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Fuel Cell as Range Extender in Battery Electric Vehicles for Supply Chain Fleets

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Additional information is available at the end of the chapter

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Abstract

The aim of this chapter is to present an outlook about implementation of a range extender system based on fuel cells for battery electric vehicles. Such a system is highly feasible to be implemented in electric vehicles, in particular those used by beverage industry in city centres. The tourism is another industry that uses electric vehicles, for instance in resorts, hotels, airports, zoos, etc. As well, public transportation is another sector involved with this vehicular technology. These sectors are all the time looking for high efficiency and low costs; however, they also need to extend the range of the vehicles to fulfill some logistics requirements in a route. This chapter presents a numerical example for illustrating an implementation of fuel cell range extender system. Advantages, disadvantages, and business opportunities in fuel cell technology are presented.

Keywords: fuel cells, range extender, electric vehicles, supply chains, utility cars, renewable energies

1. Fuel cell overview

In the beginning of 2016, the Fuel Cell Technologies Office of the US Department of Energy (DOE) released its 2015 recapitulation on the advances on fuel cells and related application technologies.¹ Fuel cells are electrochemical devices, similar to batteries, that convert the chemical energy of a compound (i.e.) directly into electricity; therefore they are electricity generators. The

¹ It is well recognized that DOE's technology and economic goals are taken as serious global reference for those involved and interested in advanced technologies, such as fuel cells, that can bring promising alternatives for the transportation sector. (Fuel Cell Technologies Office: 2015 Recap and the Year Ahead, email news service sent to authors and generated on behalf of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy).

main difference of a fuel cell, compared to a battery, is that the fuel is stored outside the fuel cell and is continuously fed to the generator. As the fuel is physically stored in a tank, there is no need to recharge the fuel cell but instead the fuel tank is refilled, which only takes a few minutes. In spite of the cost needed to produce it and store it, the preferred fuel for transportation fuel cells is compressed hydrogen gas. Hydrogen has almost three times more energy² (33.33 kWh/kg) than gasoline (≈ 12.0 kWh/kg) per unit mass and when fed to a fuel cell, the energy conversion efficiency for electricity generation is much higher (up to 60%) compared to internal combustion engines. Besides, when using hydrogen as a fuel, the only emission is pure water and some heat.

DOE's communication highlights several recent accomplishment but what stands out as the "most notable" fact is the availability today of commercial personal vehicles by Toyota and Honda using fuel cells technology. Using fuel cells in a car means electrical traction (electric transportation) with zero emissions, similar or larger range compared to conventional gasoline cars and the possibility of having a replacement for gasoline, i.e. hydrogen fuel. What is also interesting about hydrogen is that although it does not exist freely in nature, it is contained in several available compounds, notably in water. Besides, when combined with renewable energy sources for its production, for example via electrolysis, hydrogen becomes a sustainable and clean fuel for energy use.

The same way gasoline is an added value product, hydrogen is also seen as an energy carrier once produced and stored, an important fact is that its availability can be seen as the other attractive side of the fuel cells business.

Besides these two car companies, other international car manufacturers have fuel cell cars programs with the intention of selling them in the near future. Beyond recognizing a car market of more than 82 million cars sold annually according to consulting firm IHS Automotive [1], is that the automotive industry will have to renew its infrastructure industry, including its value and supply chains, as fuel cell cars are completely different from conventional cars in its components. Instead of an internal combustion engine, FC cars have an electricity generator which is coupled to an electric motor that provides power for traction. To properly operate, the electric motor will require power electronics to condition the unregulated d.c. voltage electricity coming from the fuel cell. Fuel cell devices are a completely different technology from what we know now, they incorporate electrochemical engineering components like electrodes, electrolytes, electric and structural pieces that give rise to a brand new industry. Fuel cells as generators will need its own balance of plant (BOP), which will keep the fuel cell operation at a level that ensures power delivery as specified. BOP components include gas valves, fuel piping, sensors, and activated elements, supervised by an electronic control. Such electronic control takes care of variables such as fuel pressure and flow, fuel cell temperature, oxidant (typically air) flow into the fuel cell, and a very complex balance of water content inside the system produced by the reaction and that is needed to lower electrolyte resistance but if abundant it may lower power production.

² Hydrogen lower heating value, taken as reference from *HyWeb The Hydrogen and Fuel Cell Information System*, managed by Ludwig-Böw-Systemtechnik GmbH, Germany

If the car industry is going to switch to electric cars as the main technology and where probably fuel cells are the preferred choice, then car manufacturers will need to change their actual production line based on mechanical and thermal components to a more chemical engineering and electric/electronics-like industry.

As the fuel cell industry has consistently grown in the last few years at a 30% rate and with more than 50,000 fuel cells totaling over 180 MW capacity shipped in 2014, that amounts sales of more than \$2.2 billion that year, this technology is being reaching maturity with an undeniable impact in energy markets, including transportation and definitely in our society.

While the latter is true, the economics still depend on the production volume to approach competitive targets, at least in the transportation sector, particularly personal mobility vehicles. An example of this is that state-of-the-art fuel cell system technology is projected to reach a cost of \$55/kW at a volume of 500,000 units per annum (upa) or \$270/kW at 20,000 upa. On the fuel side of the story, high-volume cost projections for 700 bar compressed hydrogen storage systems based on composite materials are \$15/kWh. This gives an idea of what the retail costs can be when fuel cell-based vehicles are introduced in the transportation market.

