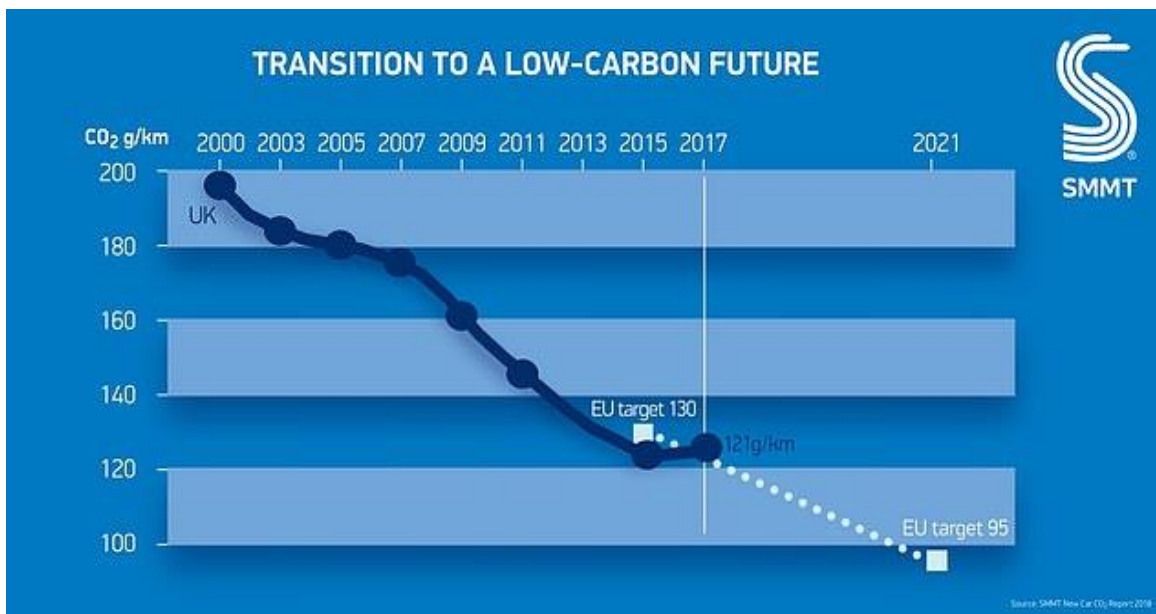


EMISSIONS



Richard Osborne

Emissions Control and Diagnostics

M5X02202

Contents

Contents	1
1.0 Introduction.....	2
2.0 Research and literature	3
2.1 Catalytic Converter/Temperature	3
2.2 EVAP	4
2.3 EGR	4
2.4 SAIR.....	5
2.5 PCV.....	6
2.6 Air/Fuel Ratio.....	7
2.7 Euro 6/7	8
2.7.1 Euro 1.....	8
2.7.2 Euro 2.....	8
2.7.3 Euro 3.....	9
2.7.4 Euro 4.....	9
2.7.5 Euro 5.....	9
2.7.6 Euro 6.....	9
2.7.7 Euro 7.....	11
3.0 Conclusion	12
3.1 HEVs.....	12
3.2 PEVs	12
3.3 PHEVs.....	13
3.4 Emissions Benefits	13
4.0 References.....	14

1.0 Introduction

This report will discuss past emissions standards, emissions control systems and also future control measures manufacturers will be implementing to keep up with ever-changing emissions regulations. The purpose of this report is to gain a comprehensive understanding of emission control systems, their protocols and future plans from OEM's (Original Equipment Manufacturer's) to tackle the latest Euro 6 and future Euro 7 emission standards. Many OEM's are currently working on the possibility of all future vehicles becoming fully Electric Vehicles (EV's) and also Plug-In Hybrid Electric Vehicles (PHEV's).

Research into a number of emissions control systems will be carried out and also look into the future of the automotive industry and the different approaches used to work towards Zero Emissions Vehicles (ZEVs) of the future.

It is believed that EVs and even Autonomous Vehicles are the future of the automotive industry, but the immediate future, or at least for the next few decades, Internal Combustion Engines (ICEs) will still be in production albeit used in Hybrid vehicles.

2.0 Research and literature

2.1 Catalytic Converter/Temperature

Catalytic Converters were first introduced in 1975, “In 1993, it became law for all petrol cars manufactured in the UK to have a catalytic converter fitted to the exhaust to meet European emissions standards.” As stated by Rac.co.uk (2018).

