport baggage tractors at Memphis International Airport.

Within the next three years, the supplier hopes to broaden its portfolio to include taxis, trucks and longer-range buses. The company is targeting vehicles that can return to a home depot to be refueled.

In its main business, fuel-cell forklifts, Plug Power claims more than 90% of the global market, with sales of 5,000 zero-emission range-extender units in 2018. The fuel cell charges the battery when it falls below a specific level during vehicle operation. Customers include Amazon, Wal-Mart, Colruyt, Ikea, Golden State Foods (one of the biggest suppliers to McDonald’s), Kroger, Procter & Gamble, STIHL, USA and Sysco.

Plug Power believes global demand could grow to $30 billion annually by 2030. It estimates 6 million forklifts could eventually be converted. The supplier has capacity to produce 20,000 fuel cells annually and is projecting sales of between $175 million and $190 million in 2018.

PHOTO COPYRIGHT © GETTY IMAGES

VI. Q&A

Air Liquide's

PIERRE-ETIENNE FRANC

Pierre-Etienne Franc is co-secretary of the Hydrogen Council and vice president of Air Liquide. Hydrogen Council members believe 10 million fuel-cell vehicles will be on the road worldwide by 2030, with annual sales reaching about 1 million units by then.

Wards Intelligence: Looking at the Hydrogen Council's roadmap, it seems infrastructure and hydrogen production are the two biggest obstacles to introducing more hydrogen-powered cars.

Franc: That's a part of the issue, but it is progressively being solved with dedicated infrastructure schemes being put in place, like in Germany, Japan and California. We also need more cars on the road.

Wards Intelligence: With respect to the cars, it seems automakers already have solved most of the technical problems.

Franc: There are two areas that automakers need to make focused efforts to help the popularization of fuel-cell vehicles. The first is cost, the second durability and reliability. The cost of fuel-cell vehicles needs to come down to the level that will allow even more customers the option of choosing one. Currently, because it is all-new technology, the costs are still prohibitive.

As for durability and reliability of the fuel-cell system, both can still be improved. By doing these things, the marketability of fuel-cell vehicles will be enhanced.

Wards Intelligence: Do you feel the Council's 2030-2035 targets are realistic?

Franc: We have put together estimates which are ambitious but which we believe can be achieved if we get the right regulations and government support. We say that one out of 10 cars produced in the future will be powered by hydrogen fuel cells. We asked members of the Council about what typically would be the case in Japan, Germany, California in the U.S., and a couple of other countries and, in the end, concluded the parc could grow to between 10 million and 15 million units.

Let me be clear. This is not a commitment. It is not a goal. It is a trajectory that we think is reachable. But we will need infrastructure.

Wards Intelligence: Will this trajectory depend on the active participation of governments, energy companies and every one of the stakeholders?

Franc: If we consider the climate-change goals and if the governments take the necessary decisions in terms of regulations and support schemes, yes, the industry is capable of delivering that.

Wards Intelligence: How do you deal with a situation such as the U.S. no longer being a part of the Paris Agreement climate accord?

Franc: We don't know what's going to happen with the politics. But we do know that California, along with other states, continues to push for stringent emissions regulations. And California, by the way, is where we have most of the fuel-cell cars today. We also know the rest of the world is accelerating its fuel-cell vehicle activities significantly.

But today, the key numbers are: We've got 10,000 fuel-cell cars on the road globally. Half of them are in California. We've got 500 fuel-cell delivery trucks on the road in China in less than two years, which is more than has ever been built in Europe, and more than 500 fuel-cell buses in China, which is more than has ever been built in the rest of the world.

The key car companies, by moving into BEVs (battery-electric vehicles), have developed the manufacturing skills to produce electric powertrains. They are gearing up to mass-produce both fuel-cell and battery-electric vehicles.

On the infrastructure side, the industry, through a hydrogen infrastructure consortium in Japan, already has set up more than 100 hydrogen fueling stations and is moving toward 160 by 2020. The government of Japan has suggested that 160 stations should be sufficient to fuel approximately 40,000 fuel-cell vehicles. So it is partly just a question of the cars being available and affordable.

In Germany, it is much the same. We have a consortium (that) has already built 52 stations and will increase that number to 100 by the end of 2019 and 400 by the end of 2023.

California has 30 stations up and running. It is not enough compared to the number of cars. The government there has a big plan to support infrastructure development and the market has shown an appetite for the technology.

If we want to fuel 10 million cars, the number we have in mind, we basically need 10,000 stations, which is a lot. But (it) is not so much in 12 years considering we already have 300 in operation globally and that a country like Germany has 15,000 petrol (gasoline) stations. So, 10,000 stations worldwide in the next 12 years isn't huge.

Wards Intelligence: If the Council meets its 2030 targets, how many FCVs would be sold annually?

Franc: If we put 10 million on the road by 2030, that would probably mean annual sales of close to 1 million involving at least 10 OEMs, including Toyota, Honda, Hyundai, Daimler, BMW, Volkswagen and Audi, Weichei and Great Wall Motors from China, and GM. Peugeot has announced it will start producing a small series of commercial vehicles post-2020.

It is a question of ambition. Look at the way battery-electric market has grown in the last five years. Today, we are close to 1 million sales per year. Five years ago, the market was probably 100,000. When the market starts, it will go fast. And it will start in the 2020s decade.

We are getting most of the parts of the value chain ready. What we need now is for the governments to be clear and to give us the tools to make it happen.

Wards Intelligence: Coal electric-power generation is still very high in

China and India, the world's largest and fifth-largest auto markets. Is this going to be a deterrent to converting to hydrogen? Is hydrogen really clean in these markets?

Franc: That is a fundamental issue. Hydrogen needs to be decarbonized, which means it needs to be produced using carbon-capturing storage technology, electrolysis or fuels obtained from renewable sources.

We are ready to go to 100% decarbonized hydrogen stocks by 2030 provided countries give us the right regulations to push that, because the price of decarbonized hydrogen is basically 20%-30% higher than gray hydrogen, and we will need to find the right financing scheme to have it covered.

That being said, the best way to make green hydrogen is electrolysis using green energy, but it is still more expensive and that will likely take time. Interim options are available such as natural gas and carbon-capture and storage or using biogas.

Wards Intelligence: Where do you expect fuel-cell system cost to be 10 years from now?

Franc: Ten years ago, fuel-cell systems cost around $500/kW. Today, on a normalized volume basis, cost has fallen below $100. We know that ultimately cost can fall below $60/kW. Consider that against the cost of batteries, which are having difficulty getting below $100-$150/kWh.

Fuel cells have a natural advantage, but we need volume to reach those lower cost levels.

Wards Intelligence: How do hydrogen fueling station costs compare with the most advanced fast-charging stations for EVs, which reportedly cost upwards of $100,000?

