Universitat de Lleida

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Design and Building Process of a Hybrid Go-Kart – A Comparison Between Electric and Combustion Drive Systems

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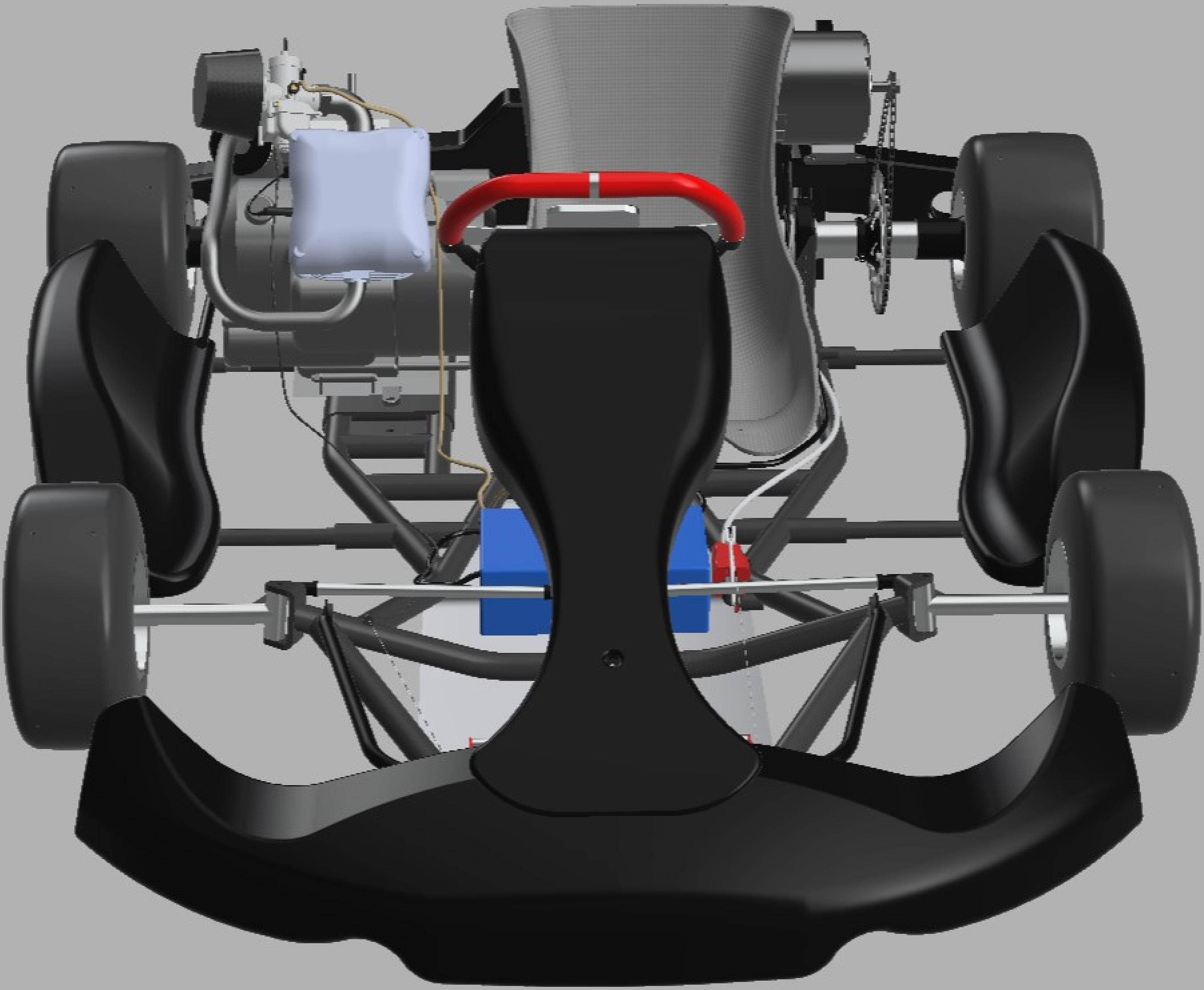

Design and Building Process of a Hybrid Go-Kart: A Comparison Between Electric and Combustion Drive Systems

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Tutor: *Alex Abad*

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Introduction

to the *Design and Building Process of a Hybrid Go-kart: A Comparison between Petrol and Electric Drive Systems*

How did it all start?

I have always been fascinated by the transport and automotive world. Cars, trains, planes, ships… it all amazed me in such a way that, as I grew up, it turned into my great passion.

There is something else which I have always enjoyed doing: building things. Even when I was a small boy, I liked to build my own paper or cardboard models of cars, tractors, motorbikes etc. I have always dreamed of one day becoming an engineer and this dream has not been left at wishes alone. It is not the first time I think of starting a project like this. I have previously had the chance to build two downhill trolley racers. But never anything motorized. This is the reason I decided to make the best of this wonderful opportunity to bring these two passions of mine together and take the whole experience one step further, learning new skills and exploring new areas of the engineering world. The choice of topic for this research project was clear to me from the start. It combines two things I really enjoy doing and opens to a wide set of innovative possibilities.

In addition, and since there is starting to be more emphasis on our responsibility to look after our planet and its resources, I decided to do some research into alternative and eco-friendly power sources. I wanted to discover to what extent they had been developed to the present day and what the future would most likely hold for them, especially in the transport and automotive fields. I wanted to compare the two drive methods: electric and petrol. The construction of a go-kart presented a great opportunity to explore this new emerging world, integrating the use of the knowledge acquired through the research into the design of the prototype.

Initially I thought about building an all-electric go-kart. However, thinking about how I would compare the electric and petrol drives in a fair test (with the same controlled variables of weight, area of contact with the ground, aerodynamics, friction, chassis flexibility and so on), I decided to design and build a hybrid go-kart instead. This way, I would have both the electric and petrol drive systems and I could make the tests more fairly, with the same controlled variables and with the two independent variables of electric or petrol drive systems.

Initial Aims of the Project

Initially, I set myself a few main aims for the project. As it evolved, some goals I set myself became less relevant, while others took their place as main objectives. Throughout the project, the aims have been:

1. To learn about the **history of the automobile** and the way it has *evolved through time.*

   To understand what the future might hold for the automobile; it is necessary to know its past. I have done some research on how our concept of automobile has evolved and what difficulties and obstacles there have been in developing this amazing feat of engineering, which we now see as so normal.

2. To **inform** myself on **new techniques and technologies** involved in the use of **renewable power sources**, especially in the *automotive and transport* world.

   To have a theoretical overview of the topic and its present stage I have done some *general research* on *renewable power* sources but also specifically on their *automotive applications*. I have done some research on the technical side of both electric and combustion drive systems, studying their components and how they work together.

   Finally, I have obtained real data on *pollution*, *emissions* and *global warming* to evaluate the actual effects we are causing to our planet, and the *impact that electric or alternative energy vehicles would have on this data*.

3. To complete the *design and building* process of a **hybrid go-kart prototype**.

   This part of the project consisted of the practical application of the knowledge acquired in the research and horizon scanning to build the prototype. The prototype then helped me to see the practical or performance differences between combustion and electric drive systems, enabling me to compare the two and, combined with the research, extract the conclusions of the project.

   First, I did some **research** to put together a design that contemplated cost, available tools, components and materials, time, aesthetics, aerodynamics, weight and resulting performance. This determined the materials I used and the general layout of the go-kart.

The second phase was the computer **design**. With the 3D design software *Fusion 360*, I created a 3D computer version of the go-kart I then built. This enabled me to run tests and simulations on the model and compare the results to the real life.

The final phase was building the go-kart, which I documented with pictures and videos.

This third aim included a set of secondary goals:

- To learn how to use *3D design software* such as *Fusion 360*
- To learn how to use the *welding machine*
- To learn more about how *electric motors* work and their components

4. To **compare** and **evaluate** the two drive systems: *electric* vs *petrol*

This is the main question of this project: *Which drive system is a better choice in the automotive world: electric or combustion?* The question has a wide range of possible approaches, and I have covered all the main aspects to answer the question objectively.

In this section, I have designed and run tests on the go-kart prototype to compare the performance of the two drive systems. This allowed me to make a comparison of the performance benefits and downsides of electric powered and fuel powered drive systems.

Considering these aspects and the aspects studied in the theory section, I have extracted a conclusion as to which of the two is better, not only considering the performance but also considering the wider picture of the impacts on our environment and our lives.

5. To create a **video** to illustrate the whole process of *designing*, *building* and *testing* the go-kart.

Seeing as I cannot present the go-kart physically in Spain (I have built it at home in England), I have taken the opportunity to create a short video that will serve as illustration of my whole project, from the early design stages to the final product.

6. To **finance** the project with *crowdfunding*.

To get more familiar with how professional investigation works, I have funded part of the project with *crowdfunding*. This way I have not only lowered the personal cost that the project has implied for me, but I have also worked in a more real-life situation.

Layout and Methodology

The way I have laid my project out is in two main parts: the ***theoretical section***, which consists of the *research* and *horizon scanning* mentioned previously; and the ***practical section***, which includes the *design*, *building* and *testing* of the hybrid go-kart prototype.

I have dedicated a further section to the **comparisons and conclusions**, which outline the results of the tests and an overview of all the elements considered when making the final conclusion.

The project has been completed during this summer (2019).

Questions

The main question I want to answer with this project is: *Which drive system is a better choice in the automotive world: electric or combustion?*

To answer this big question, I have broken it down into smaller and more specific ones to make the whole thing a little easier. To make a comparison, you must consider lots of different aspects, some more important than others. There are different automotive applications that require these aspects to be different: sports cars, long distance cars, city cars and daily use/middle distance cars all have different requirements, for example. I have evaluated from those four points of view, valuing each aspect (ex. autonomy, top speed, power etc.) differently for each application. The aspects I have considered are be both practical (performance), and theoretical (impacts on the environment and the life of the consumers). As the area of automobility is changing so rapidly, especially with electric cars, I have also considered the changes that time could bring to these aspects, thus giving a wider answer.

Hypothesis

Before starting the project, I stated the hypothesis I wanted to verify:

For a *sports car* application, what you value is the power and top speed that the car can give you, which translates to fast acceleration. This power requires an equally powerful source. Electric motors are the best at accelerating but, on the long run, the power these cars ask for is enormous and batteries would struggle to deliver over long periods due to storage limitations. You might get high power out of them, but not for long.

Again, *long distance* cars ask for power over long periods. You cannot be stopping off at every single charging facility for half an hour to charge your car. So far, electric power falls short here.

On the other hand, *city cars* ask for neither high speeds, nor high autonomy. Nowadays it is possible to have an electric car charger at home, so the autonomy provided by the batteries would more than suffice to have the car going for any in-city trip, charging the batteries at home when not using them. A big problem in large cities is pollution. When a petrol or diesel car stops at the traffic lights, it is still burning fuel, which is not only a waste of money, but also a source of pollution. With electric cars, we would be greatly reducing this problem, if not taking it out completely.

Medium distance cars are an in-between. However, as technology advances and batteries get better, electric cars could easily get to a point where they could take the role of medium distance cars, where the big problem is, again, autonomy.

In summary, my hypothesis is:

*As of **now**, for **sports car**, **long distance car** and **medium distance car** applications, the best choice of drive system is **combustion,** whereas for **city car** applications, the best choice is **electric**. However, **soon**, as battery technologies advance, the best choice of drive system for **medium distance cars** could easily change to **electric**.*

Theory Section

The Automobile: Combustion and Electric Drive Systems

Introduction

This theory section will focus on the history and technical concepts of both electric and combustion cars as well as the differences that set them apart from each other. To do this, we will go through some of their key components. We will also explore some of the alternative and renewable energy sources and their applications in the automotive and transport world.

Past, Present and…

Automobiles, as we see them today, have been an ever-changing reality. Even today, new technologies are being developed in the area of automobiles. But, where did the idea originally come from?

A wheel-based vehicle is mentioned as far back as Homer's *Iliad.* Later, in the 15th century, *Leonardo Da Vinci* considered the idea of a self-propelled vehicle. By the 17th century, in the Netherlands, two-masted wind-propelled carriages were being driven at speeds of 30km/h, the idea deriving from *Robert Valturio's* plans in 1472, which he never put to practice. Simultaneously in Germany, *Otto Von Guericke* developed the first air engine, and was the first to make the air pump, cylinders and connecting rods, basic components still used in engines today (M. Robertson, s.f.).

Jacques Vaucanson proposed the clockwork engine in the 18th century and other alternatives were invented by *Christiaan Huygens* and *Denis Papin*.

However, most historians agree that the first *true automobile* was not invented until ***1769***, when French inventor ***Nicolas-Joseph Cugnot*** drove the first *steam-powered tricycle*, said to have run for 20 minutes at 3.6 km/h while carrying four people. Soon, other inventors took to the idea of the steam-powered carriages and they became very popular during the last decade of the 18th century and flourishing towards the 1830s. By the 1840s, however, the era of steam coaches was drawing to an end and the *Locomotives on Highways Act of 1865* finished stifling them in England for good. It was time for the electric car (M. Robertson, s.f.).

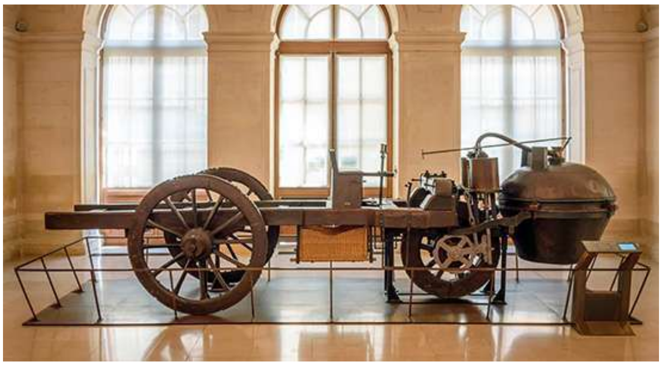

Figure 1 *Nicholas-Joseph Cugnot's Steam-Powered Tricycle (1769) Retrieved from: https://automobilemafia.blogspot.com/2019/03/ history-of-car.html*

During the first half of the 19th century, steam-powered cars had been making all the noise. However, the *electric motor* had been invented as far back as the 1820s. One known case is that of *Anyos Jedlik*, who built his own electric motor in *1828* and used it to power a small model of a car. Later on, in **1832** and 1839, a larger motor was developed by Scottish inventor ***Robert Anderson*** and used to drive a carriage. (G. C. Cromer, O. C. Cromer, C. G. Foster, K. W. Purdy, 2018)

It was not until ***Thomas Davenport*** that the ***first electric car powered by batteries*** was created. However, the batteries were not rechargeable, and the problem of range still existed. *The first electric vehicle considered practical* was created in the late 1800s by *William Morrison*, although it still lacked autonomy. Unfortunately, the First World War demanded long range, and the charging technologies available at the time were not sufficient for the task. Electric vehicles were put to one side and the internal combustion engine took the relay baton (M. Robertson, s.f.).

Figure 2 *Morrison Electrics Car (1890)*
Retrieved from: http://hid0141.blogspot.com/2016/12/veiculos-inicio-fotos-pessoas.html

The idea of the *internal combustion engine* goes back to the 15th century when *Christiaan Huygens* designed, although he never built it, the first gunpowder-fuelled precursor of the present-day internal combustion engine. Hugely because of the steam engine, however, the internal combustion engine was discarded until the 19th century (S. Rajiu, 2003).

Several designs led up to the first successful combustion engine brought into production. In 1807, *Francois Isaac de Rivaz* built an engine for his car that used a mixture of oxygen and hydrogen as fuel. His experiments were unsuccessful, and the design came to nothing. Later, in 1824, *Samuel Brown* adapted one of Huygens' ideas to run on hydrogen gas. The engine worked but the lacking practicality prevented its adoption (S. Rajiu, 2003).

In 1858, Belgian engineer *Jean Joseph Lenoir* invented an *electric spark-ignition* engine fuelled by coal gas. His design was successful and, in 1863, he improved the engine and attached it to a wagon that achieved an historic 80.5 km road trip (M. Robertson, s.f.).

In 1866, improvements were made to Lenoir's designs by *Eugen Langen* and ***Nikolaus August Otto*** to make a more efficient gas engine. Ten years later, Otto invented the first successful ***four-stroke engine***, known as the "***Otto Cycle***" and still used today with very few modifications. In the same year, the first successful ***two-stroke engine*** was invented by ***Sir Dougald Clerk***. (S. Rajiu, 2003)

In 1885, ***Gottlieb Daimler*** invented a *gasoline gas engine* with a vertical cylinder and a carburettor to inject the gasoline. It is considered the prototype of the modern gasoline engine. A year later, Daimler built ***the world's first four-wheeled motor vehicle***, the same year that *Karl Benz* patented his gasoline-fuelled car.

Figure 3 *Gottlieb Daimler and his Son Adolf on the "Motor Car", the First Four-Wheeled Motor Vehicle. Retrieved from: https://ccn-journal-prod.azurewebsites.net/2019/03/29/motorcar-maternity-wards-daimler-preserves-historic-structures/*

So far, all the engines that had been invented needed a spark to ignite the fuel mixture in the chamber. In 1893, after being criticized by many engineers who pressured him to desist in his research, ***Rudolf Diesel*** built the first ***compression ignition engine***.

Other engineers that also contributed to the invention of the internal combustion engine include: *James Atkinson*, who improved the efficiency of the four-stroke engine with the Atkinson cycle in 1882; *Alphonse Beau de Rochas*, who designed a four-stroke engine in 1862; *Siegfried Marcus*, who built the world's first gasoline-powered vehicle in 1864; *Wilhelm Maybach*, who built the first four-cylinder, four-stroke engine in 1890; *Edouard Delamare-Deboutteville* and *George Brayton.* (G. C. Cromer, O. C. Cromer, C. G. Foster, K. W. Purdy, 2018)

Today, it looks like we are picking electric cars up from where we left off in 1914. We have massively developed and perfected internal combustion engines to the present day. However, electric cars are only at the beginning of their developing stages, especially in the aspect of batteries and autonomy. But, looking at the history of the automobile and all the problems these engineers had to solve, all the attempts they had to do before coming up with the right design, and knowing they overcame those obstacles; I am confident that, in the future, the same thing will be said about electric cars.

Combustion Cars and Components

Combustion cars are the most commonly seen on our roads today. But, how do they work? In this section, we will look at the different components and parts that make up a combustion car.

A combustion car uses an *internal combustion engine*. It works thanks to the explosion of a *combustible fuel* inside a combustion chamber, causing the reciprocation of a piston, which turns the axel by means of a crankshaft or another *transmission system*. The turning moment is then transmitted to the wheels, which propel the car.

Internal Combustion Engine

There are several *types* of **internal combustion engines,** which can be classified following different criteria. This section will focus on the engines used for automobiles and other similar applications:

1. Based on the *working cycle*

   The working cycle of an engine comprises the different processes the engine completes from one explosion to the next (V. R. Chennu, 2015). There are two different kinds of working cycles, depending on the number of reciprocations the piston completes between each explosion:

   Two-stroke engine

   The two-stroke engine requires only two movements of the piston (one cycle) to complete one explosion. The working cycle of a two-stroke engine contains two processes, one per stroke:

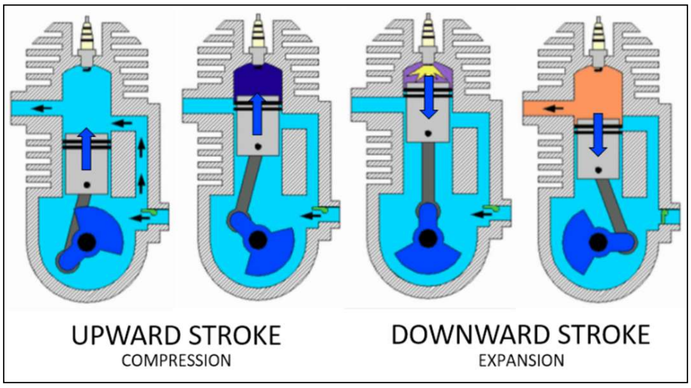

Figure 4 *Two-Stroke Engine Working Cycle*

Compression Stroke – In the compression stroke, the inlets open and the mixture of air and fuel enters the compression chamber. The piston moves up and compresses the mixture. When it arrives at the top, the spark plug ignites the mixture and the power stroke commences.

Power Stroke – The mixture ignites and the explosion takes place, pushing the piston down (*expansion*). The exhaust valve opens and the waste gases and heat are pushed out by the new fuel mixture entering the chamber. The compression stroke begins again. (B. Afework, J. Donev, 2018)

One problem these engines have is that, because they have no valves and the exhaust is opened and closed by the same movement of the piston, there can be losses of unexploded fuel via the exhaust, or even burnt fuel trapped in the chamber. If the timing is not right, this can result in lower pressures in the moment of the explosion and so can make the engine lose power. If the exhaust is closed too early, there is less fuel mixture in the chamber; however, if the valve closes too late, unexploded mixture is lost. This problem can be fixed with the modification of engine geometry or other components to increase the efficiency of the engine and prevent fuel and power loss. (R. T. Balmer, 2011)

Two stroke engines are used for applications where light weight and simplicity are important and high *power-to-weight ratio* is required. Two-stroke engines have another advantage: they can be lubricated by simply adding oil to the fuel mixture. Thanks to this, they require no oil reservoir dependant on gravity and so can be used in any orientation, which can be useful for things like chainsaws and other power tools. Other applications include dirt bikes, go-karts, motorbikes, outboard motors, lawnmowers and other small propulsion applications. (B. Afework, J. Donev, 2018)

Four-stroke engine

The four-stroke engine requires four movements of the piston (two cycles) to complete one explosion. The working cycle of a four-stroke engine contains four processes, one per stroke:

Intake Stroke – The piston, initially at the top of the chamber, moves down and the intake valve opens, allowing the fuel and air mixture to enter the chamber.

Compression Stroke – The piston reaches the bottom of the chamber and the intake valve closes. The piston moves back up the chamber, compressing the mixture. As the piston arrives at the top of the chamber, the spark plug ignites the mixture.

Power Stroke – The explosion takes place and the piston is pushed down by the increased pressure.

Exhaust Stroke – When the piston reaches the bottom of the chamber, the exhaust valve opens and the piston moves up, pushing out the burned gases. The intake stroke begins again. (B. Afework, J. Donev, 2019)

The four-stroke engine is the most commonly used in larger vehicles like cars, trucks, buses and the like, especially for vehicles that use gasoline as fuel. They are generally more durable than two-stroke engines and offer more power at low RPM, but they are also more expensive due to their higher mechanical complexity (B. Afework, J. Donev, 2019).

