Executive Summary

Hybrid vehicles seem to be, for the foreseeable future, the only way forward in lowering CO_2 emissions of private transport. The objective of this project is to analyze the two forms of hybridization: The series and the parallel hybrids, and compare their advantages and disadvantages.

On sale today, the Toyota Pruis, a parallel hybrid, is the best selling hybrid. Its main competitor is the Honda Civic Hybrid, recognized as a series hybrid. These two examples were studied and compared in different everyday driving situations.

The Prius has the better fuel economy and emissions. However, for its lower drag co-efficient, less powerful petrol engine and more powerful electric motor, it only gains minimal drop in CO_2 emissions over the Civic. Improvements to the Civic should include emission free operation at low speeds. A hybrid system for the Prius should be developed that has lower weight; at present, it has two electric motors and two batteries.

Further analysis should still be carried out in an attempt to improve hybrid vehicles further. Performance at low speeds (<40km/h) should be investigated further, concentrating on prolonged periods of city driving.

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1. Introduction

1.1 Background Information

In previous years, the automotive industry has tried to design faster and faster vehicles, each competitor trying to out-do the other. This has generally meant car engines increasing in size, but improving efficiency has also been a main objective. Many different new technologies have helped with improving efficiency. Carburetors have been replaced with fuel injectors and variable valve timing has been introduced to increase efficiency and performance. However, now the car industry's main concern is global warming. The carbon dioxide emitted from their vehicles is starting to cost their customers more money, as well as becoming social, and in the near future legally, unacceptable for high emission vehicles.

Carbon dioxide pollution is a relatively new concern; however, it was one of the first gases to be distinguished from air in the 17th Century. Due to world media, possibly the best known source of CO_2 emissions is from car exhausts, but the single highest source CO_2 emissions is humans breathing. This accounts for around 50% of all CO_2 produced. There are small amounts of CO_2 in the air already, making up part of the Earth's atmosphere. However, increased levels of CO_2 is causing global warming. Some of the sun's rays pass through the atmosphere to the Earth's surface they then reflect off the surface, but too much is being reflected back towards earth by the increased quantity of CO_2.

CO_2 comes from many sources; such as deodorant sprays or fizzy drinks, in its frozen form it is known as dry ice and is used widely in the food industry. Despite this, fossil fuels are often advertised as the only problem source.

When wood, a tree say, is burned it releases CO_2 in greater quantities than when coal is burned. However, all the CO_2 emitted by the tree has been taken out of the atmosphere over a 40 year period or so, thus can be considered a carbon neutral process. Fossil fuel has had no effect on the atmosphere in millions of years, so when it is burned the CO_2 emitted is effectively new to the environment, thus is a carbon positive process. A tree or plant, just living, is a carbon negative process as it is reducing the amount of CO_2 in the atmosphere.

Along with global climate concerns, the motor vehicles dependence on oil is another concern. At this point in time, it has been speculated that around 50% of the global oil reserves remain, although this can not be proven it is considered a reasonable estimate. However, not all oil is recoverable and even more is not considered economically viable to be recovered. Much of the oil recovered has been over land or relatively shallow sea, which leaves deep-sea wells. This is expensive to recover and there will come a point when, although the oil has not run out, consumers will not pay the cost for the recovery, leaving the oil companies to loose money to recover it, or more likely, not recovering it at all. Also, of all the oil in a reservoir, only a certain percentage can be recovered. This means that new and more efficient recovery techniques are being employed to increase the total amount of recoverable oil. Due these techniques, oil wells are being revisited to recover more oil. There is also political concern over who owns the oil. Fig. 1.1 shows the location of oil and the quantities there are based on predicted consumption. North America is the biggest consumer of oil used for petrol, but has the least reserves.

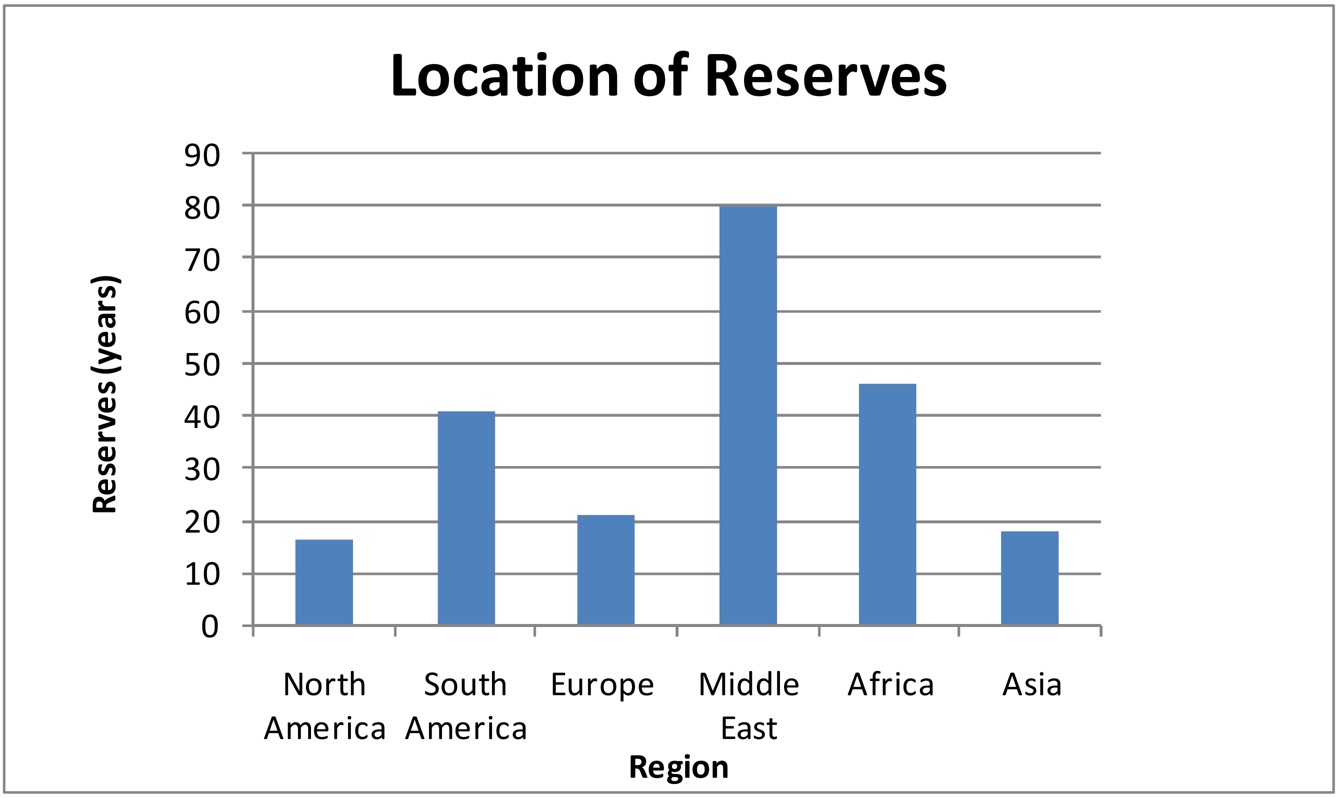

Fig. 1.1: Location of Oil Reserves.

Due to these growing concerns of global warming and oil reserves, especially in the current global financial situation, more and more car-makers are moving to producing cars with *acceptable* performance, with significant reduction in fuel consumption.

Indeed, the European Parliament is enforcing laws to reduce CO_2 emissions across all car manufacturers. By 2015, all current car manufacturers need to have a fleet average CO_2 emission of 130 g/km. Toyota currently averages 140 g/km, much lower than the industry average, and has no powerful sports cars to lower its average. The target for 2020 is a staggering 95 g/km of CO_2. Currently only three cars on sale today achieve that target; the Seat Ibiza 1.4 TDI Ecomotive and the Volks Wagon Polo 1.4 TDI Bluemotion (these cars were both developed by VW Group, therefore share all major components) and the Ford Fiesta Econetic 1.6 TDCI . All of these cars are powered by diesel engines.

Fig. 1.2: Second Generation Diesels.
From left: Ford Fiesta Econetic; VW Polo Bluemotion; Seat Ibiza Ecomotive.

Car manufacturers have invested huge amounts of money in finding a solution to this problem and many different concepts have been conceived. Cars powered solely by electricity, so-called plug-in battery-electric vehicles, as the batteries need to be charged by plugging them in to a power supply, have been researched thoroughly and can offer many advantages. A plug-in vehicle produces no emissions and most have been designed to use a 230V supply that can be found in homes. The GM Volt, due in 2011, will cost less than 1€ to *fill.* However, the range of these vehicles is currently, at best around 40 km and there is nowhere for the battery to be recharged. Also, CO_2 will still be produced from the power stations supplying the homes with electricity. Honda have invested huge amounts of money in developing a zero emission vehicle. The FCX is powered by hydrogen and is available just now, but the hydrogen fuel station infra-structure is still poor, as to make it an impractical alternative around the globe.

Fig. 1.3: The Honda FCX Clarity and the GM Concept Volt.

There are many different types of vehicles on sale today. The average amount of CO_2 emitted by a vehicle in Europe today is 180 grams per kilometre driven. There are luxury vehicles such as a Ferrari or Range Rover that are way above the average and typical family cars that are producing CO_2 just below the average. The Toyota Prius is one of the lowest emitting vehicles on sale today. However, with little alteration, the Prius can be adapted to run on an ethanol mixture to further reduce CO_2 emissions. Honda have developed the FCX Clarity that emits no CO_2.

