

DRIVE-CYCLE REQUIREMENT

SPECIFICATIONS

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1. ABSTRACT

In this report, the details of an EV to hydrogen-EV hybrid conversion are specified. A certain portion of the battery from the EV is replaced with hydrogen fuel cell, as per requirement from a customer's demand. All the components necessary to complete the hydrogen fuel cell powertrain such as fuel cell type, fuel cell stack and fuel tank are meticulously selected and the new hybrid vehicle is compared to the original EV based on various performance parameters. This was done by comparing the WLTP drive cycles of the vehicle before and after hybridization by using MATLAB. The main performance parameters looked into are WLTP range, WLTP consumption, tractive forces acting on the vehicle, energy used, power required and energy regenerated during a drive cycle. In the end, 66.626% of the battery was removed which reduced the weight of the vehicle by about 11.51%. The WLTP range increased by 13% and WLTP consumption increased by about 47%. The tractive forces acting on the vehicle, energy used, power required and energy regenerated during a drive cycle reduced by around 13%, 11%, 19% and 13% respectively.

2. INTRODUCTION

It is well known that Internal Combustion Engines (ICE) are far from being the cleanest form of powering a vehicle. With the ever rising concerns regarding the use of fossil fuels and the emissions related to them, the UK Government has decided to put a ban on the sale of new vehicles with ICE by 2030 and hybrid vehicles with ICE by 2035. Similar decisions were made by the EU Government as well. This has brought the requirement for new alternate forms of powering vehicles.

As a result, all the major mass volume auto manufacturers decided to shift their focus towards electric vehicles and stopped developing any new internal combustion engines. Some manufacturers have also tried developing other methods of powering their vehicles such as using hydrogen or biofuels but with lesser success in terms of volume by sales compared to electric vehicles. This brought a wave of new manufacturers into the sector as well.

Even though the ban on ICE vehicles is still set to take place, the rate of development of infrastructure to support the drastic increase in electric vehicle is widely considered to be underwhelming. In the UK, most fast charging stations today are owned by Tesla and they provide very little support to vehicles from other manufacturers. The government needs to improve the network of charging stations in order to convince people to invest in electric cars.

Due to recent geopolitical events and UK's reliance on foreign nations for their sources of generating electricity has exposed the fact that relying only on electric vehicles is not an option. Also, the price of electricity per unit has drastically increased as well. As a result, there have been discussions in the automotive community on whether the plan to achieve net-zero carbon emission by 2035 is a realistic goal.

This report looks at an alternate option to tackle this issue. Here, the use of a hybrid vehicle is discussed. The hybrid technology suggested here is combination of batteries and hydrogen to power the vehicle. The feasibility of this hybridization is determined by using WLTP (Worldwide harmonized Light vehicle Test Procedure) over a complete drive cycle. The vehicle being used for this test is a Tesla Model 3 Performance. First, the different performance parameters such as WLTP range, Wh/km, energy consumed, power required etc. are tested for the pure electric Tesla. Then a certain percentage of the battery is removed and a hydrogen fuel cell is added to the vehicle. The same tests are repeated again with the hybrid vehicle to determine its performance.

3. CUSTOMER REQUIREMENT

Speed Rentals is a startup company that is looking to provide trackday experiences to its customers. Their focus is on providing race prepped rental cars for people to use on trackdays. As the ban on sale of petrol and diesel vehicles is only a couple of years away, they plan to be one of the early adopters of zero emission trackday cars. The plan is to open shops all over the UK at or around the major racing circuits. The first batch of cars that they plan on using are Tesla Model 3 Performance with the 75 kWh battery as they are relatively inexpensive compared to other performance EVs for the price.

As the batteries in EVs are constantly charged and discharged, the capacity of the batteries reduce drastically. Batteries are very heavy anyway and with the decrease in capacity, the range and performance of a vehicle takes a huge hit. Also, replacing a battery pack is every expensive and their disposal is a huge problem as well (Wan and Wang, 2022). Hence, they decided to look for different fuelling options. A decision matrix of the process can be seen in Table 1 below.

Table 1: Decision Matrix for Type of Fuel

	Fuel	1= Poor	5=Excellent	
Criteria	EV	Hydrogen	Plug-in Hybrid	EV-hydrogen Hybrid
Fuelling time	2	5	4	4
Fuel Cost	5	1	4	3
Fuel/charger availability	3	1	3	2
Weight	1	4	3	4
Performance	5	3	4	4
Performance over time	2	5	3	4
Carbon Emission	5	5	2	5
Sum	23	24	23	26
Proceed?	No	No	No	Yes

So, in order to cause as little environmental impact as possible, they plan to embrace forms of hybridization for their fleet of electric vehicles over the next few years. Their main focus is on using hydrogen as the energy density of hydrogen is high and same amount of energy can be acquired for very low fuel weight compared to EVs. But they don't want to remove the battery packs completely as hydrogen powered vehicles generally make less power and the performance of the cars will drastically decrease. They plan to replace somewhere between 50 to 70 percent of the battery initially.

In the UK, there are only a limited number of hydrogen refuelling stations. Fig. 1 shows all the major publicly available fuel stations.