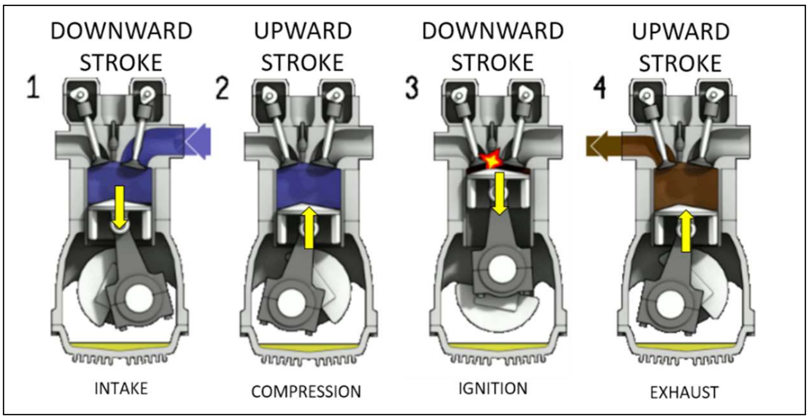

Figure 5 *Four-Stroke Engine Working Cycle*

(It is important to note that, although the examples set in the diagrams are spark ignition engines, the same applies to compression ignition engines. The working cycle does not necessarily determine the ignition system.)

2. Based on the *operating cycle*

The most common operating cycle used in automobiles today is the original ***Otto Cycle***, named after *Nikolaus Otto*, its inventor. However, over the years, there have been several modifications made to this original *Otto*

Cycle to improve some aspects like fuel efficiency, power etc. (V. R. Chennu, 2015).

The ***Atkinson Cycle*** was invented by British engineer *James Atkinson*. His idea was that, if less fuel mixture was allowed to enter the cylinder, but the volume for expansion was kept the same, so as to make the most of the explosion, there would be less fuel used to the same effect. To do this, he used a complex mechanical system to restrict the distance that the piston could travel down the cylinder on the intake stroke. This resulted in less fuel mixture entering the cylinder, while the restriction was taken out on the expansion stroke. (K. Hall-Geisler, 2012)

Of course, it is not as simple as this in the sense that less fuel means less power. For this reason and because of the high complexity of the design, the idea was discarded for 140 years until *Toyota* redesigned a new version of the *Atkinson Cycle* based on the same principle.

The redesigned version of the *Atkinson Cycle* uses the same Otto Cycle four-stroke working cycle with one small change in valve timing. Instead of limiting the displacement of the piston on the intake stroke, the intake valve is left open for a little longer, allowing the piston to push some of the mixture that is absorbed into the cylinder back out on the return stroke and reducing the compression ratio, while keeping the expansion ratio the same. This has the same effect as the original *Atkinson Cycle* but with a much simpler implementation thanks to the new valve technology, which James Atkinson did not have at his disposal 140 years ago. (Lexus, 2015)

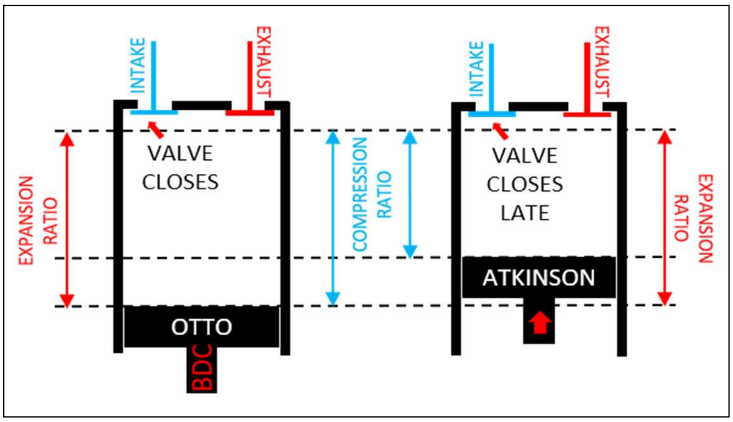

Figure 6 *Compression and Expansion Ratios of the Otto and the Atkinson Cycle*

This technology has been widely used by *Toyota* in hybrid cars. They have been able to use valve technology in order to seamlessly switch between the two operating cycles (Atkinson and Otto) by just changing the valve timings, and so taking the best efficiency and power out of the same engine.

The ***Miller Cycle*** is a variation of the *Atkinson Cycle* invented by German engineer *R. H. Miller* in the 1940s. The idea was to increase power and efficiency at the same time.

The *Miller Cycle* uses an early or late closing of the intake valve, just as in the *Atkinson cycle*. However, whereas in the *Atkinson Cycle* this is done solely to reduce the compression ratio, the *Miller Cycle* has further purposes:

R. H. Miller realized that closing the intake valve at bottom dead centre (BDC) meant that the piston would have to exert pressure on the fuel mixture from a position where it didn't have leverage to push it back up. However, by delaying the intake valve's closing, at BDC the piston would have to exert no pressure and it could gain leverage as it rose, at which time the intake valve would close and the piston would start to compress the mixture. The same effect would be created if the intake valve closing time was anticipated (J. D. Naber, J. E. Johnson, 2014).

Normally, this would mean less power, given that there is less charge in the cylinder, as in the *Atkinson Cycle*. The *Miller Cycle* counters this by using a *turbocharger* or a *supercharger*. This brings a series of benefits that improve engine performance:

The *turbocharger* uses the thermal and kinetic energy of the exhaust fumes to spin a turbine wheel, which is attached to a compressor wheel. This compressor wheel is used to compress the air that goes into the engine, making up for some of the lost compression rate and fuel mixture. In effect, the *compression stroke* in the *Miller Cycle* is divided into two. For the first 20-30% of the stroke, the compression is done by the *turbocharger*, while the piston does the remaining 70-80%, once it has gained more leverage.

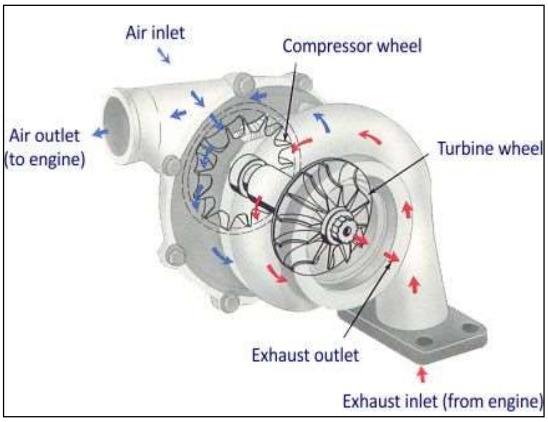

Figure 7 *Turbocharger. Retrieved from: http://neo-drive.com/image1024-post/3166-compressor-10.jpg.html*

Another benefit of having a *turbocharger* is that, between it and the intake valve there is an *intercooler*. As the air is compressed in the *turbocharger*, it gains temperature. This is compensated by having an *intercooler* to cool the air back down, to temperatures even lower than an *Otto Cycle* engine would have. This lower final temperature increases efficiency still further, reduces the risk of early combustion and even reduces NOx emissions in diesel engines.

In summary, the *Miller Cycle* has a different purpose to that of the *Atkinson Cycle*, although it does share some benefits. It is based on the principle of relieving the load from the piston during the first part of the compression stroke by means of a *turbocharger*, resulting in more output horsepower and increasing efficiency by about 15%. Other benefits include better combustion timing and higher expansion ratio in relation to that of compression.

The ***Diesel Cycle*** was invented by *Rudolf Diesel* in 1893. The principle was the same as that of the four-stroke *Otto Cycle*, but with one difference: there was no spark plug to ignite the mixture.

During the intake stroke of a diesel engine, air is let into the cylinder instead of the fuel mixture. This air is then compressed to high pressures. When the piston arrives at the top of the cylinder and the maximum compression of the air has been achieved, fuel is injected into the cylinder and combustion takes place spontaneously. The power stroke and the exhaust stroke stay the same as in the *Otto Cycle* (P. Breeze, 2018).

This cycle has the highest *thermal efficiency* of all, arriving at over 50% in low-speed diesel engines like those used in ships. They can convert the biggest percentages of the heat they produce into work.

3. Based on the mixture preparations

There are two main different ways of taking the fuel to the cylinder: the fuel can be *injected* into the cylinder via a fuel injector, or it can be mixed in a *carburetor* and introduced into the cylinder via an intake valve (V. R. Chennu, 2015).

Most new now cars do not use ***carburetors***, however until the 20th century, *carburetion* was the most common way of introducing fuel into the engine. Nowadays, *carburetion* is used in smaller vehicle applications like motorbikes, go-karts, lawnmowers etc. where the fuel is mixed in and introduced via a *carburetor*.

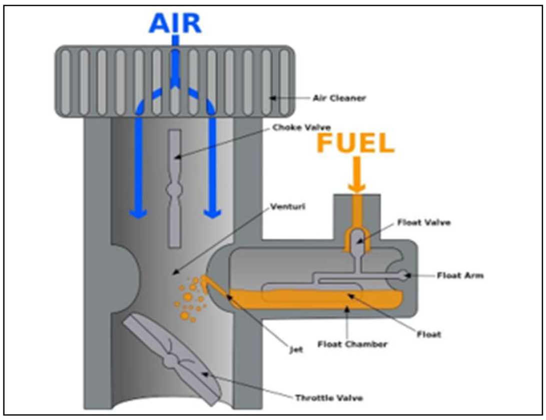

Figure 8 *Cross Section of a Carburetor. Retrieved from: https://tecnofisicadotnet.wordpress.com/aplicaciones-del-principio-de-bernoulli/*

The *carburetor* is a simple mechanical device composed of two perpendicular tube sections. One of them takes the main air flow through a filter and a series of valves (choke and throttle) through to the cylinder. The second tube holds a certain amount of fuel and is joined to the main tube at a place where the aforementioned narrows down. When the air flows through this narrowed section in the main tube, it creates a space of lower pressure (*Bernoulli Principle*), enabling the fuel to drip from the second tube, which is at a higher atmospheric pressure, into the airflow of the main tube, through a small hole in its narrowed section. This way, the fuel-air mixture is created and transported to the engine (D. Tracy, 2013).

The throttle valve simply opens and closes, depending on how much the throttle cable is pulled, to let more or less fuel mixture into the engine, thus changing its speed. While the throttle is not being pressed, the throttle valve is closed so, to keep the engine going while idling, there is also a bypass of this valve that supplies the engine with the right amount of fuel mixture.

The choke is used to partially close the airflow in order to supply a low air to fuel ratio mixture for starting the engine.

Fuel injection is presently the most common way of introducing fuel into the cylinders in cars. In gasoline engines, a fuel injector is positioned just behind the intake valve and injects the right amount of fuel into the air that flows into

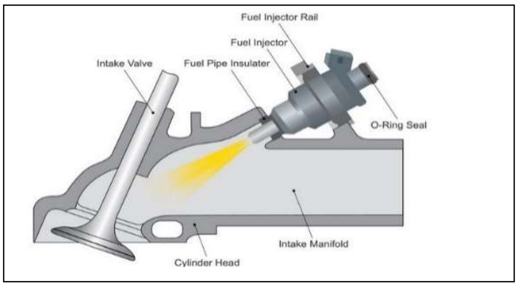

Figure 9 *Fuel Injector Assembly on a Gasoline Engine. Retrieved from: https://jbrsurplusautoparts.com/blogs/news/fuel-injection-how-it-works*

the cylinder, creating the mixture. In diesel engines, the injector introduces the fuel directly into the cylinder and the mixture is made inside it.

With new technology, this opens to a range of possibilities when creating the best air to fuel ratio depending on the demands placed on the engine.

4. Based on ignition

There are two different ignition systems, which have already been mentioned: *spark ignition* (SI) and *compression ignition* (CI).

In the *spark ignition* system, several components work together to create a spark in the cylinder at the moment of maximum pressure, when all the gases are compressed by the piston. There are several kinds of *spark ignition* systems. Some get the current supply from *batteries* and some from a *magneto*, which is a small generator attached to the axel of the engine. This second way of getting the current for the *spark plugs* is more common in small applications (M. Marks, 2014). The system works as illustrated in the diagram:

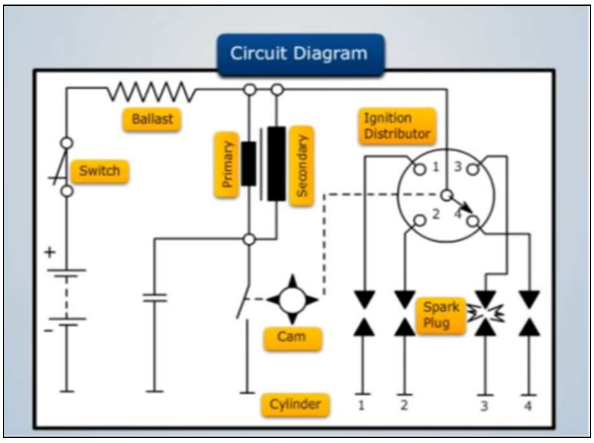

Figure 10 *Circuit Diagram of a Spark Ignition System Retrieved from: https://www.youtube.com/watch?v=OMLSNwQiiKg*

The *battery,* or the *magneto,* supplies a constant 12V current to the primary winding in the *ignition coil.* The *ignition coil*'s purpose is to step up this voltage to the 22,000V or over that the *spark plugs* require, and it is composed of two *wire windings* around a *magnetic soft iron core*. The primary winding has about 200-300 turns and is connected to two exterior terminals. The secondary winding has 21,000 turns and has one exterior terminal (high tension wire

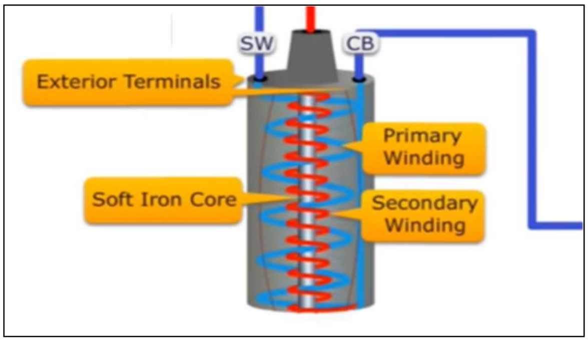

Figure 11 *Ignition Coil. Retrieved from: https://www.youtube.com/watch?v=OMLSNwQiiKg*

connected to the distributor). The other end is connected to the primary winding. (M. Marks, 2014)

As the current arrives at the primary winding, it creates a magnetic field around the soft iron core. The current then comes out of the *ignition coil* and arrives at the *contact breaker*.

The *contact* breaker is in charge of connecting and breaking the main circuit and it is made up of two metal pins, one movable and another fixed. The movable pin is attached to a spring-loaded pivot arm that keeps the two pins in contact, thereby closing the primary circuit. The pivot arm rests on a cam, which is connected to a camshaft and driven by the engine. As the cam spins, it pushes the pivot arm up and disconnects the two pins, breaking the main circuit. (M. Marks, 2014)

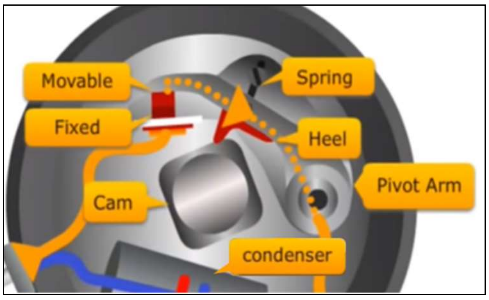

Figure 12 *Contact Breaker. Retrieved from: https://www.youtube.com/watch?v=OMLSNwQiiKg*

A *condenser* is connected in parallel with the *contact breaker* and, as the main circuit is broken, the *condenser* charges up, bringing down the primary current and the magnetic field. This change in the magnetic field induces a current in the secondary winding in the direction of the primary circuit. This charges the *condenser* to a much higher voltage (but much lower current) than that of the battery or magneto. The *condenser* then reverses the current and magnetic field, taking the high voltage through the high tension wire to the *distributor*. (M. Marks, 2014)

The *distributor* is a simple mechanical device that consists of a rotor attached to the camshaft and a metallic *electrode* for each *spark plug*. As the rotor passes by the *electrodes*, the high current travels through them and arrives at the *spark plugs*.

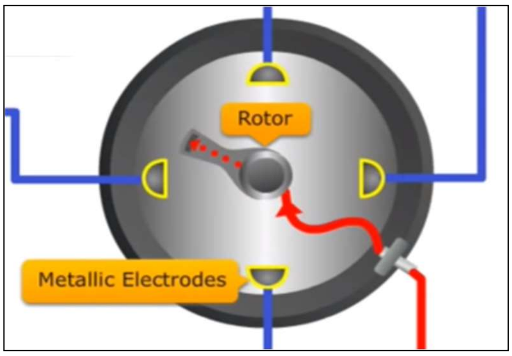

Figure 13 *Distributor. Retrieved from: https://www.youtube.com/watch?v=OMLSNwQiiKg*

The *spark plugs* are composed of a *central electrode*, through which the high voltage arrives, and an exterior *ground electrode*, separated by a few millimetres. Due to the high potential difference between the two *electrodes*, the gases between them are *ionized* and turned into conductors, finally causing the spark (M. Marks, 2014).

In *Compression Ignition* engines, none of this system is required. There is no spark needed so no spark plugs or current. In CI engines, the ignition takes place due to the high compression and temperatures when the fuel is injected into the cylinder.

To achieve these high pressures, CI engines have higher compression ratios. In SI, compression ratios range between 6 and 10; whereas in CI engines, they vary from 16 to 20. Because of the elevated pressures, CI engines are bigger and heavier. This also makes them slower. However, what CI engines lack in speed, they make up for in thermal efficiency thanks to the higher compression ratios.

Generally, SI engines run on *gasoline* (using the Otto Cycle or similar). Gasoline has a high self-ignition temperature. This prevents the fuel from igniting itself and causing the engine to “Knock”. On the other hand, this is the very principle on which CI engines work, so they use *diesel*, which has a much lower self-ignition temperature.

Combustible Fuels

There are different kinds of fuels used in combustion engines. The most common fuels used today are *fossil fuels*. There are two main *fossil fuels* used in cars –*diesel* and *gasoline*– and a further one used in planes –*kerosene*. The latter has the advantage that it freezes at much lower temperatures, making it more suited to the operation temperatures required for planes.

Diesel is a crude oil derivative used in diesel engines. It has a low self-ignition temperature, which makes it the perfect choice for compression ignition engines.

Gasoline is also a crude oil derivative, but it is used in engines that run on the Otto Cycle and other variations. It has a high self-ignition temperature, which prevents “knocking” in spark ignition engines.

Whether the fuel is gasoline or diesel, at some point in the cycle of the engine the fuel is mixed with air. In the mixture, the air acts as an *oxidiser*. It provides the engine with the oxygen needed for combustion. The air-fuel ratio is important in order to take the most out of the combustion. Depending on the requirements placed on the engine (power, low emissions), these ratios may vary. In diesel and gasoline engines, the molar air to fuel ratio for low emissions and good performance is generally around 14.6 to 1.

Carbon Emissions: A cause of Global Warming

Aside from the fact that fossil fuels will one day run out, the most common issue that people see when they think of combustion cars (Diesel or Gasoline) is pollution. Everybody has at least about the fact that combustion cars are one of the big sources of pollution and causes of global warming. However, is this actually true? Are they the only ones that should take the blame? And, exactly what do we mean when we speak about global warming?

Carbon dioxide (CO_2) is a gas formed by carbon and oxygen. A colourless, odourless gas, it is produced in *combustion* and in the respiration of *living aerobic organisms*. Carbon dioxide is naturally present in the atmosphere of our planet at low concentrations. It contributes to what is known as the "*Greenhouse Effect*".

The "*Greenhouse Effect*" is a *natural phenomenon* caused by *greenhouse gases (GHGs)*. These gases (including carbon dioxide and methane) absorb the *infrared radiation* from the sun which deflects off the earth's surface, not letting it escape from the earth's atmosphere and making the temperatures inside it higher. Ultimately, the resulting effect is the same as that of a garden greenhouse, but on a much larger scale. It is thanks to this effect that the earth is a comfortable place to live. Without this phenomenon, the earth's temperatures would be too low for any living organism to survive easily.

However, we are currently having problems on the other extreme. Having too much concentration of greenhouse gases in our atmosphere can cause the greenhouse effect to increase and result in *"**global warming**"*.

Global warming is the increase of temperature across the whole of the globe. The temperatures we have adapted to are very specific, and the earth provides just the right range. Life is comfortable on our planet highly due to its specific temperatures. Low temperatures can be contrary to life, but so can high temperatures. Wind currents, rain patterns, sea levels, seasons, weather, pH… all these things depend on the temperatures of the earth's atmosphere, which we depend on in turn, and the truth is that the natural processes of *global warming* are accelerating very unnaturally (California Air Resources Board, 2018).

Over the past 170 years there has been a significant increase in average global temperatures[1]. The start of this unprecedented change coincides precisely with the time when industry made its first booms. It is undeniable that this was the most decisive cause for the occurrence of this anomaly. However, the anomaly has only continued to grow since then, in stride with global industry. (H. Ritchie, M. Roser, 2017)

As I explained earlier, carbon dioxide is one of the so-called "*greenhouse gases*". Since pre-industrial times, the concentration of carbon dioxide in the atmosphere has increased by by over 25%[2].

Having a look at the different sources of GHG emissions[3], we can see that, according to the California Air Resources Board, in 2016 the highest source of GHG emissions in that state was transport, with 41% of the emissions coming from that sector. Second, after transport, came industry, with 23% of total emissions; and thirdly came electricity generation, comprising 16% of total GHG emissions (California Air Resources Board, 2018).

Therefore, we can see that, indeed, transport is the biggest source of GHGs, which cause global warming and can affect our planet severely. However, we can also see that transport is not the only significant source of GHGs. Asides from the fact that transport is not solely composed of cars, Industry and electricity generation make up 39% of the total GHG emissions. This project does not have the purpose of going into the topic of industry. However, we will explore the other two significant sectors, transport and electricity generation, to see the impact that electric cars would have on these figures.

Electric Cars: The solution?