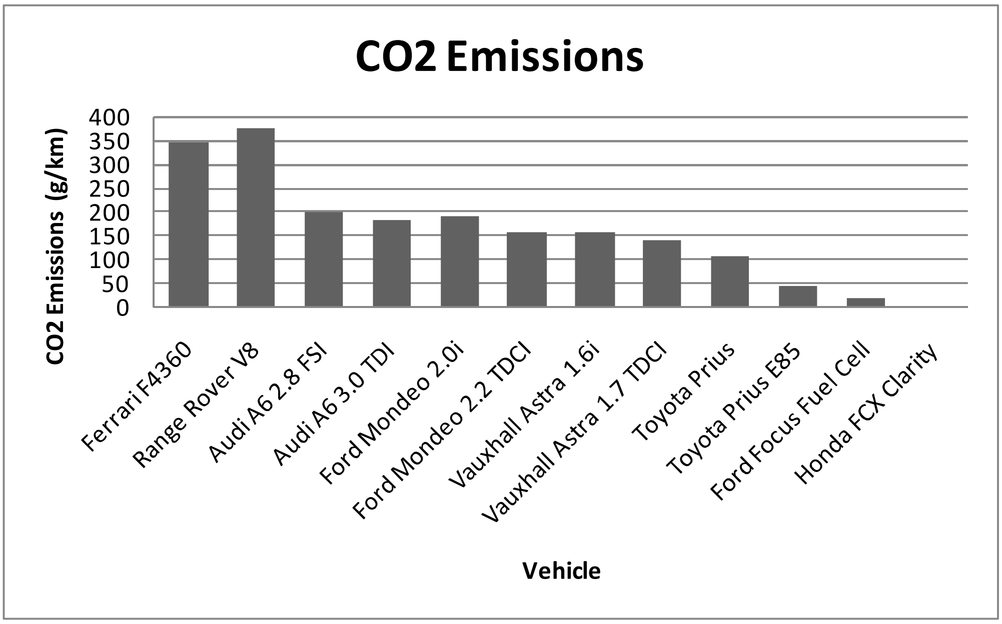

Fig. 1.4: CO_2 Emissions of Vehicles.

So far, only one potential solution has caught on; the petrol-electric hybrid. Car manufacturers, such as Toyota and Honda, are investing huge amounts of money in petrol-electric hybrid designs. While Toyota's effort, the Prius, achieves 104 g/km and Honda's Civic Hybrid achieves 109 g/km, neither of these can compare to the 2020 target.

1.2 Objectives

The diesel Internal Combustion Engine (ICE) is generally seen as the most efficient and cleanest way of powering family cars, but although they have been vastly improved over the years, they still produce much more vibrations and noise than petrol engines. Hybrids aim to give the smoothness and comfort of a petrol engine, with the fuel consumption of a diesel engine.

There are several different types of hybrid vehicles and this report aims to class the different types of petrol-electric hybrid vehicles and explain how they work and their main operating philosophies. A comparison will then be made of the different designs with a discussion of both the advantages and disadvantages of the designs. Taking into account the factors outlined, variations and a combination of the designs will be considered in order to suggest possible design improvements.

Hybrid vehicles could have a big impact on the environment and some of the more prominent points will be considered. The cost of a hybrid will also be considered and the resulting effects of this.

2. Study of Hybrid Vehicles

2.1 Basic Concepts

A hybrid can be any vehicle that uses two or more different energy sources to power the vehicle. For example, a mo-ped is a hybrid vehicle; the petrol engine along with pedal power. However, it is the petrol-electric hybrids, such as the Honda Civic Hybrid and Toyota Prius that will be considered.

Most of the time, the power required from an ICE is much less than its peak power, but because of that small fraction of time, the engines have to be designed to cope with the additional stresses involved. The idea behind a hybrid is that a battery and Electric Motor (EM) can be used to assist the ICE when that additional power is required. This means that the ICE required can be much lighter and more efficient, the engine can also be tuned to rev lower, therefore further reducing the stresses in the engine. The ICE is at its most efficient at low speeds, but as a relatively small amount of power is required to power a family size car at low speeds; this can be done by the electric motor, maximizing the vehicles efficiency.

Hybrids use relatively low powered EM's, because the batteries required for high power electric motors would be far too big and heavy to be practical. Due to this, the electric system on its own is advantageous only at low speeds. At constant motorway speeds the small petrol engine uses more power, therefore fuel, due to the increased weight of the electric system.

The stated combined fuel economy is from lab testing and car reviews (and owners) have all too often complained that the stated figures are no where near the real world figure, which means that the CO_2 emitted is higher than stated. Although, theoretically, all cars should under perform with real world fuel consumption, none seem to be as far off as the hybrids.

Both the Prius and Civic have been carefully designed to give a low aerodynamic drag factor, both use special, thin tyres to decrease the rolling resistance and both try to minimize weight, without sacrificing the comfort and practicality of a standard hatchback. This, along with the ambitious fuel consumption, it could be argued that the hybrid system is only a gimmick. Hybrids are also much more expensive than an equivalent car; the Honda Civic Hybrid costs £17,470, while a standard Civic costs £14,250. Due to this Hybrids are often considered a social class statement rather than an eco-friendly option.

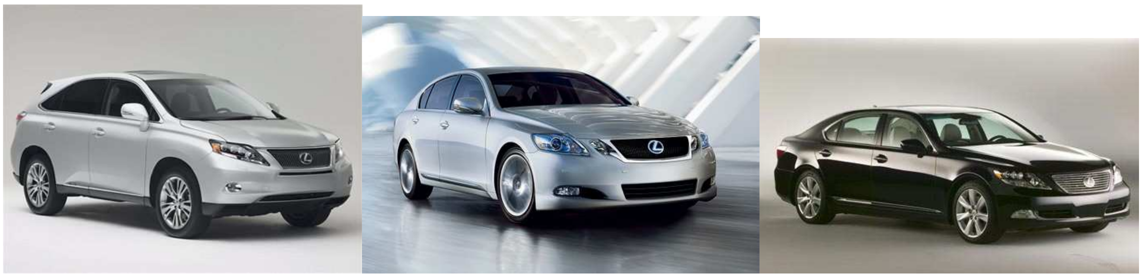

Fig. 2.1: Lexus Hybrid Range
From left: RX450h; GS450h; LS600h

Hybrids are still very rare and use very new technology. Currently there are only five hybrid cars on sale in Europe today; the Lexus LS600h, GS450h and RX450h; the Toyota Prius; and the Honda Civic Hybrid. The Lexus' use identical four wheel drive hybrid technology and are part of Toyota, so share very similar designs as the Prius. As the technology is developed on a wider scale, by more manufactures, it will, not only become cheaper, it will become more efficient and therefore more eco-friendly.

2.2 Mild Hybrids

The fuel saving advantages, inherent to hybrids, is not due to the electric motor alone. Much of the technology and design that is used in hybrids can be found on other vehicles. All mainstream manufacturers now have diesel engines in their range, and have had for some time. Now, though, this is not enough. Ford, Seat and VW have not designed full hybrids, but their cars have been designed in such a way that they are classed as mild hybrids. Along with the Toyota and Honda, these cars use many weight saving materials, so that the overall weight is less but, luxuries such as air-con can still be included. The vehicles have been designed to cut through the air as cleanly as possible. Things such as smaller wing mirrors and a more streamlined shape have helped lower the drag co-efficients and specially designed tyres have been developed to lower the rolling resistance.

One main technological feature if a hybrid is regenerative braking. When a vehicle uses its disc (or drum) brakes, the kinetic energy is lost as heat energy. Regenerative braking makes use of the drive shaft connecting to the EM. When the accelerator is released, the EM acts as a generator and applies a resistive force to the driveshaft. This is converted by the generator into electrical energy and stored in the batteries for when it can be used effectively, whilst slowing down the vehicle.

Even this technology again is not restricted to hybrids, though and BMW, for example, use this technology to charge the battery that powers what is effectively an oversized starter motor. This allows the vehicle to operate an engine stop-start system which cuts the fuel consumption in traffic jams. Due to this, the BMW 330i, which produces 272 BHP has a combined fuel economy of 39 mpg and CO_2 emissions of 172 g/km.

Figure 1 shows how CO_2 emissions compare with different fuels from some manufacturers. It appears that while, obviously, the traditional petrol’s and diesel's emit the most CO_2, and the more expensive, more complex hybrids are less efficient than the efficient diesels. In fact, in the UK, cars emitting less than 100 g/km of CO_2 are exempt from road tax charges. Only the efficient diesels manage to fall into that category.

