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| BEng (Hons) Automotive and Motorsport Engineering  Staffordshire University |
| The Effects of Different Fuel Blends on Vehicle Performance and Fuel Efficiency |
| DTA Individual Engineering Project  ENGG61010 |
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**Abstract**

As of 2024, the United Kingdom uses two different levels of ethanol within fuel, E5 and E10 to reduce the number of emissions from the transport sector. This report investigates the effect of power, torque fuel consumption, and Carbon Dioxide Emissions when ethanol content is increased within the fuel. This is to determine what the ideal amount of ethanol mixed within fuel is when comparing these 4 parameters. Using Realis WAVE 2023.1 fluid dynamic simulation software, ethanol was mixed with gasoline and then indolene in 5% increments from E5 up to E100. These fuels were then simulated, changing the AFR of each fuel to ensure complete combustion. Results were then analysed, comparing each fuel against an ideal value to create a total score. When considering fuel consumption for both Indolene-ethanol blends and gasoline-ethanol blends standard gasoline and standard ethanol produced the best performance compared to the ethanol blends. However, when not considering fuel consumption E100 provided better performance than any ethanol-Indolene blend as well as E95, E90, E85, E80, and E5 performing better than base Indolene. E100 was found to create the highest amount of power and torque in all cases while E5 would have the least amount of fuel consumption when mixed with gasoline. E65 gasoline-ethanol and E70 indolene-ethanol produced the least amount of carbon dioxide. Without changing other parameters within an engine including compression ratio and burn temperature, the extra power and torque that ethanol would provide an engine cannot be correctly utilised when mixed with other fuels. This results in the higher fuel consumption offsetting any positive effect ethanol would have on overall performance.

**Acknowledgement**

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# List of Abbreviations

AFR- Air to Fuel Ratio

CH4 - Methane

CO2- Carbon Dioxide

E5- 5% Ethanol-Gasoline Blend

E10- 10% Ethanol-Gasoline Blend

g- Grams

GHG- Greenhouse Gas

HR- Hour

kg- Kilograms

kW- Kilowatts

Mg/s- Milograms per second

MJ- Megajoules

N – Nitrogen

Nm- Newton Meters

N20 – Nitrous Oxide

RON – Research Octane Number

RPM- Revolutions per minute

TWh- Terawatt Hour

UK- United Kingdom

USA- United States of America

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# Introduction

Biofuels have emerged over the past few years as the most likely replacement for petroleum-based fuels (Kalgahati, 2018) to achieve the emission goals, set by or considered by around 140 countries across the globe (Climate Action Tracker, 2022). Biofuels used for transport include biodiesel, biomethanol, bioethanol, biobutanol, bio propanol, bio-oil, and jet fuels (Kallon, 2021). Of these, the most notable is ethanol fuels due to their production of renewable bio-resources that possess a green combustible nature (Azhaganathan, 2022). Ethanol's renewability is greatly increased because of large-scale production from sugar-containing raw materials and starch crops which are undesirable food sources and often by-products of already-established production chains (Borsa, 2017).

The countries leading the efforts for net zero emissions are Suriname and Bhutan having already achieved net zero emissions, followed by Sweden with a legally binding agreement to be net zero by 2045 as well as the United Kingdom, France, Denmark, New Zealand, and Hungary all having a legally binding agreement with the target date at 2050 (Fominova, 2022). However, due to Covid and other reasons such as financing, these targets that have been set look unlikely, and many countries are not on track to reach net zero by 2050 (United Nations, 2022)

One of the countries that are struggling to reach their set targets is the United Kingdom with the prime minister, Rishi Sunak, stating that the UK is easing the transition to electric vehicles (The Guardian, 2023) setting back the initial plan of discontinuing the sales of new petrol and diesel vehicles from 2030 to 2035, as well as the transitions from boilers for heat pumps having the same setback. With the average age of scrap vehicles being 14 years (SMMT, 2023), single-fueled vehicles will likely be the primary type of vehicle on roads up to 2045 and perhaps beyond. As a result, the number of single-fueled vehicles is likely to continue to rise, increasing the already 20.7% of global Carbon Dioxide (CO2) emissions that are a result of transportation (See Figure 1) (Tiseo, 2023).

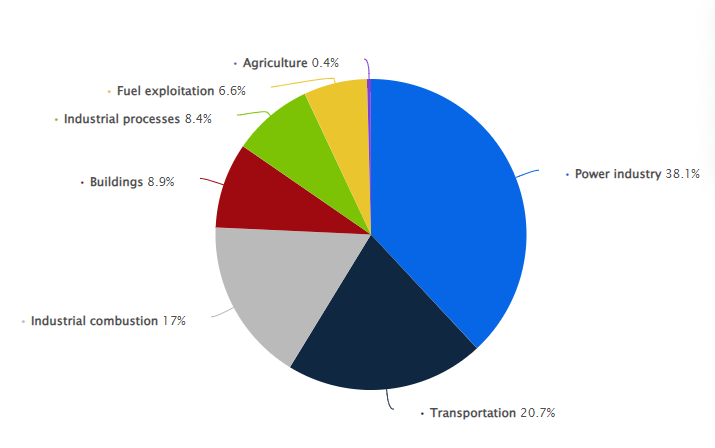


Figure 1- Distribution of carbon dioxide emissions worldwide in 2022, by sector (Tiseo, 2023)

Given the above, vehicles that run on traditional fossil fuels such as petrol and diesel must continue to adapt in a way that reduces emissions until they are no longer the majority form of vehicle on the road. In 2021, E10 was introduced to UK fuel pumps alongside the existing E5 (GOV.UK, 2022). The “E Rating” of these fuels refers to the amount of ethanol within the fuel as a percentage. The introduction of E5 and E10 fuel resulted in a total reduction of emissions by 2%. However, there were concerns that up to 800,000 older vehicles would be unable to use the E10 fuel variant (Griffiths, 2019). Given this information and the use of E85 fuel within motorsport applications, further research should be undertaken to determine the ideal ratio of ethanol and gasoline to maximize engine power and torque while minimizing fuel consumption and emissions. Though this research will apply to different uses of combustion engines, due to the transportation industry holding a vast majority of CO2 emissions, the research will be conducted with vehicle internal combustion engines in mind.

This report will contain a literature review, covering historical and modern information on biofuels as well as the current applications and production of ethanol, and its effect on fuel as well as an engine. Following that will be a segment of fuel creation within the chosen software and set up of an engine to simulate the fuels. Continuing from that will be the outcome of the simulation, an analysis of the results, a conclusion of the findings, and further recommendations of potential areas of research that would add to or complement the findings of the paper.