Another subsector in transportation is the utility vehicles market that covers a large proportion of vehicles sold in the world. In this subsector, costs are a second priority against productivity. An example of this is the possibility of extending the range or the number of hours of operation of utility vehicles such as forklifts, auxiliary vehicles at airport operations. A similar situation presents when we talk about backup systems that increase reliability to critical operations like banks, hospitals, data handling centers, among other industries. It is important to mention that the economic activities and investment opportunities go beyond the final sale of a fuel cell system. The application of fuel cell technologies also represents the need for value chains, especial technical services, new tools and instruments, as well as protocols during services, new components specifically dedicated to the application. Examples are power electronics, sensors, new fuel storage systems, their testing, etc. There is no doubt that the introduction or now arrival of these technologies means a varied range of opportunities for new businesses.

2. Classification of electric vehicles

A typical classification of the electric vehicles is illustrated in **Table 1**, as well some main features of each [2].

This chapter deals with the implementation of a range extender system in a BEV, which means in practical terms that a BEV is converted to an FCEV. The typical powertrain of an FCEV is shown in **Figure 1**.

The fuel cell is connected to the inverter (DC-AC converter) through a DC-DC converter; meanwhile, the battery bank is directly connected to the inverter. The traction motor is driven by both power sources to provide mechanical power to the tires.

Hybrid electric vehicles (HEVs)



HEV uses a battery-powered electric motor to supplement its traditional combustion engine. The electrical system acts as a generator when a driver applies the brakes, converting kinetic energy into electrical energy. Combustion engine is still the primary motor. At low speed the vehicle operates with zero emissions.

Plug-in hybrid electric vehicles (PHEVs)



A PHEV operates similar to a HEV. However, it utilizes a larger battery bank that can be recharged by plugging the vehicle into an electrical outlet or charging station. After the battery energy is exhausted, the engine starts and the vehicle acts like a normal HEV.

Battery electric vehicles (BEVs)



The BEV operates a 100% with the battery bank. They do not include a combustion engine and rely solely on their electric motor for propulsion.

Fuel cell electric vehicles (FCEVs)



The FCEV operates with a fuel cell as the main power source. The energy comes to the hydrogen tank. The batteries are used to absorb high peaks of currents, while fuel cell provides the principal energy requirement.

Table 1. Classification of electric vehicles

In the electrical vehicle classifications, BEV is one of the most supported by governments, in particular in china [3], because this vehicle has not an internal combustion engine to its operation. Therefore, there are no emissions in site. However, some important issues that limit the use of the BEVs are charging time and range of the vehicle [4]. Especially, when these vehicles are in a daily regimen of operation. A solution to overcome those issues is to install a fuel cell pack as the main power source of the vehicle. Unlike batteries, fuel cell systems can recharge the energy (hydrogen) in a few minutes. Fuel cell systems can reach a range similar to the internal combustion engine car, because the range depends of the hydrogen tank and as it was mentioned in Section 1, hydrogen has three times more energy than gasoline.

Table 2 shows the range of some BEVs, PHEVs, and an HEV [5]. The range for a BEVs is between 110 and 334 km. For PHEVs, the range is between 18 and 61 km, and the range for a HEV is 2 km.

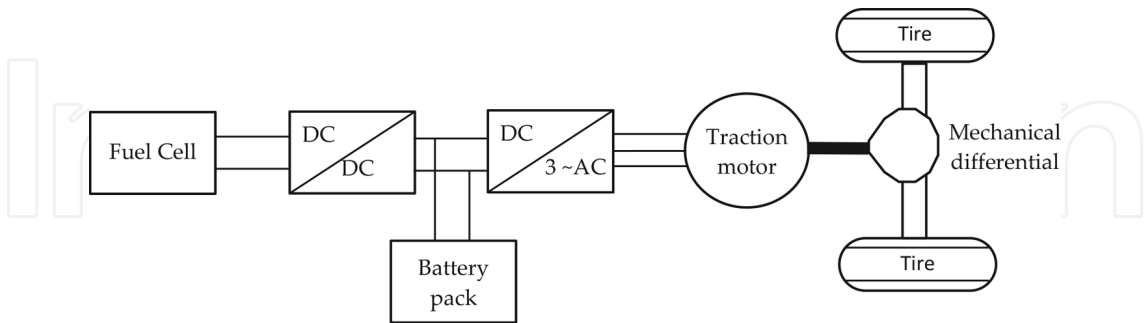


Figure 1. Typical powertrain for a FCEV.

	Type	EPA car class	Battery type	Energy storage	All-electric driving range	Full charge
Tesla Model S	BEV	Large	Li-ion	60 kWh	334 km	1 hour
BMW i3	BEV	Compact	Li-ion	18.8 kWh	128–160 km	3–6 hours
Chevrolet Spark	BEV	Compact	Li-ion	21 kWh	132 km	7 hours
Chevrolet Volt	PHEV	Mid-size	Li-ion	16.5 kWh	61 km	4 hours
Nissan Leaf S	BEV	Mid-size	Li-ion	24 kWh	135 km	4 hours
Toyota Prius Plug-in	PHEV	Mid-size	Li-ion	4.4 kWh	18 km	1.5 hours
Toyota Prius	HEV	Mid-size	Ni-MH	1.3 kWh	2 km	N/A
Ford Focus Electric	BEV	Large	Li-ion	23 kWh	122 km	3.6 hours
Honda Fit EV	BEV	Mid-size	Li-ion	20 kWh	132 km	3 hours
Smart for Two Electric	BEV	Two-seaters	Li-ion	17.6 kWh	110 km	6 hours

EPA car class: The United States Environmental Protection Agency (EPA) has developed a classification scheme used to compare fuel economy among similar vehicles. Passenger vehicles are classified based on a vehicle's total interior passenger and cargo volumes.