Fig. 1: Hydrogen Refuelling Stations in the UK (glpautogas.info, no date)

This would not be an issue for Speed Rentals as they plan to set up their own hydrogen filling station at every location along with EV charging stations. But since this process would take time, their priority is to set up workshops near circuits around London, as it has the highest density of hydrogen filling stations.

So, the customer demands from Speed Rentals are as follows:

- Replace 50 to 70 percent of the battery from Tesla Model 3 Performance.
- Choose suitable form of fuel cell.
- Compare different performance parameters of the hybrid vehicle to that of the pure EV.
- Assess if hybridization is a feasible option.

4. METHODOLOGY



Fig. 2: Methodology

Fig. 2 shows the methodology used for the conversion and assessment of the hybrid vehicle. Firstly, the given WLTP cycle data was used along with the vehicle specification in order to create a MATLAB code to determine different data in the WLTP cycle such as the different forces acting on the vehicle, energy cycle, power used in a cycle, WLTP range etc. in order to validate the model.

The specifications for the Tesla Model 3 Performance are given in Table 2.

Table 2: Tesla Model 3 Performance Specifications

Make and Model	Tesla Model 3 Performance
Mass	1980 kg

Mass Distribution	48%F-52%R
Coefficient of Drag, C_d	0.287
Battery Nominal Voltage	360 V
Battery Capacity	75 kWh
Peak Torque	639 Nm
Peak Power	336 kW
WLTP Range	530 km
WLTP Consumption	166 Wh/km
Frontal Area	2.22 m ²

The value of coefficient of drag used here, 0.287, was calculated using the real world coast down data made available using MoTeC, for more realistic results with higher accuracy rather than using the coefficient of drag of 0.23 in the spec sheet, which was confirmed to be a value picked from the internet.

The formulae used in the MATLAB code to calculate tractive effort (Newman, 2017) are as follows:

- Inertial Force (N):

$$\text{Inertial Force} = \text{Mass} * \text{Acceleration}$$

- Aerodynamic Force (N):

$$\text{Aerodynamic Force} = \frac{1}{2} * \text{Density} * \text{Frontal Area} * \text{Coefficient of Drag} * \text{Velocity}^2$$

- Rolling resistance (N):

$$\text{Rolling Resistance} = \text{coefficient of Friction} * \text{Mass} * 9.81$$

- Total Resistance:

$$\text{Total Resistance} = \text{Inertial Force} + \text{Aerodynamic Force} + \text{Rolling Resistance}$$

Using these equations for tractive effort and with the use of the code, the model was validated.

Next, for the hybrid vehicle, the type of fuel cell, fuel cell stack and the hydrogen fuel tank were chosen. This process is explained in detail in the next section.

5. HYDROGEN FUEL CELLS, STACK AND TANK

5.1 Fuel Cell

A hydrogen fuel cell is a device that uses chemical reaction to convert hydrogen to electrical power. They are electrochemical cells and very similar to batteries. The only difference between a fuel cell and a battery is that a fuel cell requires a continuous source of oxygen and fuel, i.e., hydrogen in this case.

Next, the type of fuel cell to be used in the vehicles was chosen. This was done by building a decision matrix to choose a fuel cell with the highest score in the end as the most desirable one. The fuel cells that were chosen for this were proton exchange membrane (PEM) fuel cell (Whiston et al., 2019), alkaline fuel cell (McLean et al., 2002), phosphoric acid fuel cell (Sammes et al., 2004), molten carbonate fuel cell (Bischoff, 2006) and solid oxide fuel cell (Minh, 2004). The decisions were made based on certain criteria such as their operating temperature, stack size, efficiency, cost, start-up time and management, as seen in Table 3.

Table 3: Decision Matrix for Type of Fuel Cell

	Fuel Cell Type	1= Poor	5=Excellent		
Criteria	PEM	Alkaline	Phosphoric Acid	Molten carbonate	Solid Oxide
Operating Temperature	5	5	4	2	1
Stack Size	5	4	3	2	1
Efficiency	5	5	3	4	5
Cost	3	4	3	1	5
Start-up Time	5	4	2	1	2
Management	5	3	4	2	2
Sum	28	25	19	12	16
Proceed?	Yes	No	No	No	No

From the decision matrix, it can be seen that PEM fuel cell had good score in almost all the categories. The only criteria where it did not score high was cost. Alkaline fuel cell had good operating temperature and efficiency but the stack size required is slightly higher and electrolyte management was slightly poorer. Phosphoric acid fuel cell had a relatively higher operating temperature with lower efficiency and long start-up time. For our current requirements, it performed relatively poorly compared to PEM and alkaline fuel cells. Lastly, both molten carbonate and solid oxide fuel cells had very high operating temperatures with large stack sizes, long start-up times and poor management. The only thing that differentiated them were that solid oxide fuel cell had high efficiency and low cost, which were not enough to be able to compete with the other fuel cells. Hence, with the highest score, PEM fuel cell was chosen to go into the hybrid vehicle (energy.gov, no date).

A schematic diagram of a PEM fuel cell can be seen in Fig. 3 below.