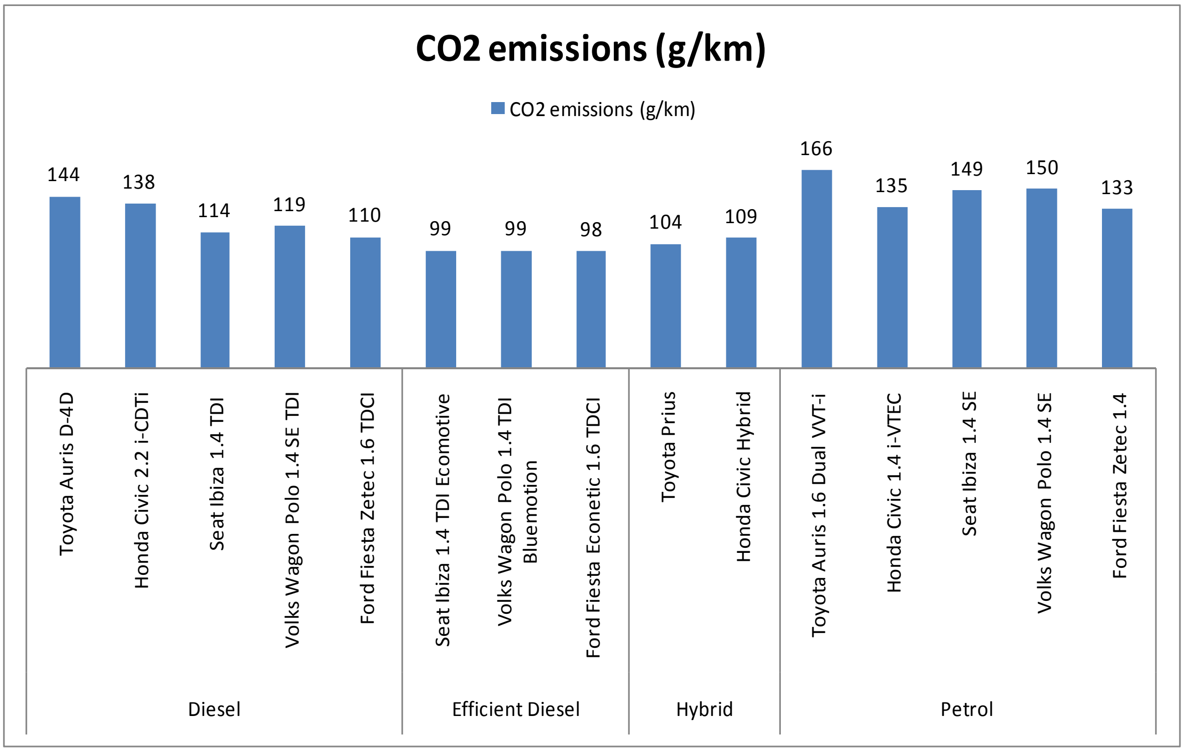

Fig. 2.2: Comparison of Emissions of Different Vehicles.

In making these diesels more efficient, however, soundproofing has been compromised and the engines have been modified, causing them to be louder and much less civilised. The hybrids on the other hand, if anything, have become quieter, as the engines rev lower and, especially in the case of the Prius, the ICE cuts out at low speeds, resulting in virtually noiseless motoring. Both the hybrids use some form of automatic gearbox, compared to the diesels manuals, which uses more fuel, but gives an easier driving experience.

The aim of both types of hybrid designs are the same: to reduce fuel consumption and lower CO_2 emissions. In both cases it is achieved by being able to make the engine smaller due to the additional power supplied from the batteries. However, this can be accomplished in different ways. There are two main types of hybrids; a series hybrid and a parallel hybrid.

2.3 Series Hybrid

A series hybrid is always powered by the EM. The power can only get to the wheels one way, hence series hybrid. There is a generator that is powered by the ICE. The generator then powers the electric motor and can also be used to charge the battery. As the power from the ICE required accelerate the vehicle rapidly, is insufficient, the battery can provide the additional power needed.

Thermodynamic limitations mean that the maximum efficiency of an ICE is around 37%, but it can often be much lower than that, the current average is around 11-14% efficiency for a standard ICE. Since the ICE does not directly power the wheels, only a generator, it can be run at its maximum efficiency constantly. The power can then be varied by the power required from the EM, which is around 95% efficient. This is ideal for low speed requirements. However, in a conventionally powered vehicle, the mechanical drive system is around 98% efficient, the electronic system is much less efficient, at around 70%. This means that when cruising at motorway speeds, when the engine is at its most efficient anyway, there is a loss in overall efficiency.

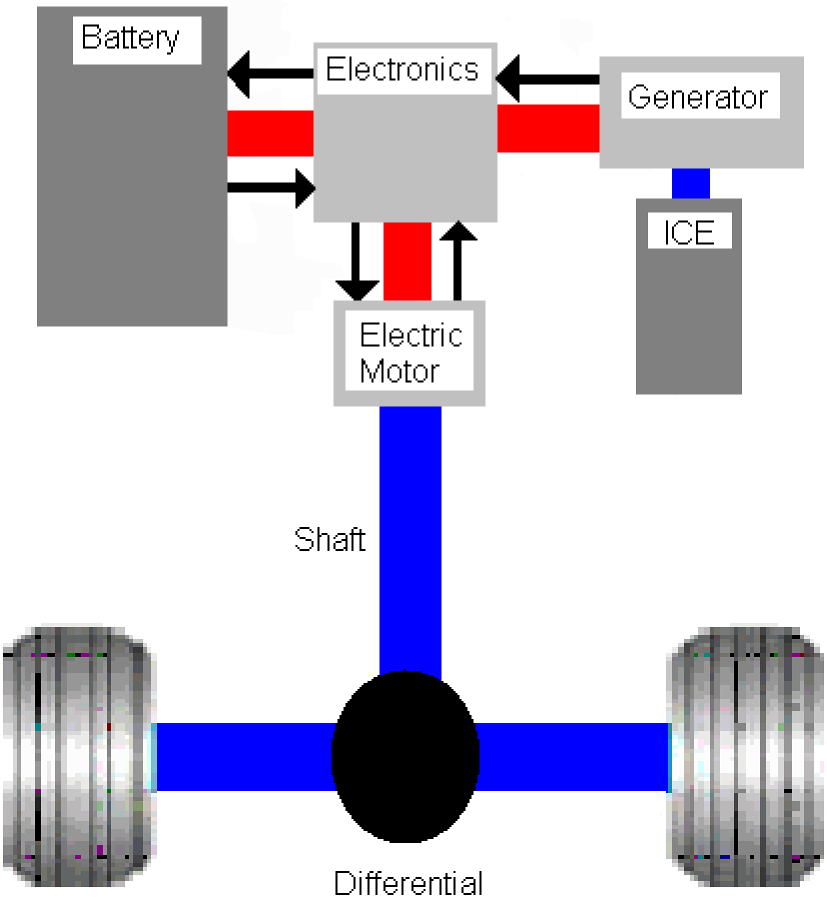

Fig. 2.3: Diagram Series Hybrid.

2.4 Parallel Hybrid

The parallel hybrid uses an EM and an ICE, both connected to a power split device. This means that the wheels can be driven by the EM, powered by the battery, or directly by the ICE, as well as a combination of the two. This means that, unlike the series hybrid, when the vehicle is cruising at motorway speed full advantage of the high mechanical drive system efficiency can be made.

When the vehicle is travelling at low speeds, in a traffic jam, for instance, when an ICE is least efficient, the EM, powered by the battery, is used to drive the vehicle. This means that, if the battery runs out, the ICE will be left to drive the vehicle, when it is at its least efficient.

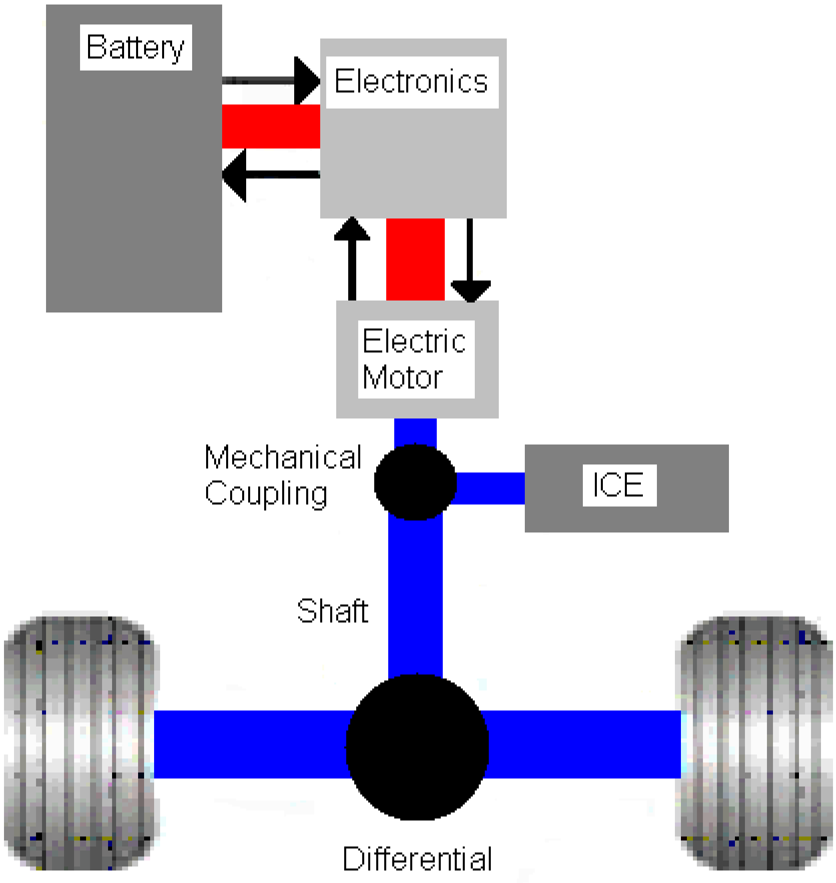

Fig. 2.4: Diagram of Parallel Hybrid.

There are different types of hybrid designs and are generally classed by their principal power unit. Some are mainly powered by the EM and others, more commonly, are mainly powered by the ICE.

3. Analysis of Toyota Prius

Fig. 3.1: Toyota Prius.

3.1 EM Assist

The Toyota Prius is a Parallel Hybrid; the vehicle can be powered by any combination of the ICE and EM. When the vehicle is traveling at a constant speed, an electric motor acts as a generator to charge the batteries. If, however, the vehicle requires a lot of power, when overtaking for example, the electric motor will draw power from the batteries to aid the ICE in accelerating the vehicle.

Traveling at low speeds the ICE is at its most inefficient, so the Prius is powered solely by the electric motor, assuming the batteries still have power, up to speeds of 40km/h before the ICE takes over. This means that, in traffic jam situations the Prius is effectively emitting zero grams of carbon dioxide.