Table 2. Battery specifications of 2014 electric vehicles.

3. Electric vehicle fleets in sustainable supply chain

Since many years ago, there are companies taking advantage of features offered by electric vehicles. Just to mention a few, they are zero emissions, low noise, and low maintenance. These features make this kind of vehicle the most convenient to distribute products related with the

beverage industry or any other in city centres. There are also other sectors like hotels, airports, zoos, resort, etc., where this kind of vehicle is widely used.

Some advantages that make this kind of vehicle a good alternative are listed below:

- *No emissions*: Many times, this is the main reason why industries decide to include electric vehicles in delivery process. Electric cars produce zero emissions on site, but emissions are at energy productions sites, but if energy is obtained by renewable sources, in practical terms, there aren't emissions.
- *Low maintenance*: An electric motor has lesser pieces in movement, in related with an internal combustion engine. Therefore, electric motor needs less lubrication and maintenance.
- *Lower noise production*: Electric motors have the capability of providing smooth drive with higher acceleration.

But also some disadvantages of electric vehicles are listed next:

- *Power source replacement*: It depends on the power source type, but in general terms, electric power sources (batteries and fuel cells) must be changed every 3–10 years.
- *Recharge points*: Both electric and hydrogen fuelling stations are not still in everywhere. Many efforts have to be done to install recharge points.
- *Recharge time*: Recharge time usually is an inconvenience in batteries because they need about 4–6 hours. But hydrogen recharge in fuel cells takes only few minutes.

The automotive industry, as one of the largest industries worldwide, has a big influence in the emission balance. The electric vehicles fleets for delivery goods purpose are a small portion of automotive market. However, this market is still growing due the advantages described before and many incentives like tax reduction, among others.

Several important companies in worldwide beverage industry, like Coca-Cola and PepsiCo, have electric vehicles fleets in their portfolio. It allows them, in addition to make more sustainable their process, deliver its products avoiding some restriction for driving in downtown of several cities.

Sustainability for such companies' represents not only an economic or environmental issue to deal with but also a regulation issue, because even when emission is a problem in big cities, not always they have constraints for movements of vehicles. When movement is a constraint, the only way to carry out many commercial activities is using electric vehicles.

In **Figure 2** is presented a general flowchart of supply chain delivery process used in the beverage industry. The process starts with the production of the syrup or some other raw material. Next, this raw material is used in the plant to filling the bottles. As is well known, bottling plants are in specific zones to provide the product for several cities. The bottled products are sent to distribution centers to conduct the supplying in the city. From distribution centers, the product is sent to supermarkets and many other points of sale (groceries, restaurants, etc.) in the city. Finally, the consumer goes to these places to buy the product.

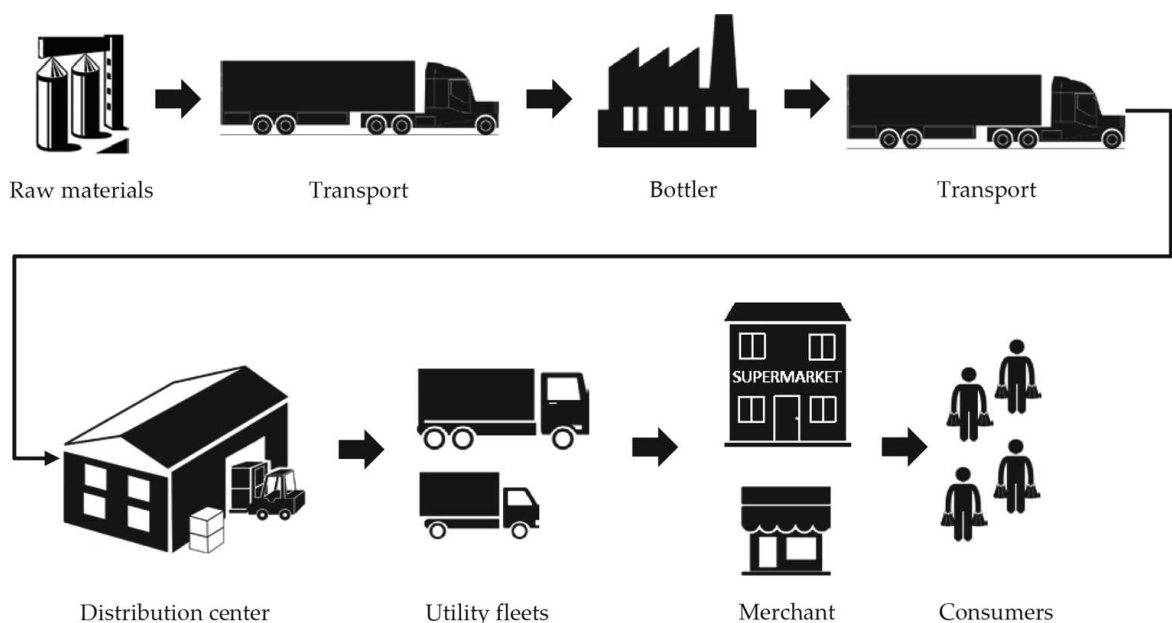


Figure 2. General supply chain in beverage industry.

The stage that we study in this supply chain is where utility vehicles fleets are used. In particular, we are going to evaluate the implementation of a fuel cell range extender system, taking into account that electric cars are used in this stage. As we mention before, many companies are using electric cars, among other things, to make sustainable their supply chain. However, there are some downsides like recharge time and range that must be addressed to overcome it. A highly efficient and friendly environmental solution is the implementation of a range extender based on fuel cells.