The catalytic converter (Cat) is found as part of the exhaust system, and is commonly mounted as close to the engine as possible to aid in its warm up. At 260 degrees Celsius the cat will begin to operate at 50% efficiency. Full working temperature ranges from 482 – 871 degrees Celsius.

A Cat has a number of elements inside it, Rhodium, Palladium and Platinum, which, at these temperatures, creates a chemical reaction. “These Elements act as catalysts. As mentioned, a catalyst is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process”. As sourced from Halderman (2016, p. 344).

As a technician evaluating the efficient operation of a catalytic converter, a number of tests can be performed. Firstly, ‘Oxygen Level Test’. This is carried out using an emissions tester found in a mot testing station. With the engine warm and the system in closed loop, the oxygen and carbon monoxide (CO) levels can be checked. A healthy Cat should be able to oxidise the extra Hydrocarbons (HC) caused by rapid acceleration. A ‘Snap-Throttle Test’ can also be carried out. This is achieved by using a suitable emissions tester for monitoring oxygen readings. To complete this test the engine must be warm and the system in closed loop. The throttle must then be rapidly depressed in park or neutral, and the oxygen readings observed.

The Catalytic Converter operation is monitored and adjusted by the engine ECU (Electronic Control Unit) via observations carried out by the pre and post Lambda Sensors. Early systems used only one lambda sensor positioned ‘Post Cat’, where modern systems now use two (Pre & Post). This is to obtain a more accurate reading so that the ECU can decide if adjustment to the Air/Fuel Ratio is required. This adjustment is carried out by changing the ‘Fuel Trim’, meaning more fuel can be added if the lambda sensors determine a lean Air/Fuel mixture (lack of fuel), or it can be reduced if the lambda sensors detect a rich Air/Fuel mixture (excessive amount of fuel). As Halderman (2016, p. 215) expresses “Fuel Trim is necessary to keep the Air/Fuel mixture within limits to allow the Catalytic Converter to operate efficiently”.

2.2 EVAP

The purpose of an EVAP system (Evaporative Control System) is to retain fuel vapours until they can be purged and used in the combustion process. These vapours were once vented into atmosphere but from the early 1970's EVAP systems were installed. "Beginning in 1996 with OBD2 vehicles, manufacturers were required to install systems that are able to detect both purge flow and Evaporative System leakage" as Halderman (2016, p. 319) states.

Modern systems are made up of a Charcoal Cannister and a number of hoses and valves. The fuel tank vapours are transported from the fuel tank to the charcoal cannister via these hoses. This is where the vapours are held until the ECU pulses the purge solenoid and the vapours are purged into the air intake. From there, the vapours flow into the combustion chamber and are burnt off instead of being released into the atmosphere. The importance of this system is to eliminate the release of HC into the atmosphere. HC reacts with air and sunlight and form smog. Due to the rapid evaporation of gasoline, an open fuel system could pollute 24 hours a day without even being driven. As observed by Fixdapp.com (2018).

2.3 EGR

EGR (Exhaust Gas Recirculation) is used to reduce NO_x (Oxides of Nitrogen) emissions that are formed due to the high temperatures found in the combustion chamber. The formation of NO_x occurs when cylinder temperatures surpass 1370 Degrees Celsius. This heat is generated in a 'Lean Burn' combustion process. When the EGR is operating (EGR on), the EGR reuses spent gas (exhaust gas) by feeding around 6-10% into the intake manifold via a connecting pipe. This replaces some charge air with gas that is chemically inactive, thus reducing the air quantity entering the combustion chamber. This results in a lower combustion temperature and lowering the production of NO_x emissions.

2.4 SAIR

SAIR (Secondary Air Injection System) is made up of an air pump, a series of pipes, one-way valves and solenoids. Early air pumps were driven by the Auxiliary belt where-as newer systems are electronically controlled to achieve precise control over the system. The SAIR system is used to pump air into the exhaust manifold or Catalytic Converter. This allows the air to mix with the unburnt HC and CO that remains after the combustion process has taken place, this is called oxidizing. The Catalytic Converter then converts these gases into water (H₂O) and Carbon Monoxide (CO₂).

The systems operation changes under hot and cold conditions. As Halderman (2016, P. 340) states

“When an engine is cold and before the oxygen sensor (Lambda Sensor) is hot enough to achieve ‘Closed Loop’, the air-flow from the air pump is directed to the exhaust manifold(s) through the one-way check valves, which keep the exhaust gases from entering the switching solenoids and the pump itself. When the engine achieves closed loop, the air is directed to the Catalytic Converter”.