When the vehicle is slowing, instead of using brakes that dissipate the energy as heat, the drive-shaft is connected to the generator which resists the forward motion, storing the energy recovered in the batteries. This process is known a regenerative braking. Conventional brakes can not be disregarded, though, as regenerative braking is ineffective when rapid deceleration is required and conventional brakes are required to bring the vehicle to a complete halt. Along with regenerative braking, the EM can act as a generator to charge the battery; the ICE is at is most efficient when traveling at constant speeds, generally above 60km/h. The Prius takes advantage of this and uses some energy from the ICE to power the generator and charge the battery,

The Toyota Prius has the ICE mounted over the front axle, similar to a conventional car. However, due to the compact form of the ICE there is space for the EM also. The battery is mounted over the rear axle. Its shape is long and flat so that it can sit under the boot, without intruding into its space.

Fig. 3.2: Toyota Prius Component Layout.

The graphs below show how the Prius differs from a conventionally powered vehicle. In these graphs, the length of time that the vehicle is in this situation can be considered infinite, as can the fuel supply, in relation to the energy stored in the battery. This assumption is based on the petrol stored in the tank will last longer than the energy stored in the battery (when the battery is being discharged).

The EM has two functions; to power the vehicle at low speeds and to assist the ICE whilst accelerating, so they only work together whilst accelerating. Fig. 3.3 plots the acceleration against the assist from the electric motor and shows how the two motors work together in different situations.

At the point of zero acceleration, the vehicle must be at a constant speed. This means the ICE is charging the battery, unless the vehicle is at a standstill. It is assumed that for small accelerations the ICE will continue to charge the battery.

The EM assists the ICE when significant additional power is required. For this reason, the there is not a single value of acceleration where the EM joins in. If a relatively large amount of power is required for a relatively slow acceleration, for example; when the vehicle is accelerating uphill, with a full load, i.e. five adults and luggage, the electric motor will assist the ICE at a relatively low acceleration. If the vehicle is using a relatively small amount of power, the EM will not assist the ICE until a larger acceleration, and therefore more power required, is reached.

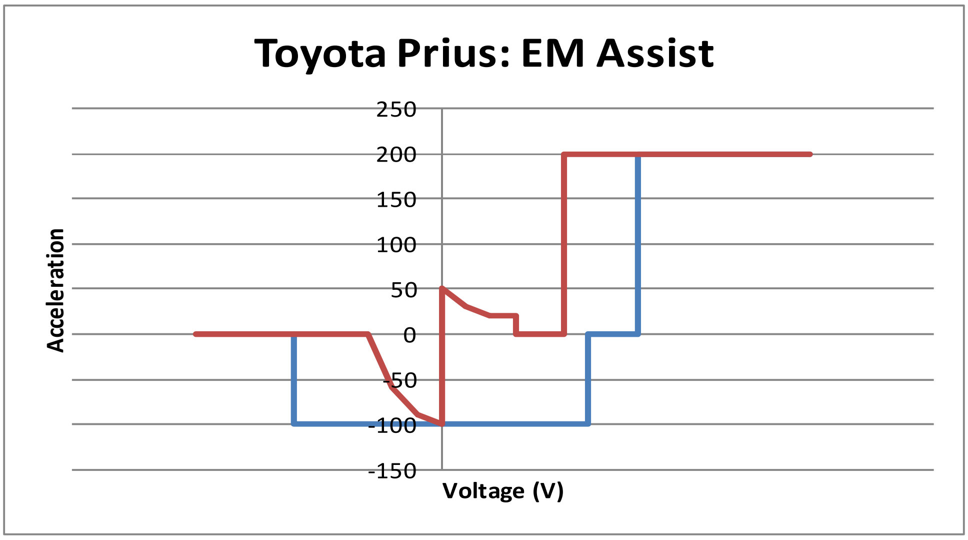

Fig. 3.3: Battery Voltage versus Acceleration for Toyota Prius.

Regenerative braking is used to recharge the batteries when the vehicle is decelerating. The vehicle can be slowed gradually using this method. Energy that would have been wasted as heat is partially recovered and used to charge the battery. As the vehicle reduces speed, regenerative braking becomes less effective and conventional braking is required to sufficiently slow the vehicle further. To rapidly decelerate the vehicle, conventional braking is required and a minimal amount of energy is recovered.

Although the maximum energy recovered is when the vehicle is left in-gear and left to slow down, it is thought that in many real-life situations leaving the vehicle in neutral is more efficient. The extra distance covered, from no resistance of the generator, will give better fuel consumption than the small amount of energy recovered.

3.2 Start-Stop

Fig. 3.4 shows how the EM is used while the vehicle starts and stops repeatedly, similar to a traffic jam situation. During traffic jams, vehicles very seldom travel above 40km/h, when the ICE is least efficient.

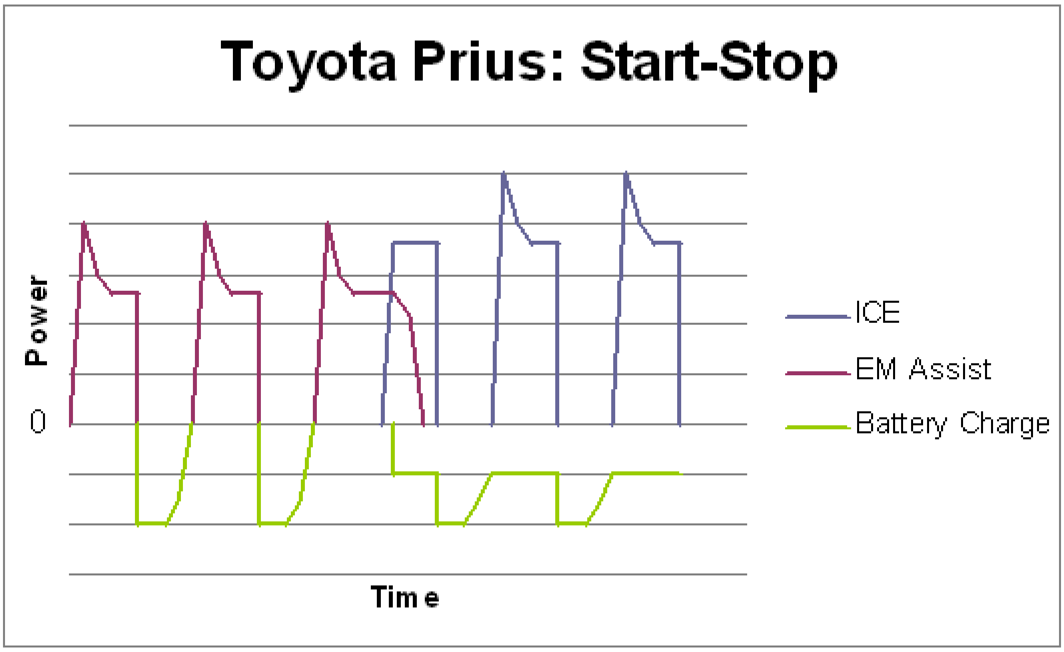

Fig. 3.4: Start-stop Situation for Toyota Prius.

The EM will power the vehicle, with no emissions, while small amounts of energy will be recovered from regenerative braking, until the battery has run out of power. At this point the ICE will take over and continue to power the car. This means that the vehicle will be operating in a conventional manner; there is even a second 12V battery, similar to that found in a conventional car, for when this happens. This means that due to the additional weight of the battery, motor and other hybrid parts, the efficiency performance will be seriously affected.

3.3 Constant Speed

Fig. 3.5 shows how the EM can act as a generator at higher speeds, when the engine is at its most efficient. The EM still used to power the vehicle at constant low speeds, for as long as the battery has power.

While traveling at high speeds, the batteries are charged relatively quickly and the additional power used to charge the batteries is then not required, which results in a drop in fuel consumption. When the vehicle is traveling at lower speeds, the same process is used, but the batteries will take longer to charge. When fully charged, there will be the similar fuel consumption reduction. The battery will not be charged fully by this method; there will be capacity to store more charge in the battery when the generator stops. This is to make use of the energy supplied by regenerative braking, whilst the vehicle slows down.

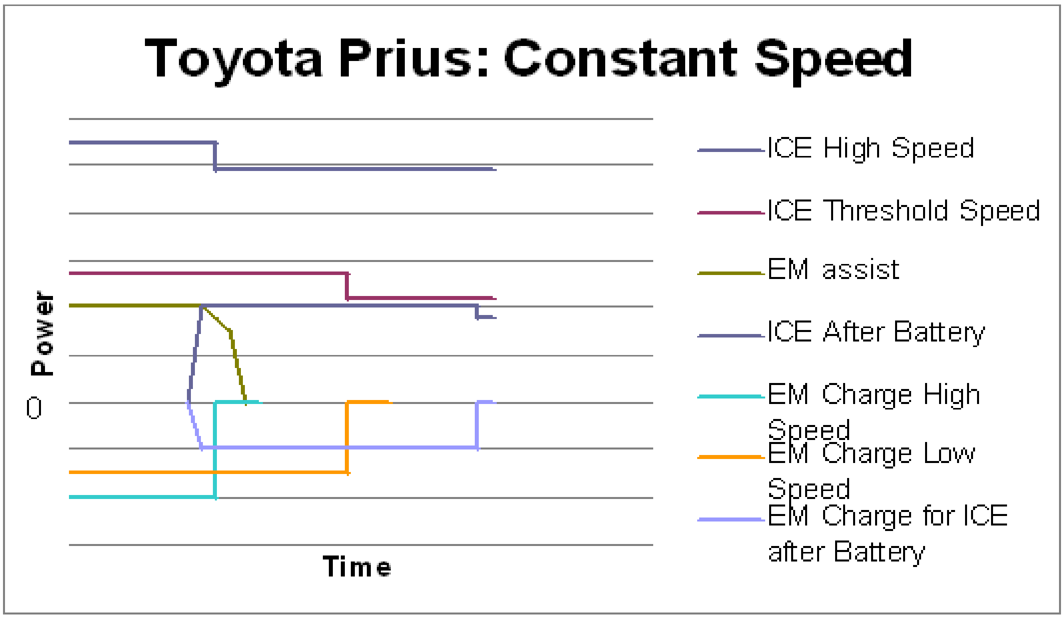

Fig. 3.5: Constant Speed for Toyota Prius.