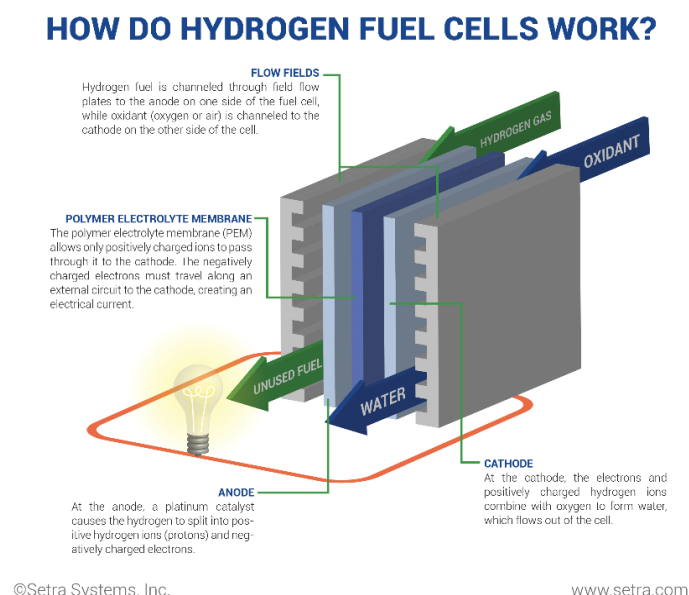


Fig. 3: PEM Fuel Cell (Lish, 2017)

5.2 Fuel Cell Stack

Next, the fuel cell stack is chosen. Again, this was done by using a decision matrix, as seen in Table 4 below.

Table 4: Decision Matrix for Fuel Cell Stack

	Fuel Cell Stack	1= Poor	5=Excellent	
Criteria	FCB130	EH-81 (100 kW)	PM 400 (64 kW)	PM 400 (71 kW)
Weight	5	3	2	1
Size	4	5	2	2
Power	5	4	1	2
Cell Count	5	4	3	3
Manufacturing Readiness	5	3	5	5
Technology readiness	5	4	5	5
Sum	29	23	18	18
Proceed?	Yes	No	No	No

From Table 4, it is observed that FCB130, the fuel stack used in Toyota Murai weighed the least while producing the most power, 128 kW (Toyota, no date). EH-81 had the best stack size but weighed more and made slightly less power of about 100-110 kW (EH-81 100 kW, no date). Lastly, PM 400 with its two variants, 64 kW (PM 400 64 kW, no date) and 71 kW (PM 400 71 kW, no date) had the largest stack sizes, weighed the highest and produced the least amount of power. Hence, the FCB130 from the Toyota Murai was chosen.

5.3 Fuel Tank

Lastly, the fuel tank that would go into the vehicle is chosen. Here, it is important to remember that the vehicle needs to weigh as little as possible to improve its dynamics. Hence,

the size of the fuel cell must be small. Also, range is not the main priority here. Table 5 shows the decision matrix for the fuel tank.

Table 5: Decision Matrix for Fuel Tank

	Fuel Tank	1= Poor	5=Excellent	
Criteria	ILJIN HYSOLUS 51L	ILJIN HYSOLUS 103L	Hydrogen Cylinder H2 Max	Voith Group Carbon4tank
Weight	5	4	2	1
Size	5	4	2	1
Operation Pressure	5	5	3	5
Tank Type	5	5	3	5
Manufacturing Readiness	5	5	5	4
Technology readiness	5	5	5	3
Sum	30	28	20	19
Proceed?	Yes	No	No	No

From the decision matrix, it is observed that ILJIN HYSOLUS 51L scored the highest and hence was chosen as the tank for the hybrid vehicle. It had an excellent score in every section. This is a proven hydrogen tank that is used in the Hyundai Nexa (ILJIN HYSOLUS 51L, no date). The ILJIN HYSOLUS 103L is very similar to its 51L variant, the only difference being that it has a larger capacity and hence weighs more and is not ideal for use in our case (ILJIN HYSOLUS 103L, no date). The Voith Group Carbon4tank (Voith Group Carbon4tank, no date) scored the least not only because of its size and weight, but also its manufacturing and technology readiness (Basu and Ghosh, 2016). Lastly, H2 Max (Hydrogen Cylinder H2 Max 290L , no date) scored slightly better than Carbon4tank but it was the only tank rated as Type III compared to the rest being Type IV (Barthelemy et al., 2016). Hence, its operational pressure is only 350 bar compared to 700 bar for the other tanks.

6. RECALCULATION OF WEIGHT AND POWER SOURCE

After the fuel cell type, fuel stack and the tank were chosen, some percentage of the original battery of the tesla was removed. In order to determine the percentage of battery to be removed, the power that could be generated using the hydrogen fuel cell was calculated.

We know, hydrogen has a specific energy of 142 MJ/kg (Alaka'I Technologies, no date)

So,

1kg of hydrogen can produce 142 MJ of energy.

Estimating 60% efficiency of fuel cell,

1kg of hydrogen can produce $0.6 * 142 = 85.2$ MJ of energy

The chosen hydrogen tank, ILJIN HYSOLUS 51L has a capacity of 2.1 kg of hydrogen.