Franc: A fast-charging station can charge maybe 10 to 15 cars per day. In contrast, a hydrogen station, which will cost between $1 million and $2 million depending on station size, can refuel between 100 and 300 cars. Hydrogen stations are more expensive but also have far greater capacity, and it takes only three to five minutes to refuel a car.

The main difference between batteries and hydrogen is that hydrogen stations can be profitable when fully utilized. I do not know anyone who has said that fast-charging stations can be profitable even when fully utilized, but I may be wrong.

The main drawback with hydrogen is that we need to develop the network first. With batteries, the operation grows in a linear way with the number of cars. Initially, the investment will be small because everyone can use his or her garage. But as volumes and momentum increase, so does the investment.

It is my view, therefore, that long-term infrastructure costs for hydrogen will be more competitive than for batteries in the future. Also, keep in mind that hydrogen will be used for other industries, an added advantage.

California Energy Commission's

KEVIN BARKER

Kevin Barker, deputy director, California Energy Commission, Fuels & Transportation Div., says his group is supporting projects for the production of clean hydrogen to meet the state's requirement that 33% of the fuel be generated from renewable resources.

Wards Intelligence: How many hydrogen fueling stations have been installed to date and how many are planned?

Barker: In January 2018, Gov. Jerry Brown issued an executive order calling for 5 million vehicles with zero tailpipe pollution on the road in California by 2030, as well as 250,000 charging stations and 200 hydrogen refueling stations by 2025. Through the state's Alternative and Renewable Fuel and Vehicle Technology Program, the California Energy Commission has funded 64 hydrogen refueling stations. Thirty-four are now open, making it one of the world's largest networks of open-retail hydrogen refueling stations for hydrogen fuel-cell electric vehicles.

Wards Intelligence: What are the obstacles? Cost, hydrogen production, state/corporate financing or the business model in general?

Barker: These are all challenges to the hydrogen market, which is still in its early commercial phase. That is why the Energy Commission is investing in a network of conveniently located refueling stations to support fuel-cell electric cars on the road now and to encourage more consumers to consider these zero-emission vehicles. The Energy Commission is also working to meet outgoing Gov. Brown's goal of 200 stations by 2025.

The Energy Commission is also supporting production of hydrogen, most recently with a May 2018 grant award to a hydrogen production facility to supply 2,000 kg/day of 100% renewable hydrogen to California's growing network of retail fueling stations. California state law currently mandates that 33.3% of the hydrogen produced for or dispensed by the fueling stations in the state-funded fueling network be made from renewable resources.

Wards Intelligence: Is the electrolyzer concept, where electricity is used to split water into hydrogen and oxygen, being considered in California?

Barker: The Energy Commission provides support for the advancement of clean transportation technology through competitive grant awards using a portfolio-based approach. Projects are awarded funds based on their eligibility and scores based on evaluation criteria. Two of the open retail Energy Commission-funded hydrogen refueling stations use electrolyzers as a source of hydrogen with two more under development.

Wards Intelligence: Do you see any potential for combined hydrogen and electric-vehicle charging?

Barker: Yes. There are already some stations that have both hydrogen refueling and electric charging.

Wards Intelligence: Where do you see the greatest potential for fuel cell vehicles – ports, delivery services, city buses, long-haul trucking, warehousing with FC-powered forklifts?

Barker: The Commission has focused its funding efforts on supporting deployment of light-duty FCEVs through expansion of California's hydrogen refueling network.

However, the Commission has funded development and deployment of medium- and heavy-duty vehicles powered by hydrogen, including trucks, delivery vehicles and buses, as well as the infrastructure to fuel these types of vehicles.

Providing the right fuel type for the right duty cycle is key to ensuring a successful transition to a clean transportation and freight sector, and there are vehicles whose need for longer range and higher power can be met by hydrogen.

Wards Intelligence: What daily or monthly volumes do you think you need to make the capital investment in hydrogen fueling infrastructure?

Barker: Again, the Energy Commission is investing in California's hydrogen refueling network to support adoption of clean hydrogen-fuel-cell electric vehicles in order to reach the state's goals on climate and petroleum reduction, as well as state and federal air-quality standards. Growth of a hydrogen refueling station network is integral to providing potential customers with confidence about driving these vehicles.

Daimler's

CHRISTIAN MOHRDIECK

Christian Mohrdieck, fuel cell director for Daimler and CEO of NuCellSys, is confident FCV costs can reach parity with plug-in hybrids. "That is our aim," he tells Wards Intelligence, "and we think it is possible to reach once we get to these (higher-volume) production numbers."

Wards Intelligence: How do you see your GLC F-Cell project advancing? Specifically, what volumes do you envivion and for fuel-cell passenger vehicles in general?

Mohrdieck: We launched the GLC F-Cell in November. Initially, sales will be a relatively small number. It won't be tens of thousands of cars. The numbers I do foresee are difficult to determine because the GLC project is still for testing market acceptance of fuel-cell technology for the purpose of providing important input into our next-generation project. For instance, how is this vehicle accepted by the market and how is the infrastructure developing? Then on the basis of this input, we can fix the number for the next-generation program.

Wards Intelligence: When do you see a tipping point when fuel-cell vehicles will move into the mainstream?

Mohrdieck: When the current generation of fuel-cell vehicles are successful, then I think in the beginning or middle of the next decade we can plan for higher numbers.

This is also a question of cost. Can we reach the cost targets with our fuel-cell vehicles? And it is also a matter of the sequence of introducing different technologies into the market, because the industrialization of a new technology, whether it's battery or fuel cells, is very costly, and I suppose that most companies can only do one technology at a time.

Since battery-electric vehicles are already a little bit further down the cost curve than fuel-cell vehicles, it makes sense to ramp up battery vehicles now, and then at some later point in time follow with fuel-cell vehicles.

Wards Intelligence: Toyota has announced it will begin focusing on heavier-duty fuel-cell trucks. What do you see in terms of how the market will bifurcate between passenger cars and heavy-duty vehicles?

Mohrdieck: Commercial vehicles are very important for the introduction of fuel-cell technology, because in the very heavy-duty area you probably don't have an alternative to fuel cells and hydrogen.

As you know, we already have fuel-cell buses on the road and we announced in July that we would introduce a battery-electric Citaro city bus (sold under the Mercedes brand), which would then also be equipped with a fuel-cell range-extender option to allow for longer ranges.

Even city buses need some range in order to really service all lines, even in flat cities like Hamburg. The daily mileage of city buses is 200-300 km (125-188 miles). For such heavy vehicles, you cannot do this with battery.

Since Daimler is a manufacturer of all types of passenger and commercial vehicles, we are of course interested in this area as well.

Wards Intelligence: What are you going to do for fueling of your new GLC?

Mohrdieck: There are three areas in the world where I would say sufficient or almost sufficient hydrogen refueling infrastructure exists. That is Germany, California and Japan. Daimler is active in all three areas.