# Aims And Objectives

## Aim

Considering that the UK government has set back the transition to electric-propelled vehicles by five years to 2035, it is more important now to research alternate uses of petroleum-based fuels that produce fewer emissions as these vehicles will be around for longer. Research has proven that higher ethanol content within fuel leads to less CO2 emissions. This project aims to test different ethanol contents within fuels using simulation programs to determine which provides the best performance based on Power, Torque, Fuel consumption, and CO2 emissions.

## Objectives

* Identify the importance of biofuels.
* Review of different biofuels during the first stages of research.
* Research what fuel is, and what fuel is used within vehicles.
* Identify the origins of ethanol within fuels and how it is created.
* Investigate current production of ethanol including the impact that production has.
* Research the general effects that ethanol has on Power, Torque, fuel consumption, and emissions when included in fuel and the reasons why.
* Highlight current developments and research that relate to the project.
* Determine what different amounts of ethanol will be ideal to obtain a fair experiment.
* Research how to create fuels in Realis Wave 2023.1.
* Determine the best engine to run simulations on for a fair experiment.
* Determine what parameters must stay the same and what must change for a fair experiment.
* Create a clear definition as to what performance relates to within this experiment.
* Obtain results through Realis Wave 2023.1 and compare the performance of each fuel blend.
* Conclude as to what content level of ethanol provides the best performance.

# Literature Review

## Greenhouse Gas

Greenhouse gases consist of carbon dioxide, methane, ozone, nitrous oxide, chlorofluorocarbons, and water vapours, which all contribute to the greenhouse effect (NASA, 2023). The greenhouse effect refers to how heat is trapped in the Earth's atmosphere (NASA, 2023). Primarily, human activities contribute to the carbon dioxide levels in the atmosphere and account for 79% of all US greenhouse gas emissions (PEA, 2023). As a result, the reduction of carbon dioxide emissions is the primary focus to reduce the effects of global warming.

Human CO2 Emissions are a result of burning fuels such as fossil fuels and biofuels. Biofuels refer to plant biomass that has been refined into a form that is combustible to create energy in the form of either heat or light (Guo et al., 2015). Items such as wood and charcoal are forms of biofuels meaning that biofuels have been being used by humans since before pre-recorded history. Up until the 19th century, the world’s energy came primarily from traditional biomass including wood, crop waste, and charcoal. However, today fossil fuels including coal, oil, and natural gas supply 80% of the world’s energy (EESI, 2021). Of the remaining 20% of global energy, biofuels make up only 6.8%, split between traditional biomass (6.2%) and modern biofuels (0.4%) as shown in Figure 2 (Ritchie & Rosado, 2020). The first conceptualization of liquid biofuels occurred in 1826 when Samuel Morey described using a mixture of ethanol and turpentine as an engine fuel. However, this mixture was instead used as a replacement for whale oil in oil lamps, rather than a fuel in engines as fossil fuels were cheaper after a tax on industrial ethanol in 1862 caused a collapse in the market (LEC, 2020). However, since then the availability of fossil fuels has decreased and extra factors other than financial aspects have been introduced to the fuel market potentially highlighting fossil fuels as not the best option.

Figure 2- Global Primary Energy Consumption By Source (Ritchie & Rosado, 2020)

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## Importance of Biofuels

Fossil fuels are formed from carbon-based organisms such as animals and plant life that died millions of years ago and have been buried and compressed over that time. This process creates carbon-rich deposits that can be burned for energy and currently provide 80% of the world’s energy. However, due to this long process of creation, they are un-renewable (ClientEarth, 2022). It is expected that fossil fuels will run out as early as 2060 if not earlier with the current increase in global energy consumption (Burek, 2010). As a result, other methods of creating energy must be explored.

As well as this the CO2 emission of fossil fuels is increasing. Since 1958 NOAA has measured the levels of CO2 in the atmosphere at the Mauna Loa Observatory in Hawaii. The data collected shows that over the past 65 years, the CO2 level in the atmosphere has risen by approximately 100 parts per million as shown in Figure 3 (NASA, 2023). As well as this, figure 4 shows that the CO2 levels are the highest they have been for the past 800,000 years (NASA, 2023). The addition of this much CO2 into the atmosphere is causing global temperatures to rise (Lindsey, 2023). This increase in temperature has resulted in glacier ice melting and sea levels rising, animal habitats shifting, and seasons changing within locations of the world (NASA, 2023). This has resulted in an upset balance to the world’s ecosystems, making it harder for animals to live naturally and increasing the number of natural disasters such as storms and wildfires.

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Figure 3- CO2 levels in the air since 1958 (NASA,2023)

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Figure 4- CO2 levels in the air for the last 800,000 years (NASA, 2023)

Considering that the spike in CO2 emissions occurred during the beginning of the Industrial Revolution, it’s clear that the burning of fossil fuels is contributing heavily to the increase in atmospheric CO2. Many studies have shown that biofuels are an appropriate replacement to currently used fossil fuels such as crude oil which is a depleting and non-renewable resource. They can expand the green landscape, create new economic opportunities for developing countries, and are sustainable and environmentally friendly producing less CO2 than standard fossil fuels (Qubeissi, 2018). If all fossil fuels were to be replaced with biofuels, then it would be expected that CO2 emissions would decrease by 48% (Mellor, 2020). However, it must be noted that some biofuels such as biodiesel can release a total average of 1.8 times more CO2 than fossil fuels due to the process of making the fuels also releasing CO2(Mellor, 2020).

## Types of Biofuels

Biofuels are split into 3 different types based on their forms, solid, liquids, and gas. The solid forms of biofuels are generally natural materials that humans have used for thousands of years while liquid and gaseous biofuels are more modern developed forms of biofuels.

## Solid Biofuels

Solid biofuels are primarily organic substances from flammable materials such as firewood, wood chips, and wood pellets. However, heating these flammable wooden substances in an area void of renewable air at excess of 400 °C yields charcoal (Guo, 2015). Under ideal conditions, 34% of wood mass can be turned into charcoal resulting in energy values of 28-33 MJ/kg (Antal & Gronli, 2003) making it more energy dense than coal (Guo, 2015). However, to create charcoal energy is required to begin with, making its overall energy yield less than that of coal, resulting in it being used less often.

## Liquid Biofuels

Liquid biofuels include the likes of bioethanol, biodiesel, pyrolysis bio-oil, and drop-in biofuels. These are all liquid fuels that are of natural origin and produced from biomass or biodegradable waste.