Therefore,

2.1kg of hydrogen can produce $2.1 * 85.2 = 178.92$ MJ of energy

We know that the Tesla battery has a capacity of 75 kWh, i.e., $75 * 3.6 * 10^6 = 270$ MJ

Therefore,

Percentage of energy that would come from the fuel cell

$$= 178.92 / 270 * 100 = 66.26\%$$

Hence, 66.26% of the Tesla battery was removed. This is within the specification given by the customer for 50 to 70 percent removal of the battery with hydrogen fuel cell.

With the percentage of battery to be removed known, the new mass of the vehicle was calculated.

- Mass of original vehicle= 1980 kg
- Mass of battery= 480 kg (Wikipedia, no date)
- Mass of 33.74% battery (66.26% removed) = $33.74 * 480 = 161.952$ kg
- Mass of hydrogen tank= 36kg
- Mass of hydrogen= 2.1 kg
- Mass of fuel stack= 52 kg

Therefore,

$$\text{New hybrid vehicle mass} = 1980 - 480 + 161.925 + 36 + 2.1 + 52 = 1752.052 \text{ kg}$$

The mass of the vehicle reduced by 11.51% as a result of the hybridization process.

Hence, using the real world coast down data made available using MoTeC, for the new mass of the vehicle, the coefficient of drag was calculated to be 0.246.

After obtaining all the values, these were added to the MATLAB code and the code was run again to obtain the data on various parameters such as WLTP range, WLTP Wh/km consumption, tractive effort, energy used, power required and energy regenerated during the cycle.

7. LIMITATIONS

There are several limitations in the entire process of converting the EV into a hydrogen-EV hybrid and assessing it. Firstly, the entire assessment is based on just one drive cycle completed in the Tesla. Even though the format of the WPTL test would remain the same, every individual drive cycle will be different and the test should be repeated multiple times for higher accuracy.

During the WLTP drive cycle, the condition of the battery for the EV is not taken into account. Things like battery life, temperatures and discharge efficiency over time are not taken into account in the MATLAB code while for the hydrogen fuel cell, its inefficiency is accounted for.

Lastly, while removing a certain part of the battery, just the mass of the battery is taken into consideration. Other components that are not required anymore such as extra wirings, bracings and cooling equipment are not taken into account.

8. RESULTS AND DISCUSSIONS

8.1 Validation

For validation, after the code was run in MATLAB, the WLTP range and consumption of the MATLAB model was compared to that of the results achieved by the actual Tesla Model 3 in the WLTP cycle. Table 6 shows the same.

Table 6: WLTP Range and WLTP Consumption for Validation

	Actual Tesla Model 3	Code for Validation
WLTP Range (km)	530	533.689
WLTP Consumption (Wh/km)	166	140.501

From Table 6, it is observed that the final WLTP range achieved was 533.689 kilometres, which is almost identical to the WLTP range of 530 kilometres provided in the Tesla spec sheet. The WLTP consumption achieved was only the lower side, i.e., 140.501 Wh/km.

It also gave the graph for the tractive effort needed by the vehicle for completion of the WLTP cycle, as shown in Fig. 4 below.

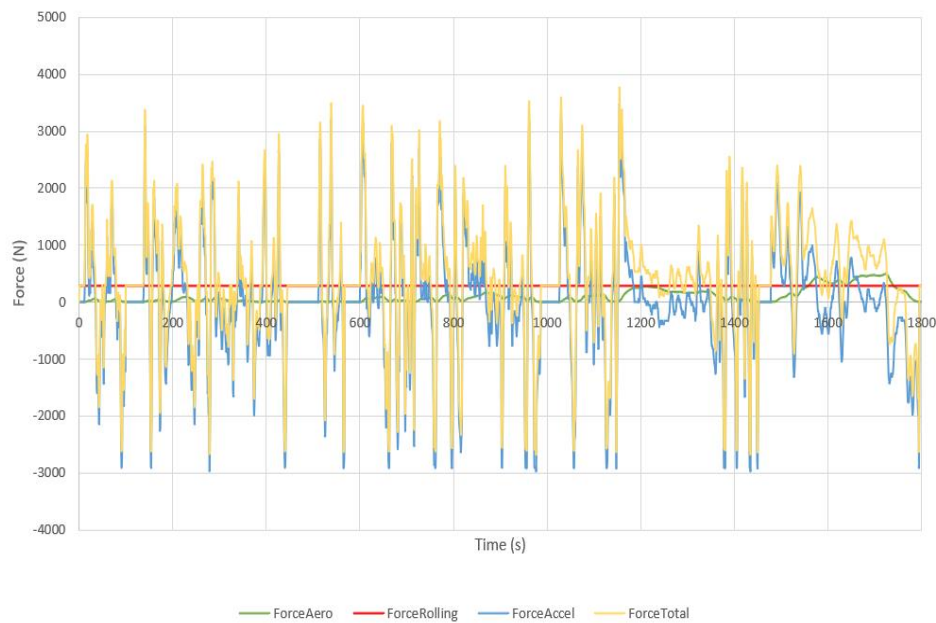


Fig. 4: Tractive Forces acting on the Tesla

Here, we can see the tractive forces acting on the vehicle during the entirety of the WLTP test. The test is done for 1800 seconds and the vehicle undergoes the same at four different speed ranges- low, medium, high and extra-high speed. ForceAero in green shows the aerodynamic forces acting on the vehicle, ForceRolling in red shows the rolling resistance acting on the vehicle, ForceAccel in blue shows the inertial forces acting on the vehicle during acceleration and ForceTotal in yellow shows the cumulative forces acting on the vehicle.