The EM will power the vehicle at speeds up to 40 km/h, as long as the battery has stored energy. When the battery looses power the ICE will take over and the EM will act as a generator to charge the battery, similar to higher speeds.

3.4 Acceleration

Fig. 3.6 shows how the EM assists the ICE during a long period of acceleration. The acceleration can be considered from a low speed, close to 0, to a high speed, close to the vehicles top speed. The point of maximum economy is when the post of maximum torque, although as the vehicle is accelerating through the gears, the fuel consumption can be taken to be an average, as points of highest and lowest economy is passed.

When the vehicle accelerates all available power is required. This means the ICE and EM work together to provide the maximum possible power output. The ICE gives a power output of 76kW and the EM output of 67kW, this power is combined through a power-split device to provide maximum acceleration.

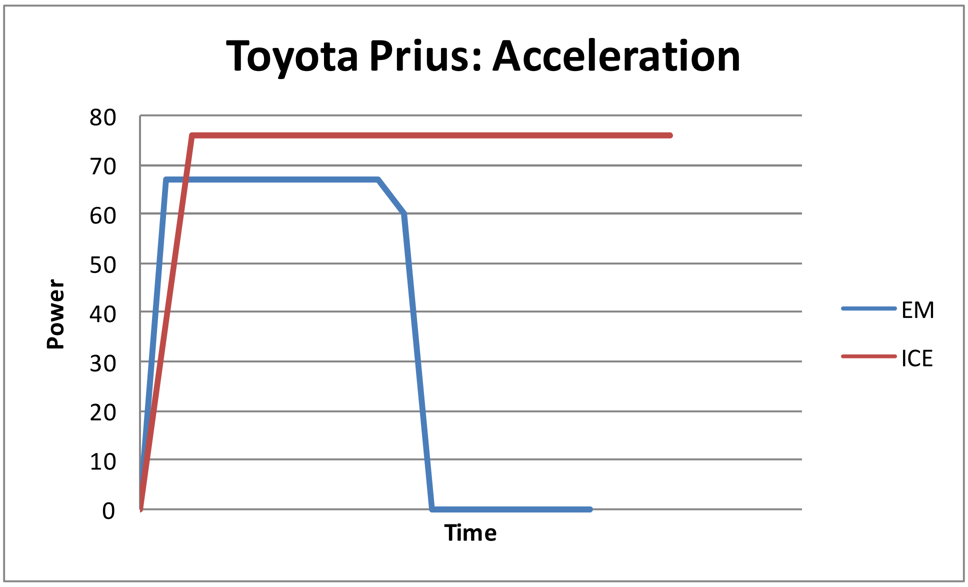

Fig. 3.6: Acceleration for Toyota Prius.

Again assuming that the petrol supply is infinite, the battery power will run out and the ICE accelerates the vehicle, unaided. As the vehicle is at maximum acceleration, i.e. the throttle pedal is fully pressed; there will be no decrease in fuel consumption. There will, however, be a decrease in performance.

4. Analysis of Honda Civic Hybrid

Fig. 4.1: Honda Civic Hybrid.

4.1 EM Assist

The Honda Civic is a Series Hybrid Vehicle; the ICE never directly powers the wheels, the electric motor provides power to the wheels, while it in turn is powered by either the battery or the ICE or in cases where maximum power is required, the EM is powered by both the ICE and battery. When the vehicle is traveling at a low constant speed, the EM, powered by the battery provides power to the wheels. The ICE cylinders are closed and, although the engine is rotating, no fuel is being used. When the vehicle is traveling at higher constant speeds, the ICE is providing the power to the EM. When the vehicle is accelerating at low speeds the EM is powered by the ICE, this takes advantage of the fact that the ICE can be at its maximum efficiency, regardless of the vehicles speed. When the vehicle is accelerating rapidly, the battery assists the ICE to give the maximum power output when required.

As with the Toyota, the compact design of the Civics ICE means that the EM can be mounted over the front axle as well. The battery was designed to be flat so that it can fit behind the rear seats. This means there is no obstruction into the spare wheel well by the battery.

Fig. 4.2: Honda Civic Hybrid Component Layout.

To recharge the battery, the Civic makes use of the energy lost while slowing down, through regenerative braking. The drive shaft is connected to the generator, so when the vehicle slows down the resistive force is used to charge the batteries. This energy would otherwise, be lost as heat. Fig. 4.3 shows the different levels of motor assist, depending on the acceleration.

At the point of zero acceleration, the vehicle can either be traveling at a constant speed or stationary. When the vehicle is stationary, the engine turns itself off. When the brake pedal is released, the electric motor is used to start the engine again. When the vehicle is moving at a relatively high constant speed, the electric motor is powered solely by the ICE. The ICE can be aided by the batteries to power the EM on two levels. For small accelerations the batteries remain redundant. For medium acceleration requirements, the batteries give half the additional power available. Then for maximum acceleration, the EM is powered by both the ICE and batteries to give maximum power and therefore acceleration. The battery does not aid the motor at a single acceleration; therefore the graph gives an area, not a line.

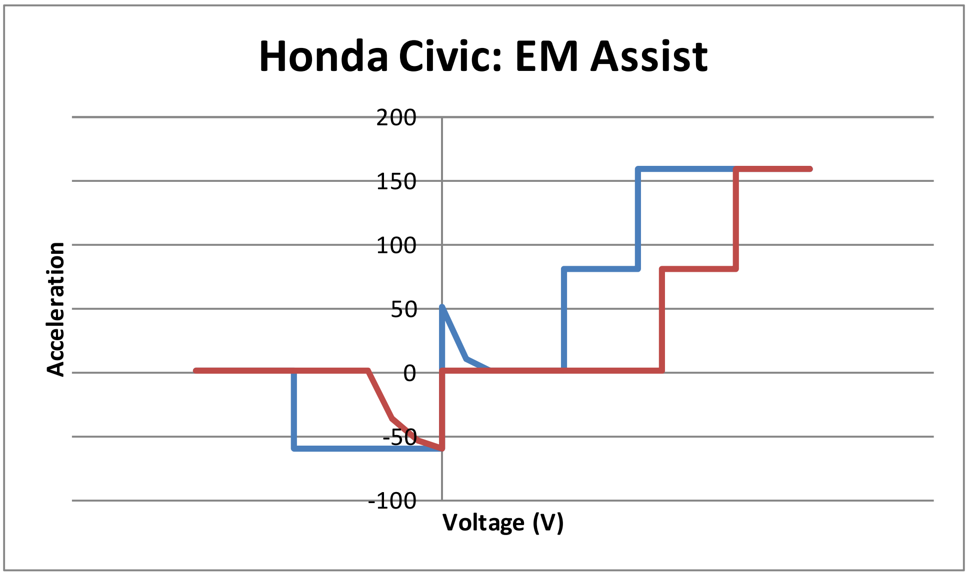

Fig. 4.3: Battery Voltage versus Acceleration for Honda Civic Hybrid.

When the vehicle decelerates, the batteries can be recharged by use of regenerative braking. Slow, steady braking or coasting allows the maximum energy to be recuperated. Regenerative braking is ineffective at low speeds and for rapid deceleration, so traditional friction brakes are still required.

Fig. 4.4: Honda Civic Hybrid Dashboard Display.

The display on the Honda Civics dashboard is shown in Fig. 4.4, as well as indicating the revs of the engine and the fuel consumption, it also shows the batteries state of charge and how the hybrid system is being used. Along with the fuel consumption display, the blue background changes colour depending on the style the vehicle is being driven; if it is being driven efficiently the background is green and at the opposite end of the spectrum it turns red, if the car is being driven inefficiently.

4.2 Start-Stop

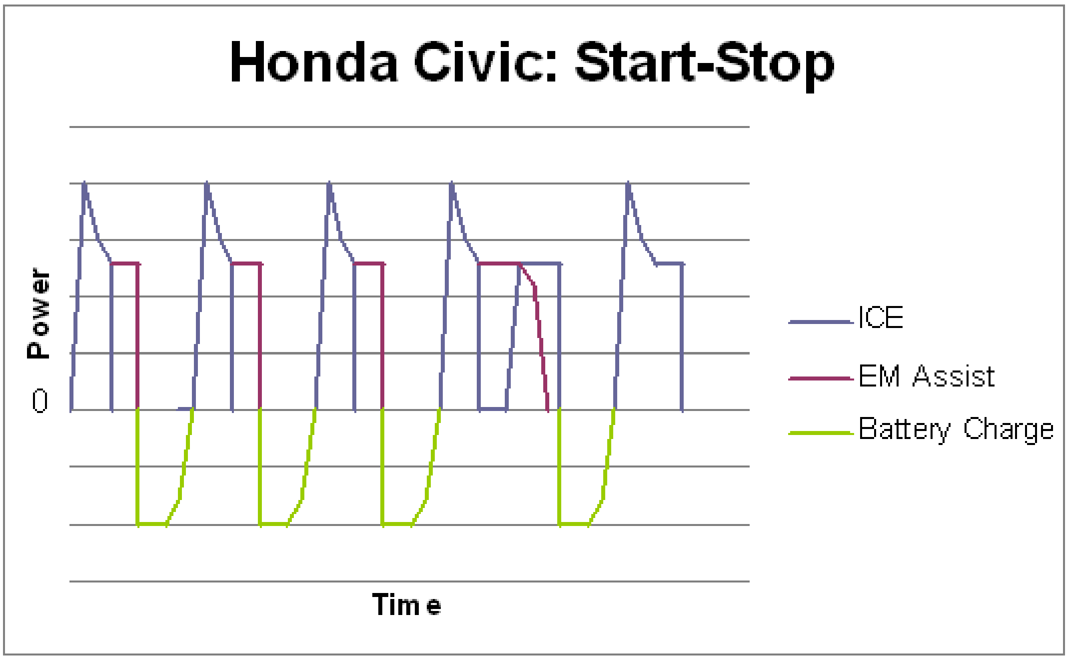

Fig. 4.5: Start-Stop Situation for Honda Civic.