In Germany, for example, we are a shareholder in a company called H2 Mobility, which is an infrastructure company with shareholders like Shell, Air Liquide, Linde, OMB, Total and Daimler, and associated partners including BMW, Toyota, Honda, Hyundai and Volkswagen.

These partners want to implement 400 hydrogen fueling stations in Germany. In October we opened the 52nd station. Already now, one can travel across the country with a fuel-cell vehicle. Admittedly it will take more time to reach some of the remote areas. But on the big highways, the network is growing. For the introduction of the GLC, we will have a refueling network that gives good coverage, at least inside Germany. I think the same thing is happening in California and Japan as well.

Wards Intelligence: Where do you expect system costs to be in the coming years?

Mohrdieck: Our cost estimation shows that fuel-cell technology is capable of reaching the same cost level as plug-in hybrids, for example, once you go to similar production numbers. So that's our goal, since plug-in hybrid and hybrid technology is widely accepted in the market.

If we can reach this cost level and have the additional benefit of zero emission, which the plug-in does not, then I think this would be a good package for the customer. That is our aim, and we think it is possible to reach once we get to these production numbers.

Wards Intelligence: Will you be using similar or common components to bring down costs?

Mohrdieck: Our current fuel-cell buses already have two B-Class F-Cell fuel-cell systems on the roof. The B-Class F-Cell is the predecessor to the GLC. So it's a twin system already. We decided not to develop a bus-specific system in that case, but to use the existing passenger-car systems, not only components but whole systems.

In the future, we want to do this in a much broader way by introducing a modular concept for the fuel cell wherever possible and then have multiples of this base module depending on the application.

Wards Intelligence: Where do you see the biggest need for breakthroughs to get your costs down?

Mohrdieck: Besides the modular approach, which is also a different word for volume bundling, which is good for driving the costs down, I see three technical areas where I would like to see improvements in terms of cost reduction.

Number one is, for sure, the stack. The fuel-cell stack is still responsible for a huge portion of the cost of a fuel-cell system. Number two is still air supply. As you might know, we use electrical turbochargers for the air supply. And you might think, "Oh, turbochargers are mainstream in internal combustion engines," which is true, but we need much more powerful turbocompressors and we need lubricant-free bearings in the turbocompressors because any lubricant would be a poison to the fuel cell. So there are specific requirements which currently lead to still very high costs in turbochargers.

Number three is the tank system, especially the tank container, which is carbon-fiber wrapped. In the carbon-fiber portion, we would like to see cost reduction and we think (that is) possible.

Wards Intelligence: In 2030 or 2035, what percentage of the market do you think fuel-cell vehicles will claim?

Mohrdieck: I would say a single-digit number is realistic. A single-digit number of the newly introduced cars, probably something in the lower one-digit area is realistic.

Wards Intelligence: Do you still face a durability problem because of purification issues in the stack?

Mohrdieck: The usual requirement for a passenger car in the internal-combustion vehicle segment is 8,000 hours. With the fuel cell we can achieve this. We could achieve this right away if you put enough platinum in the stack, but this will increase the cost. So it's a tradeoff question.

We've already achieved a 90% reduction in comparison to the B-Class F-Cell. But we still need to go down further until we reach the same level of platinum-loading as in the exhaust-gas aftertreatment system (in diesel powerplants), which is not too far away. Then we need to keep the lifetime at the same level as it is with the reduced platinum content.

On the bus side, we have much higher requirements, but we have already achieved substantially more than 10,000 hours of lifetime. We would like to get close to 20,000 or 30,000 hours. This seems to be reachable with the next generation. So from the technical side, I don't see any principal obstacles, but still there is work to do to get there.

NOW's

KLAUS BONHOFF

Klaus Bonhoff is managing director of Germany's National Organisation Hydrogen and Fuel Cell Technology. NOW oversees support programs for fuel-cell vehicle and infrastructure development in that country, which is on target to have 100 hydrogen refueling stations in place by 2020.

Wards Intelligence: Do the economics for fuel-cell vehicles get better in the larger and heavier vehicle segments?

Bonhoff: Yes. For smaller vehicles traveling over a shorter range, there is a clear cost advantage for pure battery-electric vehicles. But beyond a certain range, it is less costly with a fuel-cell system, because the fuel-cell system has its energy and power units separated from one another, whereas the battery is one black box (that) provides both energy and power.

Wards Intelligence: Where is the tipping point?

Bonhoff: The figures we see from Hyundai and others for an SUV-type vehicle put range at between 250 km and 300 km (156-187 miles). We need to be careful not to compare apples with pears, because the critical question is: What is the cost per kilowatt-hour on both the battery side and fuel-cell side in mass production? And we don't know those costs yet.

That said, the pure mathematics of it shows that the fuel-cell system is less expensive above a range of 300 km (187.5 miles). Looking at the cost of ownership, both battery-electric and fuel-cell vehicles are more costly today. But as more charging and hydrogen refueling stations become available, the total cost of ownership will merge with internal-combustion engines and plug-in hybrids by around 2025. These technologies will reach an affordable price level. Analysis shows that fuel-cell vehicles in Europe are the best option in the large-vehicle segment with longer distances in terms of CO2 abatement.

According to a comprehensive study conducted at the beginning of the decade, 50% of the car pool in Europe are midsized to large-sized and driven by customers around 15,000 km (9,400 miles) per year. This 50%

makes up 75% of CO_2 emissions related to road transport. So, if the political goal is to decrease the CO_2 footprint from transportation, this is the real lever to work on.

The other big issue, of course, is infrastructure costs. Do we need to set up both a recharging infrastructure and hydrogen refueling infrastructure? Yes, we do. And both are expensive. Germany, as part of the European Union, is obliged in the context of the alternative fuels infrastructure directive to come up with a national framework not only for hydrogen but also hydrogen infrastructure. We are in the middle of getting to the first 100 stations in Germany, which should be finalized in 2020. These 100 stations are being put in place independently of the number of vehicles.

But we are convinced we need this upfront investment in infrastructure to make sure that when vehicles become more available, customers actually make the decision to buy these vehicles because they know they can already cross Germany with hydrogen as the fuel.

Moving forward, there will actually be some kind of a mechanism in between ramping up vehicles and ramping up hydrogen stations. So we have a target of 400 stations, moving on to 1,000 stations in 2030. One thousand stations is the number of stations needed for full coverage of Germany with hydrogen fuel. It is that transition that we've now started to get us to full availability. The key focus for us is to make sure this is an infrastructure for mass-market deployment.

Talking about hydrogen, we have a very clear focus on making sure that this hydrogen is being produced by renewable fuels. The electrolyzer (used to split water into hydrogen and oxygen) becomes a key component for the transition of the overall energy system as a whole.

Reducing cost of 700-bar (70 MPa) storage is a key target. Fuel-cell stack cost reduction is a key. The real challenge is getting this into mass production, taking the stack from producing hundreds per year to tens of thousands per year and integrating all this into a complete drivetrain.