When the tractive effort is in the positive region, it depicts how much force is required to move the vehicle. The maximum total tractive force value was 3774.388 N and it was experienced at high - extra high speed region. This is due to the fact that the aerodynamic force acting on a body is directly proportional to the square of velocity. Similarly, when the tractive effort is in the negative region, it depicts that the vehicle is under braking condition. During braking, some of the energy is restored back into the battery using the regenerative braking system (Popiolek et al., 2019), which converts the kinetic energy of the vehicle into

electrical energy. In this case, the regenerative braking system only works under 3.129 m/s (7mph).

8.2 Hybrid vehicle

After replacing 66.26% of the battery with the hydrogen fuel cell and all the components required for the same, the new values of mass and coefficient of drag were added to the code and the code was run again. This gave the WLTP range and consumption for the new hybrid vehicle, as shown in Table 7.

Table 7: WLTP Range and WLTP Consumption Comparison

	Pure EV	EV-Hydrogen Hybrid
WLTP Range (km)	533.689	603.119
WLTP Consumption (Wh/km)	140.501	207.212

From Table 7, it is observed that the WLTP range for the new hybrid vehicle is 603.119 km, which is an increase in range by 69.43 km and 13%. The new WLTP consumption for the vehicle is 207.212 Wh/km, which is 66.711 Wh/km and 47.48% more. This is in line with the fact that the fuel cell has only about 60% efficiency.

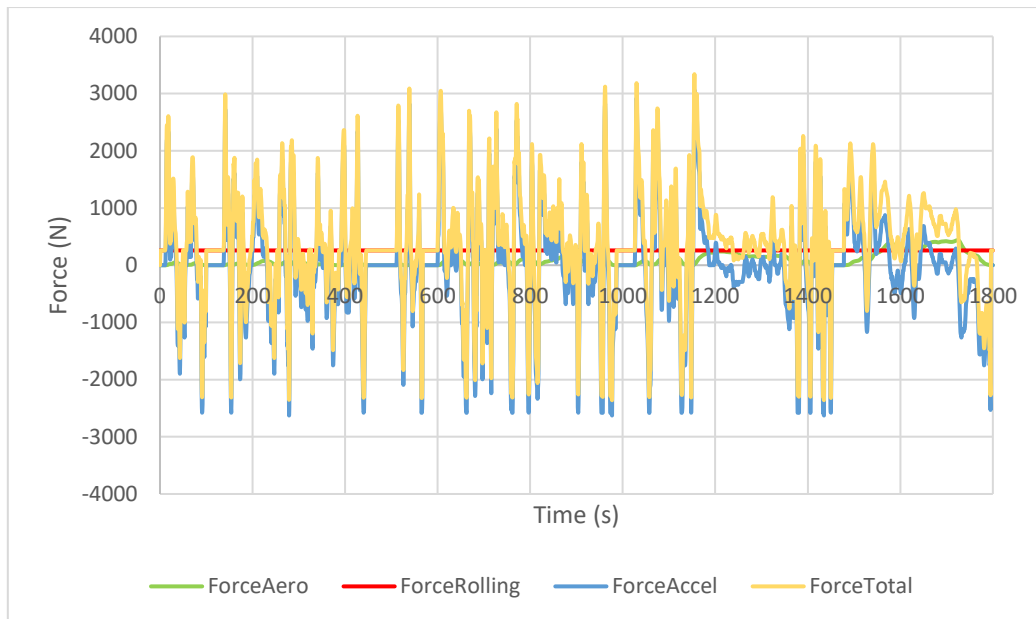


Fig. 5: Tractive Forces acting on the Hybrid Vehicle

Fig. 5 shows the graph for the tractive forces acting on the new hybrid vehicle. It shows that the maximum tractive force acting on the vehicle was 3339.86 N, which was 434.528 N and 13.01% less than the purely electric vehicle. This maximum force was experienced in the high – extra high speed region as well because the aerodynamic force acting on a body is directly proportional to the square of velocity.

8.3 Energy Cycle Comparison

Fig. 6 below shows the difference in the energy required to complete one drive cycle by the pure EV and the hybrid vehicle. For the electric vehicle, the energy required to complete one cycle was 12.29 MJ. The same for the hybrid vehicle was 10.875 MJ, which is a decrease in energy required by 1.415 MJ and 11.51%.

