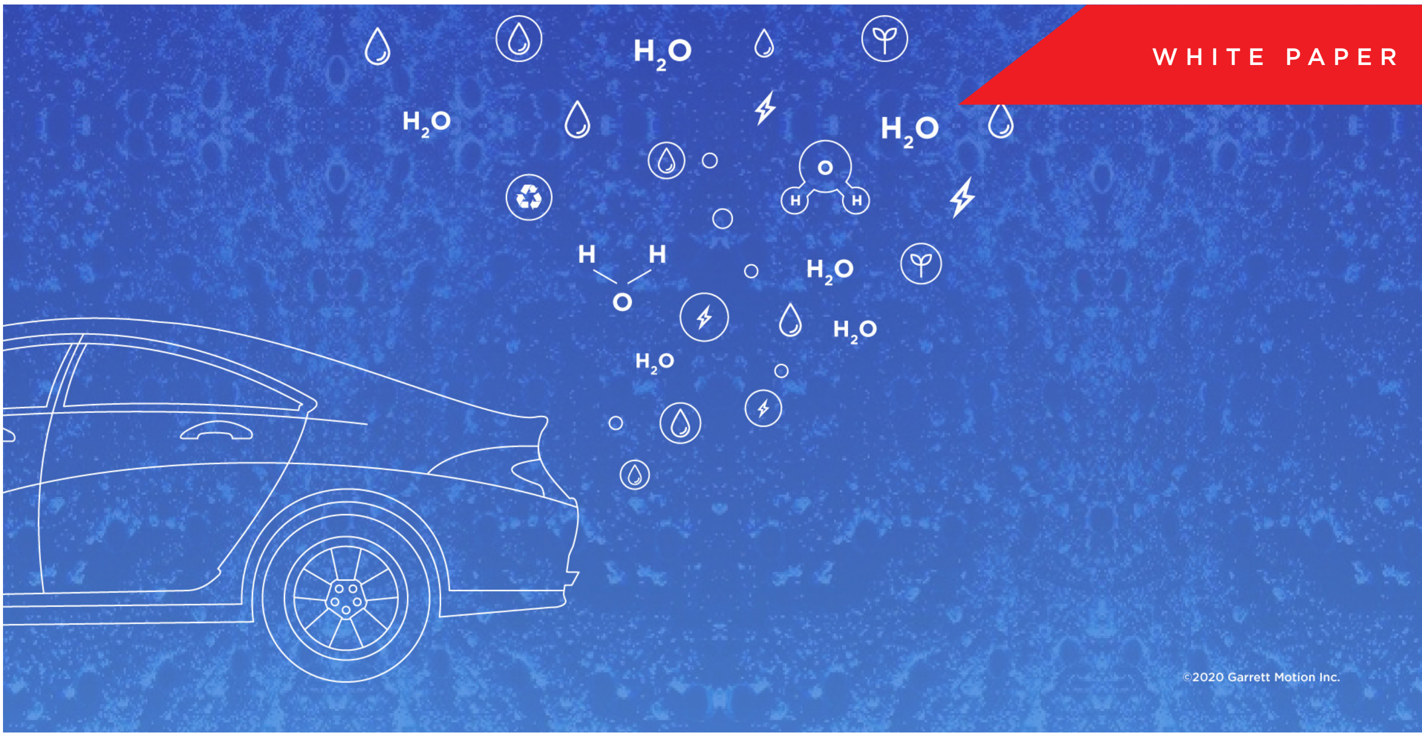
WHITE PAPER



— FEBRUARY 2020 —

Hydrogen Fuel Cell Vehicles to Accelerate Electrification in the Global Auto Industry

Garrett
ADVANCING MOTION

Executive Summary

Hydrogen fuel cell electric vehicles (FCEVs) will play a significant role alongside battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEV) in the global pursuit of zero-emission vehicles in the coming years. The auto industry is investing in a new powertrain revolution using electrification. Although sometimes positioned as competing technologies, an evolving narrative we support recognizes that neither BEVs nor FCEVs by themselves can provide for all zero-emissions transportation needs during the next several decades. Coupled with more efficient internal combustion engines and hybrid powertrains, the leap to an electrified automotive future will likely see both BEVs and FCEVs in different uses and duty cycles across passenger and commercial vehicle segments.

Each technology has advantages and shortcomings that point to preferred uses. BEVs have the advantage of easy availability of electric power, even if charging time remains long; FCEVs have the advantages of long range and much shorter refueling times. Manufacturing costs for FCEV components are also decreasing with each generation and with scale, while battery costs for BEVs remain high as costs are closely tied to commodity metals.

At their source, BEVs and FCEVs share the challenge of how to sustainably produce and store energy at scale, and eliminate the need for fossil fuels at any point in the production chain. As global electricity grids increasingly incorporate renewable but often inflexible energy sources, a combination of both green electricity and green hydrogen can be used to simultaneously power a zero-emissions transportation future, while stabilizing our utility infrastructure. Garrett has developed this position paper in support of its view that FCEVs will be required to achieve global environmental, energy efficiency and energy security goals alongside BEVs, with each technology taking advantage of its respective technological attributes.

Introduction

Wan Gang, known as the "Father of Electric Vehicles" in China, convinced the Chinese government 20 years ago to invest in battery-electric cars. So influential is Wan that half of all battery-electric vehicles sold in the world today are in China. Wan convinced the Chinese government that curbing China's dependence on oil imports and aggressively trying to cut air pollution in China's cities would be best served by moving to battery electric vehicles.

Today, Wan is leading the world's largest auto market in a different, but still electrified, direction. He has a new vision to continue China's technological revolution to complement its electrified transportation revolution. "We should look into establishing a hydrogen society," said Wan, 66, who's now a vice chairman of China's national advisory body for policy making, a role that ranks higher than a minister and gives him a voice in the nation's future planning, according to Bloomberg News. "We need to move further toward fuel cells."