For a short period of time, HC and CO levels are higher during the warm-up phase of an engine due to the low initial cylinder temperatures. Unburnt HC and CO passes the exhaust valves, but are mixed with the air supply from the SAIR pump in the exhaust manifold, Oxidizing occurs continuing the burn of HC and CO, thus reducing HC and CO pre and post Cat and also raising the Cat’s temperature faster. NO_x emissions aren’t present at this point due to the low temperatures. When Closed Loop operation is achieved, the SAIR system sends the air directly to the Catalytic Converter. HC and CO emissions are reduced pre and post Cat due to a more efficient burn in the combustion process but the secondary air system is still active to assist fast raise in temperature of the Catalytic Converter to increase the efficiency of its operation. SAIR systems normally operate for 2-4 minutes depending on demand, and are then switched off.

2.5 PCV

The purpose of PCV (Positive Crank Ventilation) is to vent the crankcase of vapours that pass the piston rings under combustion pressure. There has been no piston ring manufactured that provides the perfect seal between the piston and cylinder wall. The process of these gases passing the piston rings is called blow by, these gases, mainly Hydrocarbons, are what form the crankcase vapours. They are then vented into the air intake system and reused in the combustion process. The PCV system is made up of a PCV valve, filter and connecting hoses. As observed by Halderman (2016).

Having a PCV valve in good working order is essential, as in most cases, 30% of idle air is provided through the PCV system. A simple test to determine if the PCV is functioning correctly, is a check of the vacuum that the engine is creating. This is carried out by removing the oil fill cap, starting the engine and placing a 3" by 5" card over the opening. If the system is functioning correctly, a light vacuum will be applied to the card. If the card will not stay in place, a check of the PCV valve, hoses and vacuum port on the inlet manifold should be carried out, checking for carbon build up or passage restrictions. Faulty components should be replaced as necessary and with like for like parts. If faulty components are not replaced, the PCV system can affect emissions.

"The most common problem that afflicts PCV systems is a plugged up PCV valve. An accumulation of fuel and oil varnish deposits and/or sludge inside the valve can restrict or even block the flow of vapours through the valve. A restricted or plugged PCV valve cannot pull moisture and blowby vapours out of the crankcase. This can cause engine-damaging sludge to form, and a backup of pressure that may force oil to leak past gaskets and seals. The loss of airflow through the valve can also cause the air/fuel mixture to run richer than normal, increasing fuel consumption and emissions. The same thing can happen if the pintle inside the PCV valve sticks shut.

If the pintle inside the PCV valve sticks open, or the spring breaks, the PCV valve may flow too much air and lean out the idle mixture. This may cause a rough idle, hard starting and/or lean misfire (which increases emissions and wastes fuel). The same thing can happen if the hose that connects the valve to the throttle body, carburettor or intake manifold pulls loose, cracks, or leaks. A loose or leaky hose allows "un-metered" air to enter the engine and upset the fuel mixture, especially at idle where the idle mixture is most sensitive to vacuum leaks." As expressed by Carley (2019).

2.6 Air/Fuel Ratio

The current common Air/Fuel ratio used is 14.7:1 (14.7 parts Air by weight to 1 parts fuel by weight). This Air/Fuel Ratio is regarded as the compromise for fuel consumption, performance and contains the right amount of fuel to burn all the oxygen, this is known as the Stoichiometric Air/Fuel Ratio. There are a range of mixtures that an engine can run on without stalling, they range from 8:1 to 18.5:1. The mixture of 8:1 is the richest mixture that an engine can run on reliably and 18.5:1 is the leanest, anything outside of these tolerances will cause an engine to misfire or not run at all, as observed by Halderman (2016).

However, when adjusting the ratios, HC's and NO_x emissions also adjust. As an Air/Fuel Ratio is made richer, the HC content increases, and if adjusted to a leaner mixture, NO_x increases. Automotive manufacturers across the world are working on new technology to reduce emissions. As emission laws become ever stricter, there are ideas to raise the Air/Fuel ratio and create Lean-Burn engines. This can achieve a better, more complete burn of fuel inside each cylinder, but if the mixture is too lean, a lower power output is achieved and the engine could also fail to combust.