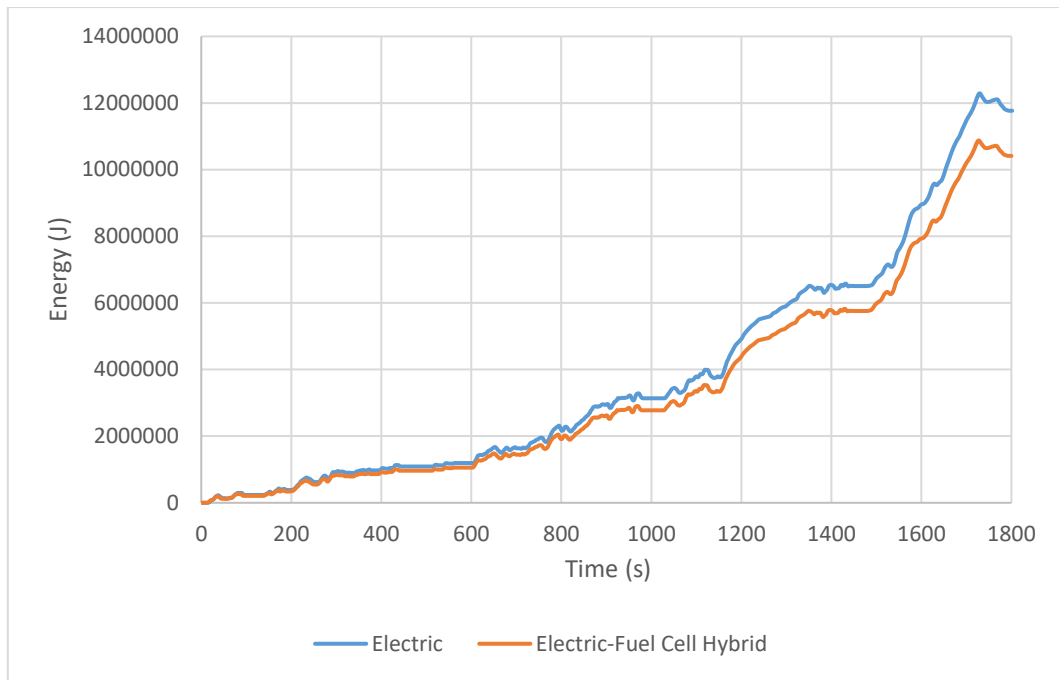


Fig. 6: Energy Used in a Cycle

8.4 Power Required

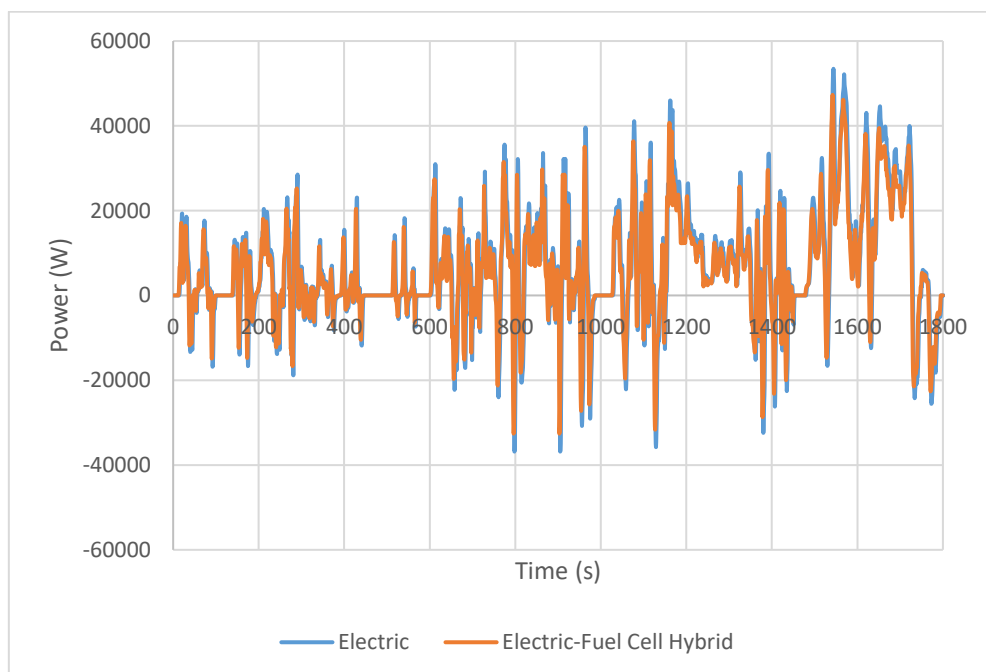


Fig. 7: Power Required During Drive Cycle

Fig. 7 shows the amount of during every second of the drive cycle. It demonstrates the power produced by the vehicle to overcome the tractive effort. It can be seen that more power is required at higher speed. This is in line with the fact that there are more aerodynamic forces acting on the vehicle as the speed of the vehicle increases. The maximum power required by the electric vehicle was 53.462 kW and 43.307 kW for the hybrid vehicle, which was 10.155 kW and 18.99% lower.