### Ethanol

The production of ethanol (alcohol) comes from fermenting plant biomass containing simple sugars including glucose and fructose (Guo, 2015). This includes corn stalks, sugar cane, and almost all vegetable matter that is capable of fermentation including weeds and daily waste food (Songstad et al., 2009). Since alcohol has been made for upwards of 9000 years, the process is very refined with little waste (Phillips, 2014).

### Biodiesel

Biodiesel is a yellowish liquid that is obtained from the fat and oils from the likes of most vegetable oils including soybeans, peanuts, rapeseed, and the fats of animals (Knothe et al., 2015). This means that biodiesel can be made from already used oils such as cooking oils. Biodiesels are miscible in all ratios with standard petrodiesel creating a mix of both Petro diesel and biodiesel, denoted using B20 to indicate that the mixture contains 20% biodiesel (Knothe et al., 2015). Pump fuels within the United Kingdom for diesel are labelled as B7 as the fuel contains 7% biodiesel to reduce CO2 emissions (Griffiths, 2019).

### Pyrolysis

Pyrolysis consists of slow irreversible decomposition of organic biomass through the medium of heat. This is done with a lack of oxygen creating an array of biproducts including charcoal, bio-oil, and gas products (Vamvuka, 2010). Since this oil is a biproduct of the creation of charcoal, it provides extra energy output with little energy cost as a result. There is the possibility that this type of biofuel could be used for boilers, diesel engines, or turbines (Vamvuka, 2010).

### Drop-in Biofuels

Drop-in Biofuels or drop-in gasoline refers to fuel produced from biomass through different thermal and chemical processes. Unlike other biofuels such as bioethanol and biodiesel, drop-in gasoline has no adverse effects on an engine as it is chemically identical to gasoline (AFDC, 2012). However, these drop-in biofuels face major production challenges as they require zero oxygen or sulphur content, which are difficult chemicals to extract from biomass while maintaining fuel-like characteristics (Nazimudheen, 2023).

## Gaseous Biofuels

Gaseous biofuels are potential replacements for currently used natural gas but are produced as either a byproduct of already established productions or through organic means.

### Biogas

Biogas is a renewable gaseous fuel that is an alternate fuel to natural gas. It is created through anaerobic (with oxygen) digestion of organic waste, energy crops, or residues (Singh, 2017). Biogas provides a versatile carrier of renewable energy as the likes of methane can be used as a replacement to fossil fuels in both power generation through heat, as well as a vehicle fuel (Weiland, 2010).

### Syngas

Syngas is another renewable gaseous biofuel that is a byproduct of the creation of charcoal and pyrolysis (Guo et al., 2015). Gasification is a common practice to produce Syngas. Carbon-rich material is rapidly heated above 700 °C within a combustion chamber with a controlled airflow resulting in charcoal produce also producing syngas which is then captured. (Guo et al., 2015).

## What Is Fuel

The dictionary defines fuel as a material that can be burned to produce heat or power. These include materials such as coal, gas oil, and biomaterials. Every fuel chemically consists of an arrangement of carbon and hydrogen atoms, which can combust under certain heat and pressure when oxygen is present.

Within a vehicle the most common fuel is petrol. Though petrol is commonly assumed to be gasoline, gasoline refers to a pure blend of fossil fuel after being refined. However, pure gasoline is not ideal for use in an engine due to its low octane number. The octane number refers to the ability of a fuel to withstand pressure and heat before combustion, often referred to or measured through a research octane number (RON) (Luecke, 2021). Without a high-octane rating, fuel will begin to self-combust under specific conditions causing a phenomenon called “knocking” in which a fuel combusts before ignition, resulting in two separate combustions occurring in a cylinder at once, causing damage to the engine.

To increase gasoline's octane rating as well as reduce gasoline's volatile nature, chemicals are included in gasoline before being put into engines. In the case of BP Ultimate 98, these chemicals include Toluene, n-hexane, benzene, methylpropane, and more (BP, 2021). As a result of these added components, the chemical makeup of unleaded petrol is not that of Gasolines C8 H18 (8 parts carbon and 18 parts hydrogen). As confirmed by Realis Wave, Indolene is closer to the chemical makeup of unleaded pump fuel with a chemical formula of C7.3 H13.9.

To obtain accurate results from the simulation that mimic what may be found in real-world applications, the simulation will be run using both Indolene and Gasoline. The results from Indolene will provide more accurate results to real-world applications however, simulating both will help determine how these extra chemicals change the effect of ethanol inclusion within the fuel blends.

## History of Ethanol

In 1826, ethanol was first used in an internal combustion engine, however, due to heavy taxing of ethanol to fund the civil war, oil and petrol became the standard fuel within motor vehicles due to it overall being cheaper (Keeney, 2011). In 1975 the United States (US) recognized the negative effects of lead in fuel as an octane enhancer and instead began using ethanol as a subsidiary (Kenny, 2021). Lead was originally included within fuel to increase the octane rating of the fuel and reduce the “knock” however, it was found that ethanol provided the same properties. Though ethanol has been included in fuel it has rarely been considered as a complete replacement for gasoline due to ethical issues with its production. Since a high percentage of ethanol production comes from plants that are required for other applications, a permanent place for ethanol within fuel wasn’t considered until the early 2000’s(Keeney, 2011).

In 2021 E10 fuel was introduced into pumps within Great Britain replacing the previously used E5 fuel (GOV.UK, 2021). Though ethanol increases the octane rating of fuel its inclusion within pump fuel was to overall reduce CO2 emissions and ended up resulting in a reduction in CO2 emissions by 750,000 tons a year (GOV.UK, 2021). This value of E10 or 10% ethanol within gasoline is a common ratio currently used around the world however, different locations do use higher or lower levels of ethanol.

For example, in 2007 legislation was passed within Brazil that required newly sold vehicles and newly manufactured vehicles to be able to run using E20 as well as possess the ability to use flex-fuels (Rico, 2007). Within the US 98% of gasoline possesses ethanol, typically E10. However, in some cases, E85 or Flex Fuel is available for use in specifically designed vehicles capable of operating on any ethanol gasoline blend up to 83%. Some states commercially sell E15 which is only approved for use in vehicles produced after 2001. (AFDC, 2024)

## Process of Ethanol Creation

Ethanol is created through the fermentation and distillation of natural matter (AFDC, 2023). Fermentation is the process of sugars being broken down by enzymes when oxygen is not present (Tay, 2019). When natural produce such as corn, wheat, grapes, and other sugar-based plant matter is placed in an environment without oxygen and with yeast present, ethanol and carbon dioxide are produced (Tay, 2019). Distillation then occurs to separate the ethanol from the waste plant produce, using either heat or a chemical reaction (Clifton, 2021).