The vehicle is initially accelerated with the ICE, and then kept at a constant speed using power from the batteries. As the vehicle accelerates up to speed the EM takes over. Regenerative braking is used to regain some of the energy that would otherwise be lost as heat, whilst slowing down. As the battery discharges, the ICE powers the EM all the time, until such times as regenerative braking has recharged the battery significantly to power the EM. Regenerative braking is significantly affected by the driving style. Slow deceleration allows the regenerative braking system to capture as much of the energy as possible.

However, as regenerative brakes are unable to slow the vehicle rapidly, hard braking causes the disc brakes to slow the vehicle, effectively wasting the energy as heat.

4.3 Constant Speed

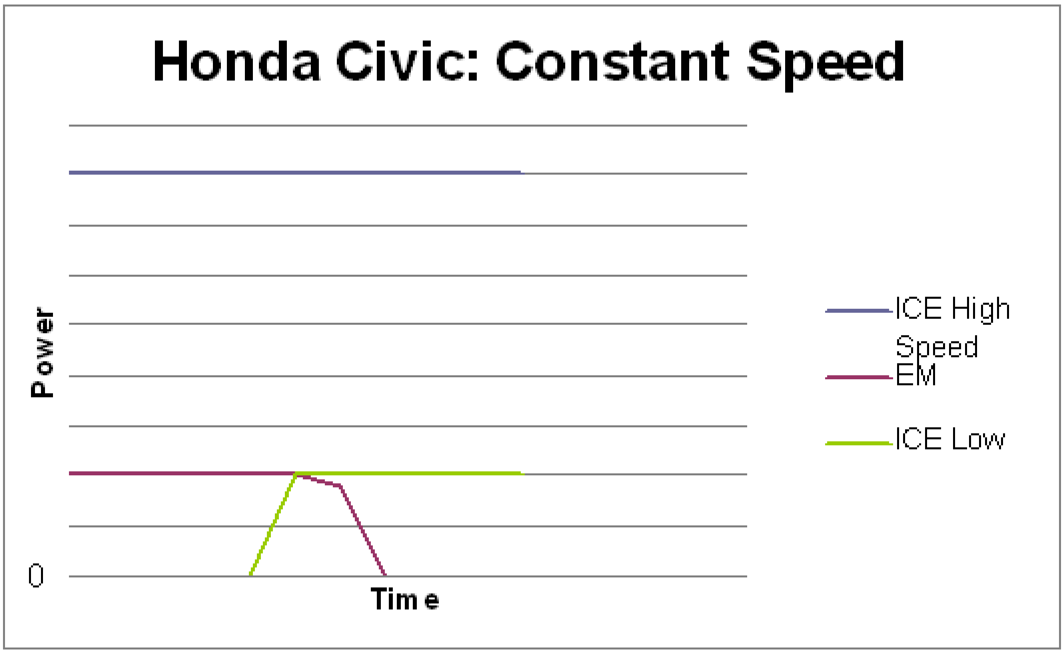

Fig. 4.6: Constant Speed for Honda Civic.

If the speed is sufficiently low, the battery powers the electric motor, until the battery runs out. As the Honda only has one EM/generator, there is no way for the battery to be charged, other than regenerative braking. So at higher speeds when the ICE is at its most efficient, it is used to power the EM.

4.4 Acceleration

When maximum acceleration is required, all the available power is needed. This means the EM is powered by the ICE and battery. If the vehicle accelerates for long enough, or the battery is not fully charged, the battery will run out and the ICE is left to power the EM. As full acceleration is still required, the ICE will not use less power when this happens, the vehicle will, however, accelerate slower.

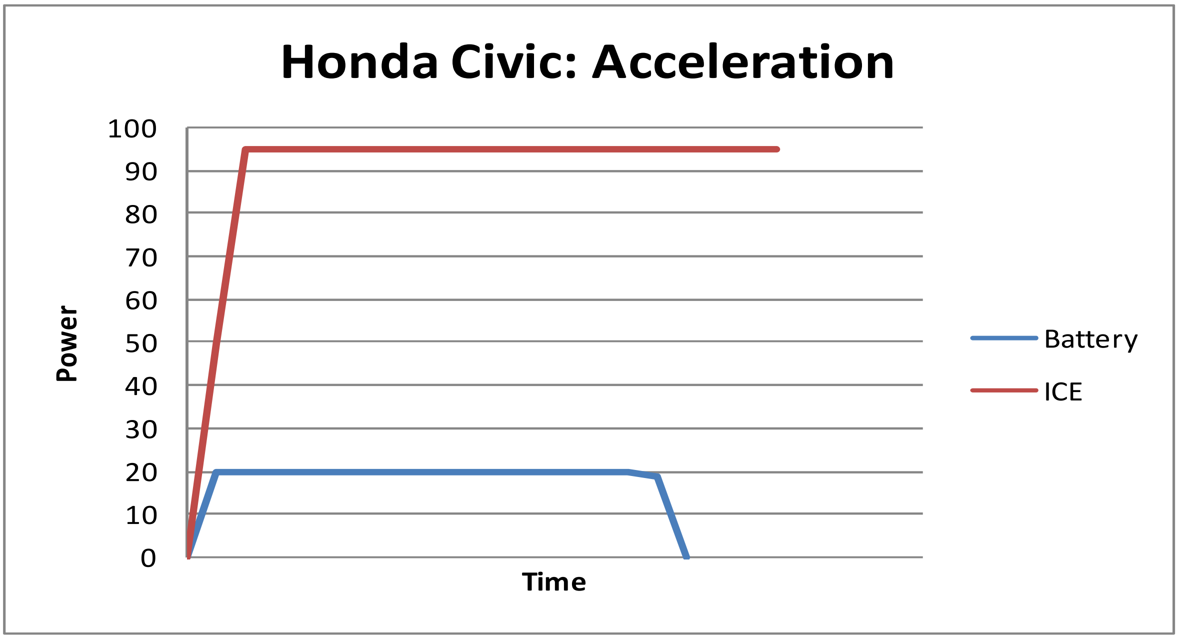

Fig. 4.7: Acceleration for Honda Civic.

5. Design Comparison

Despite the Civic Hybrid and the Prius adopting different hybrid setups, the ways in which the vehicles are powered are very similar. Both use the electric motor to power the vehicle at constant low speeds, both use only the ICE to power the vehicle at higher speeds, both use the EM and the ICE when full power is required and both use regenerative braking to recharge their batteries when slowing down.

Both vehicles use start-stop technology, where, in the case of the Prius, the EM switches off when the vehicle is stationary and the second battery is used as a starter motor to switch the EM back on when the brake is released and in the Civics case, the ICE turns off when the engine speed drops below 1000 rpm whilst decelerating; when the brakes are applied below 30 km/h or when the vehicle speed drops below 5 km/h. The Civic uses its only battery to start the ICE again when either the brake is released before the vehicle has reached a standstill, or when the accelerator is pressed.

When the Prius accelerates, there is a small margin where the ICE powers the vehicle, and then all 202 V from the electric motor join in to aid the ICE. The Civic on the other hand, allows a similar slight acceleration coming only from the ICE, but then half of the additional power from the battery assists the ICE in powering the EM. When full power is required, all the available power from the battery and ICE are used to drive the EM. As the electric assist for both vehicles varies with throttle position, the point at which the assist kicks is not at a given acceleration or speed.

When in start-stop situations, i.e. traffic jams; the Civic and Prius behave very similarly again. The main and most obvious difference is that the Civic uses the ICE to accelerate the vehicle, then the battery to keep it at a constant speed. Where as the EM is used at all times in the Prius. Most power is used for acceleration and hence more fuel is consumed. The Civic uses the ICE, and therefore petrol, when more power is required. The petrol, however, for all intents and purposes can be considered infinite compared to the battery life. The advantage then, is the battery can be used for longer when less power is required at a constant speed.

The Prius emits no CO_2, so long as the battery has power, but due to the much increased demand for accelerating, the battery will run out of power in a short time.

The Civic relies totally on regenerative braking to charge its battery. The Prius, while also makes use of regenerative braking, the battery can be charged while the vehicle is traveling at a constant speed. The ICE is at is most efficient when running at higher speeds, so when the 202V battery from the Prius needs charged, some of the power generated from the ICE is used to charge the batteries.

Although the engines at, say around 70 km/h, are running at their most efficient, hybrids, as shown from their extra urban fuel consumption, are less economical than a similar petrol engine. So while the Civic tries to minimize fuel consumption, the Prius uses some additional power from the ICE to charge its battery for use when it is needed most.

Both vehicles can combine power from their ICE and battery to give maximum power, albeit in slightly different ways. While the Civic uses the ICE aided by the battery to power the EM which drives the wheels, the Prius puts power from the ICE and EM to a power split device which then drives the wheels.

In both cases the ICE is the main power source and while the Prius' 0-100 km/h around a second faster that the Civic, the Civic has a total power output of 115 BHP while the Prius has 143 BHP . The Civic uses a 95 BHP ICE and the Prius uses a 76 BHP ICE, however the Civic only has a 20 BHP EM, while the Prius uses a 67 BHP EM. Due to the significant difference in EM power and while the Prius has a slightly more powerful battery, 202 V compared to the Civics 158V, the battery in the Civic will last longer. Also, when the battery does die the Civic has a more powerful engine to rely on.