So why the major shift in policy toward fuel cell electric vehicles in addition to BEVs?

First, the electric vehicle industry in China has reached a state of maturity, leading to the government reducing its intervention in getting BEV technology or its manufacturers off the ground. To its credit, China already has by far the largest BEV market in the world.

But the second reason revolves around air quality, especially in larger cities: battery electric vehicles haven't been the fix-all to reducing air pollution in China, and as conventional internal combustion engines and emissions controls get better, some argue that battery electrics have paradoxically made air quality worse. The reason is that China is still heavily reliant on less clean fossil-fuel electricity sources without the advanced stack emissions controls on coal-fired power plants.

> *We should look into establishing a hydrogen society. (...) We need to move further toward fuel cells."*
>
> **WAN GANG**
> **DEPUTY CHAIRMAN OF THE CHINESE PEOPLE'S POLITICAL CONSULTATIVE CONFERENCE**
>
> BLOOMBERG NEWS: JUNE 12, 2019

According to Bloomberg, “one recent study by Chinese engineers estimated that electric vehicles generate about a 50 percent increase in both greenhouse gas emissions and total energy consumption over their life cycle. The manufacture of the lithium-ion battery alone accounts for 13 percent of the energy consumption and 20 percent of the emissions.”

Of course, cleaning up China’s energy grid will take a long time, but when pressed, Wan pointed out that it wouldn’t be BEVs versus FCEVs, but that long-term planning demanded that each technology had a strong usage case based on different transportation needs and their unique characteristics for supporting a greener grid.

Some call into question the long-term benefits of BEVs from a life cycle assessment analysis, since the mining of the various metals for lithium-ion batteries aren’t inconsequential and only recently have scientists begun to tackle the problem of trying to recycle lithium-based batteries and battery packs.

Hydrogen has higher energy storage density than lithium-ion batteries both in terms of energy stored per unit weight and energy stored per unit volume. Hydrogen is preferred for weight, space, and refueling time, any time the average daily energy use is high; practically speaking, that means for lighter, less energy-hungry passenger vehicles traveling within cities, BEVs will usually make more sense, but for more energy-intensive applications like city buses or larger vehicles, FCEVs make more sense.

The currently planned elimination of China’s BEV subsidies by the end of 2020, while taking serious measures to build the still-emerging hydrogen infrastructure and helping subsidize new FCEV component and vehicle manufacturers, begins to strengthen the global case for FCEV development and adoption.

> *One recent study by Chinese engineers estimated that electric vehicles generate about a 50 percent increase in both greenhouse gas emissions and total energy consumption over their life cycle. The manufacture of the lithium-ion battery alone accounts for 13 percent of the energy consumption and 20 percent of the emissions.”*
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> BLOOMBERG NEWS

For years, the broad consensus on the future of transportation has been that today’s gasoline and diesel-powered cars will yield to an electrified transportation future, which has largely meant BEVs. Not only are BEVs more efficient than gas or diesel vehicles, but they can derive their electricity from renewable, non-carbon-based sources.

But in reality it is much more likely that electrification in the near to medium term will mean the acceleration of hybrid powertrains that combine internal combustion engines and electric motors.

Only recently, however, have public policy and technology advancements aligned to show that FCEVs can, and should, co-exist with BEVs and hybrids to help the world achieve these broad societal goals.

FCEVs can, and should, co-exist with BEVs and hybrids to help the world these broad societal goals.

Battery Electric Vehicle Overview

Battery-electric vehicles have been dominating the attention of analysts, media and regulatory bodies for good reasons.

Grid-distributed electricity is almost universally dispersed directly to businesses, homes and garages. While a few parts of the world use renewables like wind, solar, hydro or geothermal energy, most of the world's electricity is still generated using carbon-emitting fossil fuels like coal and oil, often using inefficient and outdated production equipment.

During the last 20 or so years, automakers and suppliers have spent billions of dollars developing the batteries, electric motors and power electronics required to convert electricity from the grid into energy that turns the wheels of electrified vehicles. As a result of these advancements, as well as specific mandates from large government agencies like the State of California's Air Resources Board (CARB), automakers have developed new BEVs in ever-growing numbers. Garrett Motion supports these efforts.

Automakers including Tesla, GM, Ford, Nissan, VW, BMW, Mercedes and the Hyundai/KIA Group have introduced increasingly affordable — if often subsidized (both internally by the company and by regulatory bodies) — battery-electric vehicles.

And while California, due to its heavily subsidized market push to help consumers buy both BEVs and plug-in hybrids, as well as higher-than-average gas prices, reached a record of nearly 8 percent market share, while the whole of the U.S. saw its overall market share reach just under 2 percent of total sales.

Hydrogen Fuel Cell Vehicles: The Other Electric Car

While fuel cells seem to be and are presented as new and advanced, the basic technology dates back to the middle of the 19th century, and has been under development by the auto industry for nearly 50 years (as GM pointed out a few years ago).

Fuel cells create electrical energy through a chemical reaction between hydrogen and the oxygen in the air all around us. The reaction creates electricity with the only "exhaust" being small amounts of heat and clean water.

The distribution system for electricity has been developed and refined around the world for more than 100 years. Equivalent distribution for hydrogen does not exist today, although natural gas pipelines could be re-purposed in certain cases.

This is a big advantage not only for ease of distribution, but also for the efficiency of distribution. Once produced, electricity is transmitted and distributed via a network of higher-efficiency, high-voltage power lines and lower-efficiency, lower-voltage lines. The losses suffered in transmitting the electricity varies by state based on the mix of how much transmission occurs on the big, high-voltage lines vs. the less efficient lower-voltage lines.