Since the 1960s, there has been a slow rebirth in electric vehicles. As the cost of fossil fuels like gasoline and diesel increased, governments started looking for an alternative. They financed companies to encourage the advance of technology in the area of electric cars. Several countries all over the world have set themselves targets for cutting down on fossil fuels, decreasing emissions and increasing renewable energy sources. By 2020, the total of new cars sold by automakers in the European Union will not be allowed to emit an average of over 95 grams of CO_2 per kilometre driven, with fines of 95 euros per gram for each car over the target (European Comission, s.f.)*. This*

[1] See ***Chart 1***
[2] See ***Chart 2***
[3] See ***Chart 3***

is putting carmakers under a lot of pressure, having to choose between paying the huge fines or investing money into developing electric cars and reducing their prices to attract buyers, also losing money in the process. However, we have not come all this way all in one go. Hybrid cars are providing a huge stepping-stone for electric vehicles as they gradually improve, acquiring the power and autonomy of the same standards as their gasoline predecessors.

As opposed to combustion cars, electric cars (EVs) use an electric motor to drive their wheels. The motor is typically powered by lithium batteries. Due to the novelty of this field, there are several types of motors and batteries used on electric vehicles. We will explore the main types of batteries, motors and other components of an electric car used by the biggest manufacturers of today's EVs.

The Electric Motor

There are several types of electric motors, which can be classified according to the mechanisms they use and the current they run on. They all have different advantages and disadvantages for specific applications. With EVs, the most commonly used are *AC asynchronous three-phase induction motors,* invented by *Nikola Tesla* in the 1880s.

Three-phase motors run on alternating current (AC). Alternating current is the kind used in power supplies and in homes. It is a kind of electric current that reverses its direction many times every second, at regular intervals (E. Osmanbasic, 2017). These motors run on three phases. Three-phase motors use three cables, one for each phase. They all carry the same current, but with a slight offset in oscillation, as shown on the diagram.

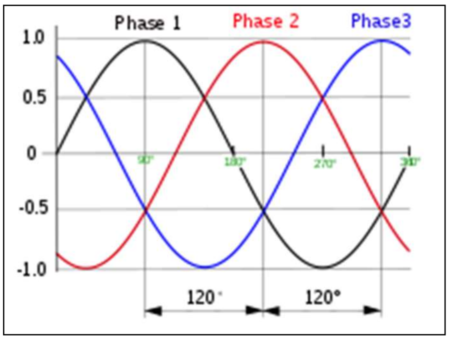

Figure 14 *Three-Phase Current (120º offset)*

The *three-phase induction motor* comprises two key independent parts: the *stator* and the *rotor*. According to *Faraday's Law of Induction*, electricity can be used to generate a magnetic field and, inversely, a varying magnetic field can induce an electric current in a conductor. This is the principle used in induction motors, where the stator provides the varying magnetic field, caused by the alternating current, and the rotor is the conductor where the electric current is induced (C. Woodford, 2019). The process is:

The three-phase current arrives at the stator windings and creates a magnetic field. Thanks to the 120º offset of the three phases and the oscillation of the alternating current, the orientation of the magnetic field changes constantly, creating the same effect as a rotating magnetic field (RMF). This moving magnetic field then induces a current in the windings of the rotor, which produce a second magnetic field. The rotor is held inside the stator by two bearings, allowing it to spin freely, thus following the RMF at a slightly lower speed (3-5%). This small difference in speed gives *asynchronous* motors their name.

In three-phase induction motors, the speed is regulated by the frequency of the current. The faster the three phases oscillate, the faster the RMF will spin. The amplitude of the current controls the power output of the motor.

The same rotating effect can be achieved with two phases instead of three, but the resulting movement is not as uniform.

Some benefits of three-phase motors for automobile applications include:

- *They have no brushes*. Three-phase induction motors are brushless. The current is induced in the rotor and so there is no need for brushes to conduct the current to the rotor. This is a good thing for an application such as a car, where durability and low maintenance are important. With brushless motors, there is one less thing to worry about.
- *They have no permanent magnet*. Motors with permanent magnets are delicate in the sense that they cannot operate at high temperatures. Permanent magnets can demagnetise if they are heated for too long. With temporary, induced magnets, this is not a problem.

The Lithium Battery

Powerful motors need a powerful source of energy. In electric vehicles, this is normally provided by lithium battery packs. Lithium batteries are present in everyone's daily lives. They are used in the majority of electronic devices –like laptops and phones– due to their light weight, high energy density and ability to recharge quickly. There are

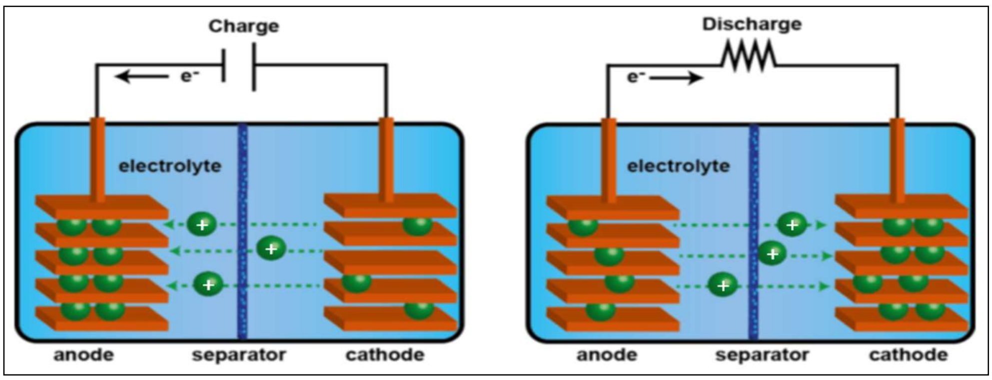

Figure 15 *Charge and Discharge Diagram of a Lithium Ion Cell. Retrieved from: https://www.gizmodo.com.au/2015/05/tomorrows-battery-technologies-that-could-power-your-home/*

several variations of the lithium battery. The most common kind is the Lithium Ion battery (Li-Ion).

The *lithium ion cell* comprises a *cathode*, an *anode*, an *electrolyte*, a *separator,* which is permeable for lithium ions but not for electrons*,* and two current *collectors*. The lithium is stored at the anode half of the cell in the form of lithium oxide when the battery is discharged, which provides a stable state for the element. When the battery is charged, the lithium is stored in its ionic form at the cathode half of the cell, which is not as stable (Learn Engineering, 2019). The lithium battery works on the principle of *electrochemical potential*: lithium, like all elements, always tends to go to its most stable state possible. In the lithium battery, we have two states: the lithium oxide (at the cathode half) and the lithium ions (at the anode half of the cell). The lithium oxide is more stable than the lithium ions and so, if we provide the means, the lithium ions will automatically join with oxygen and form lithium oxide. During this process, a flow of electrons is created. If we channel the electrons through a specific path, an electrical circuit, we create electric current (Learn Engineering, 2019). The process is:

When charging the battery, the lithium in the cathode half of the cell is ionized and one electron is released from each lithium atom. The electrons are then attracted to the cathode, while the lithium ions are attracted to the anode. This attraction causes the ions to traverse the separator, helped by the electrolyte (a liquid that acts as a transporter), and they are stored on that side of the cell. At the same time, the power supply takes an electron flow to the anode half of the cell. When the process is complete and the battery is charged, the anode half of the cell contains the separated electrons and lithium ions (U.S. Department of Energy, 2017).

As a load is placed on the battery and it discharges, the positively charged lithium ions again traverse the separator with help from the electrolyte. However, the electrons cannot get through it. This forces them to go through the current collectors and out of the cell, completing the electrical circuit and arriving at the other side, joining back up with the lithium ions and taking their place in the lithium oxide (Learn Engineering, 2019).

The Inverter

Induction motors run on AC current, while the battery supplies dual continuous current (DC). There has to be something between the two to convert the current from one to the other. That something is the inverter.

The inverter is the brains of the electric car. It not only has the job of converting the current, but also of controlling its amplitude and frequency, thus varying the speed, power output and spinning direction. Whereas this is all done mechanically in a combustion car, in electric vehicles it is all pure electronics.

The Transmission

Combustion engines can only handle peak RMP of about 3000. Electric vehicles can easily handle 18000 RPM at near constant torque. This is a huge advantage for transmission. Whereas combustion cars use all sorts of complex gear systems, all of which are energy loss points, electric cars are able to use direct transmission to the wheels. They can even switch to reverse without the need to change gears: just spin the motor the other way.

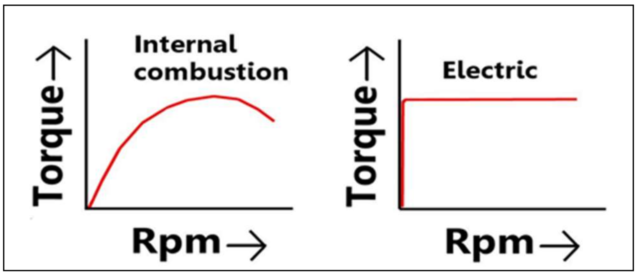

Figure 16 *Internal Combustion Engine VS. Electric Motor Torque Curve Comparison*

The graphs in Figure 16 show the torque that a combustion engine and an electric motor can deliver as a function of RPM.

Tesla Inc.

Tesla Inc. is an American car and energy company based in Palo Alto, California. It was founded in July 2003 by Martin Eberhard and Marc Tarpenning, and named "Tesla Motors", after engineer Nikola Tesla. In the early stages, the company was joined by, J. B. Straubel, Ian Wright and *Elon Musk*, who is now the CEO of "*Tesla Inc.*", renamed in 2017. According to Musk, the company's main aim is to produce electric cars that are affordable to the average customer.

In 2008, Tesla brought out to the market their first car, the *Tesla Roadster*, a low-volume high-cost vehicle. The model was discontinued in 2012. Slowly Tesla's production has moved on to bigger-volume lower-cost cars, with the *Tesla Model S* (2012), *Tesla Model X* (2015) and *Tesla Model 3* (2017).

At the moment, *Tesla Inc.* is the leading electric vehicle company in the world, with high speeds, long ranges and the fastest acceleration times on the road. They have also gone a long way into the field of autonomous driving, with all their vehicles running on up to autonomous level 3.

The Possibilities of the Electric Car

As electric cars get a grip on the road, new fields of expansion will rise up. *Tesla* has delved a good way into the field of autonomous driving. However, no car is fully self-driving –that is still years away.

There has also been a lot of research into battery technology and charging methods. Batteries still have plenty of room for improvement in terms of efficiency and especially storage capabilities (energy density). Other possibilities that the electric cars open up are Independent wheel drive with independent motors, Kinetic Energy Recovery System (KERS), regenerative braking etc. It does not just end at electric cars; there are still lots of things to improve on the basic concept.

What are the Drawbacks of electric cars?

Electric cars seem like the grand solution to all problems. No emissions, eco-friendly, increased safety, great performance… but, is there a catch?

Indeed, yes. For electric cars to be completely eco-friendly some other things would have to change asides from the vehicles themselves. The first thing to consider is the source of the electricity that the cars run on.

According to the International Energy Agency (IEA), as of 2017, only 25% of the energy consumed in the world came from renewable sources[4]. It is not a bad figure, and it is increasing, but it is nowhere near enough to say that electric cars are completely eco-friendly. The other 75% of energy consumed in 2017 came from nuclear power, coal, oil and natural gas –all non-renewable, and in some cases polluting, sources of energy (IEA, 2017). As countries all over the world update their energy production policies, these figures will hopefully change to the advantage of renewable sources and we will be able to say that electric cars run solely on renewable power.

The second issue of electric cars is with the batteries. Electric cars normally use lithium batteries. These batteries contain a certain amount of the element, which has to be extracted from mines. Lithium is extracted mainly from the "Lithium Triangle", which is an area that covers part of Chile, Argentina and Bolivia. There are also some mines in Australia. The process is very energy intensive and still does not meet the increasing need for the element (S. Hacker, 2018).

Furthermore, there is a problem when recycling these batteries. Until now, it has always been less costly to manufacture batteries using new lithium than using lithium

[4] See ***Chart 4***

from recycled batteries. However, despite not being ideal, lithium is still a much better alternative than fossil fuels and, as technologies improve and reusing old batteries becomes easier, these problems will be, at least partially, overcome.

Sure, electric vehicles are not completely clean. However, they are much more eco-friendly than the combustion alternative. They have one advantage: potential. We are only at the dawn of electric automobility. Some problems have been around for decades. However, slowly, we can begin to fix them. One of the first steps is to take in this direction is to potentiate *renewable energy sources*.

Renewable Energy

Fossil fuels are a non-renewable source of energy. They take millions of years to be replaced and our standard of usage is much faster than that. It is for this reason, and the fact that combustion produces a specific kind of gases, that there has been so much emphasis lately on switching over to renewable power sources.

Renewable energy sources are those that are self-replenishing –in other words, they do not run out. There are five main renewable energy sources: *Biomass, Hydropower, wind, solar* and *geothermal*. These sources are renewable because they will be available to us indefinitely, but only at a very limited amount per unit of time (V. Petrova, 2018).

Biomass

Biomass is an *organic material* and a renewable energy source that comes from plants and animals. Living beings store energy, be it from the sun or from what they eat. This energy is present in biomass. When biomass is burnt, that energy is transformed into heat, which can be used either directly to heat homes (this is the most common use for biomass in poor and underdeveloped countries), in industry or to generate electricity.

Some biomass sources can be converted to *liquid biofuels* (agricultural crops, waste material and decomposing organic waste in garbage) or even to *biogases* (animal manure or human sewage). Others are burnt in *solid* state, like wood and wood processing wastes. (US Energy Information Administration (EIA), 2019)

The problem with biomass is that it involves combustion, so it emits carbon dioxide, polluting the atmosphere. This is a problem that biomass will always have and, if the aim is to cut down on emissions, this option may have to be ruled out.

Biomass is not a very big component of the renewable sources, although not the smallest. In 2017, it made up 12% of the total renewable sources, which were 25% of the global energy consumption[5]. (V. Petrova, 2018)

Hydropower

Hydropower is a renewable source of energy harnessed from water by hydroelectric plants. There are three main components of a hydroelectric plant: the *reservoir*, the *dam* and the *power plant*.

Figure 17 *Hydropower Plant Showing the Reservoir, the Dam and the Power Plant. Retrieved from: https://lankainformation.lk/news/business-news/item/11953-chinese-commercial-bank-to-grant-us82-million-for-kithulgala-hydropower-project*

The reservoir contains the water that will later produce the electricity and it is usually set in a valley, where geography of the landscape is favourable for the purpose and there is an abundant water supply from rivers.

The *dam* is a thick concrete wall that keeps the water in the *reservoir* and lets it out when needed. It is thicker at the bottom and thins out as it rises. This shape helps support the wall against the enormous pressure that the water forces onto it.

The *power plant* is where the electricity is produced with the *turbines* by the principle of *Faraday's Law of Induction*. The water is channelled to push the turbine blades and make the turbines spin, converting the water's potential, and then kinetic, energy into electricity (C. Nunez, 2019).

Hydropower is currently the third biggest renewable energy producer, giving 23% of the total renewable energy produced globally in 2017[6]. (V. Petrova, 2018)

Wind

Wind power is another source of renewable energy. It works the opposite way that a fan works. It turns wind into electricity instead of electricity into wind. The blades are connected to a *turbine*, the same way as in the power plant of the hydropower generator, which generates current by the principle of *Faraday's Law of Induction*. (US Department of Energy, s.f.)

[5] See ***Chart 4***
[6] See ***Chart 4***

Wind turbines can be of different types, depending on their *geometry* (horizontal or vertical axis) and depending on *where they are* (onshore or offshore).

Horizontal axis wind turbines are the most common kind and the image that most people have in their minds when they think of a wind turbine. The axis is set horizontally and has to be kept parallel to the general direction of the wind so that it functions properly. For this reason, the head of the turbine, with the three blades, can rotate to face the wind.

Figure 18 *Horizontal Offshore Wind Turbines. Retrieved from: https://resourceglobalnetwork.com/tag/offshore-wind/*

Vertical axis wind turbines are less common, but they have one advantage over the horizontal wind turbines: they are *omnidirectional*, so they can face the wind in any direction. They have various shapes, but the general idea is the same: the axis is perpendicular to the general direction of the wind and the blades are attached parallel to it. Their shape allows them to catch the wind on one side, but to let it escape on the other, meaning that, no matter which way the wind comes, they will still catch the wind and rotate.

Figure 19 *Vertical Onshore Wind Turbine. Retrieved from: https://coldwellbankerphuket.com/blog/could-sustainable-features-boom-phuket-property-prices*

Onshore wind turbines are set inland, normally in high but unsheltered places. The problem with this is that they can visually destroy the landscape. The solution to this problem is to have *offshore wind turbines*. They are set kilometres out to sea, where there is no shelter from the sea wind and they cannot be seen. This helps to protect the landscape, but the installation costs are higher, and they can often bring forth technical difficulties concerning maintenance.

Wind power is currently the biggest renewable energy producer, giving 37% of the total renewable energy produced globally in 2017[7]. (V. Petrova, 2018)

Solar

Solar power is harnessed from the sun's energy by means of solar panels. Different kinds of solar panels are used for different purposes.

[7] See ***Chart 4***

Thermal solar panels use the heat from the sun directly to heat water. They are used mainly in homes and can be an effective way to save electricity at home, but they do not actually generate it. They can be *active*, where the water circulates through the panels, or *passive*, where the water does not circulate.

Figure 20 *Thermal Solar Panels . Retrieved from: https://allianzenergy.com.co/capacitacion/energia-solar-termica/property-prices*

Photovoltaic solar panels are the most typical image of a solar panel; they are the ones that actually generate electricity. There are many types depending on the material they are made of, but the general concept is the same in all of them. The principle is called the *photoelectric effect*.

Figure 21 *Photovoltaic Solar Panels in a Solar Power Plant. Retrieved from: http://www.sinagph.com/*

The photoelectric effect was first noted in 1839 by French scientist *Edmund Bequerel*. He found that certain materials produced a small current when they were exposed to light. In 1905, *Albert Einstein* described this phenomenon as the *photoelectric effect*, on which the photovoltaic solar panel technology is based. (J. Hanania, K. Stenhouse, J. Donev, 2015)

All metals have what is called a *limit frequency.* If an incident wave has a frequency equal to or larger than this limit frequency, the metal ionizes and releases one electron, which can be translated as electricity. The *photons* that compose visible light have a certain *frequency* (between 430 and 770 THz), so photovoltaic solar panels are made of materials with the most suitable limit frequencies to use the sun's light efficiently. (G. Knier, 2008)

In terms of solar energy, the most useful to create a sustainable source of electricity are *photovoltaic solar panels.* They are the kind used to produce solar power in homes but also in large scale solar power plants.

Solar power is currently the second biggest renewable energy producer, giving 28% of the total renewable energy produced globally in 2017[8]. (V. Petrova, 2018)

Geothermal

Geothermal energy is a renewable power source that uses the internal heat of the earth's crust. By drilling wells of between 3 and 10 km deep in specific places, the heat can be extracted from the ground, mostly using water and steam. The water can be pumped through houses to provide hot water and the steam can be used to turn generators and produce electricity.

Geothermal power, however, has several disadvantages. It can only be used in places with specific geologic requirements. Places like Iceland, New Zealand and Hawaii, which are volcanic or tectonically active, are very developed in this energy source. However, geothermal energy still makes up a small percentage of the total renewable energy production in the world.

Moreover, apart from the fact that geothermal extraction must be managed appropriately so it does not alter the temperatures of the earth's crust, there is also a problem with the use of groundwater. Extracting this water can cause the emission of carbon dioxide and hydrogen sulphide to the atmosphere, which contribute to pollution. Technologies are being developed to prevent this from happening and to turn geothermal into a zero-emissions source of power. (J. Carlson, s.f.)

Nuclear Power

Another potentially green energy source is nuclear power. Currently there are over 440 nuclear power plants on earth. In 2017, nuclear power accounted for 10% of the total energy production[9]. But what are the pros and cons of this alternative energy source?

Nuclear power is harnessed from the energy released in nuclear fission of *Uranium 235*, which is sparked by a chain reaction triggered by firing neutrons at the latter. The energy is released in the form of heat, which is used to heat up water. The vapour formed pushes the turbine blades, which transform the kinetic

Figure 22 *Nuclear Power Plant. Retrieved from: http://reporterpatagonia.com/mas-apoyo-a-instalacion-de-la-central-nuclear-en-sierra-grande/#.XfZqnG5FyUk*

[8] See ***Chart 4***

[9] See ***Chart 4***

energy into electricity.

Nuclear power is the case of a very low-emission, non-renewable power source. It does not create pollution directly, but the process of mining for and transporting *Uranium 235* is energy consuming and involves the emission of carbon dioxide, although this happens in very small proportions, especially when compared to the GHGs emitted by the rest of the energy generation sector.

Nevertheless, nuclear power still has one problem which is more delicate: radioactive waste. When *Uranium 235* has been used, it must be buried in radiation-proof containers. This waste still emits radiation and can be dangerous, both for the environment and for humans. Furthermore, the process of its decomposition can take thousands of years. The challenge is to make containers strong enough to safely store this waste for the required periods of time.

Nuclear power may be a good solution, but only until the next generation of waste-less nuclear power plants, like the International Thermonuclear Experimental Reactor (ITER), replaces them.

Alternatives to Batteries

Although most electric cars run on lithium batteries, there are some alternatives which could mean the solution to the problem of both the contamination caused by lithium, and the hindrances of battery weight and size.

The *Honda Clarity* is the first production car running on a *hydrogen fuel cell*. Hydrogen fuel cell cars are electric. However, unlike other electric cars, they create their own electricity via a hydrogen cell. This brings huge advantages, as they need not carry around big, heavy batteries. Instead, they carry a tank of compressed hydrogen gas (Honda Automobile, 2019).