8.5 Energy Regeneration

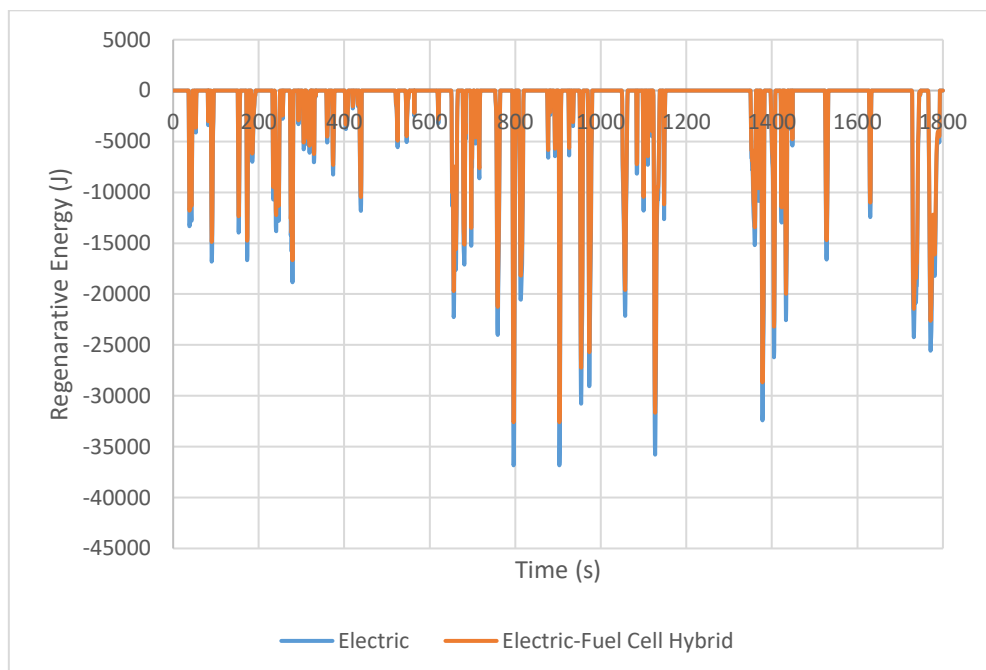


Fig. 8: Energy Regenerated During the cycle

Fig. 8 above shows the energy that is regenerated during the drive cycle. The energy regeneration graph, along with the power required graph show that there is relatively less energy regeneration during the high and very high speeds. This is because of the fact that these regions of the graph are usually on the motorway which requires minimum or relative low braking, unlike stop and go traffic in urban environments.

The maximum regeneration during the drive cycle for the electric vehicle was -36.829 kJ (negative because energy in going back to the battery) and the maximum regeneration for the hybrid vehicle was -32.589 kJ, which is 4.24 kJ and 13.01% less than the electric counterpart. We know that kinetic energy is directly proportional to mass [$KE=(1/2)mv^2$] and regeneration is the conversion of kinetic energy into electrical energy. Since the hybrid vehicle has less mass than the electric vehicle, it is in line with the fact that the hybrid vehicle regenerates less power.

8.6 Discussions

From the comparison of the pure EV and the hybrid vehicle, it is observed that there were many positive effects of swapping some portion of the battery of an electric vehicle with a fuel cell. Replacing certain amount of the battery with a fuel cell decreases the mass of the vehicle drastically. As a result of the change in mass, the tractive forces acting on the vehicle were less. Since the tractive forces were less, the energy required to complete a drive cycle were less as well. When comparing the instantaneous power required every second, the hybrid vehicle again required less power than the EV. The only part where the EV performed better was during regeneration of energy because of its higher mass and hence higher kinetic energy at any given speed.

While comparing the main WLTP factors of range and consumption, it is seen that the hybrid vehicle obtained a better overall range. However, the EV was more efficient with a lower Wh/km value. This is mainly down to the fact that the fuel cell is less efficient in generating energy compared to the battery which just stores the energy. As a result, the cost of refuelling hydrogen is higher with its already higher fuel price of around £12 per kg (Kristan, 2022).

Overall, the main aim here was to test the hybrid fuel cell conversion of Tesla Model 3 Performance. As per the requirement of removal of 50 to 70 percent of the battery, 66.26% of the battery was removed. This made the vehicle drastically lighter which would eventually result in better handling and performance of the vehicle.

Hence, from the comparison of the hybrid fuel cell vehicle to the pure EV, it can be safely said that the hybridization process of the Tesla Model 3 Performance is feasible.

9. FURTHER WORK

There are some further work that can be done in this project. The first and easiest work would be to replace some more part of the battery with fuel cell and compare the results obtained with the ones here. There is also scope of looking into the materials of the hydrogen fuel tanks used in order to reduce the mass further. Similarly, more the efficient fuel cells with higher weights can be looked into, to determine if increased efficiency is worth adding more weight or not.

Furthermore, since the cars will mainly be used on tracks, changing the suspension components could help to reduce weight. Similarly, the tyre can be changed and its effects on efficiency and energy required could be tested, as the coefficient of friction and hence rolling resistance would change.

Also, the WLTP was just tested for one cycle. The test could be repeated multiple times in different conditions in order to attain more accurate data.

10. CONCLUSION

With the ban on sales of vehicles with internal combustion engines producing carbon emissions and the geopolitical situations causing shortage of electricity, this report looked at converting an electric vehicle to a hybrid of hydrogen and electric power. This was done to cater and fulfil the requirements of a startup, Speed Rentals. Here, 66.26% of the battery of a Tesla Model 3 Performance was replaced with a hydrogen power. In the process, different components of the new powertrain such as fuel cell type, fuel stack and fuel tank were chosen based on various parameters. A MATLAB code was developed to compare the new hybrid vehicle with the original EV using WPTL drive cycle. Different performance parameters such as tractive forces acting on the vehicle, energy required, power required and energy regenerated were compared between the pure EV and hydrogen-EV hybrid.