6. Possible Design Improvements

6.1 Common Improvements

If the aim is to gain maximum fuel consumption, then even if the hybrid systems are perfect, added luxuries such as air-con or a stereo which not only add weight but increase fuel consumption, or even more so, pure aesthetics such as leather upholstery are ruining the fuel consumption.

6.2 Toyota Prius Improvements

While the Civic makes use of one battery and one EM, the Prius uses two electric motors and one battery when the vehicle is acting as a hybrid. If the battery has no power, or for some reason the hybrid system fails; the Prius has a second 12V battery, similar to a conventional vehicles battery, so the Prius can function as a normal car. While this complicated design might give better fuel economy, a design that only needs one motor the decrease in weight would be reflected in a reduction in CO_2 emissions.

When the Prius accelerates, there is a small margin where the ICE still powers the vehicle alone, then the EM powered by the EM assists. Acceleration was considered earlier, but only when all the power was required. In real driving situations, maximum power is hardly ever required. This means that when the vehicle is only required to accelerate relatively slowly, the power from the battery is being wasted. The advantage of the possibility of less petrol being used. By introducing two, or more steps in assist, the battery will only use what is required. Furthermore, if a variable assist was introduced, the ICE would always be running at its most efficient speed and the battery would last significantly longer.

6.3 Honda Civic Hybrid Improvements

By using the ICE to power the EM, it is a more efficient way of using the ICE to create kinetic energy. However, while the battery is powering the EM, the Civic has been designed so that the ICE is always turning. Despite using no fuel, some of the battery's power must be consumed to rotate the crankshaft. If the engine could be disconnected, while the EM is being powered by the battery, (with a clutch) this would result in less power being drawn from the battery.

One of the biggest advantages of the conventional ICE, is when it is free to work at the right constant speed, the point at maximum torque, the mechanical linkages are 98% efficient which means that the vehicle can achieve very close to its theoretical maximum efficiency of around 37%. By using the ICE to power a generator the system to convert electrical power to kinetic energy is only 70% efficient. It has already been said that the ICE is least efficient at low, inconsistent speeds, so increased efficiency from allowing the ICE to run at constant speeds, by using it to power a generator more than makes up for the lack of efficiency of the drive. However, at motorway speeds, when the engine is running close to its maximum efficiency anyway, the loss in efficiency creates a huge impact on fuel consumption and CO_2 emissions. By using a similar system to the Prius, where when at a constant speed the ICE recharges the battery, the ICE could power either the EM or the wheels directly. In the case of the Toyota, some of the power goes to the generator while the rest goes directly to the wheels. In the Honda's case, the power would either all go to the EM, as it does currently or all directly to the wheels. Additional weight would be added with the addition of mechanical parts, but for long motorway journeys at a constant speed, which means weight has much less impact than when accelerating, a nearly 30% decrease in fuel consumption is a major advantage. By using this method, the possibility of using a larger battery, therefore increasing possible time in a traffic jam before it runs out, and using power from the ICE to charge the battery.

7. Additional Considerations

7.1 Economical Considerations

The technology developed to make hybrids is very different to that of virtually all other vehicles on the road and this means it costs a lot to research and develop. Therefore, there is a substantial premium on all hybrids. The entry level Ford Focus, for example, considered almost unanimously by car reviews as the best medium family car, is £13990 pounds on the road. The Honda Civic Hybrid is over £3000 more expensive, at £17470 and the Prius is a further £900 more expensive than that. While the manufacturers claim that this premium can be claimed back in fuel expenses, it would take the average driver over 4 years to make the money back (Appendix B). There are also vehicles, such as the SEAT Ibiza Ecomotive that gives better fuel economy and emits less CO_2 in the process, for a lot less money.

Although, advancements in the technology used in ICE's, both diesel and petrol, are still being researched and developed, the ICE has almost reached its working maximum efficiency. However, only 15 years ago, diesels were uncommon, more expensive to buy, very unrefined and offered minimum savings in fuel and emissions. Now more diesels are purchased in the UK than petrol's and are now much more eco-friendly than petrol counterparts. Similarly, as more manufacturers begin to build hybrids, the technology will get better and as more cars get produced the price will start to fall.

7.2 Environmental Considerations

The most obvious environmental advantage is the reduction in CO_2 emissions. However, there are other concerns involving the environment. One of the main concerns with hybrids is the battery life and how it will be disposed of. The NiMH batteries used in both the Honda and Toyota have been carefully designed to extend the life of the battery as much as possible. They both are monitored by the vehicles on-board computer, which keeps the level of charge between certain values.

The Toyota's battery is monitored to stay between 40-60% charged. By doing this, Toyota claim the battery will last 180,000 miles. Honda has designed a similar system and claims a battery life of 10-12 years.

When the battery does die, they can be fully recycled. Currently, the nickel recovered from the batteries to make a profit from recycling them.

The 12V motor is no different from that found in any other car and, like them, has to be disposed of by the manufacturer. These batteries are 100% recyclable, so has a closed loop life cycle.

The ICE, if anything, will last longer than that of a normal car. The Prius uses the Atkinson cycle, instead of the common Otto cycle, as, although it produces less power, it is 12-14% more efficient. The Honda, although uses the Otto cycle, thanks to its Integrated Motor Assist System, has tuned the engine to be less powerful at higher revs. Both these designs put less stress on the engine components, which means that while smaller, lighter components can be used, the material is under less fatigue.

8. Economical Study

The cost incurred throughout this project was minimal. The foremost cost would be a computer, suitable for internet access as well as access to run several Microsoft Office programs. This would be the resultant cost required to begin the project. Smaller costs such as the electricity to power the PC, as well as lighting for the room should also be taken into account.

In addition to these costs there would be the cost of the person or persons to carry out the research and investigation. The project was carried out over 12 weeks, resulting in approximately 200 man hours going into the project. For an investigation of this level to be carried out in a company, the cost of the employee carrying out the investigation would have to be taken into consideration, as well as a supervisor. The cost associated with this is dependant on the level of skill of the person undertaking the project.

PC	500
Microsoft Office	400
Internet connection/month	25
Electricity/month	15
Salary/month	800
Supervisor Salary/month	2000
Total Initial Expences	900
Total Monthly Expences	2840
Project Duration	4
TAX	1,16
Total Expences	14221,6

Fig. 8.1: Economical Study.

The above table shows estimated costs of undertaking the project. All costs are given in Euros and are a solitary payment unless otherwise stated. All costs are subject to tax, which has been accounted for, to give the total expense of 14 221.60 €. All expenses, however, are not for exclusive use on the single project. A major company would have these as given expenses in any case, so the project can be considered cost neutral.

9. Environmental Study

The environmental impacts of this project are very small. As it was a research project there were no practical experiments to effect the environment, but there was the electricity required to power the computer. No drafts were printed, before the final copy was ready for submission, hence there was no paper used to be recycled.

10. Conclusion

The Honda Civic Hybrid and Toyota Prius are two different attempts at a solution to the same problem. Although both vehicles achieve very similar results in efficiency; the Honda achieving 109 CO_2/km and 4.6 l/km combined fuel economy and the Toyota Prius achieving 104 CO_2/km and 4.3 l/km combined fuel economy; these results are achieved in different ways. In fact, as shown in the graphs in previous sections, the only case where the two vehicles act similarly is whilst accelerating. The biggest difference is, while the Toyota is a parallel design, the Honda is a series hybrid. This means that although the valves of the ICE can close, the ICE never stops spinning, whilst the vehicle is moving. The Toyota uses its ICE to power the car in a conventional way, although the ICE itself has been altered. The Honda uses a conventional ICE, although it has been tuned to work more effectively with the EM, but uses the ICE to power an EM. This now means that the ICE engines are most efficient at different times. The Honda's ICE can now run at its most efficient, regardless of the vehicles speed, but, as a trade-off, the efficiency from the EM to wheels is less efficient than the conventional method of ICE to wheels. The Toyota makes use of the high efficiency of the mechanical drive, which means that the ICE is very inefficient at lower speeds and when the vehicle is in a traffic jam. To overcome this, the Toyota has used a much more powerful EM and larger battery which means the ICE can be left completely redundant at low speeds, unless the battery runs out. While this means that the Honda still uses the ICE to accelerate the vehicle at low speeds, there is much less reliance on the battery for the vehicle to be efficient. This is a huge advantage if the vehicles were only to be used in cities; where the Toyota could not take advantage of its ability to charge its battery from its ICE.

Even though, when accelerating rapidly, both the EM assist for both vehicles behave in the same way, the length of time the battery can aid power is limited. While the Toyota makes use of what would be considered an underpowered ICE for a car of that size, it compensates by having a powerful EM. The Honda, on the other hand, uses a slightly underpowered ICE that can be aided by a much less powerful EM. This means that, whilst there is energy in the battery of each car, the Toyota will accelerate more quickly and have better fuel economy. However, when the battery runs out, the Toyota will be left with very little power; to compensate; the driver will have to accelerate harder; causing higher revs, which will result in much higher fuel consumption. When the battery runs out in the Honda, it will have a more powerful ICE to power it.

One of the main disadvantages of the Honda is its inability to charge its battery, other than through regenerative braking. As shown in Figures 3.3 and 4.3, the Toyota can recharge its battery while traveling at higher speeds, so it can be *ready* for the next time it is driven in the city. Despite having a smaller battery, it is unlikely that regenerative braking alone would be able to recharge the battery sufficiently.