3.1. Market for electric vehicles

There is a wide size range of electric vehicles. For example, there are golf cars from about 500 kg, cars of 1200 kg, or heavy utility trucks of 12,000 kg. **Figure 3** illustrates those vehicles.



Figure 3. Electric vehicles.

An electric car type “Golf cars” is also usually used in places like airports or zoos. Cars are mainly used for personal transportation. Utility cars are used by companies for commercial purposes. The size of these cars depend on the specific application.

The next section presents a numerical example for a range extender system based in a fuel cell for a BEV. Some economical and technical issues related with such a system are shown.

4. Case study for a range extender

4.1. Methodology

This section presents a case of study of a BEV, in which as a proposal, the power source is modified to increase its range. For this purpose, a PEM fuel cell is dimensioned in such a way that the car is turned from a BEV to an FCEV. The processes for estimating it is conducted through a tool developed at Electrical Research Institute (IIE) and its flowchart is depicted in Figure 4.

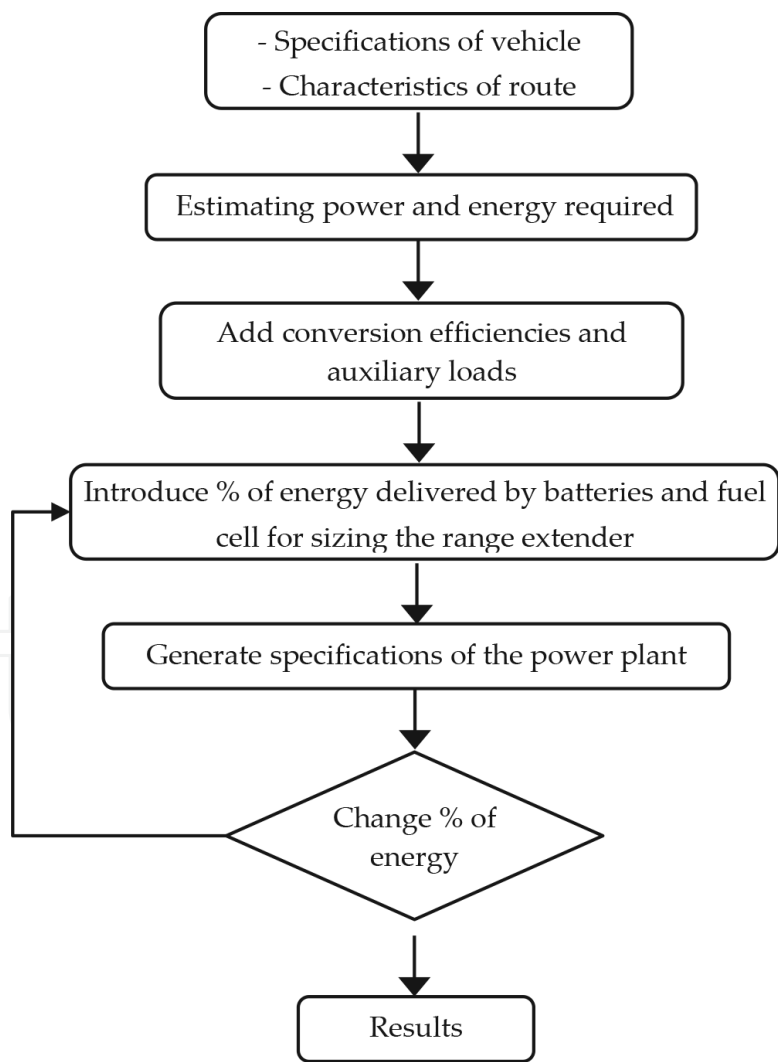


Figure 4. Flowchart to estimate a range extender based on fuel cell.

To conduct the study, first it is necessary to define some characteristics of the vehicle, like dimensions, weight, frictional coefficient, rolling resistance, etc. At the same time, the route is defined to evaluate the vehicle’s performance. Next, the power and energy required in the vehicle power plant is calculated. Then, the conversion efficiencies of electronic and mechanical elements are added, as well as the auxiliary loads. It is important to take into account the foregoing to obtain a better estimation of the energy required for the power plant. After that, the specifications of the power plant based on batteries are generated. As a result, useful information such as weight, cost, volume, is shown. The developed tool allows us also to estimate the size of the range extender system. For this purpose, we use the percentage of energy required from the battery bank and the fuel cells. We do it using both current and future prices of fuel cells. In summary, three cases of study were conducted. Finally, some conclusions are depicted to compare the performance of the vehicle using batteries and the range extender (batteries + fuel cells).

4.2. Cases of study

4.2.1. Characteristic of vehicle

For starting, this study defined the vehicle's characteristics and the route. While more information is used, results will be closer to a real operation. For this study, the vehicle information shown in **Table 3** is used.

Data	Value
Maximum height	1.82 m
Maximum width	1.2 m
Maximum length	3.0 m
Drag coefficient	0.80
Frontal area	2.18 m ²
Overall weight	700 kg
Rolling resistance coefficient	0.015

Table 3. Vehicle information

The characteristics described in **Table 3** are similar to the features of electric vehicles that are usually used in beverage industry fleets for distributing their products in city centres.

4.2.2. Characteristic of the route

The main concern of this chapter is the evaluation of range extender system, as well its impacts in supply chains; we used a simple route consisting of 32 km to be covered in 5.7 hours. This route consists of a first trip of 4 km, then, there are 60 delivery points where the vehicle stays

5 minutes in each. Finally, there is a trip of 4 km until the starting point. **Figure 5** depicts the characteristics along the route, in terms of distance and vehicle's speed.