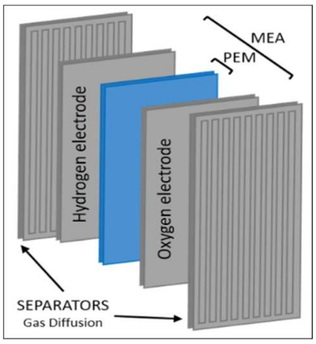

Figure 23 *Structure of a Fuel Cell*

Hydrogen fuel cell cars have three key components: the *motor*, the *hydrogen tank* and the *fuel cell stack*, which converts the gas into electricity. The fuel cell stack comprises many individual cells stacked together. Each is composed of a *membrane electrode assembly (MEA)* between two *separators*. The MEA is composed of a *proton exchange membrane (PEM)* sitting between a hydrogen and oxygen electrode. As the hydrogen passes over the hydrogen electrode, it is ionized and loses an electron. The positively charged hydrogen ion, the proton, then passes through the PEM and joins up with the oxygen from the air and forms water. The freed electron passes through an external circuit and creates an electric current. (Honda Automobile, 2010)

Water vapour is the only waste gas that a fuel cell produces. However, as with battery-powered cars, the fuel source, or the source of any other alternative energy, also counts. The good thing about hydrogen as a fuel is that it is collected via electrolysis, which is a near emission-free process if renewable energy is used. However, this process is very expensive, which is where hydrogen fuel cars are at a disadvantage. The price of hydrogen is even higher than that of gasoline. The technology is very new and there are not that many refill facilities. Hopefully, as technology advances, this will change in hydrogen fuel cell's favour.

Safety is also an important factor that has to be considered in hydrogen fuel cell cars, as carrying compressed hydrogen, which is highly explosive, can be dangerous.

Performance wise, the Honda Clarity is easily at the level of combustion cars, with the possible exception of range, which is only of about 580 km with combustion cars having an average of about 700 km. (Honda Automobile, 2019)

Other alternatives to lithium batteries have opened up thanks to the discovery of the material *graphene*. Its incredible properties have made possible the combination of *supercapacitors'* great power output and lasting life with the high energy density of lithium batteries, at the same time creating a safer and more ecological solution to the power demands of all electric devices, especially EVs.

Hybrid Cars

There is always something needed to transition between two extremes. With electric and combustion automobiles, the steppingstone is the hybrid car.

Hybrid cars are essentially combustion cars that also have an electric motor. The motor has restricted autonomy but can assist the combustion engine, as well as operate independently at low speeds. This can be very useful for in-city trips and can also make the car much cheaper to run, as it means less fuel consumption.

There are two main kinds of hybrid cars: *non plug-in* and *plug-in*. *Non plug-in hybrid cars* transform some of the otherwise lost energy that the engine produces to electricity, through systems like Regenerative Breaking and Kinetic Energy Recovery System (KERS), to charge the batteries. *Plug-in hybrid* cars have the same functions but with one added feature: their battery can also be charged via an external means such as a supercharger.

Generally, hybrid cars can deliver the same performance as any other combustion car, with the possible difference in weight. Hybrid cars not only have to carry the weight of, the engine, but also that of the electric motor and the batteries. This makes them slightly heavier and clumsier.

On the whole, hybrid cars are a great way to transition from combustion cars to electric vehicles. They can give an idea as to what electric cars can do, gradually increasing their reliability and general acceptance, while still having the traditional combustion option that everyone is familiar with.

Other Transport Implementations of Renewable Power

It is not just cars that pollute the environment; all combustion vehicles do. Although cars are the most obvious and accessible source for us, if you add up the pollution caused by ships, planes and other combustion vehicles, the numbers rise higher even than those of cars. Electric means of propulsion in areas other than cars is not very extended. However, here are some examples:

Marine

One large container ship pollutes millions of times as much as a car. With about 50,000 container ships operating in the world, any improvement on this is much needed. The problem here is range. Some ships have to cover thousands of kilometres without stopping at any port to recharge. This could be a reason why electric propulsion in ships is virtually non-existent. However, several companies are developing electric container ships for short trips. One such company is *PortLiner*.

Figure 24 *PortLiner e-Barge. Retrieved from: https://www.gvt.nl/nl/nieuws/completely-electric-propelled-inland-vessels*

PortLiner is a shipbuilding company from the Netherlands. A few years ago, they started a 100 million “Zero emission” project that consisted in building 15 crewless all-electric shipping container ships. The ships are expected to remove 23,000 trucks annually off the roads, cutting down on carbon emissions. This is a huge step towards making marine vehicles non-polluting, which would also have a huge impact on GHG emissions (S. Fadilpasic, 2019).

Other companies have developed ideas including hybrid ships for longer distances and smaller all-electric passenger ferries for shorter trips.

Aviation

One plane pollutes, on average, 125 times as much as a car. But, as ever, the same problem applies to electric planes: range. At the moment, there is no viable option for electric propulsion in terms of big commercial and passenger planes. However, several companies have developed small two-passenger planes for pilot training. They serve the same purpose as their fuel counterparts, but they reduce the flight hour cost considerably –they do not use fuel– and they deliver great performance.

Pipistrel is one such company, with the *Alpha Electro* trainer plane. The aircraft is used to train pilots and can sustain flight for 1:30 hrs, with top speeds of 250 km/h. The *Pipistrel Alpha Electro* can cut down the cost of flight training by about 70%, making flying more affordable than ever. (Pipistrel, s.f.)

Figure 25 *Pipistrel Alpha Electro: Electric Two-Seater Flight Training Plane. Retrieved from: https://thebarentsobserver.com/en/travel/2018/01/norway-goes-electric-planes-next-list*

Formula E

Formula E is a relatively new motorsport that was founded by *Alejandro Agag* and inaugurated in 2014, with the first E-Prix held in Beijing. Formula E is sanctioned by the *International Federation of the Automobile (FIA)*, Agag being the current chairman of Formula E holdings.

Twenty-two drivers, two to a team, contest the Formula E championship. The racing takes place in temporary city-centre tracks between 2 and 3.5 km long. However, what makes Formula E so special is that it uses all-electric cars only.

The first Formula E car used in the championship was the Spark Racing Technology built *Spark-Renault SRT_01E*. It had a maximum output of 200kW (about 270 horsepower) and could accelerate from 0 to 100 km/h in 3 seconds, with top speeds of around 225 km/h (B. Lucareli, 2013). This car was used from 2014 to 2018.

The new second-generation Formula E car, the *Spark SRT05e ("Gen2 car")*, was introduced in the 2018-2019 championship. It held several significant technological advantages over the previous *Spark-Renault SRT_01E,* with a power rise to 250kW (about 335 horsepower) and top speeds of 280 km/h (J. M. Gitlin, 2018).

Figure 26 *Spark SRT05e ("Gen 2 Car"). Retrieved from: https://www.voestalpine.com/group/de/media/presseaussendungen/2018-05-08-voestalpine-wird-hauptsponsor-der-europaeischen-formel-e-rennen/*

Just like Formula 1, which is the birthplace of all the important advances in combustion technology, Formula E is not just a sport. It could mean huge improvements on electric technology, to be used later in production road cars.

Go-kart

Although it might not seem like there are many go-karting places where they have electric go-karts, this new world is just around the corner. More people are getting interested in going all-electric and even important go-kart brands have made their first electric go-karts.

The SODI RSX is an electric go-kart manufactured by Sodikart. It is the leading kart in the electric go-kart rental industry, featuring the latest generation lithium batteries and asynchronous, three-phase motor (Sodikart, s.f.).

On the racing side of go-karting, Rotax has also made their first electric go-kart. The Rotax THUNDeR can achieve an acceleration from 0 to 100 km/h in just 3.5 seconds and top speeds of 130 km/h (Rotax, 2017). This is just the beginning of a whole new category of go-kart racing.

Figure 27 *SODI RSX Electric Go-Kart. Retrieved from: https://www.e-kartszlin.cz/galerie/*

Figure 28 *Rotax THUNDeR Electric Go-Kart. Retrieved from: https://us.motorsport.com/kart/news/brp-rotax-electric-powerpack-ekart-959273/3049154/*

Practical Section

Design and Building Process of a Motorized Go-Kart

Introduction

To compare the practical aspects of the two drive systems, electric and combustion, I will verify my hypothesis via a series of tests I will run on a hybrid go-kart prototype. The go-kart will have both an electric motor and a combustion engine, which will enable me to compare the performance of both drive systems. In this section, I will explain the process I undertook in order to build the prototype, from the early design stages, through to the final design and, lastly, to the final product.

Design Methodology and Criteria

The methodology I used follows the structure of any product development project. The phases I followed in this part of my project are:

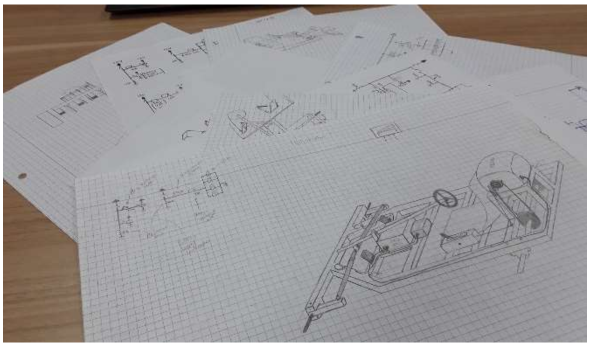

Figure 29 *Design Ideas and Brainstorming on Paper*

1. Idea Generation

In this phase, through brainstorms and diagrams on paper, I came up with the basic idea for the go-kart design, and a set of design criteria for the product to meet.

The *design criteria* I used to design my go-kart are:

MUST HAVE

- The go-kart *must* have both a petrol and an electric motor, with the possibility to use them separately
- The go-kart *must* be able to carry an adult at reasonably fast speeds on both the electric and petrol motors
- The go-kart *must* use a generic TonyKart OTK 401S chassis or similar in order to have a wide range of compatibility
- The go-kart *must* have the safety measures for cutting the power to both the electric and the petrol motors
- The go-kart *must* have a battery monitoring system and speedometer on the dashboard, along with all the other controls
- The go-kart *must* have a reverse drive feature on the electric setting

NICE TO HAVE

- It would be *nice to* use a generator to charge the batteries when the electric motor is not being used to drive the go-kart
- It would be *nice to* have the option to use both the engine and the motor simultaneously

2. Research and development (R&D)

In this phase of the project, I completed the design of the go-kart on Fusion 360. Once the design was finished, I was ready to build the go-kart prototype and move onto the testing phase.

3. Testing

This part of the project was dedicated to running tests on the go-kart to detect any possible detail that could be improved. On several occasions, I had to go back as far as the design stage to fix some of the issues that I encountered while testing.

Design Process

In this section, I will explain the design process I undertook from the beginning to the end.

After the ideas on paper, it was time to bring them together to make the design in Fusion 360. However, there was still one step left. Because of the budget I had from the start, I could not simply design without knowing the cost of what I was designing. I had to do some research and choose the specific parts, making the following spreadsheet containing all the parts and their prices to keep track of the cost:

Product	Weight (kg)	Price (£)	Qty.	Total Price (£)	Total Weight (kg)
Chassis with petrol engine	80	400	1	400	80
Lithium 48V 35Ah Battery	7.5	493	1	493	7.5
Motor, controller and throttle	6	100	1	100	6
Axel Sprocket	0.5	19.95	1	19.95	0.5
Toggle Switches	0.1	4	1	4	0.1
Chain	0.5	19.95	1	19.95	0.5
Sprocket Carrier	1	14.99	1	14.99	1
Motor Sprocket	0.3	5.66	1	5.66	0.3
Tools	0	19	1	19	0
Paint	0	15	1	15	0
Other Parts (Tensor, cable etc.)	0.1	0.99	1	0.99	0.1
Total				**1092.54**	**96**

Figure 30 *Breakdown of the Cost of the Components and Tools*

Once I had chosen the specific parts I would be using, I drew up the design on *Fusion 360*, which is a powerful 3D design software available to students, free of charge. It has many other benefits, like the fact that all the files are stored on the cloud, that it is flexible and that it has a wide range of file format compatibility.

I used a base go-kart design by Matteo Marchiorato, which I downloaded from *GrabCAD*. I also used this online 3D library for other small components. However, I found no designs of the engine and carburetor I wanted to use, so I modified a different engine to suit my needs, so as not to have to start from scratch.

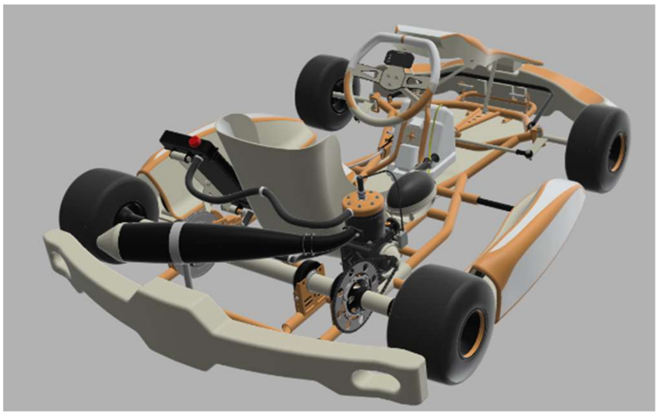

Figure 31 *Base Design by Matteo Marchiorato*

The whole process was a learning experience for me. I had never used any 3D design tool before. However, Fusion 360 is a very good choice to start with and learn as you go; and I had no problems I could not solve with reasonable ease aided by tutorials, both on the Autodesk webpage and on YouTube. From beginning to end, the process took about three weeks, working about an hour every day.

The designs I made were very helpful, not only when building the go-kart, but also when making simulations on Fusion 360, Solidworks or other 3D design and simulation software. I have not had time to delve deep into simulations in this project, but I would like to do so in the future in order to optimise the spread of the weight, the aerodynamics of the go-kart and other aspects that can improve performance and energy efficiency.

Final Designs

The final Fusion 360 designs I created are the following, with a 1800W 4500 RPM BLDC three-phase induction motor, a 48V 35Ah Li-Ion battery and a LIFAN 125cc petrol engine:

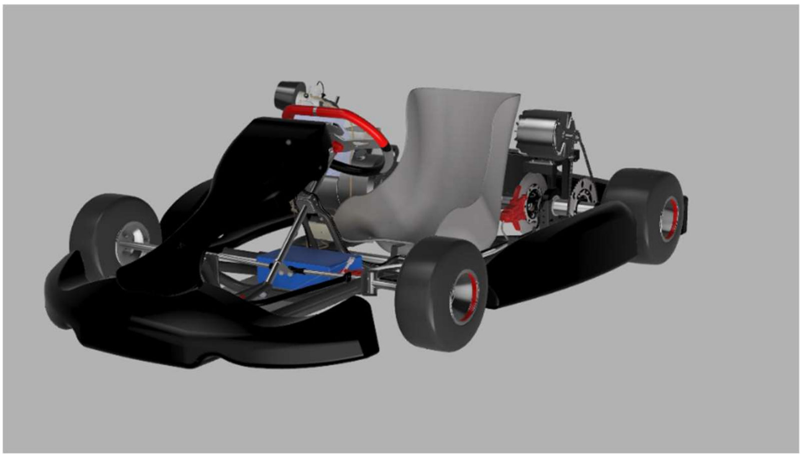

Figure 32 *Final Design: Motor Side View*

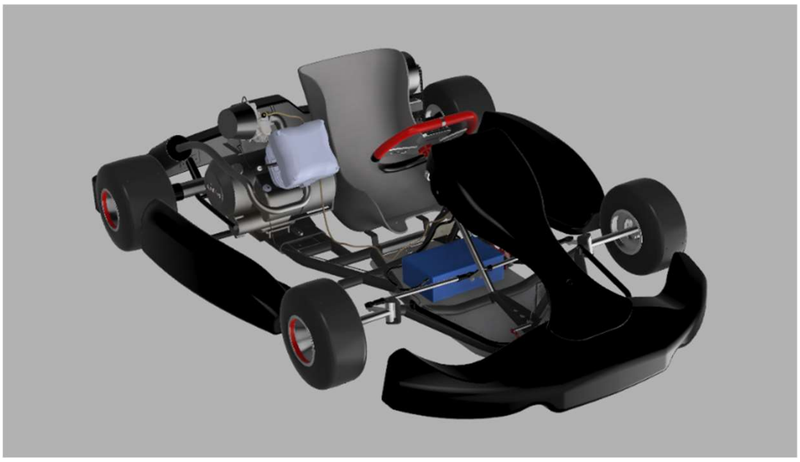

Figure 33 *Final Design: Engine Side View*

The following link shows the 3D model of the go-kart and further pictures can be found in the gallery.

Link: https://a360.co/2VLuOXP; Password: hybridgokart.

The Build

After the design was completed, it was time to bring the concept to practice. At my house, I have a workshop with all the basic tools. For this reason, all I had to do was set myself a schedule for the whole process, to make sure I got all the work done in the available time, gather all the parts and get going. In this section, I will explain the whole process from start to finish, along with the challenges and difficulties I had to overcome along the way.

The main chassis I used was, as demanded by the design criteria, a generic TonyKart OTK Chassis. It came from a second-hand petrol go-kart. I chose to buy this second-hand go-kart because there was a very big difference in prices as compared to having to buy every piece separately. The chassis was all assembled when it came, along with the 125cc LIFAN engine, the hydraulic brakes, the steering column and the seat; so I was able to get straight to adding the electric motor along with all its appliances. However, I had to take all this assembly apart to paint the chassis and do some changes to the engine's wiring later on.

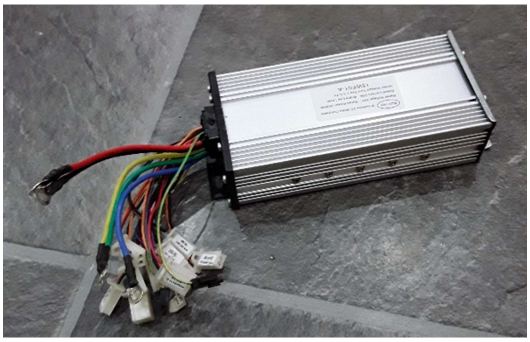
Figure 34 *Motor Controller*

The first thing I did was test the electric motor and sort out all the electrical part of the assembly: connecting the motor controller, the motor, the throttle, the start key, the reverse switch and the battery. This was the first challenge that arose for me: There were no concrete instructions anywhere on how to do this. The motor came from China and all I had were some badly translated labels on the cables of the controller. However, with the help of pictures of similar controllers I found on the internet and some trial and error, I made the circuit work… sort of. There was still one more problem:

Normally, engines and motors on go-karts and other vehicles of the same kind are mounted on the right-hand side of the driver, with the drive sprocket facing inwards. This means that, when the motor spins clockwise, the vehicle is propelled forwards. When the motor spins anti-clockwise, the vehicle is propelled backwards. The motor I bought was also meant to be mounted on the right-hand side of the driver. The problem was that, as I had mounted the petrol engine on that side, the electric motor had to go to the left of the driver, so the rotation directions were inverted.

This problem would have been easy to fix if it were not for the speed limiter (the reverse feature was activated by closing the reverse circuit via a switch, I could have simply left it open for reverse and closed it for forward). The controller that came with the motor had a feature which limited the speed of the motor when on reverse mode, to make it easier to control at low speeds. However, for me this would mean a forward limited speed and a reverse full speed capability, which was completely the opposite of what I needed. To fix this issue, I did the following:

The motor I used was a BLDC three-phase induction motor. Had it been a typical DC motor, all I would have had to do is switch the two positive and negative cables and it would have been good to go. However, with the motor I was using (induction three phase motor), it had three phase wires, with an extra "Hall" wire to each one. The purpose of the phase wires is to create a Rotating Magnetic Field[10]. Each phase has an offset of 120° with respect to the previous one. The order that the phases are connected determines the direction of the rotating motion. The "Hall" wires are used to track the speed and position of the motor's rotor, coordinating the phases to vary speed and power. Therefore, once I learnt how the motor and controller work together, all I had to do to fool the controller was switch any two of the phase wires and another two of the hall wires, reversing the direction of the motor.

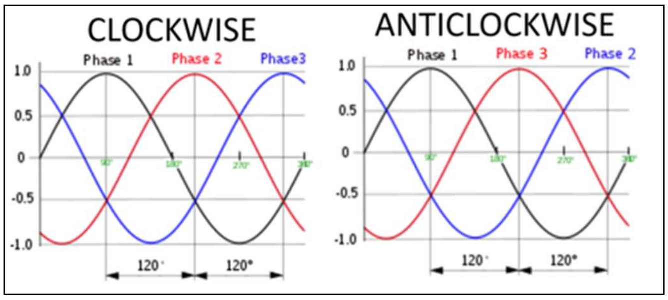

Figure 35 *Clockwise and Anti-Clockwise Rotation*

This experience helped me to understand in more detail the workings of three phase motors, as well as the ability to overcome obstacles in new and unknown areas of expertise.

The next thing I did, when all the wiring was sorted out, soldered and covered with heat-shrink, was attach it all to the go-kart. I cut out the outline of a dashboard from a spare wooden board, with holes for the key switch, the reverse and emergency power kill switches for both the motor and the engine, the battery metre and the fuel tank. I had to modify the top bumper slightly to fit the dashboard in. I also had to change the kill switch on the engine so as to be able to kill the engine from the dashboard. The last modification was to the floor tray, where I added brackets to hold the battery in place.

Figure 36 *Dashboard*

Once the electrical part of the go-kart was all done and working, I had to build a mount to attach the electric motor to the chassis. The first version of the mount I attempted to make comprised four metal rods screwed together to form a slim, double-limbed T. Another two,

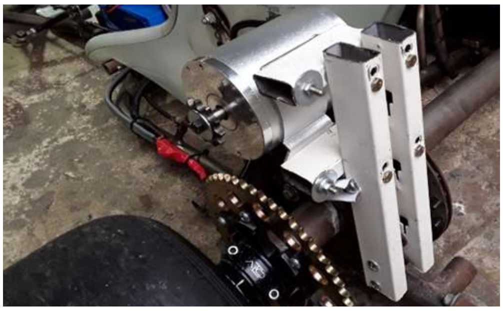

Figure 37 *Motor Mount V1.0*

[10] See section on *The Electric Motor*

slimmer, rods gave extra support to the structure. However, after shortening the chain to the right length, hooking it up to the motor and going for the first test run, I realised that it was a poor design. The motor slipped down and made the chain come loose. The design had another problem, which was its poor adaptability. I needed to be able to change the tension of the chain with ease. The design of the first mount did not permit this. Therefore, I set myself to the task of designing a new, more adaptable, mount.

This second mount, after a few further modifications, featured a movable arm and a wire tensor for adjusting the tension of the chain and permitted the desired adaptability, as well as being more effective at withstanding the strength of the chain pulling the motor down.