Wards Intelligence: Are there differences in establishing a hydrogen fueling and EV charging infrastructure?

Bonhoff: If you look at the mass market – annual sales on the order of 20 million based on a recent study – the more battery-electric vehicles we bring to the market, the more we will have to invest in extra charging outlets. So we have a more or less linear increase in investments in recharging infrastructure.

On the hydrogen-refueling side, we start building infrastructure with upfront costs that are enormous because utilization at the outset is very low. But as more vehicles come into the market, increasing utilization, we won't have to invest as much later.

Potentially, there is a positive business model around hydrogen infrastructure, while there are (ongoing) costs associated with recharging infrastructure. Both infrastructures are needed. And both are not a limiting factor to the other.

The discussion today is that fuel cells will be needed for light-duty trucks, heavy-duty trucks and rail applications. All of that is true. But I am personally convinced this tipping point discussion – between cost and range – is even more critical in the passenger-car segment. We need volume in the passenger-car segment to really drive the costs down and make fuel cells attractive.

Wards Intelligence: So, the issue then is the most cost-effective way to establish a refueling infrastructure?

Bonhoff: Ultimately, this is an investor decision that will have to be made. Why did Panasonic or BYD years ago…(invest) in batteries for electrified vehicles? Because they believed there was a market for them, and now they are leading in the market.

The next race will be in fuel-cell stack mass manufacturing. Toyota has announced it (will produce) 30,000 fuel-cell cars by 2020. We know Hyundai is on that same pathway. So the race is on.

We need to be careful – we as German and European companies – that we are part of this game. Otherwise, five years down the road we will be having the same discussion we are having today about battery cells and why don't we make them in Germany and Europe.

Wards Intelligence: Is a range-extender powertrain that uses a small fuel cell a good concept?

Bonhoff: I think so. French La Post has put a fleet of pure battery-electric Kangoos into operation. They were not satisfied with the range, especially during winter months. A French startup company had developed a 5-kW range extender fuel-cell system to add to the existing battery system, effectively doubling the range of the battery-electric vehicle.

If you look at cost per range, instead of doubling or tripling the size of the battery, it is less expensive to add a range extender using a small fuel-cell system.

Wards Intelligence: What is the tipping point in terms of percentage of sales?

Bonhoff: Generally, once you've exceeded 1% of new-car sales with a new technology, then you are at a tipping point where things start moving up. That is where we're at with batteries today. I hope we see that with fuel cells in the next five years.

Hyundai's

SAE HOON KIM

Sae Hoon Kim, vice president-Fuel Cell Group, Research & Development Group at Hyundai, says China will be the biggest market for FCVs initially, but Europe will be first to have a fueling infrastructure in place.

Wards Intelligence: What has been the response to the Nexo (fuel-cell vehicle)?

Kim: We received more than 2,100 advanced orders in Korea through September, where our plan was to sell around 700 units in 2018. So we've had difficulty keeping pace with demand. The response so far has been much better than expected. Globally, we are targeting sales of between 3,000 and 4,000 units in 2019. The number isn't fixed, but I expect it will be several hundred more than 3,000.

Wards Intelligence: How many years do you expect to stay at the 3,000-4,000 range?

Kim: It is difficult to forecast. We can easily raise capacity, but that will depend on the market situation. But if demand increases, our facility is designed so that we can respond accordingly.

Wards Intelligence: Is the Nexo built in a dedicated plant?

Kim: Our fuel-cell stack and system plant is dedicated. It is actually Hyundai Mobis' plant. Hyundai Mobis produces the stack starting from the membrane electrode assembly and then procures components from suppliers including the blowers, valves, humidifiers and compressors to make the stack. It then does the final system assembly. The assembled system is then transported to Ulsan where the Nexo is assembled at our Ulsan vehicle plant.

Wards Intelligence: Is production capacity to build the stack and tanks a concern?

Kim: The bottleneck is how fast can you produce the components in the stack. Other components such as compressors, pumps and blowers are produced by our suppliers and, in fact, they say more is better.

Wards Intelligence: Apart from reducing cost, are there any particular technical targets you see as critical?

Kim: We want to stay in lower operating-pressure ranges in order to reduce parasitic loss. Also, we want to reduce NVH to levels of electric cars.

Wards Intelligence: What do you see as the biggest obstacles to FCVs?

Kim: One is infrastructure. Hydrogen supply has to become cheaper. We need more stations. But we also need support from the government, because OEMs cannot do this by themselves. We need energy companies, gas companies and utilities to join the infrastructure development.

On the technical side, the second point, we have to get costs down. Hyundai is really focusing on this. It is not just material costs, it is also the fuel-cell structure and concept. We have to reduce the use of platinum.

In addition, we have to address stack durability. As things stand today, we must plan for putting fuel cells not only in passenger cars but also in trucks and buses, which require around 10 times more durability than cars.

Wards Intelligence: To what cost level do you think the stack must come down to make FCVs viable commercially?

Kim: Our first target will be the price of electric vehicles. If we would like to lower cost to electric-vehicle levels, we will have to increase volume. In order to do that we need more hydrogen stations. So they are linked – production volume and the number of fueling stations. But if volumes increase, I think we will achieve our cost target.

Wards Intelligence: Why is Hyundai putting so much effort into fuel-cell technology?

Kim: We are developing both battery-electric and fuel-cell vehicles. Battery-electric vehicles are very good for small cars, but there are limits for batteries.

Wards Intelligence: Where do you see the cutoff?

Kim: Price-wise, fuel cells will be more cost competitive for large SUVs. But the advantage for vehicles over 5 tons or 10 tons (gross vehicle weight) is even more pronounced. And as we move into the heavier-duty segments, including 40-ton trucks, there are practical limits to increasing the size of the battery pack.

Wards Intelligence: Which markets have the greatest potential?

Kim: I think China will be the biggest market. But Europe will be first with a hydrogen (infrastructure) in place. We have already announced plans to put 1,000 hydrogen fuel-cell trucks into operation in Switzerland. I think we will see inroads in other markets as well, especially in Germany, which is concerned about air quality and is planning to ban diesel cars and trucks in cities. You can switch from diesel cars to gasoline cars and hybrids, but as most buses and trucks are diesels, these offer good potential for fuel cells, (as will) anything that deals with logistics.

Wards Intelligence: Will this be short or long-haul trucking?

Kim: I think it will be for short distances first, up to about 400 km (250 miles). But we are also looking into the feasibility of longer ranges, because it only takes around 10 minutes to refuel a fuel-cell truck. Range of course depends on the number and pressure levels of the fuel tanks. So while I don't think we can reach 2,000 km (1,250 miles), I think 400-600 km (250-375 miles) is achievable.

Wards Intelligence: Do you have a solution for reducing degradation of the fuel-cell stack?