That said, once the electricity is delivered and the vehicle is purchased or leased, BEVs are extremely cost- and energy-efficient in specific driving cycles. For an apples-to-apples comparison, the University of Michigan's Transportation Research Institute calculated the average cost per mile for 2016 BEVs, FCEVs and gasoline power ICE Vehicles (see chart below):

POWERTRAIN	AVERAGE FUEL ECONOMY	COST PER MILE
BEVs	105.2 MPGe (EPA, 2015)	$0.04
FCEVs	58.5 MPGe (EPA, 2015)	$0.09
ICE (GASOLINE)	23.3 MPG (EPA, 2015)	$0.10

For current gasoline-powered ICE vehicles the fuel economy was coupled with a fuel price of $2.35 per gallon (Alternative Fuels Data Center, 2015)

The fuel cell stack itself is roughly 60 percent efficient, compared to roughly 25 percent for conventional gas engines but still less efficient than BEVs.

So today, in terms of operating costs and operating efficiency, BEVs have an advantage over FCEVs under certain parameters. Part of this stems from the fact that hydrogen, while the most abundant element in the universe, isn't easily obtained in its natural state; hydrogen is always chemically attached to some other element or elements and is created by reforming compounds as simple as water (H20) into its two elemental building blocks (oxygen and hydrogen).

This reformation of natural gas (the cheapest and most common means of producing hydrogen) requires energy inputs and a fossil-fuel feedstock to produce hydrogen gas. Once the hydrogen is isolated from its previous compound, it must be compressed and stored as liquid hydrogen at extremely low temperatures or as a highly compressed gas in order to deliver the potential energy density to the fuel cell stack. Each of these steps requires more energy inputs and involves marginal losses of efficiency.

One would be tempted to conclude based on the comparisons above that BEVs soundly beat FCEVs in their market viability, and markets have agreed — until recently. As this paper will show, FCEVs have significant advantages over BEVs that cannot be ignored.

Use Cases for BEVs and FCEVs

Before discussing these most recent developments for FCEVs, it is prudent to review the current challenges facing BEVs. The first is the cost. While BEV manufacturing volumes are increasing globally, battery electrics remain expensive to manufacture and purchase, largely due to the commodity metals found in the battery packs.

Despite the enormous efficiency advantage BEVs have over conventional vehicles (with much less of an advantage over FCEVs), lithium-ion batteries — the best batteries in volume production today— store 1/100th, or 1 percent, the energy density of gasoline.

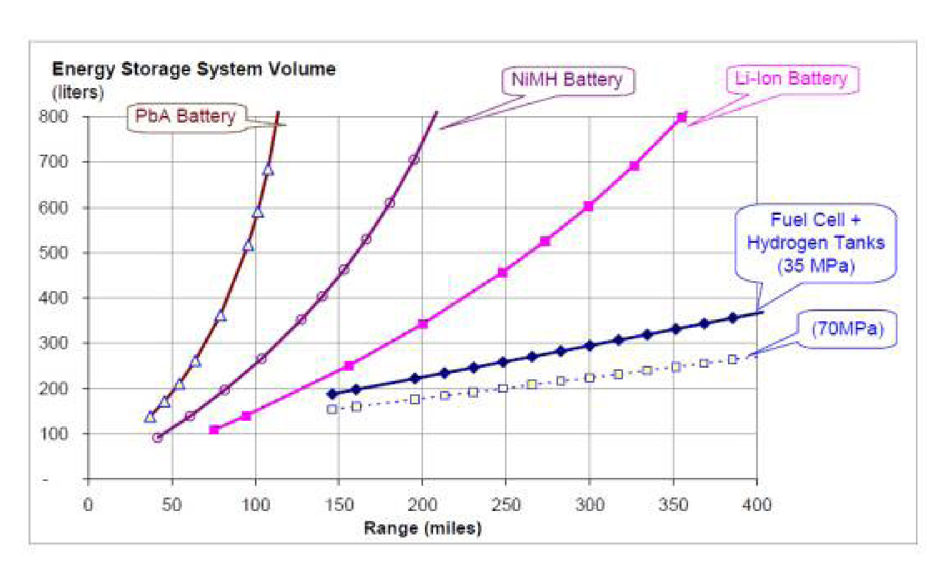
In practical terms, that means the longest-range BEV sold in the U.S. today, the Tesla Model S with the upgraded, bigger battery pack has a range just over 370 miles. The Model S costs between $79,900 and $133,000. A more affordable Chevrolet Bolt electric vehicle with a range of up to 238 miles can be purchased for around $30,000 after incentives and before taxes.

While 238 miles of range for $30k is a tremendous achievement, it's important to recognize that the Bolt is the same size as the even more affordable fossil-fueled Chevrolet Malibu, which has even more space inside and a larger trunk for much less money, and has almost twice as much driving range.

Moreover, both plug-in hybrids (PHEVs) and BEVs suffer loss of range for drivers in seasonal climates with colder winters (which is to say, much of the industrialized world).

For urban commuters, the range isn't as much an issue (but recharging is, as explained on the next page), especially since for many consumers the lower fuel costs, lower maintenance bills and acceptable purchase price — and even refueling subsidies — more than make up for the abbreviated range.

Fuel cell vehicles and conventional ICE vehicles hold an advantage with regards to driving range over BEVs; this begins to explain why BEVs are better suited for lower-power, short-range vehicles (like small city cars), whereas FCEVs are better suited for larger, more power-intensive applications like city buses or commercial vehicles.



PbA = lead acid; NiMH = nickel metal hydride; Li-Ion = lithium ion; MPa = megapascal, a unit of pressure (1MPa = 145 psi). Source: Cadex Electronics (CH)

The driving range as a function of energy storage by volume is linear on ICEs and FCEVs, but the driving range of a BEV in terms of energy storage is logarithmic.

This is one of the biggest reasons why many, including us, believe that for lighter, less power-hungry applications like city cars, BEVs make more sense, but for larger, more power-intensive applications like city buses and commercial vehicles, FCEVs are more appropriate.