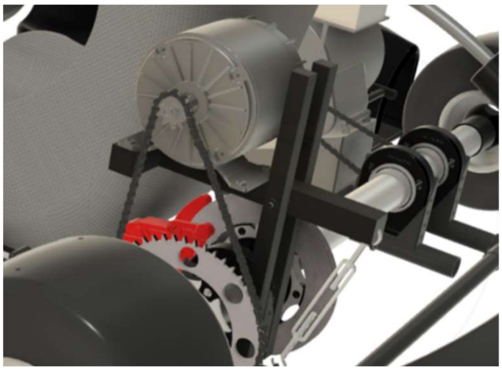

Figure 38 *Motor Mount V2.0*

After the motor was safely installed to the chassis and had been tested, it was time to give the chassis a paint job. I took the seat, the brake pump, the steering wheel, the floor tray and the bumpers off and painted the chassis with black protective paint. The go-kart was ready for the test.

Looking back at the design criteria, I accomplished all the MUST HAVEs. However, the NICE TO HAVEs have been left aside for this project and are possible improvements I could do in the future. The go-kart works very well but could be optimised a lot, and this is something that I would like to do further on.

These links show videos of the design, the building process, and the final product:

3D Design Walkthrough:

https://tinyurl.com/3DDesignWalkthrough

Building Process:

https://tinyurl.com/GoKartBuildingProcessAnonymus

Gasoline Mode:

https://tinyurl.com/GasolineMode

Electric Mode:

https://tinyurl.com/GoKartElectricMode

The Test

This section will cover the tests I ran on the go-kart prototype in order to collect data for the comparison later on.

The tests were:

Top Speed

The top speed test was done on a flat, straight strip of road, three times for electric and three times for combustion. The top speed was recorded with a GPS speedometer mobile application. The highest top speed for each of the drive systems was the final recorded result.

Acceleration

In the acceleration test, I calculated the time the go-kart took to get to 30 km/h using a timer and a speedometer, four times on each motor. The mean time determined the final recorded result. This test was also done on a flat, straight strip of road, starting from a standstill.

Autonomy

In the autonomy test, I ran the go-kart on electric and gasoline for as long as possible at medium load, counting the kilometres via GPS. The test was done once for each drive system. Here, I had to bear in mind that the fuel tank can be easily replaced with a bigger one or refilled to increase autonomy, while in the electric system autonomy is not so cheap and easy to increase.

Weight

For the electric drive, I added up the weight of the motor and the batteries, taking the numbers provided by the manufacturers. For the combustion engine, I used the weight of the engine and only half of the weight of the fuel, as it does not remain constant and decreases with time.

Horsepower

For horsepower, I took the numbers provided by the manufacturers.

Overview of the Test

The *controlled variables* were:

- Top Speed

- Acceleration
- Autonomy
- Weight of the drive systems
- Horsepower

The *independent variables* were:

- The roads and conditions in which the tests were run
- The measuring systems (speedometer etc.)
- The overall weight of the go-kart

Once the results had been recorded, they were translated into graphs[11], which estimate the general tendencies of the aspects relative to weight, price and horsepower, and help to determine the scores for the comparison.

Figure 39 *Testing The Go-Kart at Tockwith Motorsports Centre*

[11] See **Charts 5 to 13** in the *References* section

Comparison

The Electric and Combustion Drive System

Method

To answer the big question, “Are electric drive systems better than combustion drive systems?”, I have broken it down into smaller and more specific ones to make the whole thing a little easier. To make a comparison, you have to consider lots of different aspects, some more important than others. There are different automotive applications that require some aspects to be different: sports cars, long distance cars, city cars, daily use/middle distance cars etc.

I have evaluated those four points of view, valuing each aspect (autonomy, top speed, power etc.) differently for each application.

Another thing I have considered is the change that time may bring. In the next few years, the technology available could change quickly, and this is an important factor. I have given each aspect two scores from 1 to 10, one for the present and one for the future, which make the weighed mean score for each aspect (the present has a weight of 75%, the future has a weight of 25%). With these scores I have worked out a weighted average score for each of the four chosen applications. The individual weights of the different aspects vary depending on the needs of the specific applications. In total, I have given 50% weight to the theoretical scores and 50% to the practical scores worked out with the go-kart prototype.

Theoretical Aspects

The purpose of this project is to compare the two drive systems discussed so far: the electric and combustion drive trains. In this section of the project, I will determine the aspects that compose the theoretical evaluation of the two drive systems.

One of the big reasons there has been much emphasis applied on electric power is because combustion engines cause **pollution**. In some cities this pollution is visible from the ground in the form of grey clouds in the sky formed by *GHGs*. Furthermore, there is an issue with the sources of the fossil fuels. The extraction and refining process of the fuel is a very energy-consuming and contaminating process and, in addition, many countries import fuel from the outside, which adds to the energy consumption and pollution. Considering what has been discussed on this topic in a previous part of the project, this will be one of the aspects to compare in this section.

Another important aspect is **efficiency**. It is always important to extract the biggest amount of useful work from both the fuel/batteries and the motor/engine.

Durability and reliability are two very important factors to consider. As of now, electric cars are new, and the technology is yet to be tested by time. On the other hand, combustion engines have been studied to exhaustion. Most immediate problems have been hurdled effectively. This leads to them being much more reliable, for the moment.

Initial Cost is always a deciding aspect in everything, and it may be what scares buyers away from electric cars the most. Combustion cars have become relatively cheap, compared to electric vehicles, and they are getting even more so. However, this may just be too good to be true because, after the initial cost, combustion cars continue to eat greedily at your pocket. Within two to three years, your combustion car may have eaten up as much money in fuel as it would have taken to buy an electric car, which is much cheaper on the long run. This is why **Energy Cost** is so important. Furthermore, the initial cost of electric cars will get lower in time, whereas fuel prices will only rise. With electric cars, you could be talking about saving thousands of pounds a year within no time.

Comfort of use, in the sense of the facilities and services available, is also important. At the moment, there are relatively few charging facilities around the world, whereas there are thousands of fuel stations. Charging batteries takes time, whereas with fuel, it takes no more than five to ten minutes to get a full tank. Furthermore, in case of a breakdown or a technical fault in the car, it is much easier to have a combustion car fixed in any garage than an electric car. This also spells a difference in **maintenance** costs.

All these aspects will be considered in the theoretical comparison. However, it is important to note that some will likely change in the near future. This will be considered in the weights of the aspects.

Practical Aspects

This section will cover the more practical aspects of the comparison (performance), via the series of tests run on the hybrid go-kart prototype. The aspects that will be compared are: ***top speed****,* ***acceleration****,* ***horsepower****,* ***weight*** *and* ***autonomy****.*

After running the tests and recording the results on an Excel Spreadsheet, I created some graphs[12] and tables to compare all these aspects relative to weight, horsepower and price. I also complemented these results with real life data from two production cars: the Tesla Model X Performance (electric) and the BMW x5 M Performance (combustion).

Test Results

In terms of *speed*, the tests show that the petrol engine achieves much better results. However, when we compare the results relative to weight and horsepower, the electric motor has similar results to the petrol engine. In addition, electric motors have still much more room for improvement than combustion engines. Nevertheless, price is what lets the electric option down. *For the moment, combustion cars are still kings of the road in top speed*.

Again, in terms of *acceleration*, the tests show better results for the petrol engine. For smaller applications, like go-karts, where the size of the motor and the battery packs is limited, combustion engines tend to have better performance. However, the real-life data tells another story when we look at Tesla, which has achieved the fastest acceleration times on the road, nearly as fast as Formula 1 cars. *Electric cars have won this terrain over from combustion cars, and they can only get better*.

ELECRTIC Test Results	
Top Speed (km/h)	39.41
Acceleration 0-30 km/h (s)	15.543
Autonomy (km)	13.851
Weight (kg)	13
Horsepower (hp)	2.446
Price (£)	593

COMBUSTION Test Results	
Top Speed (km/h)	70.3
Acceleration 0-30 km/h (s)	4
Autonomy (km)	16
Weight (kg)	36.85
Horsepower (hp)	6.5
Price (£)	227

Figure 40 *Test Results*

Tesla Model X Performance Real Life Data	
Top Speed (km/h)	250
Acceleration 0-100 km/h (s)	2.7
Autonomy (km)	483
Weight (kg)	2460
Horsepower (hp)	260
Price (£)	96000

BMW x5 M Performance Real Life Data	
Top Speed (km/h)	250
Acceleration 0-100 km/h (s)	4,3
Autonomy (km)	550
Weight (kg)	2110
Horsepower (hp)	530
Price (£)	71635

Figure 41 *Real Life Data: Tesla Model X and BMW x5*

[12] See **Charts 5 to 13** in the *References* section

Autonomy test results were better than expected for the electric motor. The graphs show the electric drive system to be even better than the combustion drive system relative to weight and horsepower. However, the price is, again, the factor that lets the electric option down. Also, when we look at production cars, autonomy drops rapidly. *Combustion cars, for the moment, have better autonomy,* although electric cars can still improve on this aspect enough to get to their standards.

Weight is also generally higher in combustion at low power applications, like the go-kart, where the engine alone weighs 35 kg whereas the motor only weighs about 5 kg. However, when comparing production cars, like Tesla, where the battery and the motor combined weigh about 570 kg, and BMW, where the engine weighs only about 270 kg, things change. The battery in electric cars alone weighs over 500 kg. Electric cars require less weight in the transmission and other systems. However, whatever weight they lose in transmission, they gain in the charger and inverter, and the battery. Electric production cars, *for the moment, are generally slightly heavier*.

All these results have to be looked at from the perspective that the electric motor used for testing has no gearbox, whereas the petrol engine does, that the petrol engine is much bigger and heavier than the electric motor, and that the electric motor assembly in general could be optimised much more. This is something that I have not had time to include in this project but that I would like to do in the near future.

Final Scores

The final scores for the two drive systems in each application, present and future, are:

OVERVIEW OF RESULTS

ELECTRIC

	Long Distance				Medium Distance				City Car				Sports Car				OVERALL
	Theory	Practice	Total		Theory	Practice	Total		Theory	Practice	Total		Theory	Practice	Total		
Present	6,3	6,8	6,55	Pres.	6,3	7,65	6,975	Pres.	6,4	8,3	7,35	Pres.	6,5	9,05	7,775	Pres.	7,1625
Future	10	10	10	Fut.	10	10	10	Fut.	10	10	10	Fut.	10	10	10	Fut.	10
Mean	7,225	7,6	7,4125	Mn.	7,225	8,2375	7,7313	Mn.	7,3	8,725	8,013	Mn.	7,375	9,2875	8,3313	Mn.	7,872

COMBUSTION

	Long Distance				Medium Distance				City Car				Sports Car				OVERALL
	Theory	Practice	Total		Theory	Practice	Total		Theory	Practice	Total		Theory	Practice	Total		
Present	7,1	8,8	7,95	Pres.	7	8,7	7,85	Pres.	6,1	8,6	7,35	Pres.	7,1	8,4	7,75	Pres.	7,725
Future	7,35	9,8	8,575	Fut.	7,35	9,7	8,525	Fut.	6,45	9,6	8,025	Fut.	7,9	9,4	8,65	Fut.	8,44375
Mean	7,1625	9,05	8,1063	Mn.	7,0875	8,95	8,0188	Mn.	6,1875	8,85	7,519	Mn.	7,3	8,65	7,975	Mn.	7,905

Figure 42 *Final Scores*

We can see that, for the present, in *long distance* and *medium distance* cars, the combustion option is much better. Electric vehicles are way behind on these two. However, for *city car* and *sports car* applications, the electric car is just in front of its combustion counterpart. On average, at the present, the combustion car has a better score than electric cars. However, with the huge potential that the electric car has, the services and comfort of their use could easily match and even overcome those of the combustion car in the future. With the additional improvement of energy storage systems, performance can improve a lot too. This gives an average potential future score to electric cars of 10, where combustion cars can only hope for 8.44.

In summary, as we stand now, for *long distance* and *medium distance*, combustion cars have better scores. On the other hand, for *city* and *sports* car applications, the electric vehicle is just ahead of its combustion counterpart. In the future, the electric car has the potential to overcome the combustion car for all four applications.

The complete spreadsheet showing the comparison can be seen in this link:

https://tinyurl.com/ComparativeSpreadsheet

Conclusions

In conclusion, the question posed is not as simple as to be answered in a "black or white" manner. Many aspects relate to each other and some others I will have doubtless missed too. However, we can still extract a set of conclusions which can help each individual person to determine the answer for themselves.

In the *theory*, and for the present, the conclusions are:

We will not solve the problem of ***pollution*** *with electric cars.* Cars are only a small proportion of the total polluting sources. A single container ship can pollute as much as millions of cars, planes can pollute as much as hundreds of cars, industry pollutes on a massive scale and so does energy production. Overall, cars are a very small part of all this. However, if we look at specific places, like cities, cars can be one of the major sources of pollution. We may not cut down on pollution on a massive scale but, at least, cities will be cleaner, resulting in a better quality of life.

Furthermore, and asides from the issue with the lithium in Li-Ion batteries, electric cars can be just as polluting as combustion cars depending on the source of the electricity they use. This is why it is not true to say that electric cars are completely emissions-free, for the moment. To make at least a small change towards a cleaner environment, *we need to change more than just the cars; we need to change the source of the* *electricity they use, promoting renewable energy.* At the moment, electric cars are not improving as much as it seems on this point.

Another downside of electric cars is that they are an emerging technology. Major manufacturers are not yet committed to them, services are not well established, and this makes **prices** much higher. The fact that they are so new also makes electric cars more liable to break down and therefore they have higher **maintenance costs**. Also, repair services are much more limited. On average, a combustion car has a repair time of one day. Tesla, which is the leading electric car manufacturer, has twice the average repair time, while more difficult repairs can take weeks or even over a month. This hinders the **reliability** of the electric car and the **comfort** of its use, which also frightens away potential buyers. I hope this will change in time as companies commit more to electric cars and services become better established.

On the other hand, the fact that electric cars are a new emerging technology can also be a good thing. It means they have plenty of *room for improvement* and, if they are already at a point where they can challenge their combustion counterparts, they could well replace them in the future. The issues they have can be solved by promoting renewable energy sources and finding new ways to store that energy.

Another benefit of electric cars is the increased **efficiency**. Combustion engines are incredibly inefficient. The most efficient engines have thermal efficiencies of no more than 50%, whereas Li-Ion batteries all have an efficiency of about 99%, with the motor converting around 85% of the electrical power supplied to mechanical power. With the now increasing need to make the most of the energy we use, this is an important point in favour of electric cars.

Speaking of conserving energy, we also have to look at where we get the fossil fuels from. Not all countries can provide their own fuel for themselves. Most countries import fossil fuels from outside and this is a very expensive, polluting and energy-consuming process. With electric cars, countries could generate their own electricity or "fuel". None of the infrastructure required to transport the fuel would be necessary, and the money could be invested in renewable energies instead.

Finally, while electric cars are expensive in the short term, they can be much cheaper in the long term. Insurance prices are higher for EVs (in the UK, EV owners are taxed £750-850, while combustion car owners are taxed £500-600). However, electric cars have a much lower **energy cost** and, therefore, are a lot cheaper to run. According to a *British Gas* study, a 160 km charge for EVs costs about £4, against the £14 of a 160 km fuel refill. According to them, supposing an annual 16,000 km on a small car, the savings can rise up to £1,500. This can be increased even further with the use of solar panels at home or other renewable sources (British Gas, s.f.). For people who travel a lot by car, this can be a very important factor to consider.

Electric cars have a very important advantage over combustion cars: *Potential*. We all know that we will one day have to replace combustion cars with an alternative. Electric cars are only at their beginnings, they are not perfect. However, *they have the great potential of running sustainably.*

In the *practice*, and for the present, the conclusions are:

In terms of production cars, EVs are nearly at the same level as their combustion cousins in all aspects of performance. Electric cars have the same ranges of **horsepower** and **top speeds** as any combustion car. The two differences are autonomy and acceleration.

The problem with electric cars has always been **autonomy**, and always will be unless we find an alternative means of storing energy. The typical combustion car has an autonomy of about 660 km, while the longest ranging EVs have ranges of no more than 540 km. Asides from that, EVs being so new, there are not many charging facilities on the roads, although the number has increased considerably during the last few years. However, there are many ways of storing electricity, while fuel can only be stored in a fuel tank, so I hope this issue will one day be fixed in a way that will both make electric cars less pollutant to the environment and increase their range to even higher distances of than those of combustion cars. However, for the present we have a different solution: *hybrid cars*.

It is very difficult to change the minds of people in ways that affect their lives so directly. *Hybrid cars* are an excellent stepping-stone in this ongoing transition to electric vehicles. They combine the power and autonomy of a combustion car with the extra emission-free support of an electric motor. However, they still involve the use of fossil fuels, which will one day disappear from our list of available resources and, eventually, we will have to leave them behind too.

The other performance difference that EVs bring with respect to combustion cars is **acceleration**. Electric cars have none of the energy loss and mechanical complexity issues of gearboxes. Their transmission is simple and direct. While normal combustion cars can only safely rev up to some 3000 RPM, electric cars can easily handle 18000 RPM. Not only this, but they can do so with nearly instant maximum torque. This allows for incredibly fast acceleration times. In this field, electric cars will always be on top of their combustion counterparts.

In summary, and going back to the four applications we are comparing (sports cars, long distance cars, city cars, daily use/middle distance cars etc.), the conclusion is:

As of ***now****, EVs are only up to the standards of combustion cars for* ***sports car*** *and* ***city car*** *applications****,*** *whereas for* ***medium distance*** *and* ***long distance*** *applications, in terms of comfort of use, they lack the sufficient autonomy and reliability. In these last two cases, the best choice is* ***combustion****, although electric cars are much cheaper to run in the long term. However, in the* ***near future****, as battery technologies advance, the best choice of drive system for* ***medium distance*** *and* ***long distance cars*** *could easily change to* ***electric****. Meanwhile,* ***hybrid cars*** *are a good option to seamlessly transition between the two.*

Conclusions

Conclusions

The realisation of this project has been for me a dream come true. I have been able to do something that I have always felt passionate about at the same time as getting a better feel for what investigation is like in the professional world. I feel I have succeeded in achieving all the initial aims I set myself prior to making this project:

I have learnt about the history of the automobile and the way it has evolved through time. This helped me to understand the origins of what I was studying. It helped me to understand how the combustion car came to be, which is something that is repeating itself in some ways with electric vehicles.

I have also gained a better insight into the world of renewable and sustainable power. I feel it is important to look at where the energy comes from, and not only where and how we use it. After the research I did, I now understand the combustion car and the electric car much better: how they work, what components they carry, how they can affect our lives, etc.

Thirdly, I have been able to build a hybrid go-kart, achieving successfully all the design criteria I set myself initially. I have even been able to fund part of the project with crowdfunding. However, this will not end here. There are still many things I could do to keep improving the performance of the go-kart, and I intend to do them soon. This is only the beginning.

Finally, thanks to the knowledge acquired in the research and thanks to the practical tests I ran on the go-kart, I have been able to make a comparison of the two drive systems and extract a satisfactory conclusion to the main question of this project. What surprised me was the number of factors that you have to consider to make this kind of comparison. However, it has been very interesting to learn about all these aspects of automobility which are normally never considered.

I thoroughly enjoyed doing this project. I feel I learnt many valuable concepts and skills that will be very useful for me. I learnt about electric motors and electric power, the sources, the issues they create and how they can be solved. I learnt to use Fusion 360 and other 3D design platforms. I learnt about how to structure and present a research project. Most importantly, I learnt to think critically and to see all the possible approaches to solving a problem. I would definitely do this project again if I had a second chance.

Acknowledgements

I would like to thank the people who have made this project possible, each in their own way. I am very grateful for their help.