## Benefits Of Ethanol

Since combustion engines use liquid-based fuels, the likes of Drop-in biofuels, Pyrolysis, Biodiesel and Ethanol are the potential types of biofuels that can replace the current standard used fossil fuels. However, as mentioned above the likes of Pyrolysis and Drop-in biofuels are difficult to obtain and provide even further problems when trying to be obtained in large quantities, the likes of which are required for consistent running of an internal combustion engine.

Ethanol is an attractive alternative fuel to standard fossil fuels due to it being a renewable bio-based resource that is oxygenated, allowing for a reduction in emissions when present in a compression engine (Agarwal, 2007). It has been found that ethanol produced using US corn results in between 44%-52% lower combustion emissions than gasoline (Sarisky-Reed, 2022). Though this is lower than the life-cycle greenhouse gas emissions reduction from the use of biodiesel rather than petroleum diesel at 40%-86%(Hui Xu, 2022), gasoline vehicles make up 35.8% of new European Union (EU) sales compared to diesels at 14.1% (see Figure 5(ACEA, 2023) resulting in a greater total reduction from the use of ethanol within petrol vehicles than biodiesel within diesel vehicles.

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Figure 5- New passenger cars by fuel type in the EU 2022 (ACEA,2023)

As well as this, petroleum-fuelled vehicles have been the dominant vehicle sold new in the market since 2017 (see Figures 6-10).

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Figure 6- New passenger cars by fuel type in the EU 2021(ACEA, 2022)

A graph of fuel prices

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Figure 7- New passenger cars by fuel type in the EU 2020 (ACEA, 2021)

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Figure 8- New passenger cars by fuel type in the EU 2018 (ACEA,2019).

A graph of fuel prices

Description automatically generated

Figure 9- New passenger cars by fuel type in the EU 2017 (ACEA,2018)

A diagram of a number of electric vehicles

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Figure 10- New passenger cars by fuel type in the EU 2019 (ACEA, 2020).

## Current Production of Ethanol

As of 2021, the global production of ethanol was at 27.27 billion gallons. Primarily the production of ethanol occurs within America and Brazil, producing 82% of global production through Corn and Sugar Cane respectively (Renewable Fuels Association, 2022). The global production of ethanol decreased during Covid 19 and has since not returned to the larger total production that occurred in 2019 at 29.33 billion gallons (See Figure 11).

A graph of different colored bars

Description automatically generated

Figure 11- Graph showing Global Production of Ethanol by Country (Renewable Fuels Association, 2022)

In 2014 (when production of ethanol within the US was at 14.31 billion gallons (Renewable Fuels Association, 2022)) the total area of land used to produce ethanol was 21.5 million acres and used up 26% of the total US corn production (Mumm, 2014). It can then be assumed that as of 2021 the corn used by the US to produce its 15.04 billion gallons of ethanol (Renewable Fuels Association, 2022) is grown using between 22 and 23 million acres of land. The production of ethanol within the US is split between multiple organizations with Poet Biorefining in South Dakota producing the most at 2,692 million gallons of ethanol per year (Statista, 2023). The amount of land required for ethanol production within the US is another factor currently impacting ethanol use within fuels.

### Why is ethanol produced in these locations?

Ethanol is produced primarily within the United States and Brazil because of planted area, yield, and harvest conditions (IEA, 2019). These factors are directly related to the climate of the area. For example, the area of growth within the US for corn, known as the corn belt, is one of the most fertile regions on earth because of the consistent temperatures and steady rainfall, with the corn itself affecting the climate around the corn belt to have decreased temperatures and increased rainfall by 35% compared to surrounding regions. This is because of the corn plants themselves increase the amount of atmospheric water vapour (Hickok, 2018). In the case of Brazil, the Amazon rainforest provides plentiful nutrients and an ideal climate to produce sugar cane, however, this comes at the cost of deforestation to create the area required for the plantations that produce the sugar cane (Rodrguez, 2021). Producing outside these ideal locations may lead to increased lifecycle emissions, reducing the positive effect of including ethanol within fuel.

### Production of Ethanol within the UK

Since the UK has limited land area for crop growth for use in the creation of ethanol, ethanol production within the UK in 2020 was 565 million litres (Epure, 2020). This is compared to the 9,992 million litres produced across Europe during this year. These figures are likely to be lower than current-day production due to COVID-19 reducing the global production of ethanol. This means that the UK rely on external import of ethanol which increases the life cycle emissions of ethanol production due to increased CO2 emissions through transport.

## Impact of current production

### Water Waste

The production of ethanol in such large quantities results in other environmental factors that need to be considered, including the CO2 produced during the ethanol combustion. One of the requirements of ethanol production is a sizeable amount of water to ensure the fermentation temperatures stay at a specific level through evaporative cooling (Sippy et al., 2011). Some of these cooling systems are more intense than others. In Brazil, sugar cane fermentation requires as much as 3900 circulating litres to keep temperatures ideal (Sippy et al., 2011). The larger scale factories then require centrifugal technology to treat the wastewater for it to be safe for other uses (Lixin et al., 2006). All of this results in further energy loss due to the energy required for the water treatment after use.

### Transportation

Another potential source of ethanol production causing environmental impact is the transportation of ethanol. Within countries that produce ethanol, most transportation is done via road through tankers. In some cases, namely Brazil, 10% of the transportation is done via pipelines or railroads (Braz, 2016). This means that an increase in the production of ethanol may result in an increase in emissions due to extra required transport. However, international transportation of ethanol is done via shipping (Sippy et al., 2011) which, while energy-efficient due to the volume that can be shipped simultaneously, contributes heavily to emissions due to a lack of regulations. Only recently, as of January 2024, has the EU’s trading emissions regulations extended to cover the emissions of all large ships entering EU ports. This legislation however only covers CO2 emissions, with regulations including methane (CH4) and nitrous oxide (N2O) set to be introduced by 2026. As well as this, to ensure a smooth transition to new regulations, companies are only required to contribute allowances for a portion of the previous year’s emissions starting at 40% for 2025 and increasing steadily to 100% by 2027 (European Union, 2021). This means that previously, before 2024 most maritime transportation wasn’t governed by emissions standards resulting in high levels of pollution.

Furthermore, maritime transportation also runs the risk of potential sea spillage of chemical substances that will damage the environment and harm sea life.

## Different products used for Ethanol.

Since ethanol is created using any sugar-based biomass, there are many different studies in different regions evaluating the Greenhouse Gas (GHG) emissions lifecycle of these different biomass. Comparisons have been made between 5 main models presented by BioGrace (Europe), GHGenius (Canada), GREET (USA), NEW EC (Europe), and VSB (Brazil) showing that the Canadian model and the Brazilian model are the most up-to-date with recent data (Bonomi.Et.Al, 2018). Considering that the Canadian model provides more data and is publicly available, it has been chosen as the most dependable for accurate lifecycle emission data during this study.