Said another way, if you want more range in a gas or fuel cell vehicle, you just install a bigger gas/fuel tank . . . but because even the best EV batteries store so relatively little energy by weight and size (volume), adding additional energy storage by way of bigger battery packs doesn't create as much additional driving range and actually works against you with an increased weight penalty.

In addition to less range, BEVs face another challenge to its application opportunities: time to refuel.

Recharging BEVs vs. Refueling FCEVs

The BEV/PHEV charging station maker Clipper Creek shows the charging times with various battery electric vehicles in the extensive chart here. Charge times range from as few as 30 minutes on the Level 3, high-voltage chargers that exist to more typically 3-18 hours on home units.

Charging times are wholly dependent on the on-board battery charger, the power source and the size of battery, all of which vary widely in today's market.

For many drivers who have a garage or somewhere to charge overnight, these charge times — typically measured in several hours even on 240-volt service — are acceptable.

Especially for commercial vehicles, taking two to four hours out of an eight-hour shift to recharge is not economically plausible. For very low-powered applications, like India's electric rickshaws, having easily accessible battery packs that are swapped, more or less on the fly, becomes a very real solution to the still-as-yet-unresolved long-wait battery charging problem.

For commercial vehicles like buses or garbage trucks, the batteries become too large and heavy to easily swap.

Companies are rolling out much faster charging stations, including Tesla's V3 charging stations, just opened at their Fremont, CA manufacturing facility. These represent an advancement over the company's existing Supercharger network, which provides for faster charging times; however, we should note that these charging stations will require significant infrastructure development as the addition of these stations will be the equivalent of adding hundreds or thousands of homes to the grid.

> **Hydrogen fuel cell vehicles have a filling time of about five minutes.**

In the still-new world of charging BEVs at public stations, researchers have found that well over half of the time that BEVs park in spaces used for public charging they aren't being charged.

So even with faster charging, owners want to park and leave, thereby preventing someone else from refueling. Hydrogen fuel cell vehicles don't share this issue with BEVs, as FCEVs fill up — like their gasoline equivalents — in about five minutes. This short refilling time means that drivers aren't inclined to walk away during a refill, unlike BEVs.

Challenges of Scale

As we pointed out to investors in September 2018, the material costs of battery production aren't meaningfully diminishing despite increases in manufacturing volumes. According to the UBS "Evidence Lab Electric Car Teardown" from May 2017, there's no doubt that BEV battery costs will come down, but not as fast as the cost of fuel cell technology.

Garrett expects fuel cell technology will be 1/10th of its 2016 cost by 2025 due to economy-of-scale for increased volumes and improved manufacturing processes.

These benefits do not fully extend to BEVs because the basic challenge faced by both car companies and battery makers alike is that a substantial portion of the cost of the batteries is tied up in fairly expensive industrial metals like lithium, but especially cobalt and nickel.

Even if the industry reduces these costs down to the $100/kWh imagined by Tesla and others (Chinese batteries average $174/kWh for lithium nickel cobalt manganese batteries and $145/kWh for lithium iron phosphate batteries), the raw material costs will ultimately limit the shape of the cost curve according to experts.

It's important to note that all electrified vehicles with a traction motor have a battery. For an FCEV, the cost of its nickel metal hydride battery and much smaller size and different material makeup makes it much more affordable than the expensive lithium-ion batteries in BEVs.

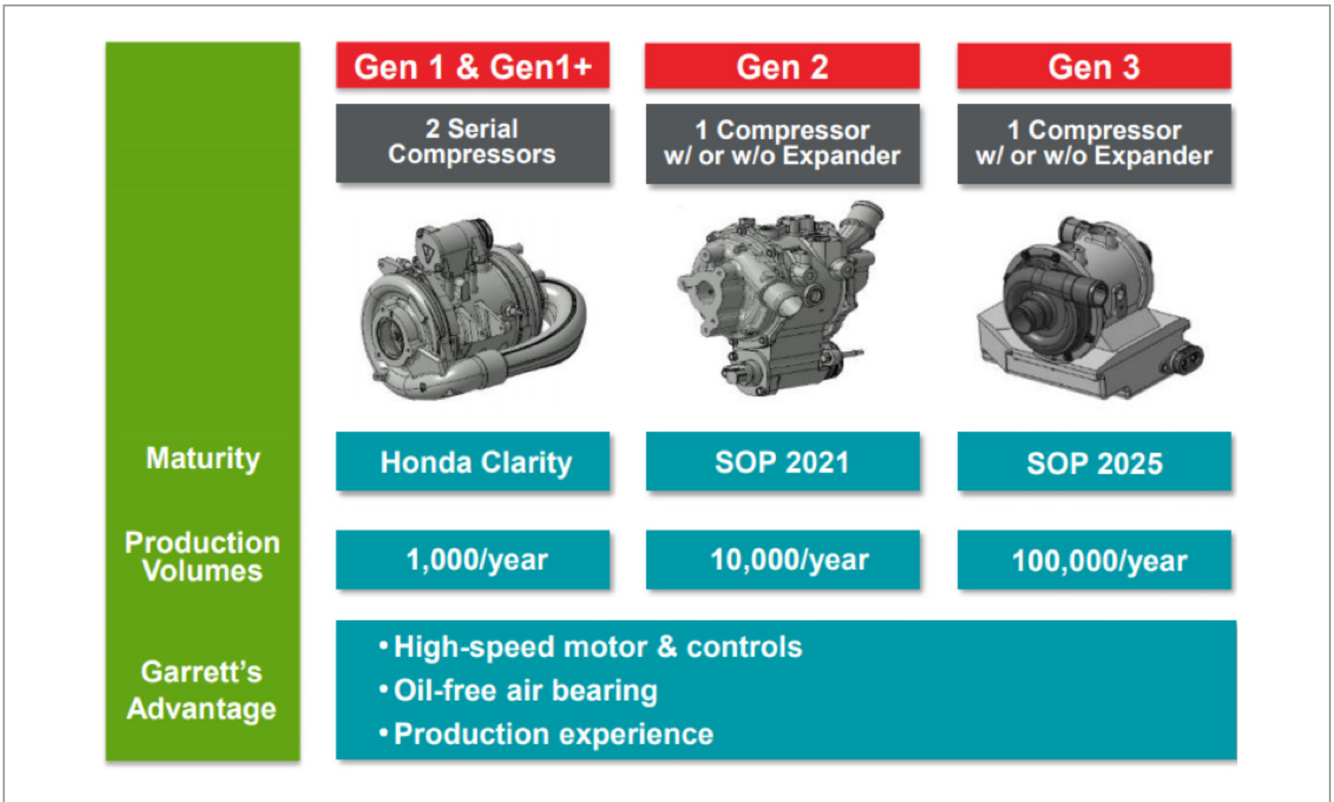
The basic challenge faced by car and battery makers alike is the substantial portion that raw industrial materials like lithium, but especially cobalt and nickel, have in the overall battery cost.