Kim: We are working on developing highly durable stacks and I am confident we can eventually meet the requirements for trucks. To give you some indication of how the industry is progressing, if you go back to the first U.S. Department of Energy demonstration in 2004, stack durability was only around 800 hours. By the second demonstration in 2008, we increased durability to 1,200 hours. By 2012: 3,500 hours. Our Nexo is over 5,000 hours.

Ballard and UTC Power claim to have reached more than 10,000 hours, even 20,000 hours. So I am quite sure that we will meet the Energy Department's future 25,000-hour target.

Reaching 50,000 hours, needed to achieve 100,000 km (62,500 miles) and 10 years of operation for heavy-duty trucks, will be challenging. But I am confident we can reach 25,000 hours.

Wards Intelligence: When do you think you will reach mass production of fuel-cell vehicles?

Kim: Between 2025 and 2030. Clean-air regulations around the world and particularly in Europe could also accelerate competition.

Wards Intelligence: Will Nexo components, including stacks and hydrogen tanks, be shared with your fuel-cell trucks?

Kim: Yes, we use almost the same components, except trucks need larger tanks.

Honda's

STEVE ELLIS

Steve Ellis, manager-Fuel Cell Vehicle Marketing for American Honda, says commercial vehicles represent the lowest-hanging fruit for fuel cells, but "we won't solve society's transportation challenges with zero-emission vehicles if we only look at heavy-duty. We are not doing this for the next five years. We are doing this for the next 50 years."

Wards Intelligence: How long will the current Clarity Fuel Cell vehicle be on the market before it undergoes a major change?

Ellis: This car will run as a platform somewhere near 2021. Everything beyond that is to be decided. The only thing we've said beyond that is joint manufacturing of the fuel-cell powertrain with (General Motors) will be applied around that time.

Wards Intelligence: Why is Honda putting so many eggs into the fuel-cell basket, considering there are still serious problems with hydrogen as a fuel?

Ellis: Every new fuel is the problem. But you don't not act just because the fuel is a problem. Foundationally, philosophically and operationally, hydrogen fuel-cell vehicles mimic what we do today with gasoline vehicles: three-to-five minutes refueling time and long-range operation. Up to this point, we have not met that same metric with plug-in electric vehicles.

So it is not a this versus that. It's a this *and* that. When you say eggs in one basket, it is really eggs in multiple baskets. It is too early to say this is the winner, therefore let's go all in. It is simply too early. There is a value to each of the technologies.

The beauty of the Clarity line is that it gives people a choice. People have a choice of limited electrification with the plug-in hybrid by virtue of its plug-in range, which meets most people's needs – 9 to 5, five days a week on their commute – and then if you choose to pick up and go across country, you can do it with one car.

The battery-electric vehicle meets the needs of people who have a plug-in infrastructure in their home, wake up every day with a full battery, which meets their daily needs. It is zero-emission transportation with very low carbon and fuel costs.

Hydrogen fuel-cell technology is scalable across the entire platform of (an automaker's) vehicles, if society is asking for SUVs, minivans and medium- and heavy-duty trucks. That is the value of hydrogen fuel cells.

The only way to get there, however, is to keep developing the technology, keep advancing it and then build this infrastructure called hydrogen stations.

Wards Intelligence: Before building the infrastructure, isn't the production of hydrogen expensive?

Ellis: The beauty of hydrogen, unlike gasoline which comes from oil, is that it reduces our dependence on oil and, particularly, on foreign oil. We as a nation are over 50% dependent on imported oil. Hydrogen can be made both from natural gas and water. You have a diversity of feedstocks. You will never import hydrogen. You wouldn't do it, because you have your energy from which to make it.

Wards Intelligence: Toyota has made a shift to begin using fuel-cell technology for commercial vehicles and trucks. What is your view?

Ellis: When you say it that way – and I don't speak for Toyota – you broadly portray Toyota's decision as if it's a shift from one to the other, when in reality it's both. Hence, what I said before: The fuel cell can be applied broadly across all these platforms. So, it is not if, it's when people start broadening the technology's application.

Light-duty transportation, like the Honda Clarity and Toyota Mirai, and heavy-duty transportation are the two bookends. Now you can fill in the books – come backwards from heavy-duty to medium-duty and from trucks to other larger passenger-vehicle applications – or push it from the light-duty side to medium and heavy-duty. We are not doing this for the next five years. We are doing this for the next 50 years.

Wards Intelligence: Toyota has indicated that from an infrastructure standpoint, heavy-duty applications make a lot of sense, if these vehicles are viable from a durability standpoint, in that you get 20 times more load.

Ellis: Absolutely. The same thing applies to CNG and LNG. One could say that the same thing applies to diesel trucks. The difference is that we have already been doing diesel trucks for the last 50-plus years.

So, one can invest in an energy station, whether it is to supply electricity, hydrogen, CNG or LNG for heavy-duty vehicles, and literally from Day 1 turn a profit.

It is easier to do than for light-duty vehicles, which are more challenging. We are on an upward path to develop hydrogen stations from what were 50-kg (110-lb.) stations to 250-kg (550-lb.) stations. 500-kg (1,100-lb.) stations are going to be the next phase. And eventually we will get beyond 1,000 kg (2,200 lbs.). That's when the economics come into play.

Wards Intelligence: When will we get to 250 kg, 500 kg and 1,000 kg?

Ellis: 250-kg is today. The next stations awarded in California will be 500 kg. Those will be much higher capacity. The difficulty is that we haven't even begun to reach the economics where that is really viable.

But full circle back to your point: If you start heavy-duty from Day 1, you could be doing thousands of kilograms per day if you establish a station for a fleet of trucks.

Wards Intelligence: So, this gets to the need for a central depot?

Ellis: Again, heavy-duty is the lowest-hanging fruit. That's easy. But we won't solve society's transportation challenges with zero-emission vehicles if we only look at heavy-duty.

Wards Intelligence: But if you look at Exxon Mobil's forecast, the truck sector is very polluting.

Ellis: Let's connect the dots. Heavy-duty is the lowest-hanging fruit from an infrastructure standpoint. Heavy-duty is also the lowest-hanging fruit from an emissions-reduction standpoint. Los Angeles's air quality is much cleaner today. That didn't happen by a few thousand or tens of thousands of electric cars. That happened by cleaning gasoline vehicles, but in a bigger way the buses, the trucks and the trash trucks (mostly diesels). It is a model of success people come to look at: How did LA get its air so clean so fast?

All of that was done by focusing on the lowest-hanging fruit. The vehicles at the ports were uncatalyzed. Their engines were running all the time. Then the fleet of LA MTA (Metropolitan Transportation Authority) buses. And the challenge was that those buses were emitting diesel emissions in the communities where people lived, as were the trash trucks.