GHGenius breaks down the CO2 emissions for different forms of fuel from the use of land, extraction of the fuel, processing of the fuel, transportation, and combustion. Upon analysing the Total CO2 emissions for light-duty Internal Combustion Engine Vehicles (ICEVs) data shows that diesel and gasoline from all forms of feedstocks result in larger lifecycle CO2 emissions than all forms of ethanol created with biomass.

Of the various forms of feedstock used to create ethanol, peas result in the least amount of lifecycle CO2 emissions, producing 7.8% less emissions than Gasoline due to their elevated level of fuel co-products and land management reducing overall CO2 emissions (See Appendix A). However, through general production sugarcane produces the least amount of CO2, though over its life cycle generates more CO2 than Corn because of storage and recovery emissions (See Appendix B).

As well as this, peas produce the least amount of CO2/MJ when compared to the different forms of feedstock because of their co-products. As a result, of the different forms of feedstock that are currently used to create ethanol, peas are the most beneficial when trying to minimize CO2 emissions while obtaining the most amount of energy possible.

Though this is the case, the current produce of ethanol is commonly corn or sugar cane due to the environments they are grown in being more suitable allowing for greater production. This means that the current production of ethanol is not as efficient as it could be in terms of CO2 emissions.

## Ethical Issues of Ethanol

The requirement for biomass to possess sugar to create ethanol means in most cases the biomass that is used to create ethanol could be used for other purposes such as food. Corn, sugar cane and peas are all food crops. As a result, there are disputes that the increased land used for ethanol has increased food prices (Nuffield Bioethics, 2011). As well as this, deforestation is a major problem when creating an area for biomass production for ethanol. Though the cultivation of sugar cane within the Amazon rainforest in Brazil has been banned other woodland areas within Brazil are susceptible to deforestation to create land area for sugar cane cultivation (Bordonal, 2018). This has resulted in a large increase in corn-based ethanol by 800% in the past 5 years. However, corn-based ethanol shares the same land area as soybean production as an interim harvest resulting in alternate use for already occupied land rather than more area being taken up by corn grown for ethanol (Bispo, Trigo, 2023).

## Effects of ethanol on engine

### Effects on Combustion

Ethanol is comprised of Carbon, Hydrogen, and Oxygen with the Molecular formula of C2H60 (NIH,2004). Since this is different from that of Gasoline which has the molecular formula of C8H18 (NIH, 2004) the optimal air-to-fuel ratio for complete combustion will change depending on the amount of ethanol present in the fuel. As a result, vehicles that use ethanol-based fuels need to be able to measure the quantity of ethanol present within the provided fuel and change the amount of air provided for combustion accordingly.

### Effects on Fuel Consumption

Fuels with a lower energy density than others will require more fuel to create the same amount of power from the engine, which would result in a larger amount of fuel consumption for the same results. 98% Ethanol or Denatured ethanol contains 30% less energy than gasoline (AFDC, 2023). This means that it can be assumed that to create the same amount of power using 98% ethanol fuel, 30% more fuel would be consumed assuming perfect and complete combustion as well as 100% energy conversion efficiency.

### Effects on Engine Power

A fuel’s ability to withstand in-cylinder heat and pressure before igniting is defined by its octane and measured through a research octane number (RON) (Luecke, 2021). Ethanol is used in fuel to increase its octane number as ethanol has a higher octane rating than gasoline (AFDC, 2023). This means that ethanol can withstand higher levels of compression before self-ignition occurs (Gudmundsson, 2014). As a result of this increased resistance to pressure, ethanol can provide the engine with more power and greater performance under the correct conditions (AFDC, 2023). An increased RON number also prevents the occurrence of “knock”, a phenomenon that causes secondary, high-pressure shockwaves during the combustion process, causing damage to the engine. With a higher RON rating, an engine can run at higher compression ratios without the risk of “knock”, providing more engine power.

### Effects on Torque

Since ethanol increases the octane number of fuel mixtures, the effect is an increase in torque. Current research on a 150cc motorcycle engine results in a torque increase of 6.7-8.4% at 1000-2000rpm when comparing E0 to E10 (Adian et al, 2020). As a result, it is expected that as the ethanol content increases within the fuel blends, the torque will also increase.

### Effects on Sustainability

Though ethanol within fuel increases torque and provides an engine with greater power, it comes at a cost that ethanol can retain water content. This results in potential rust of components and the separation of the ethanol from the fuel making the fuel unusable (Threewit, 2013). As well as this, ethanol can cause considerable damage to older fuel system components due to its corrosive properties, which can lead to clogging through the fuel system (Threewit, 2013). Clogging can also occur due to the absorbed water separating the ethanol from the gasoline creating a corrosive sludge capable of clogging up the fuel filters, as well as eroding metal over time (BIOBOR, 2023). The chance of this occurring increases the longer fuel is stagnant without mixing or use. This is due to the ethanol having more time to absorb atmospheric moisture and separate from the gasoline. (BIOBOR, 2023)

As previously mentioned, ethanol is a more sustainable fuel option, being able to be made from fully natural products and therefore being renewable. The fact that ethanol is produced using crops means not only does the production of ethanol produce 40% less greenhouse gases throughout its lifecycle (US.gov, 2024) but these CO2 emissions are offset by the crop absorbing CO2 during growth (Cooper, 2022).

### Effects on Engine Components

Though most road-going vehicles are unable to use higher blends of ethanol such as E85, flex-fuel vehicles can run on both gasoline and high-level ethanol blends. This is because the vehicles have specifically designed parts which can withstand ethanol's corrosive properties. These include the fuel tank and in-tank components, as well as gaskets, seals, fuel lines and fuel injectors, all of which would become damaged by ethanol on a non-purpose-built vehicle (Chandler, 2008). However, these changes to an engine do not affect the cost of the vehicle to produce and neither do they affect the retail price (Chandler, 2008).

Of the 282 million vehicles registered in the US in 2021 (Statista, 2024) just over 27 million of them were flex fuel vehicles (AFDC, 2024). Considering that flex-fuel vehicles make up only 9% of total vehicles in the US, high ethanol blend fuel is not commercially available as it is not profitable for companies to stock the fuel due to the low number of flex-fuel vehicles on the road. Current road vehicles can be modified to become flex-fuel vehicles. However, this would cost the owner of the vehicle money, which in some cases may cost more than the vehicle's worth.