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Table of Acronyms and Abbreviations

Acronym or Abbreviation	Explanation
RPM	Revolutions Per Minute
SI	Spark Ignition
CI	Compression Ignition
GHGs	Greenhouse Gases
EV	Electric Vehicle
AC	Alternating Current
RMF	Rotating Magnetic Field
Li-Ion	Lithium Ion (kind of battery)
DC	Dual Continuous
KERS	Kinetic Energy Recovery System
IEA	International Energy Agency
ITER	International Thermonuclear Experimental Reactor
MEA	Membrane Electrode Assembly
PEM	Proton Exchange Membrane
FIA	International Federation of the Automobile
BLDC	Brushless Dual Continuous (kind of induction motor)
GPS	Geo-Positioning System
EIA	US Energy Information Administration

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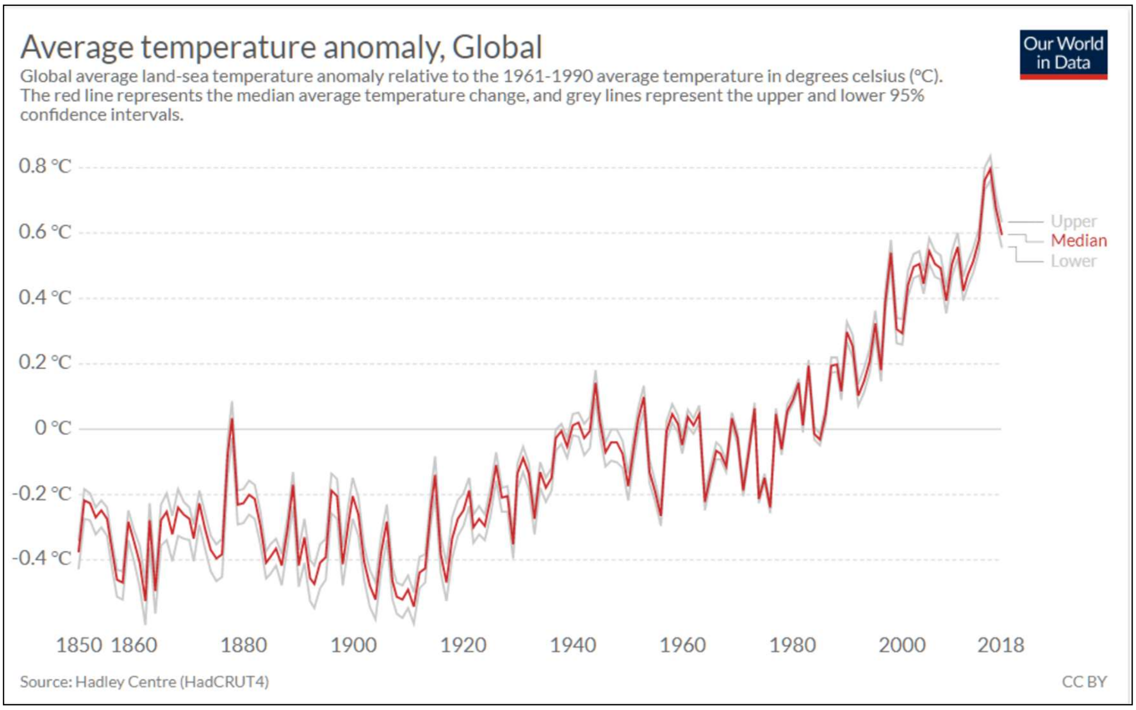

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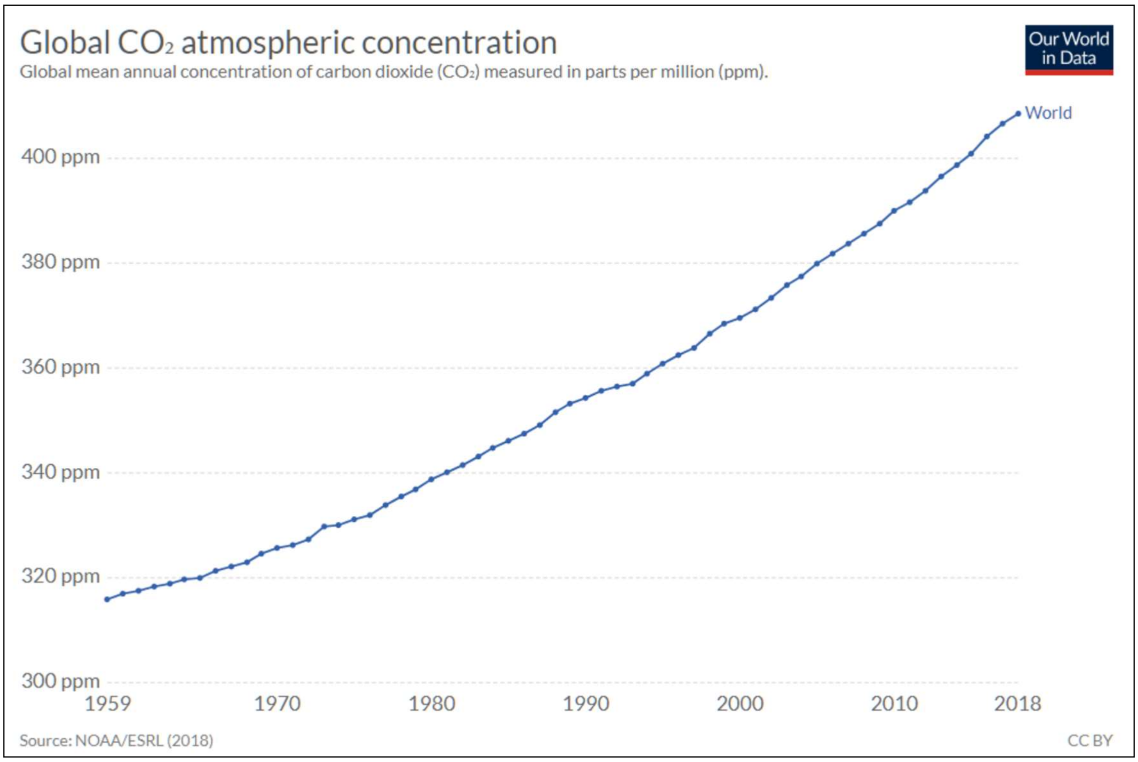

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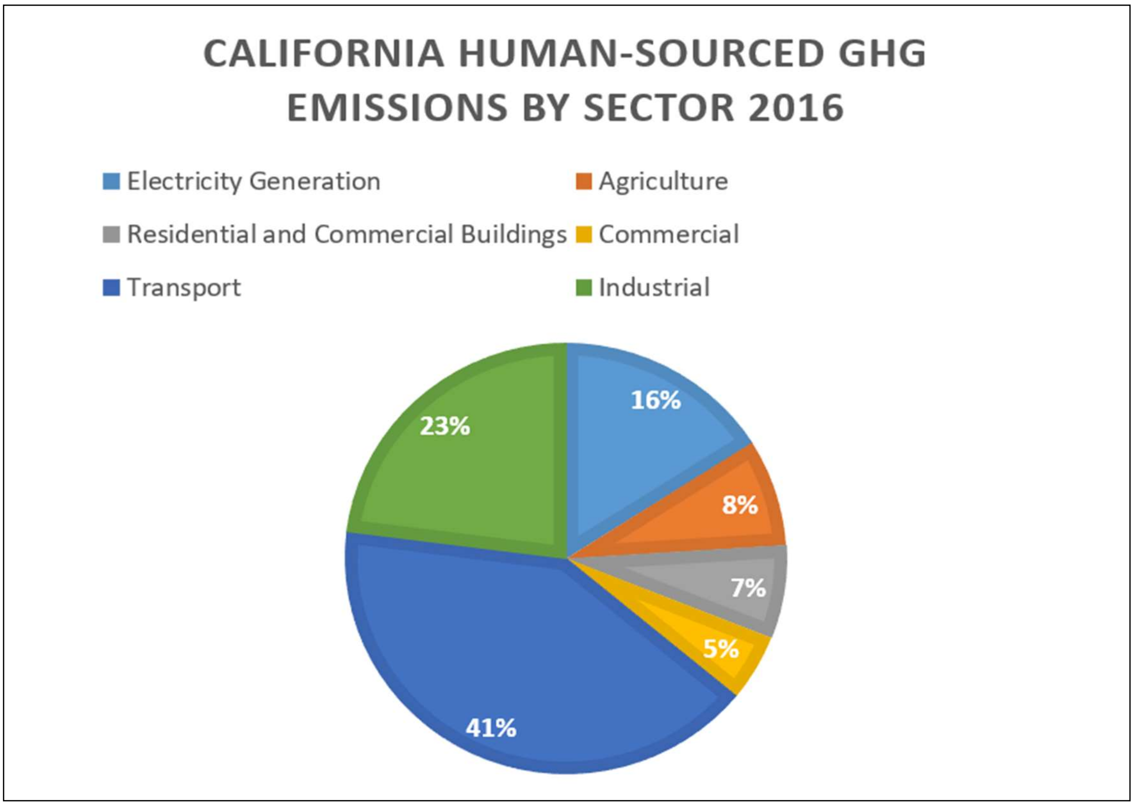

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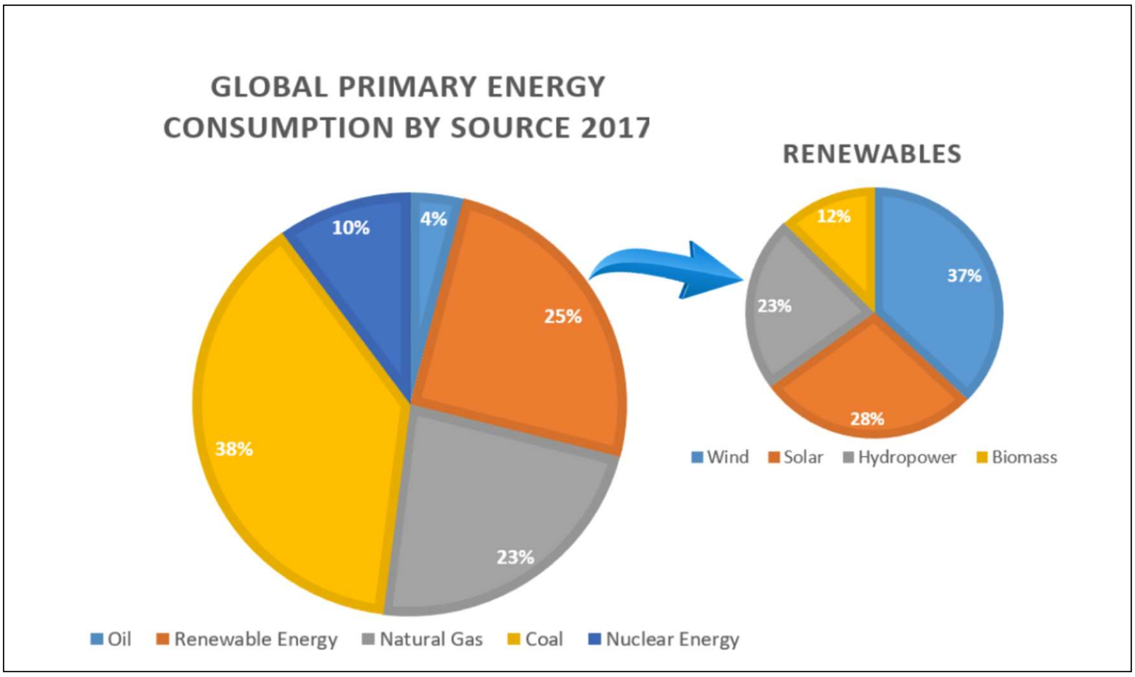

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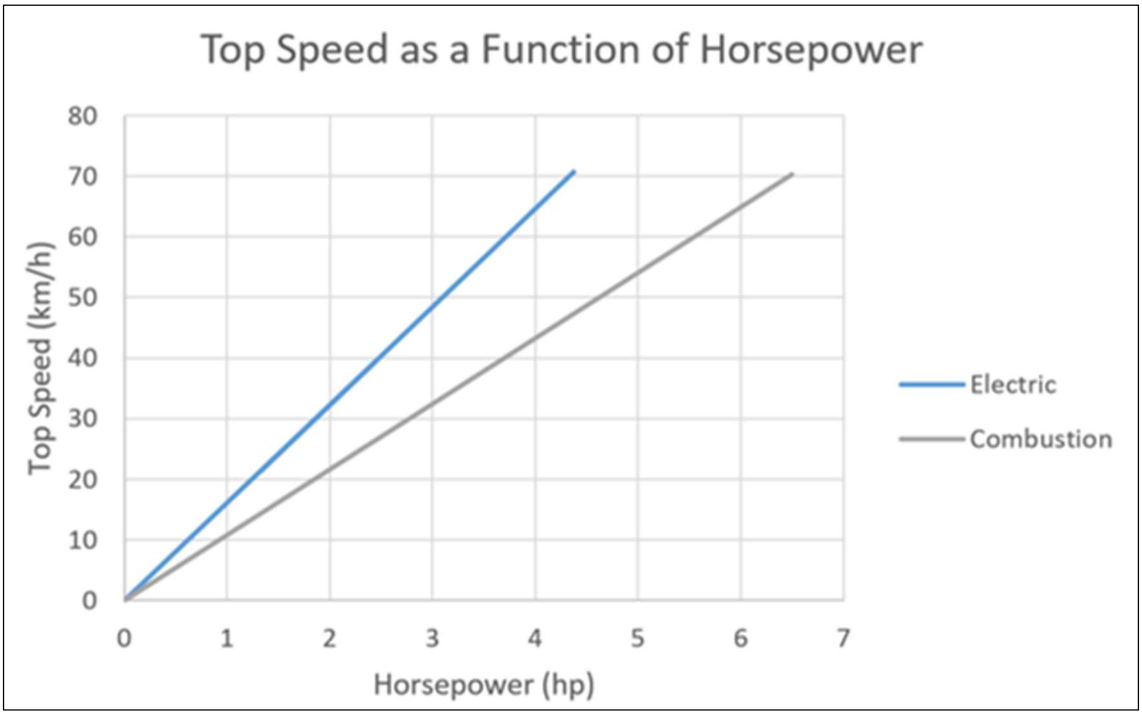

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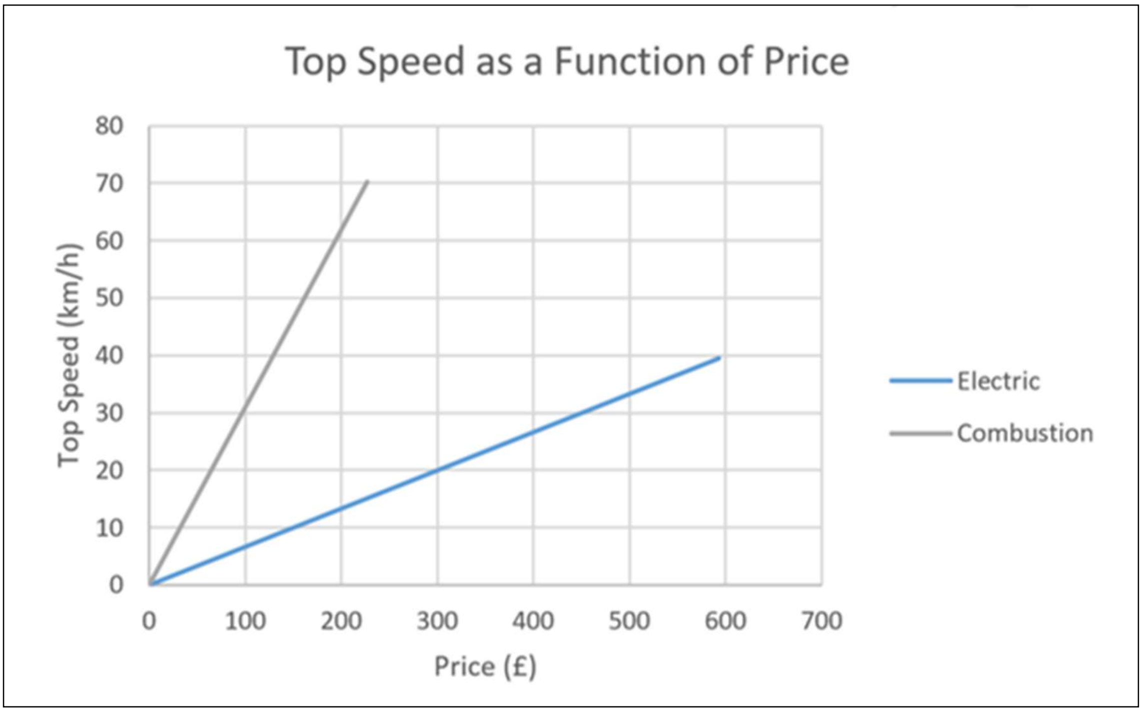

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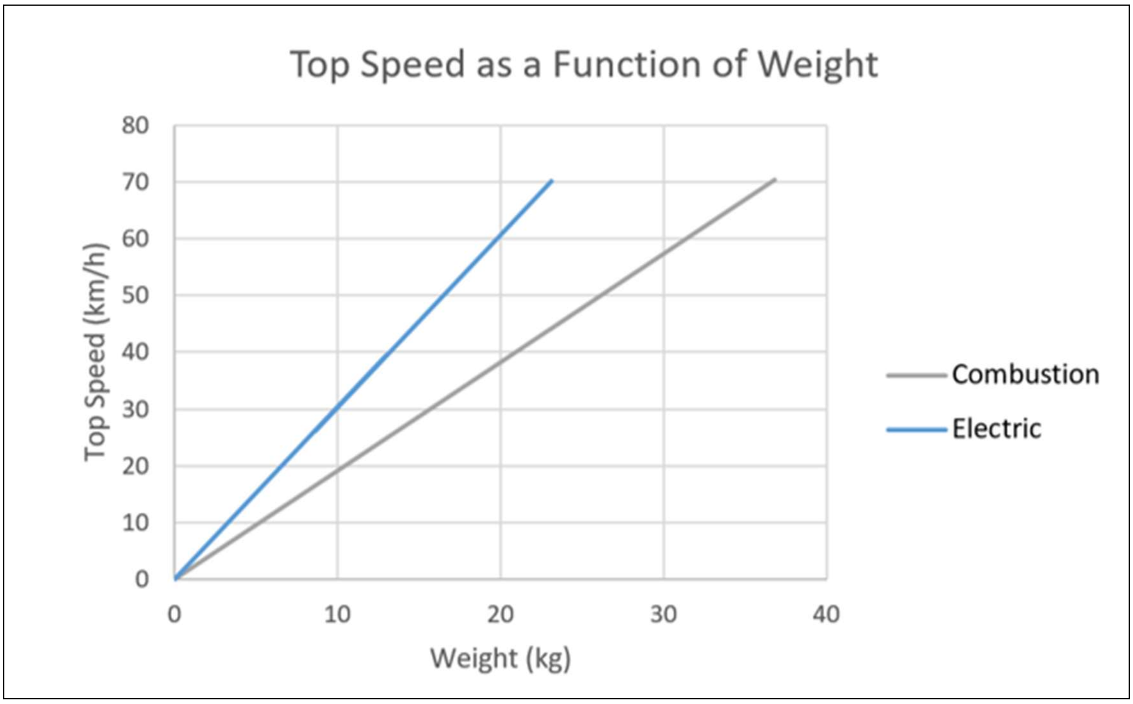

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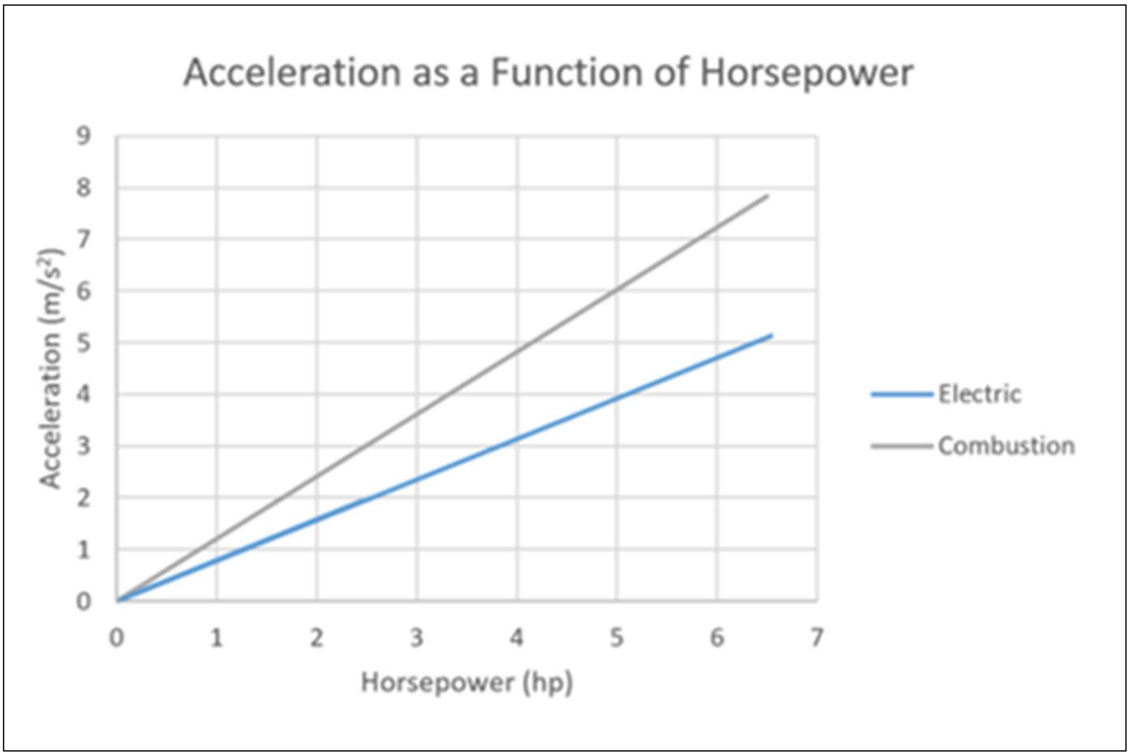

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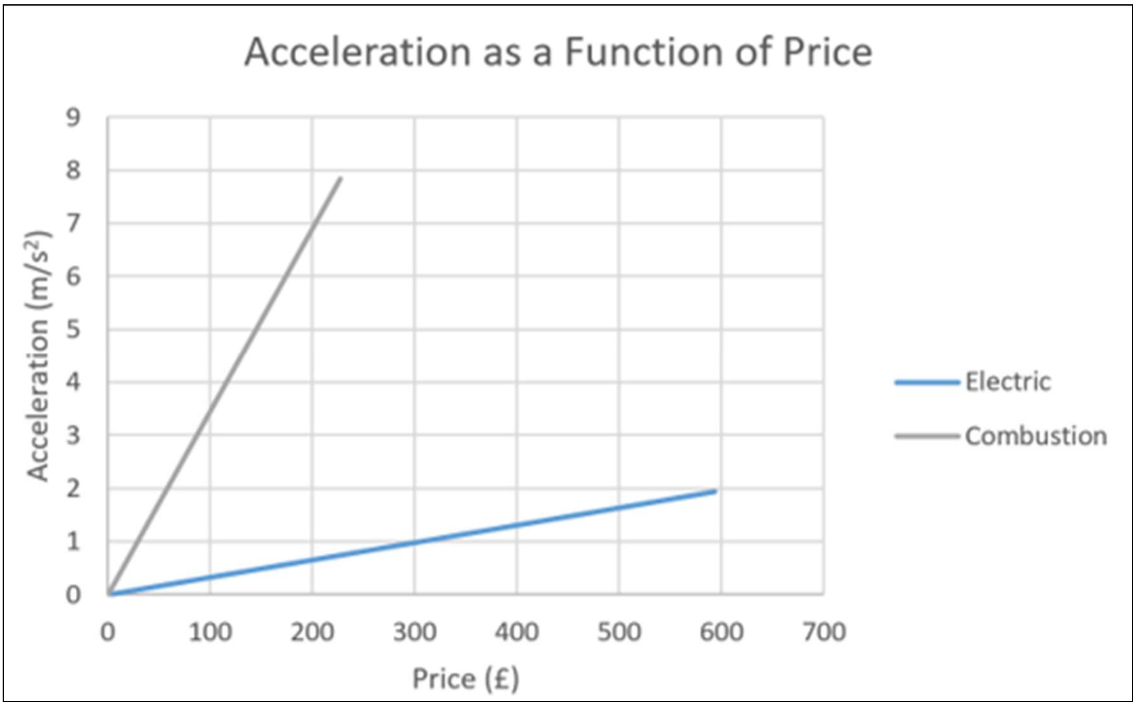