Fuel Cell Economics

Fuel cell stacks and related hydrogen technologies are seeing prices fall as volumes rise and new technologies develop rapidly. Garrett, for example, has been manufacturing electric compressors to move air through the fuel cell since 2016.

The cost for this one component is expected to be 1/10th the price of what Garrett began producing for commercial application (Honda Clarity) by 2025. Garrett is currently working with 10 different auto and truck companies to help them develop fuel cell vehicles for both passenger car and commercial vehicle applications.

GARRETT HYDROGEN FUEL CELL COMPRESSOR ROADMAP



The cost of Garrett Motion's Gen 2 compressor is expected to be 1/3 the price of the Gen 1 compressor, while the Gen 3 compressor is expected to drop to 1/10 the price by 2025. Source: Garrett Motion

The Billion-Dollar Question: Where to Get the Hydrogen

Before reviewing potential solutions to mass, industrial-scale hydrogen production, it is instructive to see these potential solutions as part of an overall "greening of the grid," that is, the global shift from fossil fuels for electricity generation to non-carbon-based renewables, namely wind, solar and hydro electrical production as well as geothermal.

The discussion about the future of both FCEVs and BEVs must take place within the context of tomorrow's green energy grid.

As a study from the National Renewable Energy Laboratory shows, moving society from fossil-fuel power plants to renewables creates new challenges for the electrical grid.

In short, wind and sun are intermittent sources of electricity, which means that other sources of electricity have to come online to provide all the power the grid demands at any given time. Today, that largely means natural gas and coal-fired plants, with pockets of high nuclear, hydro and geothermal electrical production. But it also means that there are times when electricity production from renewables could and does exceed demand. This excess energy production from renewables, if stored as hydrogen gas, could potentially power millions of vehicles.

The push to increase the renewable content of global grids will make this problem much worse. In 2018, California passed a law mandating 50 percent renewable energy by 2025, increasing to 100 percent "zero carbon" by 2045. Germany has set an ambitious goal of 65 percent by 2030.

As mentioned previously, much of the industrial hydrogen created today globally happens via steam reformation of natural gas. Clearly, using a fossil fuel to create hydrogen doesn't advance low-carbon or renewable energy goals.

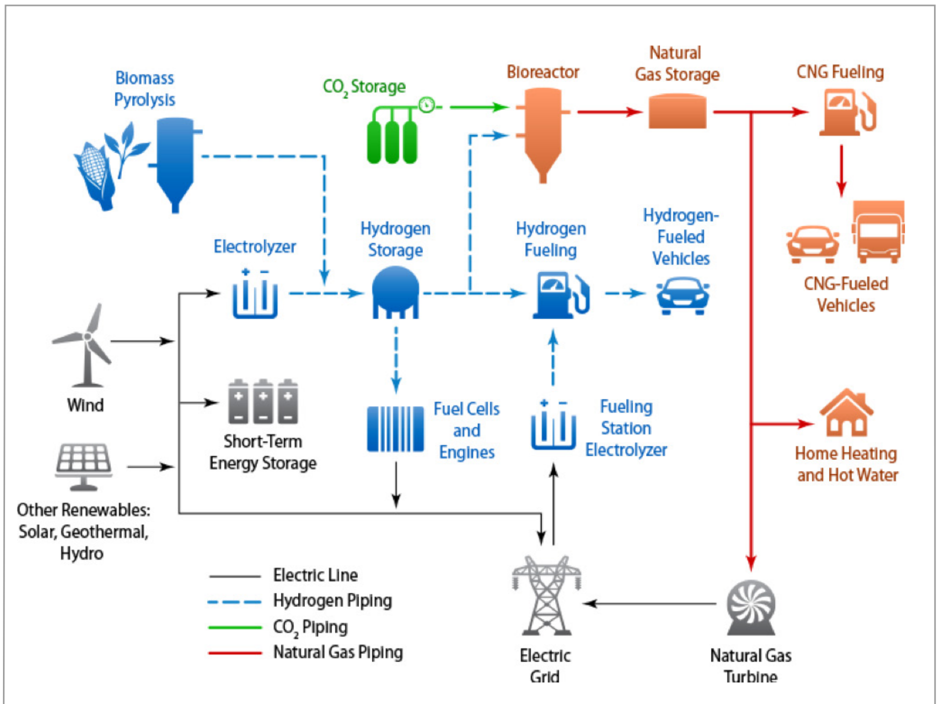
But electrolysis is a clean, albeit less efficient, way of creating renewable hydrogen from water. Essentially, an electric charge is passed through water, which separates the water into hydrogen and oxygen.

So as the green grid emerges, and these grids experience a surplus of electrical generation from uneven and intermittent renewable sources of electricity, the grid could incorporate electrolysis facilities that utilize excess electricity to create and store hydrogen.