Since higher levels of ethanol lead to a more corrosive fuel, different components of a vehicle need replacing depending on what level of ethanol content a fuel contains (Azhaganathan, 2022). Figure 12 shows that vehicles only require a replacement carburettor to safely operate using any ethanol level between E5 and E10. The number of replacements required for ethanol levels between E10 and E25 increases from 1 component to 8. As a result, most countries only commercially sell E5 and E10 fuel since all road vehicles are capable of using these fuels with minimal manufacturing changes required.

Figure 12- Requirement of engine components modification in SI engine for different ranges of ethanol blends (Azhaganathan, 2022)

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### Additional Components and Features

Not only does the use of ethanol in a vehicle require existing parts to be replaced with ones that can withstand the corrosive effects of ethanol, but different sensors are also required. For example, flex-fuel vehicles need to be able to recognize the ethanol content within the fuel to adjust the vehicle operating AFR to achieve ideal combustion of the fuel (Azhaganathan, 2022). As a result, these vehicles are installed with specialized ethanol sensors, which then relay information to the Electrical control unit (ECU) so the vehicle can adjust the amount of air being supplied to the engine.

Recognizing the type of fuel within the vehicle also provides information for ignition timing, cylinder pressure, and fuel temperature as all the ideal values for these parameters change as more ethanol is introduced to fuel (Azhaganathan, 2022).

As well as this, as seen in Figure 12, adjustments to the Cold start systems are required for a vehicle to operate effectively while using fuel with elevated levels of ethanol. A fuel heating unit is used to allow ethanol to combust during a cold start. This is required as ethanol has a higher burn temperature and pressure than ethanol, making cold starts more difficult as the ethanol content within the engine increases resulting in the fuel failing to combust as ignition temperatures are not met.

A common use of ethanol within fuel currently is to increase the Research Octane Number (RON) of the fuel and reduce knock (Schmitt, 2022). Knock refers to the premature combustion of fuel within an engine before the ignition has fired (Britannica, 2015). Conventionally, the ignition should fire igniting the fuel directly next to it, with the flame front continuing through the fuel smoothly until all fuel is burned. Since ethanol has a higher octane rating than gasoline, including ethanol within the fuel will increase the octane rating, combustibility, and RON number of the fuel reducing the likelihood of knock occurring. This means that including ethanol within fuel allows the engine to operate at higher levels of internal pressure without the risk of knock occurring.

## Summary of restricting factors

Overall, Ethanol production and consumption produce fewer total emissions when compared to fossil fuel alternatives. However, to grow bioproducts to create ethanol in the most efficient way possible, large amounts of fertile land is required with the cleanest bioproduct for ethanol creation (peas) requiring far greater land area than more commonly grown crops such as sugar cane and corn.

As discussed, large-scale production can also lead to food shortages resulting in increased prices of common crops. Large-scale production may also in the short-term lead to a sudden increase in emissions due to the current lack of maritime CO2 legislation.

Though Ethanol, under the correct conditions, can provide an engine with more power, torque and decreased emissions, the required components that would need to be replaced on current road-going vehicles to safely operate on high ethanol content fuels make large-scale adoption of the fuels for commercial use difficult to achieve.

## Current/On-going developments

### Chinese Coal-To-ethanol Production Plant

Last year, the annual demand for ethanol within China was 10 million tons compared to the produced 2.7 million tons. This led to the country importing the remaining ethanol to keep up with demand. To reduce the amount of import required, China has begun setting up Coal-to-Ethanol production plants which use methanol from coke oven gas to generate ethanol (Paleja, 2024). This oven gas is a by-product of coke production which is made from coal to create steel (Safarian 2023). Though the increase in coal burning results in a large amount of CO2 emissions, the creation of ethanol comes from a byproduct of an already established production, resulting in extra fuel for little extra production. The most recent of the plants includes a 600,000-ton facility in Hauinei Anhui which began tests on January 1st, 2024 (Paleja 2024). The use of already-established production byproducts to create ethanol will reduce the current reliance on grain which has led to rising prices (Paleja, 2024).

### Optimal Ethanol-Gasoline Blends for Turbocharged Engines

A previous study following similar parameters has been conducted, studying volume percentage between E0 and E40, tested on a Turbocharged engine measuring CO2 emissions and the octane ratings of the fuel. The study found that E32 was the lowest emitting blend with a reduction of 7.1% and that the advantage of adding ethanol to fuel was most impactful at the lower concentrations of ethanol. (Zhang, Sarathy, 2016) As a result, the study will take note of the effects of ethanol over the E40 band and around the E30 to E50 range to see if the same effects occur for a non-turbocharged example.

# Ethical Considerations

The project has a few ethical considerations. This is because of research not involving animal or human participants, directly or indirectly. The project also does not present potential social or environmental implications or collect personal information that may be deemed sensitive or enable the identification of individuals. The project will focus heavily on theoretical environmental implications but will not have any direct environmental effects.

The project will follow the code of conduct rule set out by the IMECHE, as this governing body relates closely to both the research conducted as well as the results produced. As well as, this the code of conduct focuses heavily on promoting sustainability, which is a focal point behind the reasons for this report. Within the IMECHE is also a specific section dedicated to automotive engineers, particularly the effects of fuel, making it the most appropriate governing body for this given project.

It is not expected within the project that other intellectual property will be encroached upon or that the project will be required to apply for intellectual property upon conclusion. However, the process to do so has been reviewed. As well as this it has been noted that the model in Wave is provided by Realis on installation of the software, making it freely available for use without copyright infringements. Since this project will also have no profits, a commercial license of the software is not required.

# Pre-Processing

## Software

The software used throughout this experiment is Realis WAVE. WAVE is a 1D gas dynamic simulation tool that enables performance analysis on any configuration of intake, combustion, and exhaust configuration (Realis, 2024). It is a tool that is used worldwide in industries such as ground transportation, rail, motorsport, marine, and power applications, to perform performance and acoustic analysis. It performs Navier-Strokes equations to govern and simulate the transfer of mass, momentum, and energy for different forms of compressible gas flow including combustion and emission.

For this investigation, the pre-built Realis WAVE 2.0L inline, 4-cylinder engine will be used to simulate the different fuels. This engine has been selected as 2.0L engines are very common in mid-range performance/economy vehicles and can be found in a range of different vehicle types from hot hatchbacks to luxury sedans, SUVs, and family sedans (Oldham, 2018) making them ideal for this experiment to ensure that the data acquired is highly applicable to many road going engines.