For the hybrid vehicle, it was discovered that the mass had reduced by 11.51%. The WLTP range increased by 13% but due to lower efficiency, the WLTP consumption increased by about 47%. Due to decrease in mass, the tractive forces acting on the vehicle reduced by over 13% and the energy required to complete a drive cycle reduced by over 11%. Similarly, power required to complete the cycle reduced by nearly 19%. Lastly, due to the lower mass, the kinetic energy recovery system regenerated less energy, lower by about 13%.

REFERENCES

- Wan, T., Wang, Y. (2022) *The Hazards of Electric Car Batteries and Their Recycling* IOP Conference Series: Earth and Environmental Science, Volume 1011 012026
- glpautogas.info (no date) Available at: <https://www.glpautogas.info/en/hydrogen-stations-united-kingdom.html>
- Newman, C. (2017) *Tractive Effort | Advanced Steam Traction*. Available at: <http://advanced-steam.org/ufags/tractive-effort/>
- Whiston, M.M., Azevedoa, I.L., Litster, S., Whitefoot, K.S., Samaras, C., Whitacre, J.F. (2019), *Expert assessments of the cost and expected future performance of proton exchange membrane fuel cells for vehicles*. Available at: www.pnas.org/cgi/doi/10.1073/pnas.1804221116
- McLean, G.F., Niet, T., Prince-Richard, S., Djilali, N. (2002) *An assessment of alkaline fuel cell technology*, International Journal of Hydrogen Energy, Volume 27, Issue 5, May 2002, Pages 507-526
- Sammes, N., Bove, R., Stahl, K. (2004) *Phosphoric acid fuel cells: Fundamentals and applications*, Current Opinion in Solid State and Material Science, Volume 8, Issue 5, October 2004, Pages 372-378
- Bischoff, M., (2006) *Molten carbonate fuel cells: A high temperature fuel cell on the edge to commercialization*, Journal of Power Sources, Volume 160, Issue 2, Pages 842-845
- Minh, N.Q. (2004) *Solid oxide fuel cell technology—features and applications*, Solid State Ionics, Volume 174, Issue 1-4, 29 October 2004, Pages 271-277
- energy.gov (no date) *Comparison of Fuel Cell Technologies*. Available at: <https://www.energy.gov/eere/fuelcells/comparison-fuel-cell-technologies>
- Toyota (no date) *Toyota Mirai Technical Specifications*. Available at: <https://media.toyota.co.uk/wp-content/uploads/sites/5/pdf/210426M-NG-Mirai-Tech-Spec.pdf>
- EH-81 100 kW (no date) Available at: <https://hyfindr.com/marketplace/components/fuel-cell-stacks/pem-stacks/fuel-cell-stack-eh-81-100-kw/>

- PM 400 64 kW (no date) Available at:
<https://hyfindr.com/marketplace/components/fuel-cell-stack-module/fuel-cell-stack-module-pm-400-64-kw/>
- PM 400 71 kW (no date) Available at:
<https://hyfindr.com/marketplace/components/fuel-cell-stack-module/fuel-cell-stack-module-pm-400-71-kw/>
- ILJIN HYSOLUS 51L (no date) Available at:
<https://hyfindr.com/marketplace/components/hydrogen-tanks/hydrogen-type-4-cylinder-700-bar-51l/>
- ILJIN HYSOLUS 103L (no date) Available at:
<https://hyfindr.com/marketplace/components/hydrogen-tanks/hydrogen-type-4-cylinder-700-bar-103l/>
- Voith Group Carbon4tank (no date) Available at:
<https://hyfindr.com/marketplace/components/hydrogen-tanks/gaseous-hydrogen-tanks/carbon4tank-hydrogen-vessel-700-bar-350-l/>
- Basu, B., Ghosh, S. (2016) *Assessment of Technology and Manufacturing Readiness Levels* Biomaterials for Musculoskeletal Regeneration, pp 235-246
- Hydrogen Cylinder H2 Max 290L (no date) Available at:
<https://hyfindr.com/marketplace/components/hydrogen-tanks/hydrogen-cylinder-h2-max-290l/>
- Barthelemy, H., Weber, M., Barbier, F. (2016) *Hydrogen Storage: Recent Improvements and Industrial Perspectives* International Journal of Hydrogen Energy 42 (2017) 7254-7262
- Alaka'i Technologies (no date) *Hydrogen Details*. Available at:
<https://www.alakai.com/hydrogen-details#:~:text=The%20specific%20energy%20of%20hydrogen,offer%20more%20energy%20per%20kilogram.>
- Wikipedia (no date) *Tesla Model 3*. Available at:
https://en.wikipedia.org/wiki/Tesla_Model_3#:~:text=The%20Standard%20Range%20version%20carries,density%20of%20150%20Wh%2Fkg.

- Popiołek, K., Detka, T., Żebrowski, K., Małe, K. (2019) *Analysis of Regenerative Braking Strategies*, PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 95 NR 6/2019
- Kristen, L. (2022) *Hydrogen Fuel Cell Cars Explained: Should I Buy A Hydrogen Fuel Cell Car?* Available at: <https://www.autotrader.co.uk/content/advice/hydrogen-fuel-cell-cars-overview>