There are other ways to store excess electrical power, the most common of which today is pumped hydroelectric storage, which takes excess power to pump water back into reservoirs, which in turn can be released to create electricity at a hydro electrical plant when demand rises. But the creation of hydrogen via electrolysis could prove an elegant and effective solution as the hydrogen can be stored for the production of additional stationary electrical production (power for the grid) or distributed for refueling FCEVs.

Some envision enormous vaults of lithium-ion battery packs storing all of the excess energy, but this isn't feasible for two reasons: the cost would be in the trillions and worse yet, these packs degrade with time. These reasons alone make storing the energy in battery packs unfeasible, but additionally, the carbon dioxide production from creating these packs would only add to atmospheric carbon emissions.

While electrolysis is less efficient than reforming natural gas for hydrogen, the energy for electrolysis in the greener grid of tomorrow would be increasingly renewable wind and solar, so that the marginal cost (both economically and in terms of CO2 emissions) of hydrogen production is relatively tiny compared to what we have today. Hydrogen fuel cells — more accurately the use of excess electricity from intermittent renewables to create hydrogen from water (and not natural gas) — represent an enormous opportunity to "store" this otherwise unusable energy as compressed hydrogen.



Source: U.S. Department of Energy's National Renewable Energy Laboratory

The chart to the left was published by the U.S. Department of Energy's National Renewable Energy Laboratory shows how renewable energy sources could feed into a broader national system for producing renewable energy and renewable electricity for residential, industrial and transportation needs.

Solid State Batteries: The Other Big Question

For many years, battery researchers have envisioned replacing the wet-solvent, flammable battery cells of today's lithium-ion batteries with inorganic, solid state materials that leapfrog the current state-of-the-art lithium-ion cells.

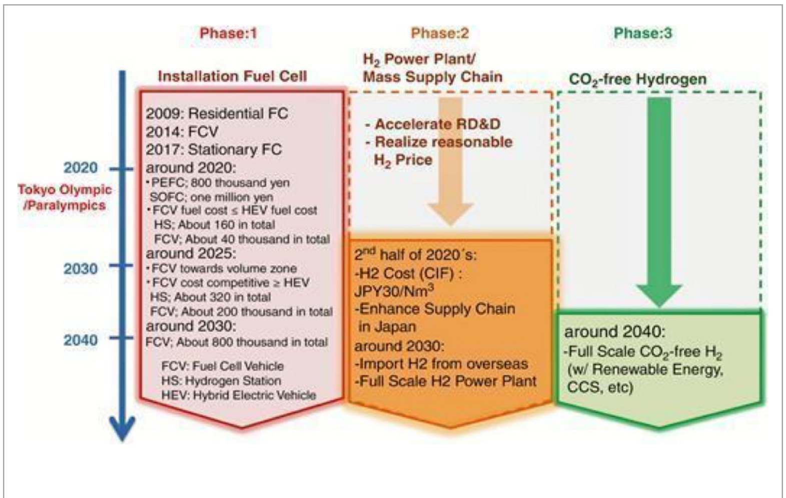
Many breakthroughs have been claimed (one Swiss company recently claimed a 4x increase in energy density over today's lithium-ion battery). And Toyota has been working on this technology for some times as well. But even if these finally become commercialized, their cost and time to recharge are still unknown. But just as lithium-ion batteries took decades to become safely and (almost) affordably industrialized, we should expect that other, new battery chemistries will take years to safely and affordably bring to mass production.

Recent Developments in Global Hydrogen Fuel Cell Policy

JAPAN

In Japan, the "Strategic Energy Plan" approved by the Japanese government in 2014 represented a serious commitment to hydrogen as way to curb energy imports and cut greenhouse gas emissions.

The Japanese Ministry of Economy, Trade and Industry (METI) subsequently published "The Strategic Roadmap for Hydrogen and Fuel Cells." It shows how Japan would utilize hydrogen, goals to be achieved in each step of production, the transport and storage of hydrogen, and collaborative efforts among industry, academia and government for achieving these goals. The roadmap sets out clear time frames for achieving the different goals with an initiative for developing hydrogen energy throughout Japanese society (including residential and commercial stationary installations). If anything, Japan's needs for providing secure sources of energy are even stronger than that of China's, and is exacerbated by Japan essentially removing nuclear from their grid in the wake of the major 2011 earthquake. Suffice to point out that Japan is extremely serious about promoting a hydrogen economy, and not just for transportation but for industrial electricity usage as well.



Source: Japanese Ministry of Economy, Trade and Industry (METI)

CHINA

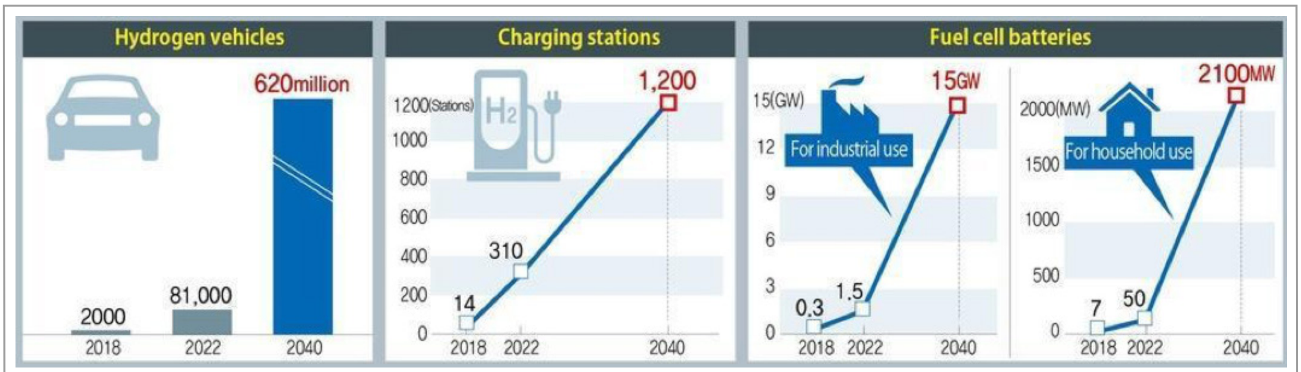
China remains an expected global supporter of fuel cell technology having spent more the equivalent of more than $12 billion via national and local subsidies in 2018. China was largely expected to continue fuel cell subsidies through 2025, as it looked to turn away from BEV subsidies. As we enter 2020, the situation is less clear. The government has signaled confirmations of subsidy support through the year but have not provided clarity for 2021 and beyond.