“Lean-burn engines overcome these issues by employing a highly efficient mixing process. Specially shaped pistons are used along with intake manifolds that are located and angled to match the pistons. Additionally, the engine's inlet ports can be shaped to cause “swirl” — a technique borrowed from direct injection diesel engines. Swirl leads to a more complete mixing of fuel and air that enables more complete burning, and in the process reduces pollutants without altering the output.

The downside of lean-burn technology is increased exhaust NO_x emissions (due to higher heat and cylinder pressure) and a somewhat narrower RPM power-band (due to slower burn rates of lean mixtures). To address these problems lean-burn engines have precise lean-metered direct fuel injection, sophisticated computer controlled engine management systems and more complex catalytic converters to further reduce NO_x emissions.” As sourced from (Gable and Gable, 2019).

“In order to keep both NO_x and HC emissions extremely low, even lean-burn engines require catalytic converters; these will be oxidation catalysts to oxidize the HC in the exhaust. Their structure is quite similar to that of the three-way catalyst, but their precious metal coating consists of platinum and palladium **without** rhodium. This catalyst is primarily effective against HC and CO and can still be effective at all lean air/fuel ratios.” As expressed by Seiffert and Walzer (1988).

2.7 Euro 6/7

Emissions regulations date back as far as the 1970's, but the Euro Emissions standards known today were introduced in 1992 and was known as Euro 1, as stated by Rac.co.uk (2018). This is when Catalytic Converters were made compulsory on all new cars sold in the UK. The purpose of these regulations is to reduce the polluting gases. These gases are, Hydrocarbons, Carbon Monoxide, Oxides of Nitrogen and also Particulate Matter. Today, Euro 6 emissions standards are enforced upon manufacturers and by 2020/21 Euro 7 standards will be in effect. By today's standards, it has been said "It would take 50 new cars today to produce the same amount of pollutant emissions as one vehicle built in the 1970s." as stated by the SMMT (Society of Motor Manufacturers and Traders) Rac.co.uk (2018).

"The SMMT has quoted the following figures in support:

- Carbon monoxide (CO): petrol down 63%, diesel down 82% since 1993
- Hydrocarbons (HC): petrol down 50% since 2001
- Nitrogen oxide (NOx): down 84% since 2001
- Particulate matter (PM): diesel down 96% since 1993"

As found on Rac.co.uk (2018).

The Euro emissions standards and their changes throughout the past 3-4 decades are shown below

2.7.1 Euro 1

Euro 1 emissions standards requested that all cars manufactured from the 31st December 1992 were:

Euro 1 emissions standards (petrol) CO: 2.72g/km HC + NOx: 0.97g/km

Euro 1 emissions standards (diesel) CO: 2.72g/km HC + NOx: 0.97g/km PM: 0.14g/km

2.7.2 Euro 2

Euro 2 emissions standards were enforced on all new cars produced from the 1st January 1997 and are displayed as follows:

Euro 2 emissions standards (petrol) CO: 2.2g/km HC + NOx: 0.5g/km

Euro 2 emissions standards (diesel) CO: 1.0g/km HC + NOx: 0.7g/km PM: 0.08g/km

2.7.3 Euro 3

Enforced on the 1st January 2001

Euro 3 emissions standards (petrol) CO: 2.3g/km THC: 0.20g/km NOx: 0.15g/km

Euro 3 emissions standards (diesel) CO: 0.66g/km HC + NOx: 0.56g/km NOx: 0.50g/km PM: 0.05g/km

*THC – Total Hydrocarbons

*PM – Particulate Matter

2.7.4 Euro 4

Enforced on the 1st January 2006

Euro 4 emissions standards (petrol) CO: 1.0g/km THC: 0.10g/km NOx: 0.08g/km

Euro 4 emissions standards (diesel) CO: 0.50g/km HC + NOx: 0.30g/km NOx: 0.25g/km PM: 0.025g/km

2.7.5 Euro 5

Enforced on the 1st January 2011

Euro 5 emissions standards (petrol) CO: 1.0g/km THC: 0.10g/km NMHC: 0.068g/km NOx: 0.06g/km PM: 0.005g/km (direct injection only)

Euro 5 emissions standards (diesel) CO: 0.50g/km HC + NOx: 0.23g/km NOx: 0.18g/km PM: 0.005g/km PN [# /km]: 6.0×10^{11} /km

2.7.6 Euro 6

Enforced on the 1st September 2015

Euro 6 emissions standards (petrol) CO: 1.0g/km THC: 0.10g/km NMHC: 0.068g/km NOx: 0.06g/km PM: 0.005g/km (direct injection only) PN [# /km]: 6.0×10^{11} /km (direct injection only)

Euro 6 emissions standards (diesel) CO: 0.50g/km HC + NOx: 0.17g/km NOx: 0.08g/km PM: 0.005g/km PN [# /km]: 6.0×10^{11} /km

Information sourced from Rac.co.uk (2018).