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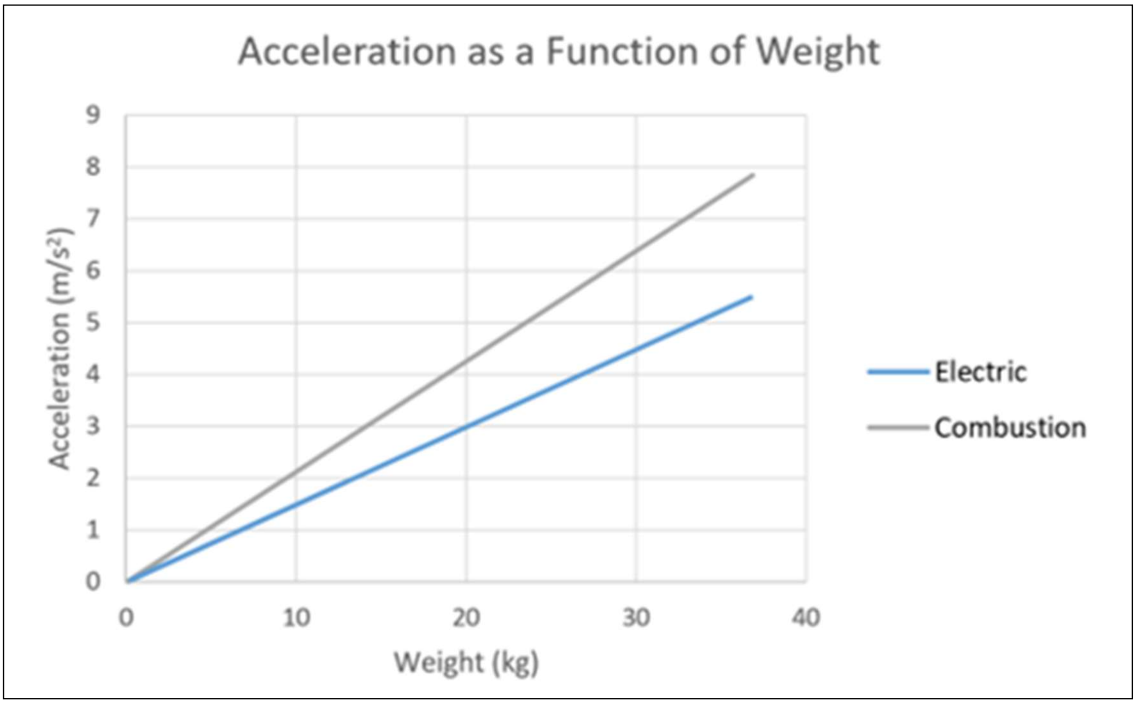

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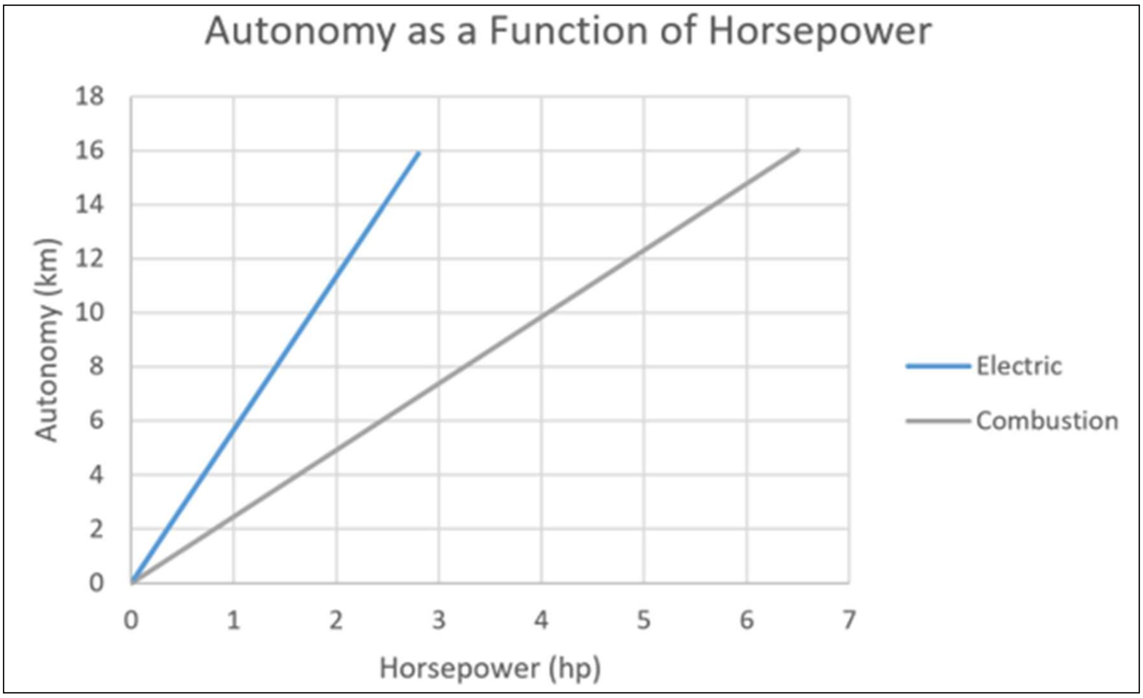

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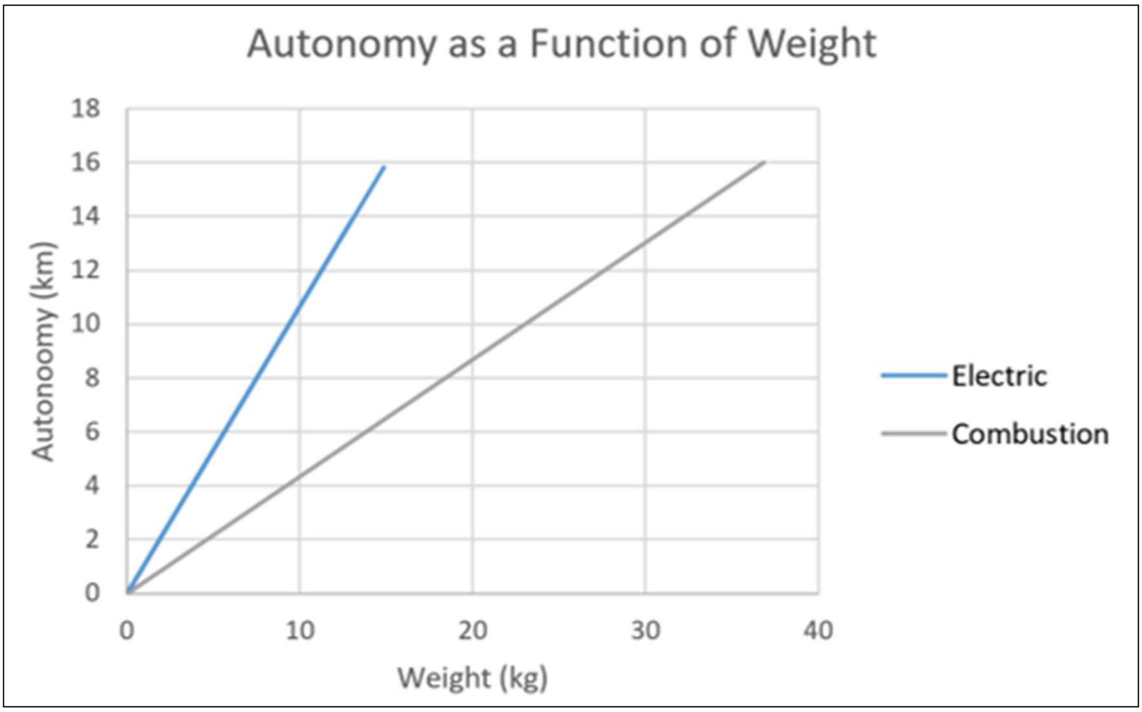

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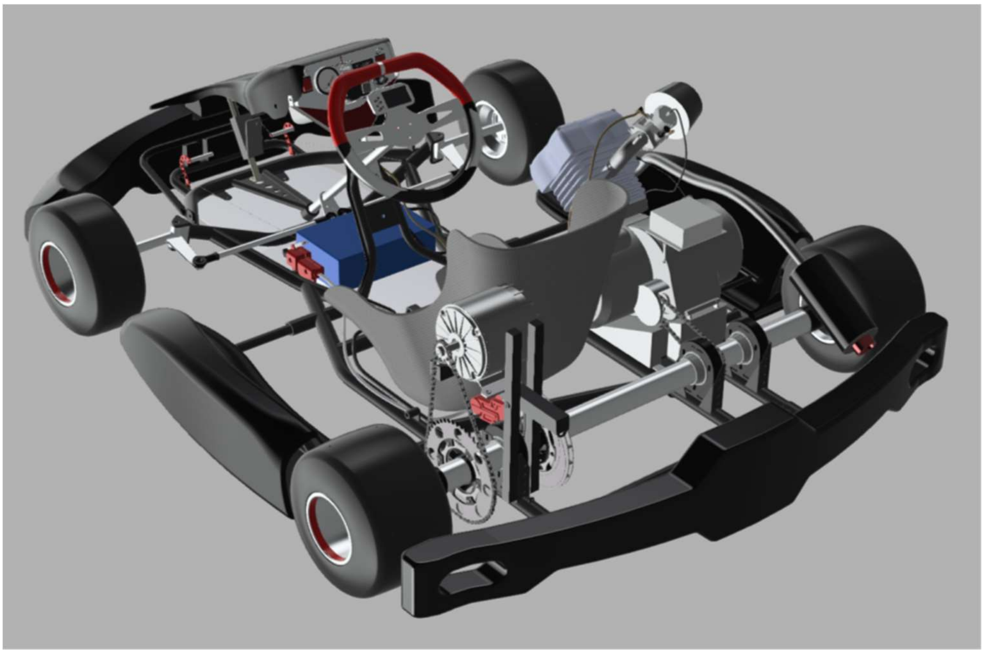

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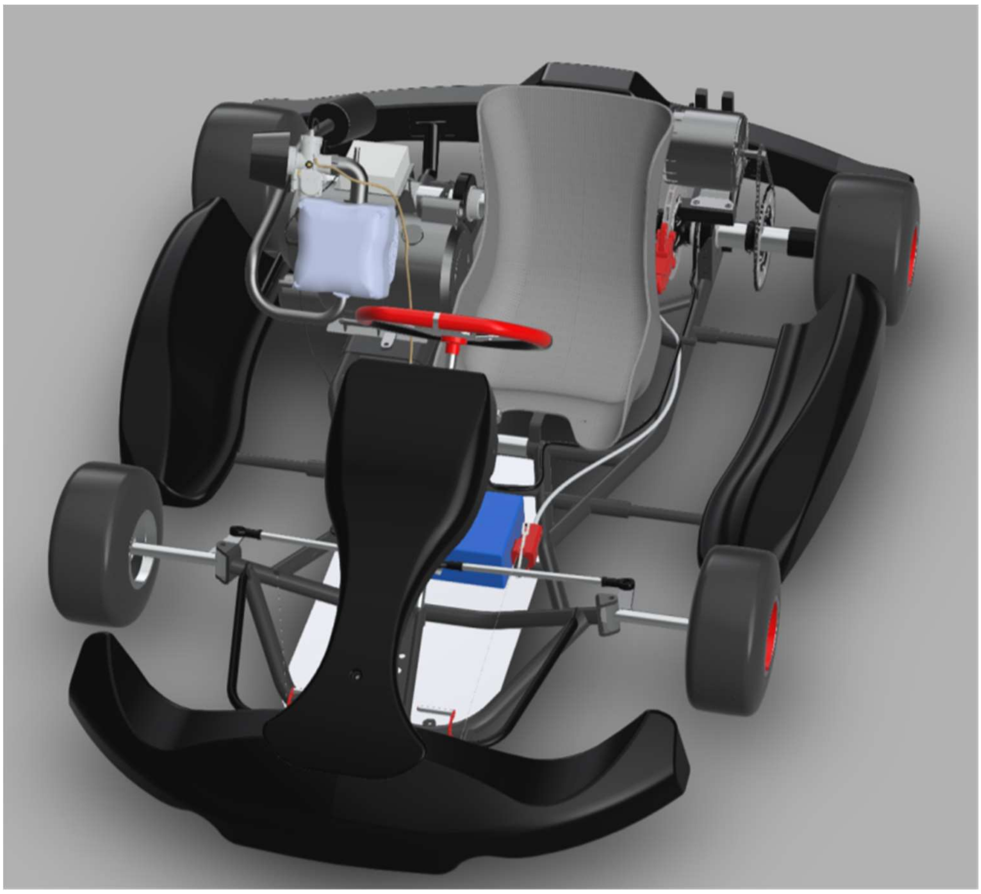

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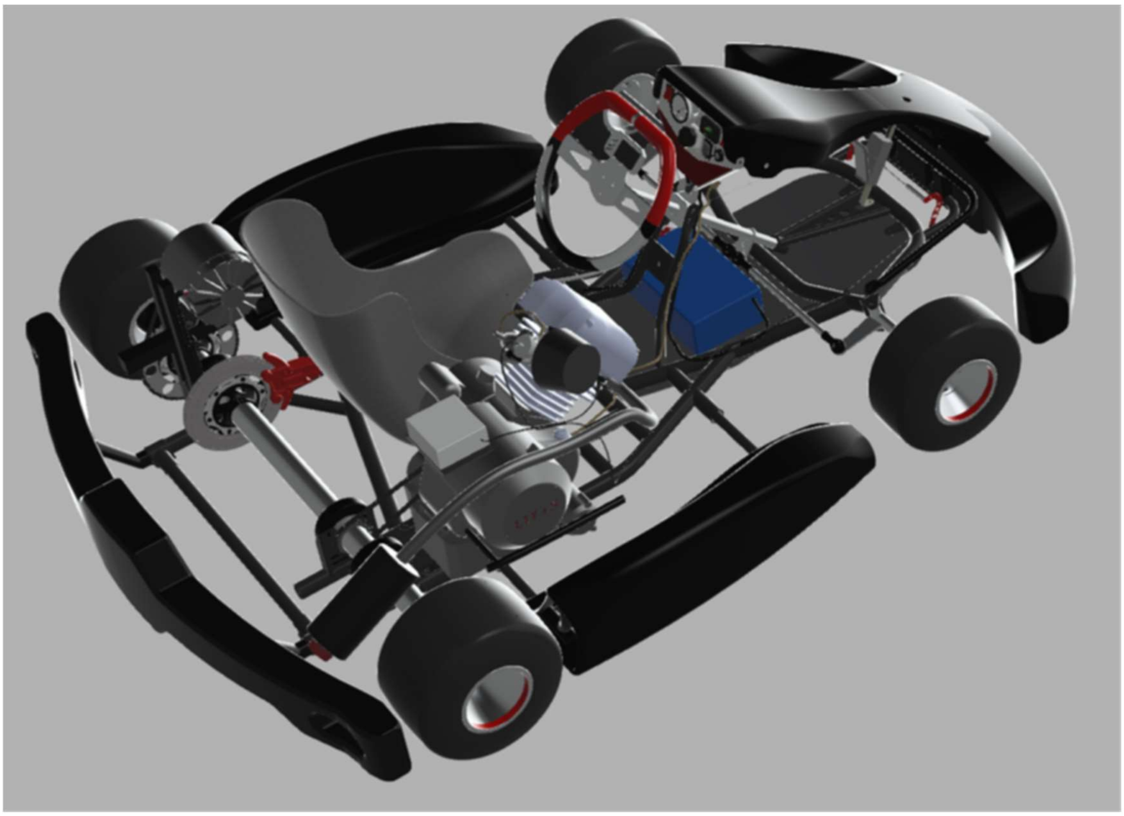