There will always be compromises when designing a hybrid power train; it could always be a subjective opinion to which compromises should be made. The figures for the CO_2 emissions for the hybrid vehicles is before the battery has run out and, although the way in which the vehicle is used greatly affects it performance, the manufacturers are not readily giving data on how long batteries last in terms of miles without being recharged. Hybrid vehicles are still very new to the car industry and there are still a lot of advancements in the technology to be made. The Toyota Prius and Honda Civic Hybrid are the fore-runners in this market and because of this, and especially compared to the petrol and diesel power trains, are relatively inexperienced efforts. However, both do offer much improved emissions figures over petrol and all but the most efficient diesels.

The aim of a modern petrol-electric hybrid is to give the smoothness of a petrol ICE, but with the efficiency of a diesel ICE. And this has been achieved by both the Toyota Prius and the Honda Civic Hybrid. However, the targets European Governments are setting for reducing CO_2 emissions are so stringent that car companies can not afford to settle for slightly improved efficiency designs and although hybrids are a step forward, there are still many improvements that have to be made in the future.

11. Recommendation for Future Investigation

As the batteries required to power a more powerful EM for any reasonable length of time would be too large and heavy to be practical, the main benefit from a hybrid comes from city driving. Extended city driving, with no stretches of driving for the battery to recharge, is when hybrids can become their least efficient. Further investigation into battery charge and discharge times should be considered.

Further investigation into the comparison of large v. small EM's and how large motors drain the power available from the battery quickly, but small motors struggle to aid the ICE.

Diesels, mentioned in the report, are now much more efficient than petrol's. Investigation into a diesel-electric should also be considered.

12. References

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13. Appendix

Table of Contents

13.1 Appendix A

Vehicle	CO2 Emissions (g/km)
Ferrari F4360	345
Range Rover V8	376
Audi A6 2.8 FSI	196
Audi A6 3.0 TDI	179
Ford Mondeo 2.0i	189
Ford Mondeo 2.2 TDCI	156
Vauxhall Astra 1.6i	155
Vauxhall Astra 1.7 TDCI	138
Toyota Prius	104
Toyota Prius E85	40
Ford Focus Fuel Cell	18
Honda FCX Clarity	0

Fig. A.1: CO_2 Emissions of Vehicles.

Diesel	Toyota Auris D-4D	144
	Honda Civic 2.2 i-CDTi	138
	Seat Ibiza 1.4 TDI	114
	Volks Wagon Polo 1.4 SE TDI	119
	Ford Fiesta Zetec 1.6 TDCI	110
Efficient Diesel	Seat Ibiza 1.4 TDI Ecomotive	99
	Volks Wagon Polo 1.4 TDI Bluemotion	99
	Ford Fiesta Econetic 1.6 TDCI	98
Hybrid	Toyota Prius	104
	Honda Civic Hybrid	109
Petrol	Toyota Auris 1.6 Dual VVT-i	166
	Honda Civic 1.4 i-VTEC	135
	Seat Ibiza 1.4 SE	149
	Volks Wagon Polo 1.4 SE	150
	Ford Fiesta Zetec 1.4	133

Fig. A.2: Comparison of Emissions of Different Vehicles.

13.2 Appendix B

Hybrid Premium

	Average miles driven per year	12000
	Average cost of petrol (GBP/gallon)	4,303
Ford Focus 1.6	On the road price of vehicle (GBP)	13990
	Combined mpg	42
	Gallons consumed per year	285,7142857
	Fuel cost per year (GBP)	1229,428571
	Road Tax (GBP)	150
Honda Civic Hybrid	On the road price of vehicle (GBP)	17470
	Premium over Ford Focus	3480
	Combined mpg	61
	Gallons consumed per year	196,7213115
	Fuel cost per year (GBP)	846,4918033
	Savings in fuel per year (GBP)	382,9367681
	Road Tax (GBP)	15
	Savings in Road Tax (GBP)	135
	Years to earn back premium	4,039504481
Toyota Prius	Cost	18370
	Premium over Ford Focus	4380

Combined mpg	65
Gallons consumed per year	184,6153846
Fuel cost per year	794,4
Savings in fuel per year (GBP)	435,0285714
Road Tax (GBP)	15
Savings in Road Tax (GBP)	135
Years to earn back premium	5,411415864

Fig. B.1: Cost of Owning a Hybrid.

13.3 Appendix C

Toyota Prius		
	Slow	Fast
-10		0
-9		0
-8		0
-7		0
-6	0	0
-6	-100	0
-5	-100	0
-4	-100	0
-3	-100	0
-2	-100	-60
-1	-100	-90
0	-100	-100
0	-100	50
1	-100	30
2	-100	20
2	-100	20
3	-100	20
3	-100	0
4	-100	0
5	-100	0
5	-100	200
6	-100	200
6	0	200
7	0	200
8	0	200
8	200	200
9	200	200
10	200	200
11	200	200
12	200	200
13	200	200
14	200	200
15	200	200

Honda Civic		
	Slow	Fast
-10	0	0
-9	0	0
-8	0	0
-7	0	0
-6	0	0
-6	-60	0
-5	-60	0
-4	-60	0
-3	-60	0
-2	-60	-36
-1	-60	-54
0	-60	-60
0	50	0
1	10	0
2	0	0
3	0	0
4	0	0
5	0	0
5	80	0
6	80	0
6	80	0
7	80	0
7	80	80
8	80	80
9	80	80
9	158	80
10	158	80
11	158	80
11	158	158
12	158	158
13	158	158
13	158	158
14	158	158
15	158	158

Fig. C.1: EM Assist for Toyota and Honda.

Toyota Prius			
	ICE	EM Assist	Battery Charge
0		0	0
1		20	
2		15	
3		13	
4		13	
5		13	0
5		0	-10
6			-10
7			-10
8			-8
9			0
9		0	
10		20	
11		15	
12		13	
13		13	
14		13	0
14		0	-10
15			-10
16			-10
17			-8
18		0	0
19		20	
20		15	
21		13	
22		13	
23	0	13	
24	18	13	0
24	18	13	-5
25	18	11	-5
26	18	0	-5
27	18		-5
27	0		-10
28			-10
29			-10
30			-8
31	0		-5
32	25		-5
33	20		-5
34	18		-5
35	18		-5
36	18		-5
36	0		-10

Honda Civic			
	ICE	EM Assist	Battery Charge
0	0		
1	20		
2	15		
3	13		
3	0	13	
4		13	
5		13	0
5		0	-10
6			-10
7			-10
8	0		-8
9	0		0
10	20		
11	15		
12	13		
12	0	13	
13		13	
14		13	0
14		0	-10
15			-10
16			-10
17			-8
18	0		0
19	20		
20	15		
21	13		
21	0	13	
22		13	
23		13	0
23		0	-10
24			-10
25			-10
26			-8
27	0		0
28	20		
29	15		
30	13		
30	0	13	
32	0	13	
33	13	13	
34	13	11	
35	13	0	
36	13		0

37			-10
38			-10
39			-8
40	0		-5
41	25		-5
42	20		-5
43	18		-5
44	18		-5
45	18		-5
45	0		

36	0		-10
37			-10
38			-10
39			-8
40	0		0
41	20		
42	15		
43	13		
44	13		
45	13		
45	0		

Fig. C.2: Start-Stop for Toyota and Honda.

Prius							
	ICE High Speed	ICE Threshold Speed	EM Assist	ICE after Battery	EM Charge High Speed	EM Charge Low Speed	EM Charge for ICE after Battery
0	55	27	20		-20	-15	
1	55	27	20		-20	-15	
2	55	27	20		-20	-15	
3	55	27	20		-20	-15	
4	55	27	20		-20	-15	
5	55	27	20		-20	-15	
6	55	27	20		-20	-15	
7	55	27	20		-20	-15	
8	55	27	20		-20	-15	0
8	55	27	20	0	-20	-15	-10
9	55	27	20	20	-20	-15	-10
10	55	27	18	20	-20	-15	-10
10	49	27	18	20	0	-15	-10
11	49	27	15	20	0	-15	-10
12	49	27	0	20	0	-15	-10
13	49	27	0	20	0	-15	-10
14	49	27		20		-15	-10

15	49	27		20		-15	-10
16	49	27		20		-15	-10
17	49	27		20		-15	-10
18	49	27		20		-15	-10
19	49	27		20		-15	-10
19	49	22		20		0	-10
20	49	22		20		0	-10
21	49	22		20		0	-10
22	49	22		20			-10
23	49	22		20			-10
24	49	22		20			-10
25	49	22		20			-10
26	49	22		20			-10
27	49	22		20			-10
28	49	22		20			-10
28	49	22		18			0
29	49	22		18			0

Fig. C3: Constant Speed for Toyota.

Civic			
	ICE High Speed	EM	ICE Low Speed
0	80	20	
1	80	20	
2	80	20	
3	80	20	
4	80	20	0
5	80	20	20
6	80	18	20
7	80	0	20
8	80		20
9	80		20
10	80		20

Fig. C.4: Constant Speed for Honda.

Prius				Civic		
	EM	ICE			Battery	ICE
0	0	0		0	0	0
1	67	38		1	20	50
2	67	76		2	20	95
3	67	76		3	20	95
4	67	76		4	20	95
5	67	76		5	20	95
6	67	76		6	20	95
7	67	76		7	20	95
8	67	76		8	20	95
9	67	76		9	20	95
10	60	76		10	20	95
11	0	76		11	20	95
12	0	76		12	20	95
13	0	76		13	20	95
14	0	76		14	20	95
15	0	76		15	20	95
16	0	76		16	19	95
17	0	76		17	0	95
18		76		18		95
19		76		19		95
20		76		20		95

Fig. C.5: Acceleration for Toyota and Honda.

Fig. 3.3. Distribución mundial de