What I'm saying is that lowest-hanging fruit is both at the infrastructure side and the emission-reduction side for smog and CO2 emission. But it doesn't mean that you stop focusing on light-duty because heavy-duty is easier.

Wards Intelligence: Honda currently sells around 200 Clarity FCVs annually. Is that where you intend to be?

Ellis: We didn't launch the car until December 2016. 2017 was a ramp-up year. It has been pretty stable in 2018. Back when we introduced the FCX (in 2002), those were tens of cars. With the FCX Clarity, we're at hundreds of cars. Next will be thousands of cars, then tens of thousands of cars. Speaking generally, we cannot get the products ahead of the infrastructure. It is symbiotic.

The best recent news has been the state of California, which has invested a significant amount of funds in infrastructure for plug-in electric vehicles and hydrogen fuel cells. The state is literally doubling down from the 100-station commitment they made earlier to 200 stations in 2025. So that's a very accelerated growth model for stations and a strong commitment from government that is necessary to achieve those carbon-reduction goals.

Great Wall Motor's

TOBIAS BRUNNER

Tobias Brunner spent more than a decade working for BMW in fuel-cell and cryogenic development before joining Great Wall Motor in 2016. He currently heads Great Wall's XEV project, which covers R&D activities in hydrogen fuel-cell and energy technology, as well as future electric-vehicle platforms. While at BMW, Brunner initiated a collaboration with Toyota in fuel-cell R&D. Brunner holds a PhD in mechanical engineering from the University of Munich and a French Degree in mechanical engineering.

Wards Intelligence: What is Great Wall Motors doing in the fuel-cell-vehicle segment and, more generally, alternative powertrain vehicles?

Brunner: First, Great Wall Motors is the largest SUV and pickup-truck manufacturer in China. We have had the highest sales in these segments for 16 and 19 consecutive years, respectively. Although we own several brands, our core business is SUVs and pickup trucks, which makes it rather challenging to go electric.

Because of the Chinese government's ZEV mandates – we call them NEV for "new energy vehicle" – we need to produce plug-in hybrid vehicles, battery-electric vehicles and/or fuel-cell vehicles.

We are preparing vehicles using all three technologies.

For instance, we have a plug-in hybrid on the market, the WEY P8, and two battery-electric vehicles, the Ora iQ5 and the C30. More battery-electric vehicles will be coming soon.

We are developing fuel-cell vehicles because we believe that for SUVs and pickup trucks, this is a very viable option for China.

Wards Intelligence: In Great Wall Motors' roadmap, what percent of the mix do you expect to be battery-electric, plug-in hybrid and fuel-cell by 2020, then 2025?

Brunner: As you are aware, there is a mandate which starts at 10% in 2019, 12% in 2020 and so on based on a credit system in which automakers earn two credits for a plug-in hybrid and then three to five credits for a battery-electric or fuel-cell vehicle.

We're preparing for that and might go beyond. But that's for the market to decide.

Wards Intelligence: When will you start commercializing fuel-cell vehicles?

Brunner: We have announced plans to start production by 2022. We haven't decided volumes concretely. It will depend on how efficiently and quickly we can set up production. But our target for our first small-series model is 2022 to coincide with the Beijing Olympic Games in February 2022.

Wards Intelligence: Is your focus on the SUV segment due to greater potential benefit than pure battery-electrics, because of the generally heavier weight?

Brunner: We certainly know that there has been a series of battery-powered SUVs recently announced or close to being launched. If you compare the Hyundai Nexo with battery-electric SUVs in its class, the Nexo can travel a longer distance, which is a big advantage.

Generally, battery-electric vehicles weighing 2.5 tons and fitted with a 90-kWh or 100-kWh battery can only make 250 to 300 km (156 to 187 miles) on a German highway. These vehicles are just too heavy and inefficient for longer-distance driving at higher speed. Adding battery capacity will make them even heavier.

Secondly, the fuel-cell drive isn't materially impacted by the type of vehicle and won't get significantly heavier by the size of the vehicle. Basically, you just need to increase the capacity of the hydrogen storage tank, which will not result in a huge weight penalty. This is a big advantage.

Wards Intelligence: Do you believe commercial vehicles are a better application for fuel cells than passenger vehicles?

Brunner: It is definitely the application we should look at first, because it is both heavier and requires more energy. So that makes sense. But I also believe that fuel-cell technology has evolved to the point where we can be competitive in passenger cars very soon.

If you look at vehicles such as the Nexo and the Mirai – Toyota will bring out a new-generation model next year – I think the break-even point differential will narrow. And we see the same thing for our fuel-cell program. We will become competitive by 2025 with the technology we have on our development bench as fuel-cell passenger cars approach plug-in hybrid or even standard hybrid cars.

I also believe that moving into passenger cars gives us more incentive to downsize and lower costs than with buses or trucks. As you are aware, Toyota is now deploying its fuel-cell stack used in the Mirai for buses and trucks. And Hyundai is doing the same. They can do this without major modification.

In Great Wall's case, we're developing fuel cells and storage systems for passenger cars and purchased Shanghai Fuel Cell Powertrain in September 2018, which is a well-known fuel-cell company, to provide fuel-cell drives to third parties and for other applications. The base technologies for stacks and the storage systems will be the same.

Wards Intelligence: To clarify, Great Wall Motors is not producing medium-duty or heavy-duty trucks, correct?

Brunner: That is correct. We are not in the commercial-vehicle business as Great Wall Motors right now, but we will provide these systems for commercial vehicles by our partner company, Shanghai Fuel Cell Powertrain, and perhaps through other ventures in the future.

Wards Intelligence: In terms of Great Wall's 2025 roadmap, how big do you envision this fuel-cell-vehicle business will become?

Brunner: We believe that by 2025 we could launch two models to the market. It depends in part on infrastructure. But from 2025 to 2030 we believe we could go from a scale of 10,000 units up to 100,000.

Wards Intelligence: So, to reiterate, you don't see the stack as being the biggest problem moving forward?

Brunner: No. Stack performance will depend in part on the technology companies we choose to work with. I think, for instance, that within the next five years we can increase power density, thus make the stack smaller, which means using smaller volumes of precious metals and lowering cost. At the same time, we expect to improve stack durability and cold-start performance. Again, we don't believe the stack is our biggest challenge.

We believe our biggest challenge is refueling.

Wards Intelligence: How extensive is the hydrogen refueling network in China and where is it currently located? For instance, where would one be able to refuel a fuel-cell vehicle?

Brunner: There currently are around 15 stations in operation and another 20 under construction. The government has set an unofficial target of 100 stations by 2020, then 1,000 in 2025 and 3,000 in 2030. If the government's 2025 and 2030 targets materialize, China would have the largest hydrogen-fueling network anywhere in the world. But keep in mind that China is a very big country, so 100 stations isn't the same as 100 stations somewhere else in the world.

Wards Intelligence: When you say that Great Wall Motors is working to reduce stack and system size, can you give some context for how you compare, say, to Hyundai and the Nexo or Toyota's Mirai?