For vehicles produced prior to Euro 6 regulations, improvements were implemented to get them up to Euro 6 standard. An improvement for diesel vehicles was SCR (Selective Catalytic Reduction), this is a method used to reduce NO_x and is achieved by injecting AdBlue (Urea) into the exhaust system. As Halderman (2016) explains, "The Urea is injected into the Catalyst where it sets off a chemical reaction that converts Nitrogen Oxides (NO_x) into Nitrogen (N₂) and Water (H₂O)."

Another improvement to diesels that hasn't been talked about in this report is the use of a DPF (Diesel Particulate Filter). These were implemented in 2007 for Euro 4 Emissions regulations. The purpose of a DPF is to capture all diesel gas particulates (soot) to stop them being released into the atmosphere. These filters contain porous cells which have a silicon carbide substrate with honeycomb-cell-type channels that are used to trap the soot. These channels are blocked at one end which means the gases are forced through the porous walls, thus collecting the soot. These filters eventually block up and a process is performed called 'Regeneration', this is a downside to these filters as all the collected soot is then burnt off and vented into the atmosphere. This is carried out by a series of events that are governed by the engine ECU and its feedback from the monitoring sensors (DPF Pressure Sensor and Exhaust Gas Temperature Sensor). It can also carry out a regeneration after assessing distance since last regeneration, Fuel used since last regeneration and engine run time since last regeneration. As an example, when the ECU detects a high pressure from the DPF pressure sensor (blocking DPF), it will adjust fuel pressure, engine speed and create late/post combustion injections. This sends a higher amount of HC into the exhaust system to be oxidized by the DOC (Diesel Oxidation Catalyst – Diesel Catalyst, works similarly to a gasoline Catalytic Converter, see section 2.1), which increases the temperature in the DPF to upwards of 500 degrees Celsius and burns off the soot in the DPF.

OBD-II (On-Board Diagnostics Generation 2) is another system that was implemented early on in 1996. The previous system (OBD-I), produced in 1988, lacked the ability to monitor the Catalytic Converter, the EVAP system and the presence of an engine misfire. This resulted in the birth of OBD-II. The new system had the abilities that OBD-I did not and thus better control of the systems was obtained. OBD-II has since enhanced and with new technology, can now monitor emission control comprehensively.

"**EOBD** is the European equivalent of the American OBD-II standard. The two are essentially the same, but the European standard was implemented much later, and applies to petrol cars sold in Europe from 2001, diesels from 2004." As stated by Gendan.co.uk (n.d.).

The most problematic thing with all emission control systems is the consumer. Many consumers use their vehicles for short journeys and this doesn't allow the systems to get up to operating temperature, restricting efficiency. This has an increased effect of carbon build up, especially on diesels. Carbon build up can be a major contributor to inefficiencies of emission control systems and most of all damage to components. Furthermore, as a vehicle MOT test is only conducted once a year, it is not uncommon for consumers to leave issues unfixed until they are forced to repair them by the MOT laws, thus creating a higher pollution rate for the time that a fault is present.

2.7.7 Euro 7

The Emissions Control systems listed in this report (sections 2.1 through 2.6) are the major systems engineers and manufacturers have employed to tackle the emissions issues thus far. For Euro 7 emissions regulations, to be implemented in 2020 and enforced in 2021, the emissions targets are even lower, with talk of certain manufacturers not being able to meet the targets of Euro 7.

As expressed by Frost & Sullivan “The Euro 7 CO₂ target has a phase-in period of one year that requires that 95% of the OEM cars be compliant by 2020, and by 2021 all cars have to be compliant to the limit value curve. By analysing the technology adoption roadmaps of major OEMs, we can deduce that OEMs, such as PSA, Renault-Nissan, and Toyota will meet targets before 2020, while heavier OEMs, including Daimler and BMW, will have to introduce more ultra-low emission vehicles (ULEVs) and downsize and electrify their internal combustion (IC) engines to meet targets by 2020/2021. All 3 German OEMs analysed by Frost & Sullivan will not be compliant in 2022 and, on average, will exceed their target by 3 to 5 gm/km in 2020/2021, while all Asian OEMs will comply with their targets by 2020 and average 2 to 3 gm/km of CO₂ below their respective targets.”