Should Chinese officials turn to subsidies as a tool to positively boost a slowing economy going forward there is reason for optimism. Beijing's subsidies have a long history of drawing new startup investment capital, especially when the new FCEV subsidies go as high as $30,000 per vehicle to the manufacturer, thereby ensuring profits. Some local governments in China are adding additional subsidies to the mix, helping the hydrogen future accelerate even faster. Beijing now has a target of 1 million fuel cell vehicles on the road by 2030. But even in a situation where policy support is more limited, a rationalized market could stabilize around the strong players that already exist in China. With reports of more than 1,000 fuel cell vehicles already on the roads, these companies compete on the global scene and would be expected to move forward.

The other strategic reason to support FCEVs compared to BEVs in China is the differences in the mined metals required in enormous volumes for the two technologies. While current battery technology for BEVs require cobalt, lithium and nickel, fuel cell stacks only require metals from the platinum group, of which there is plenty in fungible global markets. Furthermore, the recent technology developments require far less platinum than in previous generations.

SOUTH KOREA

South Korea faces many of the same strategic energy constraints as do China and Japan; in response, the South Korean government just earlier this year released a very ambitious government plan to revolutionize South Korea's energy future using hydrogen.



Roadmap for a hydrogen economy by 2040. Source: South Korea Ministry of Trade, Industry and Energy

South Korea is a technology juggernaut and its government is convinced that it can leverage existing tech advantages to leapfrog regional and global competition on its way to hydrogen supremacy. “South Korea possesses advantages with its world-class technology in areas including hydrogen fuel cell electric vehicles and fuel cells, its top-of-the-line petrochemical base, its production capabilities and usage experience with byproduct hydrogen [produced as part of the petrochemical process], and its fully equipped nationwide natural gas supply capabilities,” says Cheong Seung-il, Vice Minister of Trade, Industry and Energy.

> *South Korea possesses advantages with its world-class technology in areas including hydrogen fuel cell electric vehicles and fuel cells, its top-of-the-line petrochemical base, its production capabilities and usage experience with byproduct hydrogen [produced as part of the petrochemical process], and its fully equipped nationwide natural gas supply capabilities.”*
>
> **CHEONG SEUNG-IL, VICE MINISTER OF TRADE, INDUSTRY AND ENERGY.**

Successful FCEV Programs on the Road Today

1,000 NEW HYUNDAI FCEV GROCERY TRUCKS IN SWITZERLAND

Hyundai announced in late 2018 that it would deliver 1,000 hydrogen fuel cell trucks to grocery giants Coop and Migros in Switzerland; Coop already installed the first public hydrogen filling station in canton Aargau in 2016. The project is a good example how existing industrial giants like Hyundai could work with emerging companies (in this case, Swiss start-up H2 Energy, that will take care of maintaining the fleet) to begin to build a hydrogen support system.

As the earlier page six graph pointed out, for medium distance, energy-intensive transportation, hydrogen is particularly well-suited where expensive, heavy and increasingly large battery packs would be less viable.

CALIFORNIA LEADING: PORTS OF LONG BEACH AND LOS ANGELES

Strong public-private partnerships, backed by the long-standing environmental leadership of the California Air Resources Board, have made the State of California a standard-bearer for fuel cell programs worldwide. The well-know, long-standing challenges of air quality (smog) in Southern California especially have helped build a broad consensus for experimenting with new technologies, fuels and transportation policies.

Today, California has more fuel cells on the road than anywhere in the world and is now in the middle of several FCEV programs to help clear the air at two of America's biggest commercial ports. Even Long Beach's aquarium is installing three stationary fuel cells to offset its electricity use by 80 percent (1.2 megawatts installed).

Much of the work being done, including 10 Class 8 trucks that will help bring goods from offshore docks to warehouses in nearby Ontario, Canada, is aimed at radically improving the air quality at these ports. There are also several drayage and material-handling FCEV programs, along with on-site hydrogen fueling stations, all of which are proving out the feasibility of FCEVs to address air quality at these busy ports. Current/Forthcoming Production Fuel Cell

Current/Upcoming Production Fuel Cell Electric Vehicles

TOYOTA MIRAI AND HONDA CLARITY

Both Toyota and Honda have been working on fuel cell technology for more than a decade and both have midsize FCEV passenger cars available for sale (and/or lease). The Toyota Mirai has a range over 300 miles, takes five minutes to charge, seats five and includes $15,000 worth of free fuel for the first three years. Its MSRP of $58,500 is mitigated by $5,000 in state subsidies in the State of California (where most of the FCEV and hydrogen filling station exist today in the U.S.) in addition to $7,500 in rebates from Toyota.

The Honda Clarity has an equivalent fuel efficiency rating of 68/67 MPGe and a range of 360 miles. Honda is offering Clarity on three-year leases for $379/month with $2,878 down and is only available in California. Like the Mirai, it also comes with $15,000 of free hydrogen and appeals to Californians especially since it is eligible for a HOV sticker. Garrett has supplied the fuel cell electric air compressor on the Clarity FCEV since 2016.