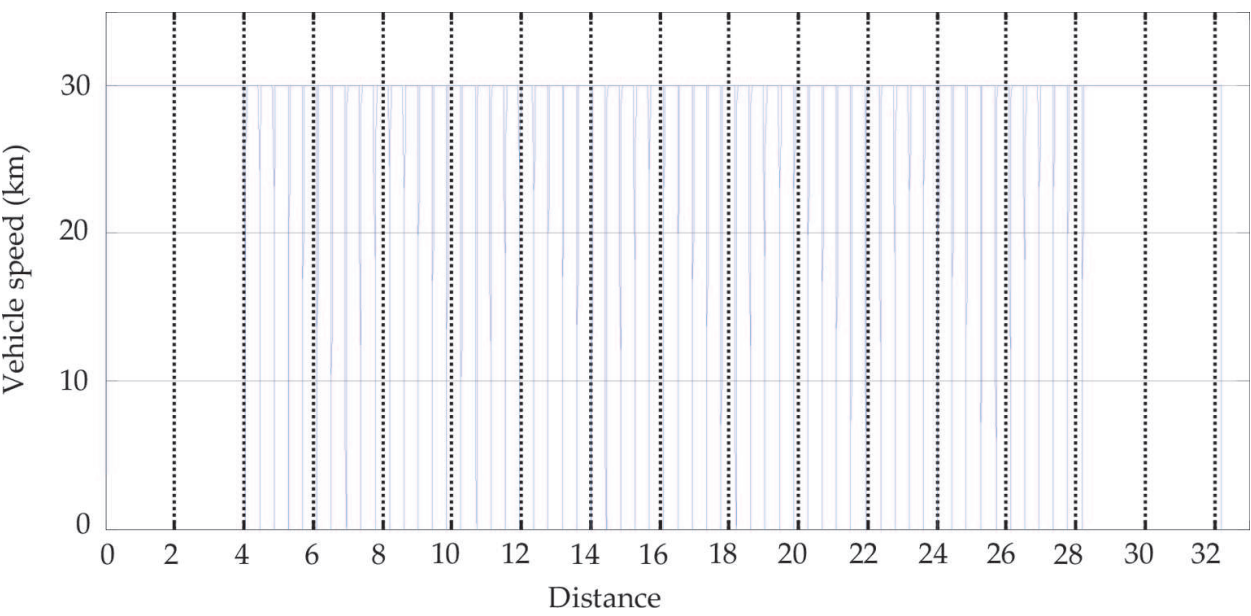


Figure 5. Speed along the route.

It is important to highlight that many other issues could be included in this analysis, like regeneration breaking system, as well a more specific route. However, it will depend on the specific system to be evaluated. Therefore, results presented in next section correspond to a scenario created to show the capabilities of the tool and issues related to the fuel cell range extender, to fulfill logistic requirements in some electric vehicles that frequently are used in a supply chain fleet.

4.2.3. Case studies description

Case	Power plant	Net energy delivered by source (%)	
Batteries	Fuel cells		
1	Current	100	0
2	Current	7	93
3	Future ^a	7	93

^aOver a mass production rate of 20,000 units per year [6].

Table 4. Description of case studies

According to the information in **Table 4**, three case studies were conducted. Additional to this information, a conversion efficiency of 95% for motor controller (DC/AC) and DC-DC converter, 95% for electric motor, and 90% for mechanical differential were used, see **Figure 1**. In

the first case, the vehicle travels 32 km according to the route. However, in cases 2 and 3, the vehicle also travels 32 km but it has the availability for incrementing the delivery points from 60 to 120, according to the energy reserve in the battery bank.

4.2.4. Specification of power plants and results

Until now, there is enough information for sizing the power source in the vehicle. For this purpose, we used the physical characteristic of the vehicle described in **Table 2**, the speed illustrated in **Figure 5**, as well the efficiency values of electro-mechanical elements in the vehicle. As a result, Figure 6 shows the power demand along the route. The energy required for the power plant for this specific route corresponds to 2.2 kWh (kilowatt hour).