It has been said that fines will be put in place for those manufacturers that don't comply in time.

As observed by Frost & Sullivan (2016) “The German OEMs are expected to pay over 1.5 to 2.0 billion euros as a fine due to existing technology roadmaps and the relative distance to their 2020 targets. The largest liability will be borne by VW group. This is going to add to vehicle costs and; hence, will be detrimental to sales.”

Gasoline Direct Injection Engines (GDI) have been used to reduce emissions in recent years. A number of manufacturers have begun the use of this technology as a reduction of 12-15% in exhaust emissions has been found, and also up to 25% improvement in fuel economy. These systems use pressurized fuel (up to 2900psi) and it is injected directly into the combustion chamber as the piston reaches the top of the compression stroke. The injectors used are high-pressure swirl injectors, and that, coupled with modified combustion chambers, produces almost instantaneous vaporisation. This, used with a higher than normal compression ratio and a leaner Air/Fuel Ratio, results in improved fuel economy, higher power output but most importantly, reduced exhaust emissions, as expressed by Halderman (2016). Lean-Burn engines (section 2.6) have been coupled with this technology.

3.0 Conclusion

On consideration of the information provided above, the general direction of the automotive industry at this time is Hybrid Electric Vehicles (HEV). These will be in production for the next decade or potentially more, along with the production of Plug-In Electric Vehicles (PEV) and also a combination of the two with Plug-In Hybrid Electric Vehicles (PHEV).

3.1 HEVs

HEVs will help to lower emissions by lowering the use of an Internal Combustion Engine (ICE). This is done by shutting off the engine when low load or coasting instances occur. For example, when the vehicle is being used for a long motor way journey or in slow moving traffic, the load on the vehicle is minimal, therefore the ICE will be switched off and the battery power will take over until the engine is required (higher vehicle load).

“Hybrid-electric vehicles (HEVs) use batteries, electric motors, regenerative braking and reduction of engine idling time to enhance a conventional internal combustion engine. The fuel consumption of HEVs is lower for a number of reasons: the electric motor provides a portion of the power for propulsion, especially at high-load conditions when the vehicle is accelerating; some of the vehicle’s inertial energy can be recaptured through regenerative braking systems and stored in vehicle batteries; an engine-stop feature reduces idling fuel consumption whenever the car is coasting, braking, or stopped.” As stated by Reynolds and Kandlikar (2007).

3.2 PEVs

Plug-In Electric Vehicles (PEVs) aren’t best known for their mileage ranges, as the only form of partial re-charge of the battery whilst driving, is under regenerative braking. This coupled with a long motorway journey, owners driving style and in-vehicle consumers would require numerous stops for recharging. However, for short journeys, i.e. commuting for work, these vehicles are ideal and emit zero emissions.

“Electric Vehicles (EV) use a high-voltage battery pack to supply electrical energy to an electric motor(s) to propel the vehicle under all driving conditions. The capacity of the battery pack in kilowatt-hours (kWh) determines the range of the vehicle and has to be plugged in to recharge the battery before it can be driven further.” As explained by Halderman (2016).

“Extreme ambient temperatures tend to reduce range, because energy from the battery must power climate control systems in addition to powering the motor. Speeding, aggressive driving, and heavy loads can also reduce range.” As sourced from Afdc.energy.gov (2014).

3.3 PHEVs

“A plug-in hybrid electric vehicle (PHEV) is a vehicle that is designed to be plugged into an electrical outlet at night to charge the batteries. By charging the batteries in the vehicle, it can operate using electric power alone (stealth mode) for a longer time, thereby reducing of the internal combustion engine (ICE). The less the ICE is operating, the less fuel is consumed and the lower the emissions.” As stated by Halderman (2016).

Jaguar Land Rover (JLR) have released the Range Rover P400e, new for 2018. This vehicle is a PHEV and utilizes a new ‘Ingenium’ 2 litre turbo charged engine and a 13.1 kWh battery pack. The engine produces 296bhp and the electric motor produces 114bhp, these combined produce 410bhp. With the CO2 emissions as low as 64g/km, this proves that PHEV technology is ample to meet Euro 7 emissions and possible future emissions regulations. Land Rover also claims 101mpg, this is obviously dependant on numerous factors, but if true, is very impressive for such a large vehicle. Batchelor (2018).