HYUNDAI NEXO

The Hyundai Nexo is also available for purchase now, and like the Honda, takes advantage of the company's previous generation of fuel cell vehicle (in this case, the Hyundai Tuscon fuel cell vehicle). Range bests the other two vehicles at an EPA-estimated 380 miles, and unlike the Toyota and Honda, the Nexo comes in a shape more and more of the world's drivers prefer, the SUV/Crossover.

DAIMLER GLC F-CELL (EUROPE)

On sale today in Europe is Daimler's unique GLC F-Cell Plug-In Hybrid, an SUV that combines hydrogen and battery power for combined range of approximately 298 miles. On-board hydrogen tanks can be filled in less than four minutes.

AUDI H-TRON (2021)

Audi Chairman Bram Schot told reporters in May of this year that Audi would be the center of competence for the VW Group and that Audi had serious concerns about sourcing the raw materials for increasing volumes on batteries for BEVs. "We really want to speed it up," Schot said. "We are going to put more priority into hydrogen fuel cells — more money, more capacity of people and more confidence."

The pilot program would have production based in Neckarsulm, Germany, where the Audi A6, A7 and A8 are currently produced.

WEICHAI AND BALLARD

In late 2018, Weichai (China) and Ballard Power Systems of Canada inked a deal that would have Ballard supply 2,000 fuel cell stacks to Weichai for commercial vehicle propulsion. According to Green Tech Media, Weichai agreed to purchase a 19.9 percent stake in proton-exchange membrane fuel cell pioneer Ballard for $163 million, representing a 15 percent premium to the latter's stock price. This created a $90-million technology transfer program for Ballard's next-generation fuel cell stack and power modules, and a joint venture to pursue China's fuel cell EV market.

Conclusion

After years of being considered "pie in the sky" technology, fuel cell electric vehicles (FCEVs) are gaining traction in global markets; FCEVs are better suited for higher-power, heavier applications for both passenger and commercial vehicles, while BEVs are better suited for shorter-range, lower-power vehicles. Especially in larger applications where big, increasingly expensive batteries yield diminishing marginal returns in driving range, fuel cells are proving to be increasingly viable for a variety of uses. While battery breakthroughs may change market dynamics in years to come, the challenges of battery technology to economically scale, despite much higher manufacturing volumes, means that fuel cells have become increasingly attractive to regulatory bodies worldwide, the auto industry and even high-profile influential consumers, showing that FCEVs are well on the way to mass appeal.

Lastly, the ability for electrification and hydrogen fuel cell production to work together brings more efficiency and balance to the developing renewable energy grid of the future, providing a map away from fossil fuels.

RECENT QUOTES ON FUEL CELLS AND BATTERY ELECTRIC VEHICLES

> *Benefits of fuel-cell vehicles include long driving range, short refueling time and zero emissions...battery electric vehicles, which are currently more popular, can't meet the needs of long distance buses, taxis, or urban logistics and long-haul transport due to their short driving range and long charging time."*
>
> **WAN GANG – DEPUTY CHAIRMAN OF THE CHINESE PEOPLE'S POLITICAL CONSULTATIVE CONFERENCE.**

> *FCEVs are already regarded as a better option than EVs in the HD/CV vehicle segment...fuel cell technology appears to be a viable option for designing HD/CVs with zero emissions, as FCEVs have suitable driving ranges and recharge times."*
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> **KEN NIHONYANGAI AND WIZUHA WATANABE, RESEARCH ANALYSTS AT BANK OF AMERICA MERRILL LYNCH RESEARCH NOTE ON TOYOTA, MARCH 18, 2019.**

> ***Focus of FCVs has shifted to commercial vehicles:*** *While Toyota continues to talk about the development of FCV passenger cars, its recent efforts have been focused on commercial vehicles. At the ports of Los Angeles and Long Beach CA, Toyota and Kenworth have launched the next generation of FCV concept trucks that offer an estimated range of 300 miles per fill, hauling cargo throughout the LA Basin. Since the project launched in April 2017, the trucks have logged more than 14,000 miles of testing and real-world drayage operations. A total of 10 new trucks from Kenworth/Toyota will start moving cargo including 4 trucks for Toyota Logistics Services and 3 for UPS."*
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> ***"Buses a second area of FCV focus:*** *In March 2018 Toyota launched sales of the Sora FCV bus, which has received vehicle certification in Japan. It targets having at least 100 FCV buses on the road by the time of the Tokyo Olympics in 2020. The focus on commercial vehicles makes it easier to deal with the challenge of developing a network of refueling centers, as commercial vehicles typically operate on predictable routes. As the infrastructure gets built out, there could be renewed interest in FCVs for passenger use, which for now is likely to remain a niche area."*

*“**FCVs seeing rapid development in China:** China’s unrelenting campaign to reduce dependence on imported oil and improve air quality has led to a broadening of its NEV strategy to focus more on FCVs, especially for commercial use. Toyota has moved swiftly to take advantage of this. In April Toyota announced it would be working with Beijing Auto subsidiary Beiqi Foton Motor to supply FCV equipment and hydrogen tanks. This month Toyota has announced similar agreements with Chinese automaker FAW and Higer Bus to supply parts for hydrogen-powered buses.”*

*“**Better potential for commercial use of FCVs than BEVs:** Overall we believe that FCVs offer a better alternative to BEVs for commercial vehicles (CVs) including trucks and buses due to the fast-refueling time. While refueling infrastructure is the biggest near-term challenge, once the infrastructure is in place, it makes use of the CVs as efficient as diesel trucks. Further, given the intensity of use of CVs, the lack of degradation in the battery over time compared with BEVs is a positive.”*

FROM ANALYST NOTE ON TOYOTA BY JANET LEWIS, CFA AND SHENTAO TANG, ANALYSTS FOR MACQUARIE CAPITAL SECURITIES (JAPAN) LIMITED, JULY 18, 2019

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