It is also important to note that some estimations made by the simulation software may result in slight variations in results when compared to real-world test cases. An example of an estimation made by Realis WAVE is the assumption that each cycle of the engine is identical with perfect burn between all cylinders. However, this is not the case and in a real-world example, the temperature across the engine can vary between cylinders over time, making each combustion slightly different from the last. Other variables that are set in WAVE that would change in a real-world application include fuel pressure, quality, air temperature, oxygen levels, and fuel amounts. Though the amount these would vary in real-world applications is minor, they are worth considering when comparing the simulation data to real-world Emissions tests and dynamometer tests.

Though this is the case, the focal point of the simulation is to compare the data acquired from simulating different amounts of ethanol in fuel under the same conditions, as well as with varied AFRs. As a result, WAVE simulating within ideal scenarios is a must for fair comparisons.

## Simulation Set-up

The simulation set-up began by saving the pre-built 2.0L engine that WAVE provides into personal files for editing. To increase the level of accuracy of the results, extra data points were added at every increment of 250 RPM, whereas the original model used increments of 500 RPM. Notes were taken of any values that changed based on RPM in the variables table and added to the newly included RPM values. An average of the values on either side of the new point was taken and used for that variable in the new point. These variables included the burn duration (BDUR) and the piston position of 50% burn duration (TBH50) (See Figure 13-14).

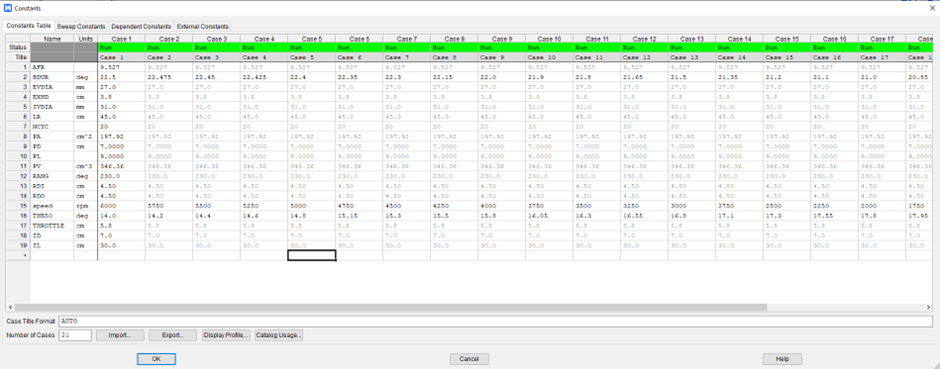


Figure 13- Figure showing Simulation Cases and parameters (Author, 2024)

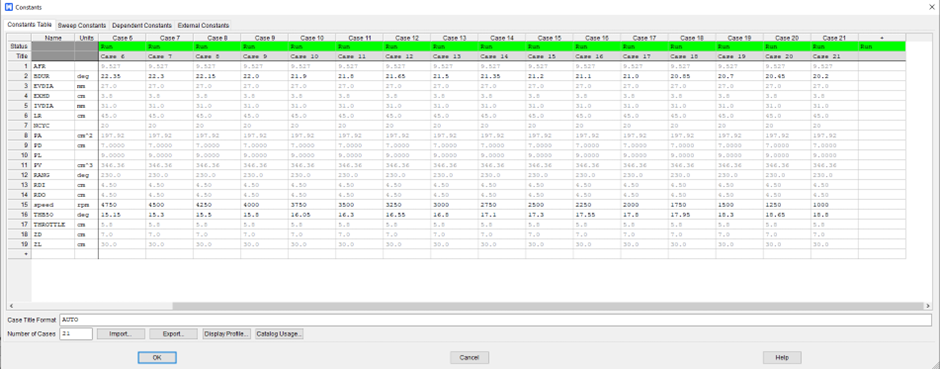


Figure 14- Figure showing Simulation Cases and parameters 2 (Author, 2024)

It was considered that the fuel injectors could be moved. Currently, the injectors are positioned in the intake manifold, with each cylinder having an individual injector. Direct injection, where the injector is positioned within the cylinder, is known to provide an engine with more power due to a better spread of fuel around the cylinder, increasing the area in which combustion can occur. However, getting direct injectors to operate ideally requires tuning. To ensure the fairest simulation possible for each fuel, the number of variables within the simulation has been kept at a minimum as each fuel may have different optimal conditions. As a result, for this simulation, the injectors have been kept with the intake manifold.

Realis WAVE can output the power, torque, and fuel consumption of an engine without any extra setup using 2D sweep plots. However, to obtain the carbon dioxide emission of each fuel an extra sensor needed to be installed in the engine. This sensor is placed within the exhaust segment of the engine to ensure that the emissions of all cylinders have combined and are measured (See Figure 16). CO2 emissions are measured in terms of mass flow and will be measured in mg/s as this provides the easiest results to both compare and understand. Mass flow is also the most common unit of measurement found in literature when referencing emission amount, commonly using g/km See Figure 15.

A screenshot of a computer

Description automatically generated

Finally, while looking at the simulation, it can be noted that the throttle is not a butterfly valve. When viewing the variables table, the size of the throttle is measured in cm as seen in Figure 14. This means that the simulation will always run at a wide-open throttle (WOT), meaning the engine is being provided with as much fuel as possible at any given time. For the full simulation model see Figure 16.

A diagram of a traffic light

Description automatically generated

Figure 15- Image showing engine model in WAVE and added CO2 Sensor (Author, 2024)

Figure 16- Screenshot Of Sensor Control Panel and Units applied (Author, 2024)

## Simulation Verification

To ensure the integrity and accuracy of simulation results, a verification study was conducted using the engine results for standard gasoline fuel, comparing them to pre-existing results found within literature. Ideally, this would have been done using data from a real-world simulation of an identical engine. However, since the simulation has been run on a pre-existing example engine provided by the software, real-world example data does not currently exist. Though this is the case, the power curve and fuel consumption curve follow the same trajectory no matter the fuel used. Using this, the data from the simulation can be verified by comparing the shape of the simulation's power and fuel consumption graph to the ones found in the literature.

As seen in Figure 17, results from literature tests mirror the shape seen in the simulation data in Figures 18 and 19, even though the values are slightly different. This is likely a result of different engine tuning or a variance in engine component size.