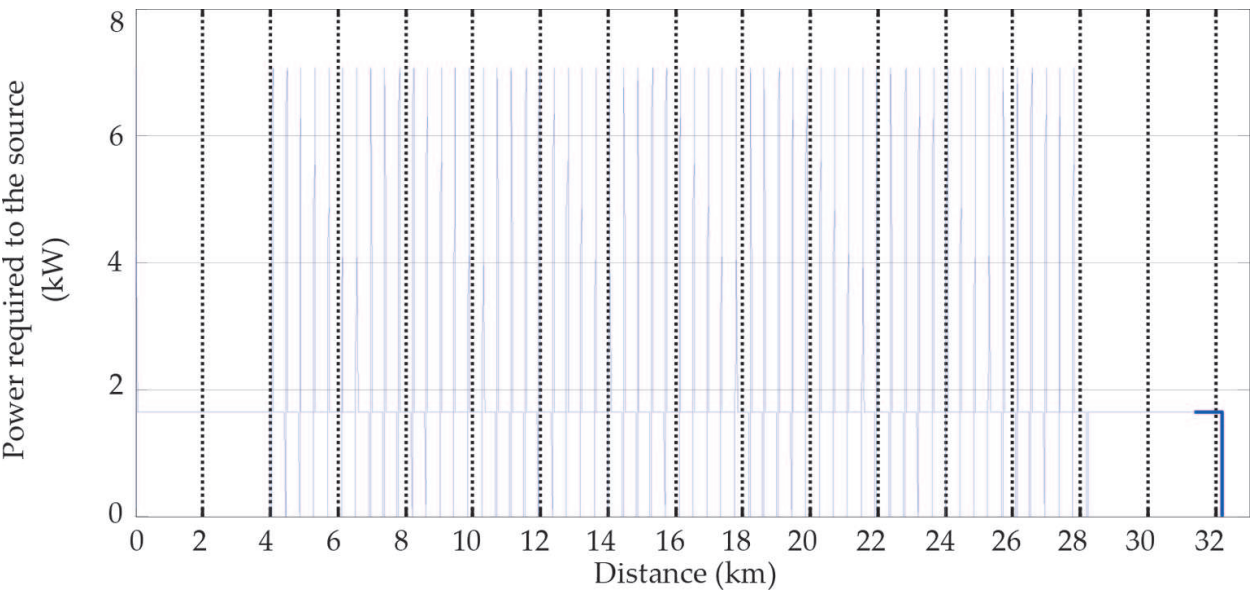


Figure 6. Distance vs power.

4.2.4.1. Case 1: Power plant based on batteries

Lithium-ion batteries	
Energy	2.7 kWh
Voltage	48 V
Weight	14.6 kg
Volume	0.004 m ³
Cost (USD)	\$ 3550
Vehicle range	32 km

Table 5. Specification of the power source (batteries).

Table 5 illustrates the characteristics of the battery bank dimensioned for the vehicle. The features of this power source are generated specifically to supply the power demand shown in **Figure 6**.

The state of charge (SOC) of the battery bank is depicted in **Figure 7**. As it is shown, the energy in the battery bank is gradually reduced along the route, until it covers all delivered points. It is well known that battery banks always are dimensioned to keep some percentage of charge at the end of the route; either for facing some extra energy required in the route or to increase the useful life of the battery bank.

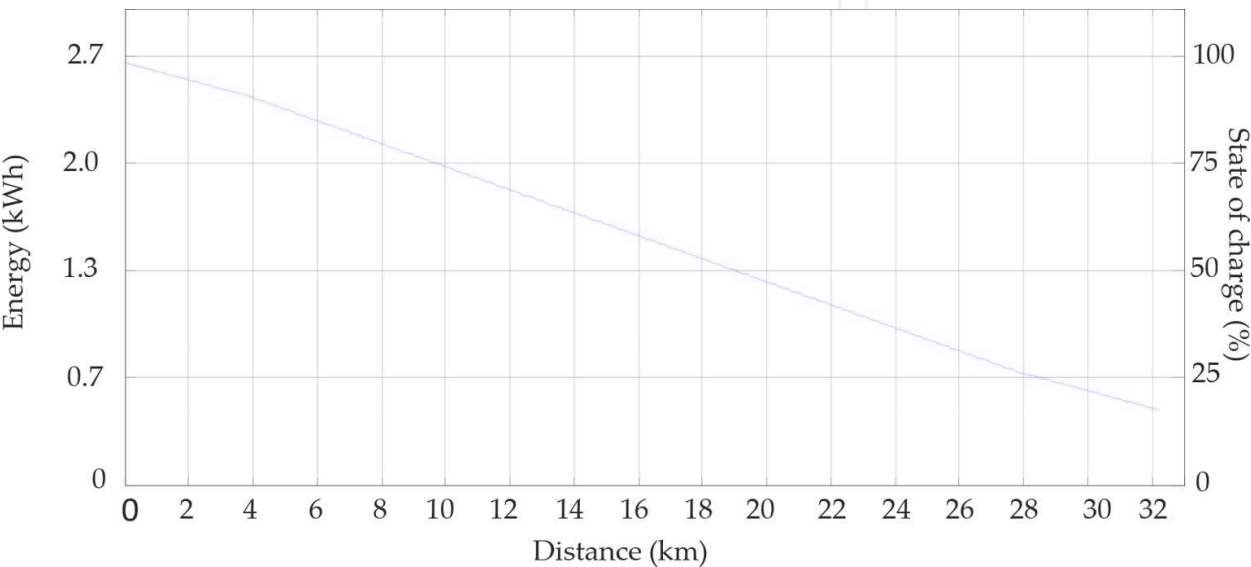


Figure 7. State of change of battery bank along the route.

4.2.4.2. Case 2: Power plant based on batteries and fuel cell (current prices)

What is important here is that the battery bank must provide main peaks of electric current, because dynamic operation of fuel cells makes it more complicated. Fuel cells are good providing big blocks of energy i.e. base load power instead of peak currents. For this case, the fuel cell provides almost all the energy required by the vehicle in the route, in such a way that at the end of the route, the battery bank will keep a SOC of over 92%.

Figure 8 shows the SOC in the battery bank, while the range extender based on fuel cells is used. As it is shown, the SOC keeps values around 90%. The final value of the SOC is 93%, which means that the vehicle has energy for traveling about 62 km. Therefore, if a fuel cell range extender is implemented, we obtain almost double the range, with only a cost increment of 43% in the power source. However, this price increment to the power source corresponds to about 15%–20% of the vehicle cost. That means that the current fleets of electric vehicles used by beverage industry or any other industry can increase the range without buying new more expensive electric vehicle, but rather using the current fleet with a fuel cell range extender.