Brunner: We have set a target for our first model of 5 kW/liter fuel-cell-stack power density.

Wards Intelligence: And that will be in 2022?

Brunner: Yes. And larger volume production will target two to three years later.

Wards Intelligence: Which factors do you think will have the biggest influence on market growth in the next 10 years? Will it be the cost and availability of rare materials, technological breakthroughs, consumer acceptance, hydrogen availability or regulatory pressure?

Brunner: We don't think we need technological breakthroughs. Concerning consumer acceptance, I don't think that fuel-cell vehicles will be at a disadvantage. I think they will have an advantage. People like the idea of refueling convenience. Thus, once they become affordable and refueling stations are in place, consumers will have a strong preference. That's based on my personal experience as well our company's belief.

The lack of availability of a refueling infrastructure, for sure, is a limiting factor, especially given the challenges we still see in fueling technologies. So that is a major concern. On the issue of cost, yes, we need to bring down costs in all areas. But with the advances we see in various technologies, we can make a business case by 2025 and surely beyond.

On the issue of rare-earth materials, we believe that by downsizing the fuel-cell drive, which includes the electric drive, we can reduce our reliance. If we can reduce overall size, that means smaller electric motors and smaller power control units.

On the issue of regulatory pressure, the Hydrogen Council has published a preliminary study on the effectiveness of policies. If you look to California, where fuel-cell vehicles are preferred over other electric vehicles by regulation, we're beginning to see a considerable accumulation there. Similarly, in China we're seeing a positive impact from policy.

VII. APPENDIX

WARDS INTELLIGENCE
2018 STUDY OF FUEL CELL VEHICLES

Survey Results

OVERVIEW

- Investigation conducted exclusively for Wards Intelligence.
- Methodology, data collection and analysis by Informa Engage Research, the research arm of Informa, parent company of Wards Intelligence.
- Data collected August 14-27, 2018.
- Methodology conforms to accepted market-research methods, practices and procedures.

METHODOLOGY

- On August 14, 2018, Informa Engage Research emailed invitations to participate in an online survey to a net 44,764 readers of Wards products.
- By August 27, 2018, Informa Engage Research had received 287 usable surveys.

RESPONSE MOTIVATION

To encourage prompt response and increase the response rate overall, the following marketing research techniques were used:

- A live link was included in the e-mail invitation to route respondents directly to the online survey.
- Reminder emails were sent to non-respondents on August 21, 2018.
- The invitations and survey were branded with the property name and logo of Wards in an effort to capitalize on subscriber brand affinity.

Which of the following best characterizes your company's business type?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Systems/Components/Parts	41%	100%	-	-
Vehicle Manufacturer	24%	-	100%	-
Engine/Engine Services	6%	-	-	17%
Other	22%	-	-	63%
Dealership	7%	-	-	21%
Respondent Count	**287**	**117**	**68**	**102**

Base = All respondents

Others listed:

Academia
Agency
Association
Auto consulting
Auto web site
Automotive distributor
Automotive engineering services
Automotive marketing consultant
Automotive training
Consultant/financing
Consulting (4 mentions)
Consulting electrical electronics
Distributor of adhesives and sealants
Engineering consultant (3 mentions)
Engineering consulting & services
Engineering services (2 mentions)
Environmental services
Equities trader
EV testing
F & I products
Facility design
Finance
Fuel systems
Fuels
Government
Heavy automotive applications
Investors
Law firm
Leasing
Lobbying for motorists
Manufacturer of truck bodies
Manufacturing design
Marketing
Metallurgical support
Packaging
Rail cars
Research
Research education
Research, standardization
Retail consultant
Sales (3 mentions)
Specialized engineering
Steel supplier
Technical education
Telematics institute
Tire company
Tooling and machinery
Training/education
Transportation
Truck dealer
Truck and bus consulting
Vehicle leasing
Vehicle valuation

Where are you headquartered?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
North America	81%	70%	85%	92%
Europe	10%	19%	7%	3%
Asia	8%	11%	7%	5%
Respondent Count	**286**	**117**	**68**	**101**

Which of the following best describes your primary job function?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Engineering/Design	25%	30%	34%	13%
Sales/Marketing	20%	21%	7%	27%
Corporate/Management	16%	14%	9%	23%
Manufacturing/Production/ Engineering	10%	14%	12%	4%
Research & Development	8%	6%	10%	9%
Quality/Testing/Reliability	5%	9%	1%	2%
Manufacturing/Production/ Operations	4%	3%	10%	2%
Purchasing	0%	–	1%	–
Other	12%	4%	13%	21%
Respondent Count	**286**	**117**	**67**	**102**

Others listed:

Analysis
Business Development
CEO
Change Management
Communications
Consultant
Consulting & Business Planning
Cybersecurity
Data Analytics
Finance (2 mentions)
Globally-Known Author Automotive Books
Industry Association Dealer OEM Relations
IP
Law/Regulatory
Metallurgical Consulting
Owner
Profit Improvement
Project Management
Research/Finance
Service Engineering
Technical Support
Trading
Training
Used Cars
Vehicle Knowledge, Training
Vehicle Repair

Which factor will have the biggest influence on fuel-cell growth in the next 10 years?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Hydrogen availability/ refueling infrastructure	37%	35%	30%	45%
Technological breakthroughs	29%	30%	27%	30%
Consumer acceptance/adoption	17%	17%	22%	13%
Government subsidies and incentives	7%	8%	6%	7%
Cost/availability of rare-earth metals	5%	6%	6%	2%
Regulatory pressure	5%	3%	9%	3%
Respondent Count	**277**	**115**	**64**	**98**

Beyond buses, what vehicle segment is most likely to be the focus of real-world fuel-cell deployment?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Local-delivery commercial vehicles	48%	55%	47%	40%
Long-haul trucks	29%	28%	24%	33%
Light-duty pickups/SUVs/crossovers	12%	10%	15%	13%
Midsize cars	6%	4%	8%	6%
Small cars	6%	3%	6%	8%
Respondent Count	**277**	**115**	**62**	**100**

Which automakers do you expect to lead in fuel-cell development/application?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Toyota	64%	70%	62%	59%
Honda	46%	45%	51%	43%
General Motors	34%	29%	46%	32%
Hyundai	15%	18%	8%	15%
Volkswagen Group	14%	15%	8%	16%
BMW	13%	14%	8%	14%
Daimler	11%	6%	16%	14%
Ford	11%	9%	15%	12%
Geely-Volvo	9%	7%	11%	11%
Renault-Nissan-Mitsubishi	6%	9%	5%	4%
BAIC	4%	5%	2%	3%
Nikola	4%	4%	3%	5%
SAIC	4%	4%	3%	3%
Chery	3%	1%	3%	4%
PSA	1%	2%	2%	-
Respondent Count	**268**	**112**	**61**	**95**

Percents may reflect multiple answers

Honda, as one example, has reduced the size of its fuel-cell stack to fit into a V-6-sized engine bay while increasing its efficiency and output. What is the next major advancement in fuel-cell vehicle technology?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Increased power output/ efficiency/range	37%	34%	37%	41%
Improved on-board hydrogen storage systems	32%	37%	24%	32%
Advancements in fuel-cell membrane materials	11%	11%	13%	8%
Further reductions in size of stack	11%	12%	11%	11%
Improved motors	3%	1%	5%	3%
Advancement in control systems	1%	1%	-	1%
Other	6%	5%	10%	4%
Respondent Count	**266**	**109**	**62**	**95**

Others listed:

Cost (2 mentions)

Cost reduction (2 mentions)

Don't know

Fuel cells are not cost-effective

Hydrogen availability

Lower cost

Manufacturing of hydrogen

Nothing! Nonsense!