3.4 Emissions Benefits

“HEVs, PHEVs, and EVs typically produce lower levels of emissions than conventional vehicles do. HEV emissions benefits vary by vehicle model and type of hybrid power system. EVs produce zero tailpipe emissions, and PHEVs produce no tailpipe emissions when in electric-only mode. The life cycle emissions of an EV or PHEV depend on how that electricity is generated, and this varies by region. In geographic areas that use relatively low-polluting energy sources for electricity generation, PHEVs and EVs have substantial life cycle emissions advantages over similar conventional vehicles running on gasoline or diesel. In regions that depend heavily on conventional fossil fuels for electricity generation, plug-in vehicles may not demonstrate as strong a life cycle benefit. Even in these areas, however, consumers may have the option of purchasing renewable energy.”

Overall emissions levels will be reduced with any of the three systems listed above, however, it is believed that future vehicles will be fully electric and no other form of power will be utilized in the everlasting chase to obtain Zero Emissions Vehicles (ZEV).

4.0 References

Afdc.energy.gov. (2014). *Hybrid and Plug-In Electric Vehicles*. [online] Available at: https://afdc.energy.gov/files/u/publication/hybrid_plugin_ev.pdf [Accessed 17 Mar. 2019].

Batchelor, J. (2018). *New Range Rover PHEV 2018 review*. [online] Auto Express. Available at: <https://www.autoexpress.co.uk/land-rover/range-rover/101912/new-range-rover-phev-2018-review> [Accessed 17 Mar. 2019].

Carley, L. (2019). *Positive Crankcase Ventilation (PCV)*. [online] Aa1car.com. Available at: <https://www.aa1car.com/library/pcv.htm> [Accessed 14 Mar. 2019].

Fixdapp.com. (2018). *Evaporative Emission Control (EVAP) System – FIXD Automotive*. [online] Available at: <https://www.fixdapp.com/blog/evap-system> [Accessed 12 Mar. 2019].

Frost & Sullivan. (2016). *European Emission Regulations - Will Stringent Emission Regulations Choke Automotive Industry Or Will OEMs Find Their Way Out?*. [online] Available at: <https://ww2.frost.com/frost-perspectives/european-emission-regulations-will-stringent-emission-regulations-choke-automotive-industry-or-will-oems-find-their-way-out/> [Accessed 10 Mar. 2019].

Gable, C. and Gable, S. (2019). *What is a Lean-Burn Engine?*. [online] ThoughtCo. Available at: <https://www.thoughtco.com/what-is-a-lean-burn-engine-85367> [Accessed 11 Mar. 2019].

Gendan.co.uk. (n.d.). *Top Tips: OBD-II, EOBD, EOBD2 - what's the difference? :: Gendan Automotive Products*. [online] Available at: https://www.gendan.co.uk/article_23.html [Accessed 16 Mar. 2019].

Halderman, J. (2016). *Automotive fuel and emissions control systems*. 4th ed. Pearson.

<https://ww2.frost.com/frost-perspectives/european-emission-regulations-will-stringent-emission-regulations-choke-automotive-industry-or-will-oems-find-their-way-out/>

Rac.co.uk. (2018). *Euro 1 to Euro 6 – find out your vehicle's emissions standard | RAC Drive*. [online] Available at: <https://www.rac.co.uk/drive/advice/emissions/euro-emissions-standards/> [Accessed 16 Mar. 2019].

Rac.co.uk. (2018). *What is a catalytic converter? | RAC Drive*. [online] Available at: <https://www.rac.co.uk/drive/advice/car-maintenance/catalytic-converters/> [Accessed 8 Mar. 2019].

Reynolds, C. and Kandlikar, M. (2007). *How hybrid-electric vehicles are different from conventional vehicles: the effect of weight and power on fuel consumption*. [online] iopscience.iop.org. Available at: <https://iopscience.iop.org/article/10.1088/1748-9326/2/1/014003/pdf> [Accessed 17 Mar. 2019].

Seiffert, U. and Walzer, P. (1988). *Lean Burn Engine - an overview* | *ScienceDirect Topics*. [online] Sciencedirect.com. Available at: <https://www.sciencedirect.com/topics/engineering/lean-burn-engine> [Accessed 15 Mar. 2019].