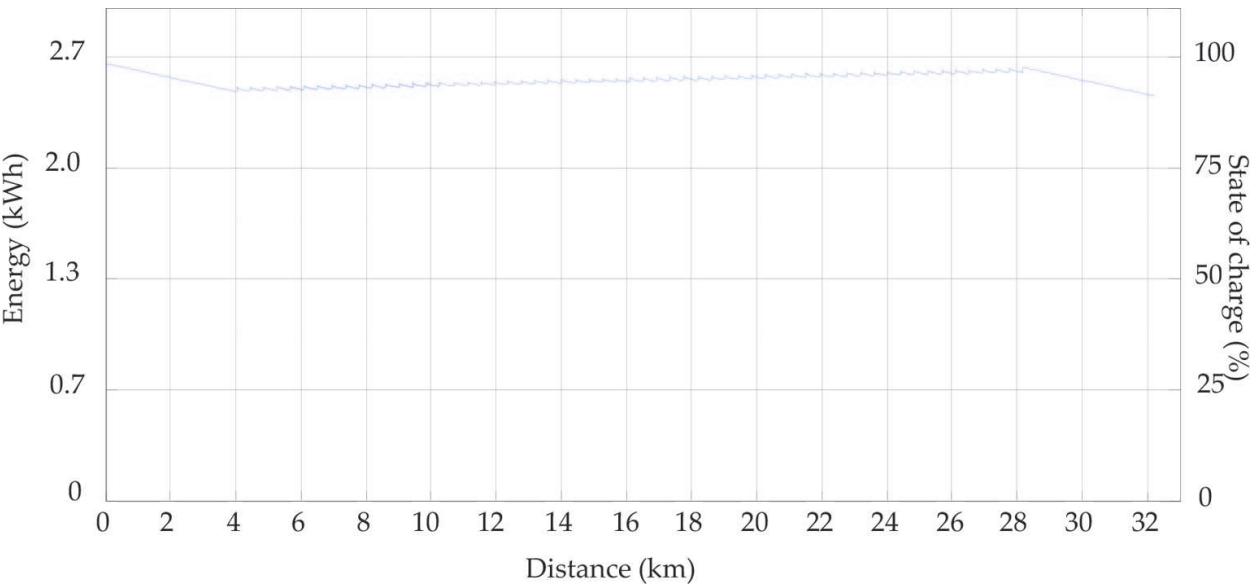


Figure 8. State of change of battery bank along the route: Case 2.

Another important issue related to the useful life in the battery bank is that its durability can be increased if the SOC is kept, as high as possible [6]. Hence, the implementation of a fuel cell range extender also helps to increase the useful life of batteries if the system is properly designed.

4.2.4.3. Case 3: Power plant based on batteries and fuel cell (future prices)

The previous case was conducted using current fuel cell prices. Nowadays, fuel cells are expensive due its low mass production. However, there are projections that indicate that future prices of fuel cells will fall, for a specific mass production value. For example, if mass production of fuel cells reaches a value of 20,000 upa, the fuel cell price by kW falls to 270 USD/kW [7]. In such a way, **Table 6** should be rewritten as shown in **Table 7**.

Lithium-ion batteries	
Energy	2.7 kWh
Voltage	48 V
Weight	14.6 kg
Volume	0.004 m³
Cost (USD)	\$ 3550
PEM fuel cell	
Type	PEMFC (proton exchange membrane fuel cell)
Nominal power (kW)	0.35 kW
Cost (USD) fuel cell + tank	\$1550

Lithium-ion batteries	
Tank capacity	0.18 kg of H ₂
Vehicle range:	62 km
Total cost (USD):	\$5100

Table 6. Specification of the power source (batteries + fuel cell)

Lithium-ion batteries	
Energy	2.7 kWh
Voltage	48 V
Weight	14.6 kg
Volume	0.004 m ³
Cost (USD)	\$3550
PEM fuel cell	
Type	PEMFC (Proton Exchange Membrane Fuel Cell)
Nominal power (kW)	0.35 kW
Cost (USD), fuel cell + tank	\$595
Tank capacity	0.18 kg of H ₂
Vehicle range:	62 km
Total cost (USD):	\$4145

Table 7. Specification of the power source (batteries + fuel cell [future prices])

For this case, the increment of price of the power source corresponds to about 5–10% of the vehicle cost. That means once the mass productions of fuel cells starts, they will be (definitely) a feasible alternative in such systems.

The economic analysis in hydrogen production is not included in this chapter, but nowadays, there are many works [8–14] where assessment of hydrogen production is made using renewable energies. In this way, operation prices of electric vehicles driven by fuel cells are highly competitive, compared to electric vehicles driven by batteries, but with the added value of using a high efficiency and more environmental friendly technology.

5. Advantages, disadvantages, and business opportunities

Nowadays, fuel cell range extender systems are under study because the electric vehicle industry is rising. Practically, every big company in the automotive industry has an electric vehicle in their portfolio. In fact, there are companies, like Tesla Motors, that have as the main product an electric vehicle.

It is well known that fuel cell systems are environmentally friendly, as they present a high well-to-tank efficiency. The capability to extend the range in such a systems depends mainly of the tank capacity. For that reason, it is possible to have high-energy density, reducing the overall weight of the power plant.

Another important advantage is the fast energy charge rate, of a few minutes, for this system. If we compare it with the time required to charge batteries, in order of hours, we can obtain many logistics advantages, as well as more availability of the vehicles.