Figure 45 *3D Design: Lateral View*

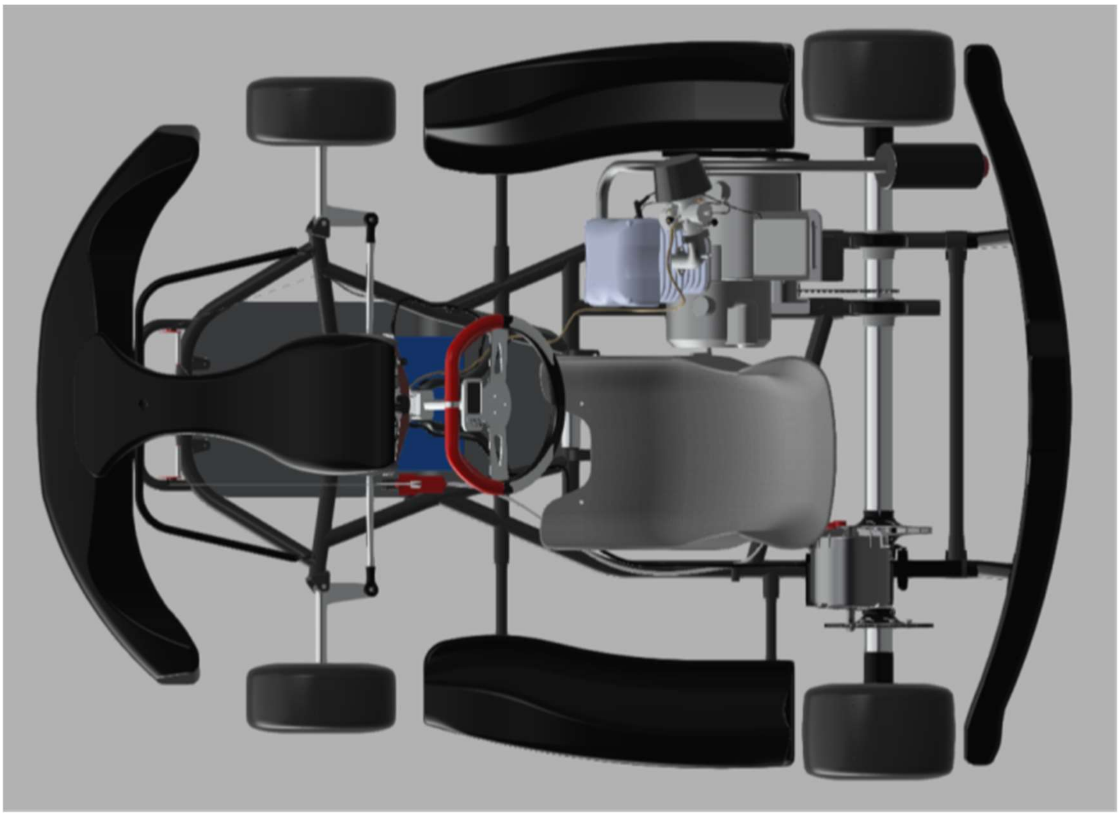

Figure 46 *3D Design: Bird's Eye View*

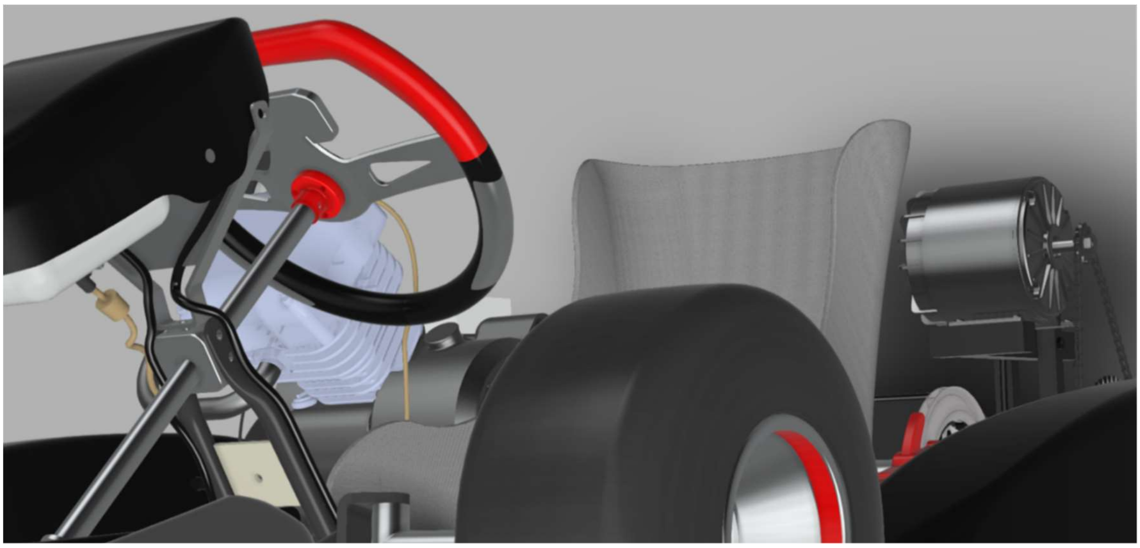

Figure 47 *3D Design: Detail View*

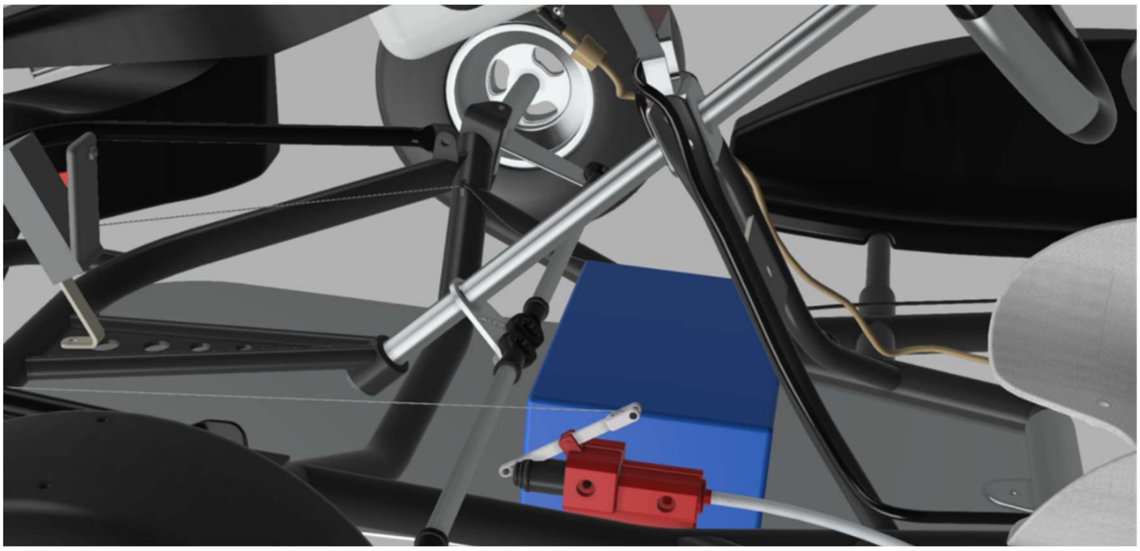

Figure 48 *3D Design: Detail View*

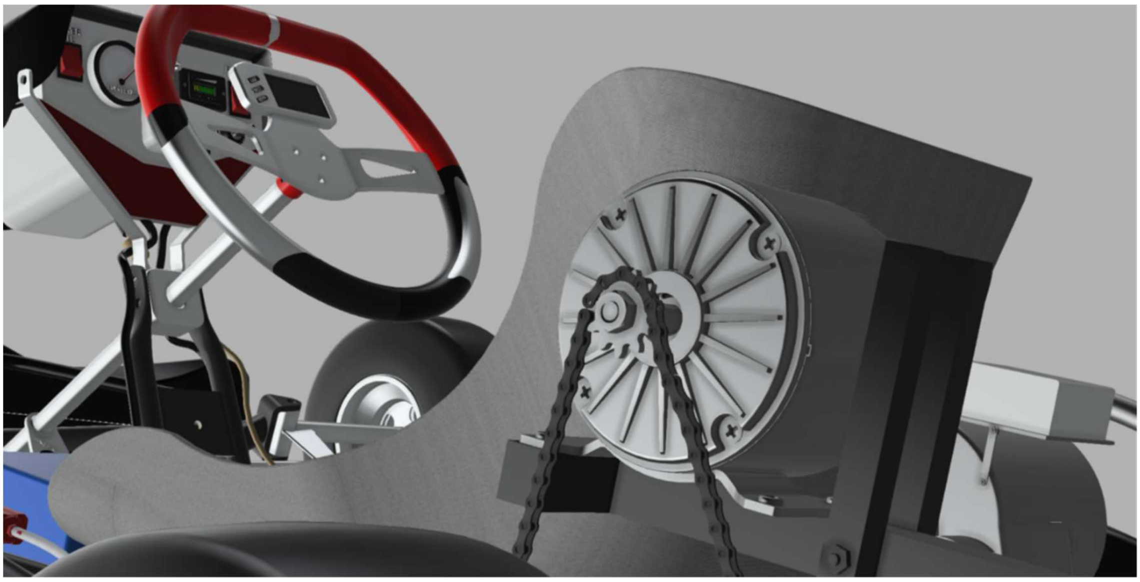

Figure 49 *3D Design: Detail View*

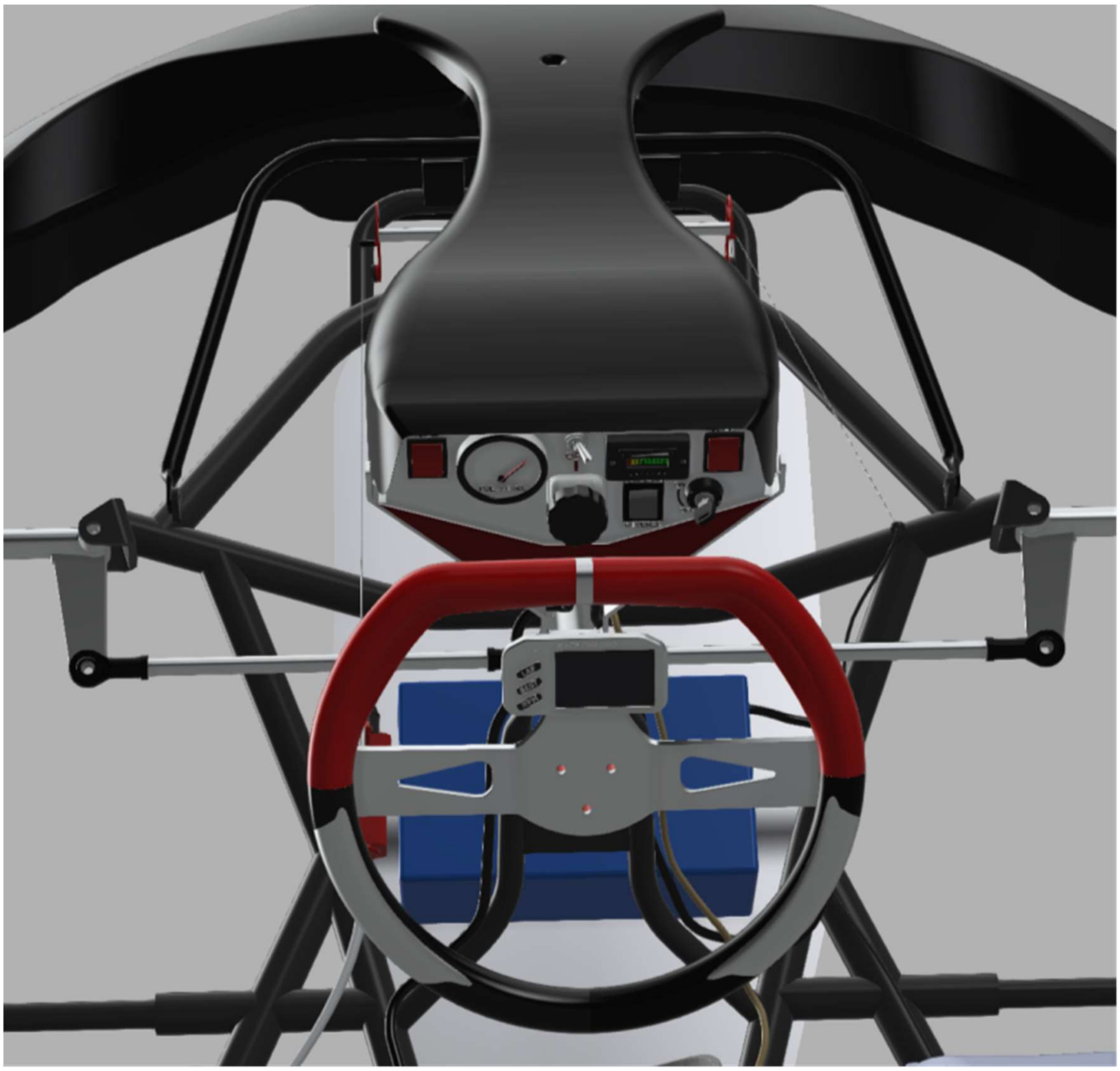

Figure 50 *3D Design: Dashboard*

Figure 51 *3D Design: Dashboard*

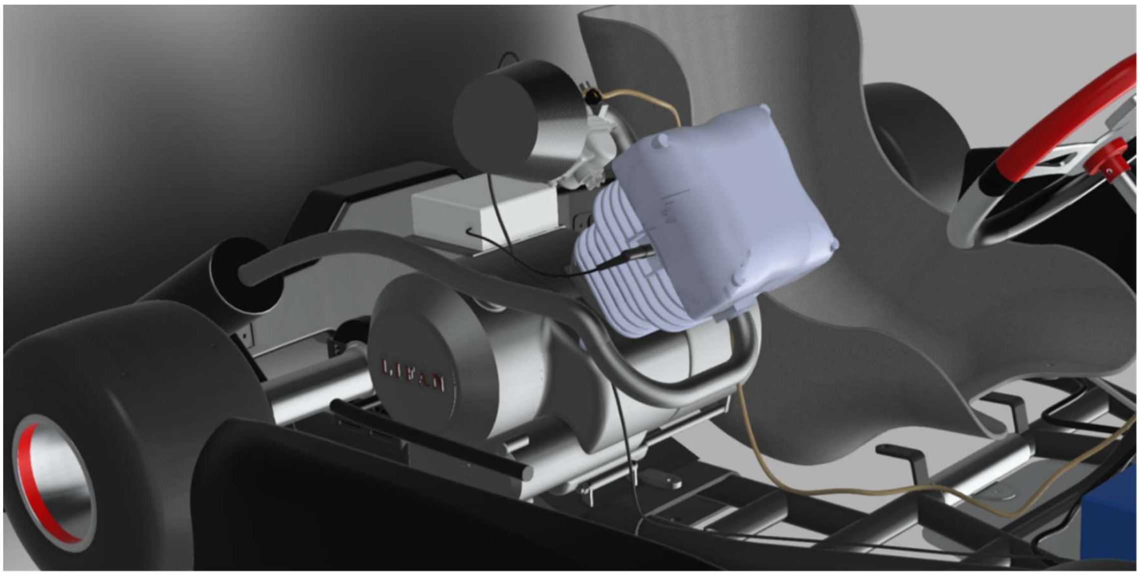

Figure 52 *3D Design: Engine*

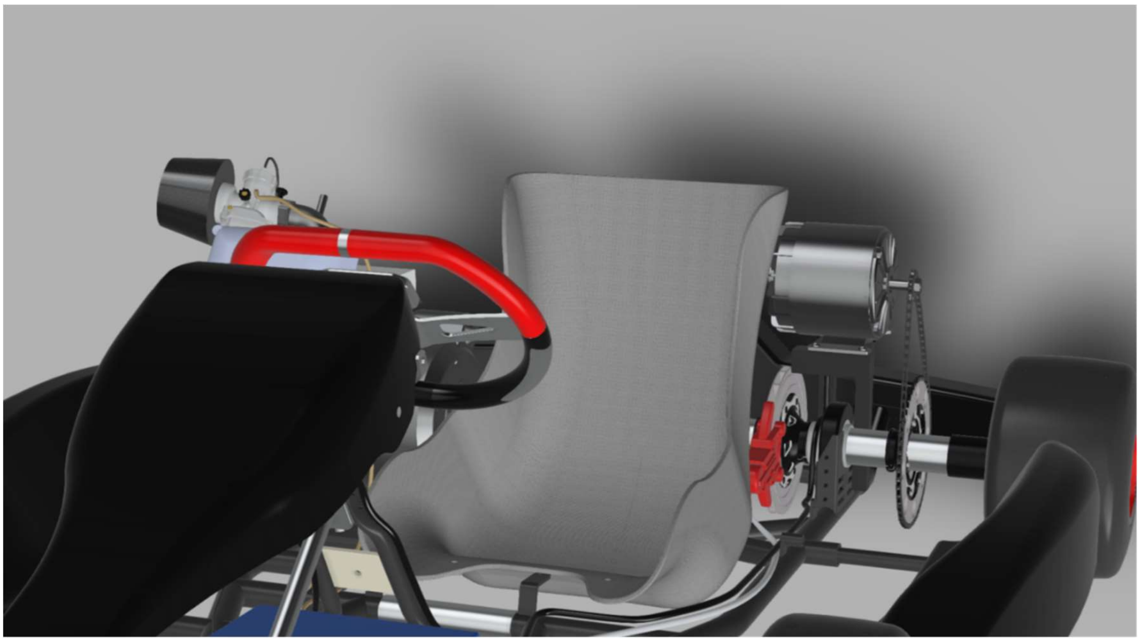

Figure 53 *3D Design: Detail View*

Figure 54 *3D Design: Side View*

Building Process

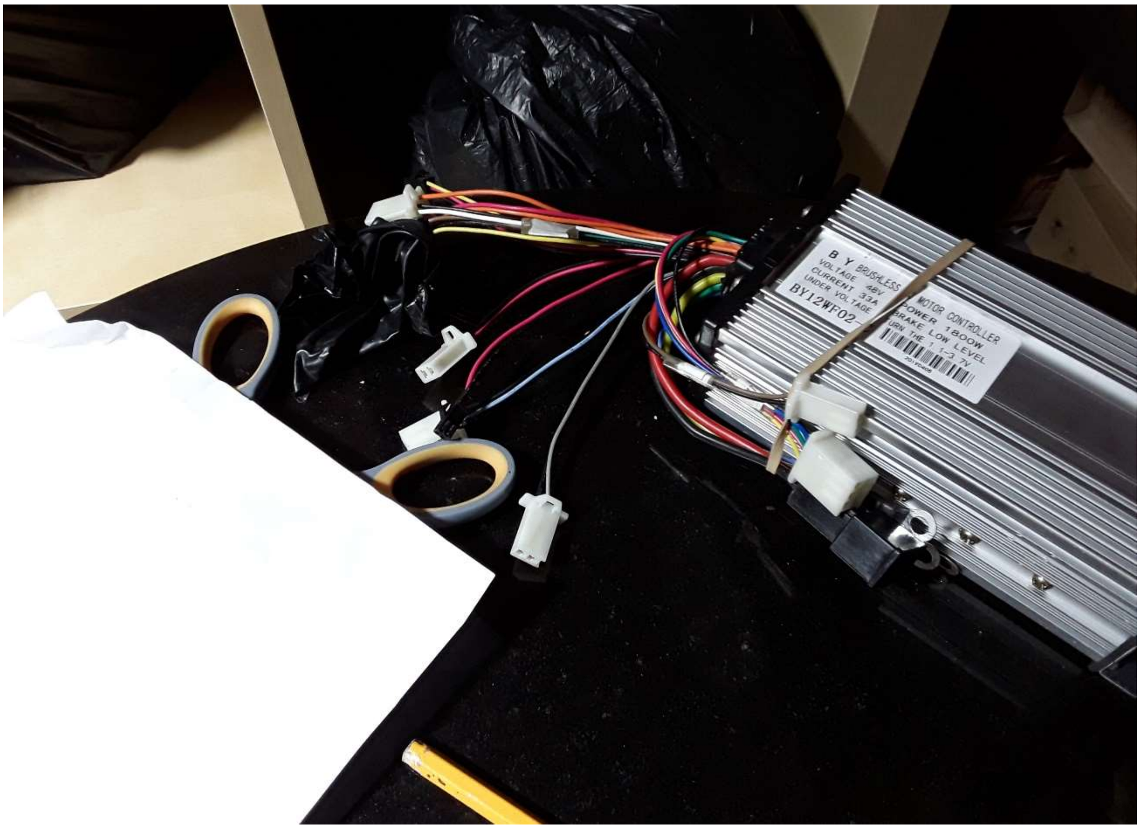

Figure 55 *Building Process: Motor Controller*

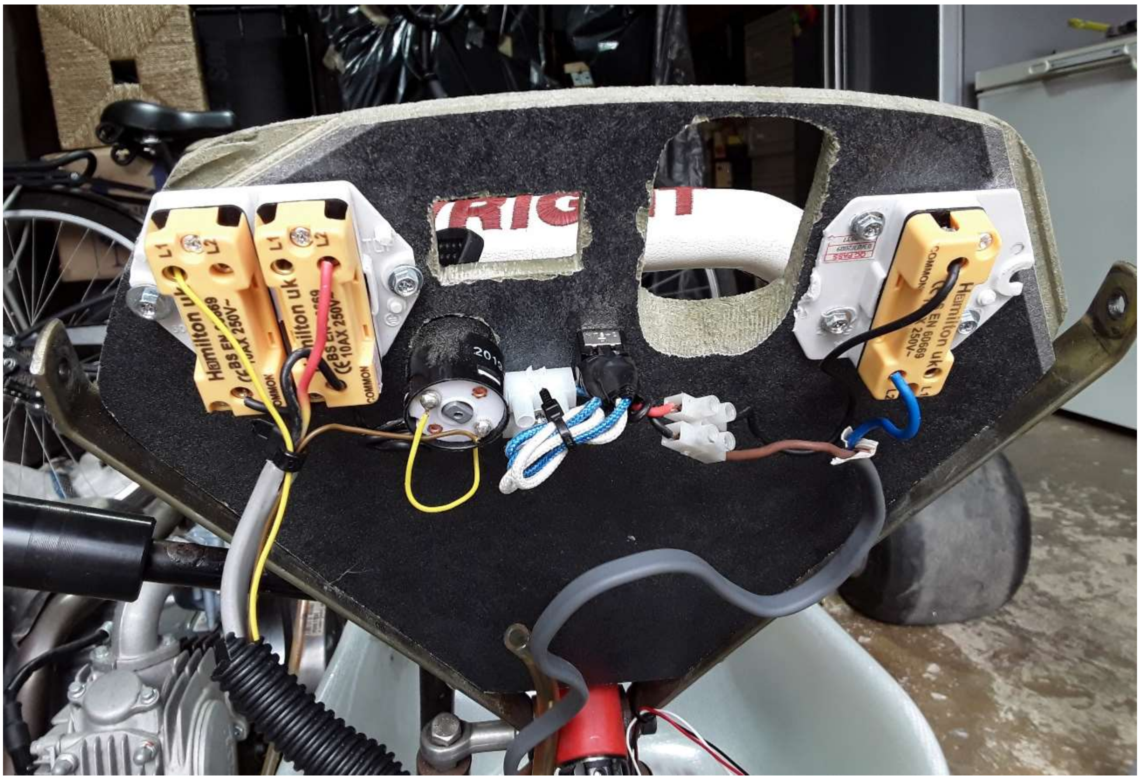

Figure 56 *Building Process: Dashboard Setup*

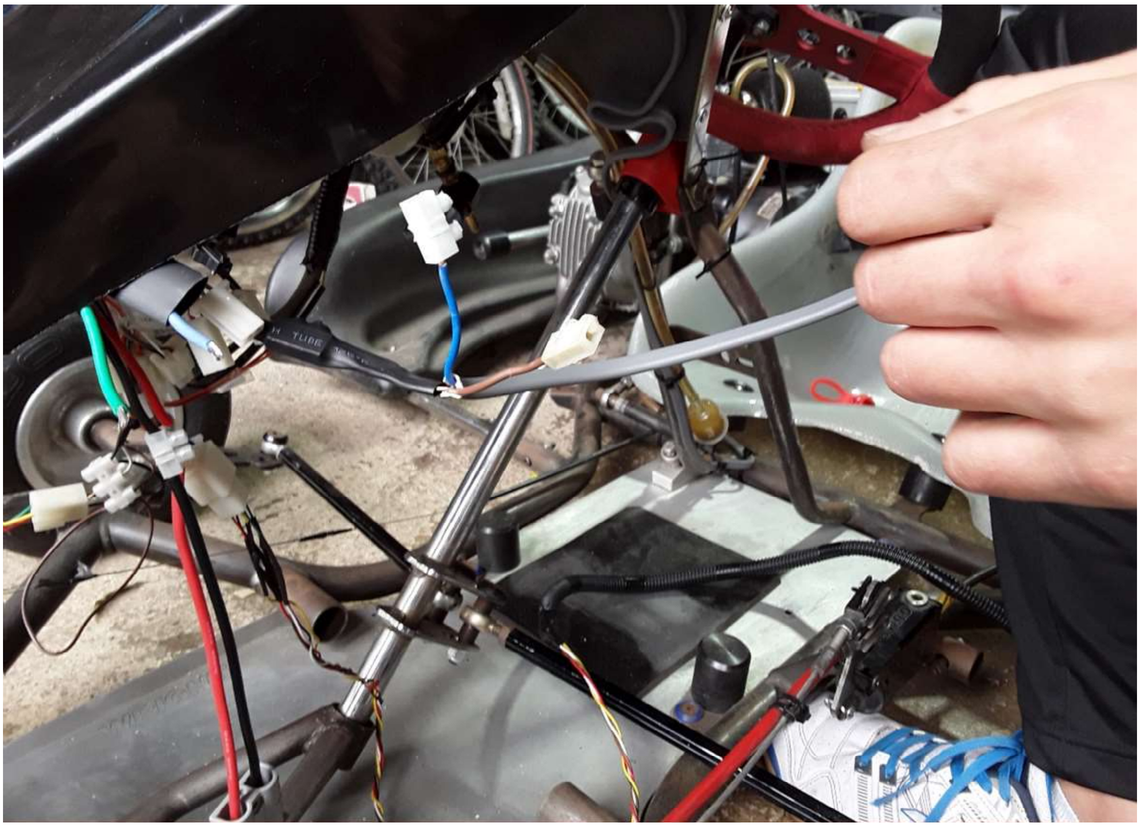

Figure 57 *Building Process: Making Connections*

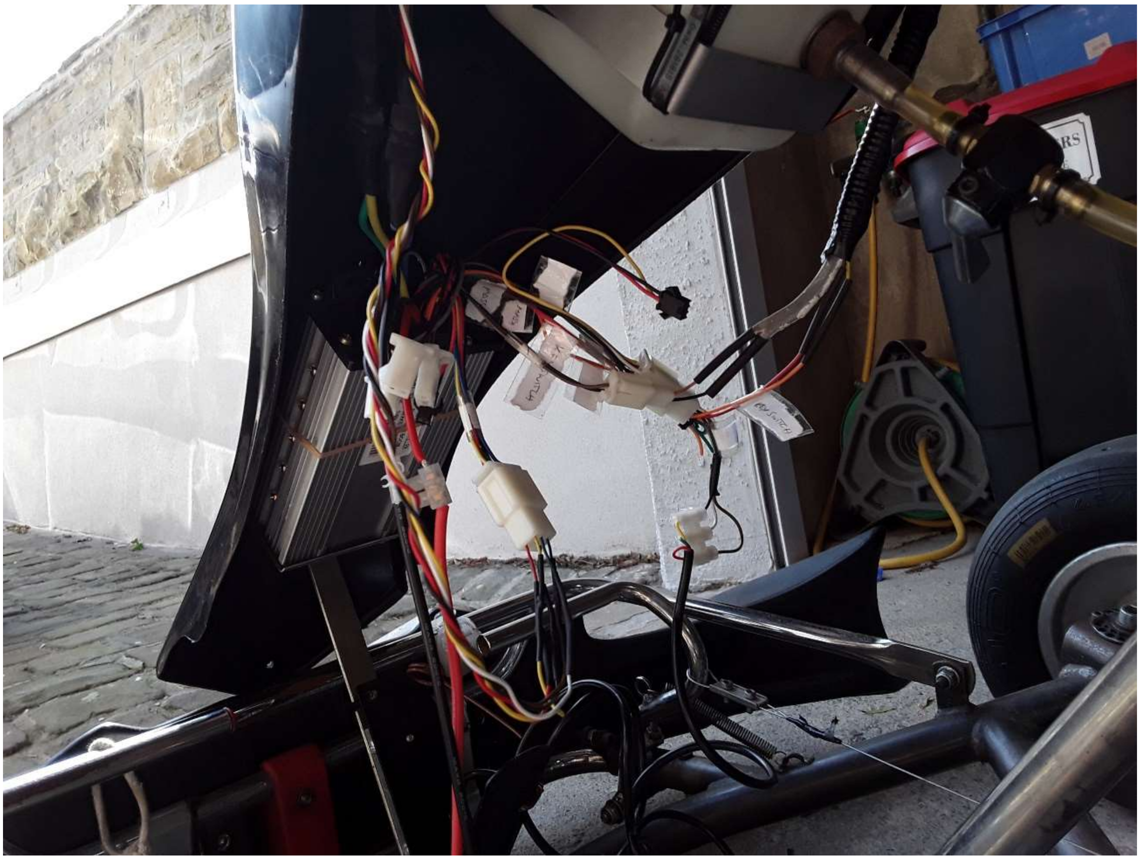

Figure 58 *Building Process: Electrical Circuit Installed*

Figure 59 *Building Process: Electrical Circuit Installed and Tidied*

Figure 60 *Building Process: Painting The Go-Kart*