On board reformers to crack distilled water.

Reduce cost

Refueling

Using non-noble metals

Which is likely to be the leading market for fuel-cell vehicles in 2025?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Japan	32%	37%	27%	29%
Europe	23%	23%	23%	23%
China	22%	20%	24%	23%
North America	19%	16%	23%	19%
Other Asia/Pacific	3%	4%	2%	2%
South Korea	2%	1%	2%	4%
South America	-	-	-	-
Respondent Count	**269**	**111**	**62**	**96**

Fuel-cell vehicles are expected to remain a small niche globally for the foreseeable future, even as more electrified vehicles are produced. When might fuel-cell vehicles reach 10% of the global market?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
2020-2030	15%	16%	5%	20%
2030-2040	34%	32%	41%	33%
2040-2050	21%	21%	23%	19%
2050-2060	14%	14%	16%	14%
Beyond 2060	5%	6%	6%	4%
Never	10%	11%	9%	11%
Respondent Count	**267**	**108**	**64**	**95**

What events might trigger a move to fuel-cell adoption?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Reduced fuel-cell vehicle cost	35%	35%	34%	35%
Widespread hydrogen availability	34%	35%	34%	34%
High gasoline prices	13%	14%	11%	13%
Government regulation	10%	8%	18%	8%
Environmental concerns	7%	7%	3%	11%
Respondent Count	**268**	**111**	**62**	**95**

Rate the prospects for onboard hydrogen reforming technology:

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Highly likely	9%	8%	3%	13%
Somewhat likely	42%	40%	32%	49%
Somewhat unlikely	35%	38%	41%	28%
Highly unlikely	15%	13%	24%	11%
Respondent Count	**260**	**107**	**59**	**94**

How important is the relative price of hydrogen in the proliferation of fuel-cell vehicles?

	ALL RESPONDENTS	SYSTEMS/ COMPONENTS/ PARTS	VEHICLE MANUFACTURER	OTHER
Highly important	48%	45%	51%	49%
Somewhat important	43%	48%	34%	44%
Somewhat unimportant	6%	7%	5%	5%
Not important at all	3%	-	10%	2%
Respondent Count	**266**	**111**	**59**	**96**

Forecast 2030: Global Fuel-Cell Vehicle Deliveries by Region

REGION	2015	2016	2017	2018	2019	2020	2025	2030
Asia-Pacific	428	1,134	829	2,213	4,428	5,686	17,807	30,945
Europe Big 5	23	119	169	593	909	885	3,999	50,720
Europe Other	13	110	84	120	328	266	3,068	71,973
North America	86	1,089	2,305	3,172	3,505	4,670	19,355	75,486
ROW	25	122	456	0	1,427	1,744	20,475	71,894
Grand Total	**575**	**2,574**	**3,843**	**6,098**	**10,597**	**13,251**	**64,704**	**301,018**

Source: LMC Automotive

Forecast 2030: Global Fuel-Cell Vehicle Market Share by Region

REGION	2015	2016	2017	2018	2019	2020	2025	2030
Asia-Pacific	74.4%	44.1%	21.6%	36.3%	41.8%	42.9%	27.5%	10.3%
Europe Big 5	4.0%	4.6%	4.4%	9.7%	8.6%	6.7%	6.2%	16.8%
Europe Other	2.3%	4.3%	2.2%	2.0%	3.1%	2.0%	4.7%	23.9%
North America	15.0%	42.3%	60.0%	52.0%	33.1%	35.2%	29.9%	25.1%
Rest of World	4.3%	4.7%	11.9%	0.0%	13.5%	13.2%	31.6%	23.9%
Grand Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: LMC Automotive

Forecast 2030: Global Fuel-Cell Vehicle Deliveries by Company

COMPANY	2015	2016	2017	2018	2019	2020	2025	2030
BMW Group	0	0	0	0	0	13	2,282	11,558
Daimler Group	0	0	0	24	244	0	4,213	14,653
Ford Group	0	0	0	0	0	37	374	11,851
General Motors Group	0	0	0	0	26	406	669	14,423
Honda Group	2	113	455	2,083	2,945	3,939	13,222	34,759
Hyundai Group	50	288	196	653	1,141	1,419	3,138	51,318
Other	25	122	456	0	1,427	1,744	20,475	85,674
Renault-Nissan-Mitsubishi	0	0	0	0	0	274	3,304	5,182
SAIC Group	0	0	0	0	0	0	135	303
Suzuki Group	0	0	0	0	0	0	429	1,448
Toyota Group	498	2,051	2,736	3,338	4,814	5,419	12,335	46,516
Volkswagen Group	0	0	0	0	0	0	4,128	23,333
Grand Total	**575**	**2,574**	**3,843**	**6,098**	**10,597**	**13,251**	**64,704**	**301,018**

Source: LMC Automotive

Forecast 2030: Global Fuel-Cell Vehicle Market Share by Company

COMPANY	2015	2016	2017	2018	2019	2020	2025	2030
BMW Group	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	3.5%	3.8%
Daimler Group	0.0%	0.0%	0.0%	0.4%	2.3%	0.0%	6.5%	4.9%
Ford Group	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.6%	3.9%
General Motors Group	0.0%	0.0%	0.0%	0.0%	0.2%	3.1%	1.0%	4.8%
Honda Group	0.3%	4.4%	11.8%	34.2%	27.8%	29.7%	20.4%	11.5%
Hyundai Group	8.7%	11.2%	5.1%	10.7%	10.8%	10.7%	4.8%	17.0%
Other	4.3%	4.7%	11.9%	0.0%	13.5%	13.2%	31.6%	28.5%
Renault-Nissan-Mitsubishi	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	5.1%	1.7%
SAIC Group	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%
Suzuki Group	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.5%
Toyota Group	86.6%	79.7%	71.2%	54.7%	45.4%	40.9%	19.1%	15.5%
Volkswagen Group	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.4%	7.8%
Grand Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: LMC Automotive