On the other hand, the main disadvantage of these systems is the high initial cost, because it is an emerging technology with low mass production; nonetheless, once mass production reaches a value of 20,000 units per year, initial costs falls to highly competitive costs. The lack of infrastructure to dispatch H_2 , like gas stations, is another disadvantage to handle fleets of electric vehicle. This can be overcome, using storage and deliver systems of H_2 in the operation base of each fleet (as with batteries), the current technology of hydrogen allow it. Another disadvantage is the need for special consideration of power converters, because the output voltage of a fuel cell presents important variations under normal operational conditions. However, this issue has been addressed by experts in the last decade[15–23].

5.1. Business opportunities

The introduction of fuel cell technology in the operation of electric vehicles opens many business opportunities, from new manufacture companies of fuel cells and hydrogen tanks to new business in both hydrogen dispatching and production.

The renewable power sources are also another sector that can be included in the new business opportunities, because feeding of electricity to electric cars, ideally, must be using renewable energies in such a way that cars are going to be efficient and environmentally friendly.

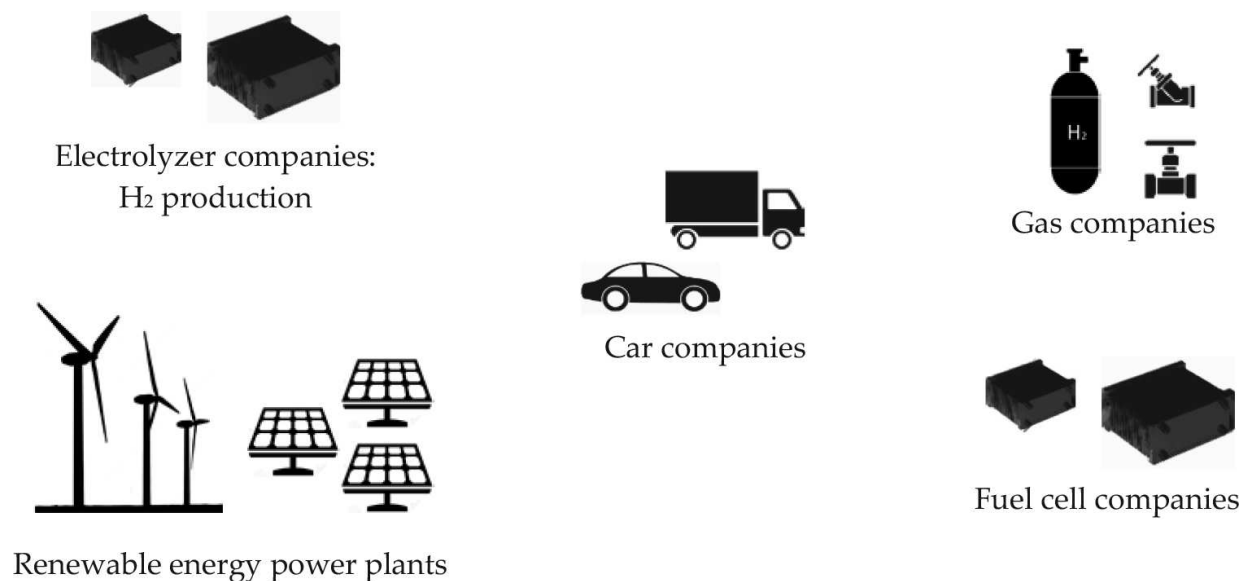


Figure 9. Sectors involved in the new business opportunities.

Figure 9 illustrates sectors involved in the new business opportunities with the mass production of fuel cell and the introduction of this technology in electric vehicles.

Companies that make electrolyzers are essential for developing the fuel cell car industry, due to the fact that hydrogen production must be conducted through electrolyzers by means of renewable energy power plants. If hydrogen is obtained using renewable energies, electric cars will be highly sustainable. For that reason, power plants based on renewable energies (solar, wind, etc.) will be involved in this new scheme, i.e. they will have a new potential user, either interconnected to the electric grid or by means of isolated systems. If we take into account the amount of energy consumed by cars, the size of the market is very high.

On the other hand, we can see (right side of **Figure 9**) that the fuel cell cars or automotive industry will need not only the fuel cell technology but also the technology of gas storage systems. Nowadays, fuel cell companies have several years operating but not at the production rate of automotive companies. That is why business opportunities appear, because more fuel cell manufacturers should be created. The same situation happens with hydrogen tanks manufacturers. The hydrogen tank is the part in the fuel cell vehicles that constraints the range of the vehicle and represents an important amount of the vehicle cost.

For sure, many other part supply companies can be created because for both mass production of fuel cells as well as electrolyzers, millions of components like elastomer seals, bipolar plates, membranes, gaskets etc, will be needed due to the fact that a fuel cell stack could need up to thousands of components.

6. Conclusion

beyond the fact that fuel cells are now a real option as an alternative power source in electric vehicles, they are an efficient and environmentally friendly technology. The use of this technology is a good way for obtaining zero emissions in electric vehicles when hydrogen is obtained from a renewable source, as we can avoid emitting CO₂. In the particular situation of the BEVs fleets, the fuel cells become an alternative to increase its range and to reduce environmental impact. In fact, fuel cells can be an alternative to increase the lifecycle of a battery bank, while fuel cells provide enough energy to keep the SOC at values where the aging of batteries is lowered.

The economics can be a matter to justify the uses of fuel cells, mainly as a range extender system. This happens because the hardware of existent BEVs can be used in such a way that the overall price of the vehicle can be increased just between 5% and 20% while the range is doubled.

New business opportunities are going to be opened not only in the automotive industry but also in renewable energies companies and the manufacture industry. The growth of the fuel cell industry will depend on adoption of this technology by electric vehicles, and also adoption of electric vehicles technology by companies that usually need fleets as a supply chain system.

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