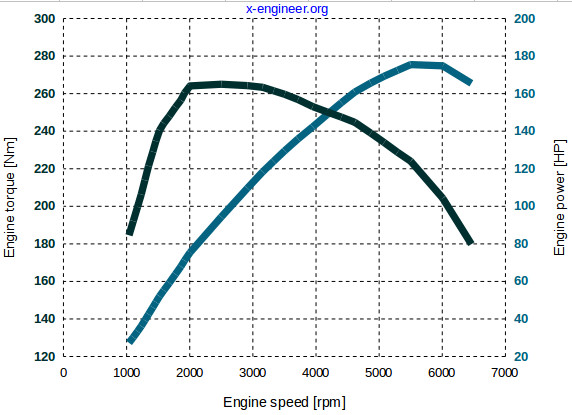


Figure 17- Graph Showing Power and Torque Curve compared to RPM for Saab 2.0T Engine (x-engineer, 2024)

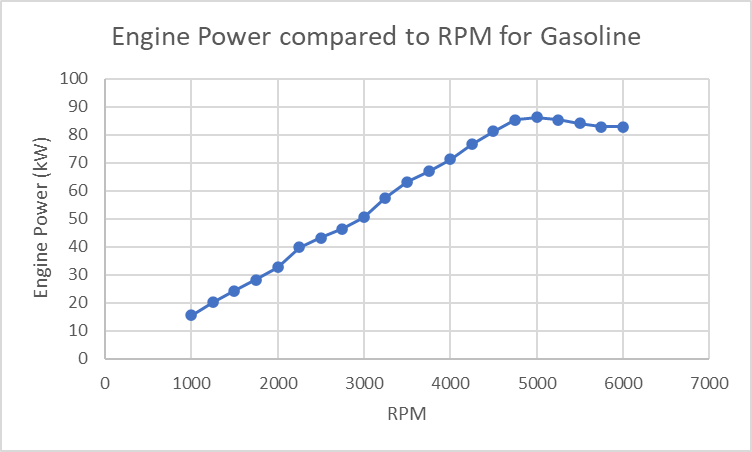


Figure 18- Graph Showing power compared to RPM for Simulated 2L engine using gasoline (Author, 2024)

Figure 19- Graph Showing Torque compared to RPM for Simulated 2L engine using gasoline (Author, 2024)

## Fuel Blend Creations

Since WAVE does not have all the different required ethanol fuel blends, they need to be made using a combination of the pre-existing indolene, gasoline and ethanol fuels that WAVE does have. This is done through the command prompt, using a built-in operation called “buildfuel” which is built into Realis WAVE (See Figure 21). Using this command fuel blends have been made every 5% increment of ethanol from 0% to 100% (See Figure 20). This should provide a range of different ethanol levels, as well as be precise enough to identify details on how the ethanol impacts the fuel consumption and the performance of the engine, while not being overly time-consuming to simulate, as increments of 1% would be.

A screenshot of a computer

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Figure 20- Screenshot of Fuel files (Author, 2024)

A computer screen shot of a black screen

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Figure 21- Screenshot showing command prompt usage for creation of fuel blends (Author, 2024)

## Air-to-Fuel Ratio Calculations

Since Ethanol is Chemically different from gasoline the optimal air-to-fuel ratio for each blend of fuel will change depending on the level of ethanol. Using the Molecular formula of each fuel (C2H60 for Ethanol and C8H18 for Gasoline) and knowing that the by-products of ideal combustion are Carbon Dioxide (CO2) and Water (H2O), carbon balancing can be done to find out how much air is required for ideal combustion of the different blends of fuel. Using this information, the chemical mass of the required air can be compared to the mass of the combined fuel types to get the air-to-fuel ratio. For this formula, the mass of air has been assumed to be 3.76 parts Nitrogen (N2) to every 1 part Oxygen (O2) due to nitrogen making up 78% of air compared to oxygens 21% (NASA, 2016).

Using the atomic mass calculated for both the input and output of combustion, calculations can be verified, ensuring that no mass is lost during combustion. (See Appendix C for Example)

Results show that as the content of the ethanol within the fuel increases the amount of air required to achieve complete combustion decreases, resulting in a decreased air-to-fuel ratio. This is expected as ethanol has less chemical mass than ethanol (See Figure 22). The rate at which the amount of oxygen required decreases is represented by a curved line in Figure 23. This shows that the amount of oxygen required changes at a non-linear rate between each fuel blend, with the rate of change decreasing as the ethanol content increases within the fuel. Figure 24 shows that Indolene ethanol blends require less oxygen for ideal combustion than gasoline. This is due to indolene initially requiring less oxygen than gasoline, affecting every blend it is mixed with.

A graph showing a line of gasoline

Description automatically generated with medium confidence

Figure 22- Graph showing Air to Fuel ratio for varied ethanol content in fuel (Author, 2024)

A graph with a line

Description automatically generated

Figure 23- Graph showing the rate of change of the AFR between ethanol content % (Author, 2024)

Figure 24- Graph comparing Indolene and Gasoline Ethanol Fuel blend AFR (Author, 2024)

## Defining Performance and Study Parameters

The performance of a vehicle refers to how well a vehicle can move and as a result the largest amount of motion the vehicle is capable of on each axis. For example, the cornering performance of a vehicle is measured through lateral movement as well as the roll of the vehicle. Considering the primary objective of an engine and fuel within a vehicle is to create forward motion, performance will be defined as such, measuring how quickly the engine can accelerate through the means of torque in Newtons per meter, as well as the maximum power the engine can create in Kilowatts (kW).

The efficiency of the fuel refers to how much power can be created in comparison to how much fuel is consumed doing so. As a result, the engine efficiency will be measured using fuel consumption. As well as this, considering that Emissions are key to this study, the amount of CO2 produced during combustion within the engine will be compared against performance measurements to obtain each fuel's environmental efficiency within the engine.

# Processing

After setting up the simulation each fuel was simulated individually using gasoline AFR and the fuel's specific ideal AFR. This was done by changing the simulation settings, switching the fuel file that the simulation read from, and re-running the simulation under the new conditions. After running each simulation and setting up the desired 2D sweep plots, the data was exported to Excel to then be presented in appropriate graphical form. Primarily, line graphs have been used to represent the data as these provide the clearest visual display of the data’s trends and comparisons between data.

# Discussion and Analysis

Within Realis Wave the fuel that closest represents standard pump fuel chemically is Indolene. As a result, a comparison has been made between both Indolene and gasoline Ethanol Blends to determine if both should be analyzed or if a single combination provides overall better results. It was determined that since there are specific ethanol contents where gasoline produces more power than indolene and vice versa, both fuels will be considered when analyzing what ethanol blend provides the best performance. Comparison of the fuel's ethanol blends will be done both individually and against each other.

## AFR Adjustment

To highlight the importance of adjusting the AFR, each ethanol gasoline blend was simulated both adjusting AFR and using gasoline standard AFR (14.7). As seen by looking at figures 25-27, adjusting the AFR for each of the ethanol fuels drastically changes the results for Power, torque, and fuel consumption. Without adjusting the AFR of the fuel, as the ethanol content increases the fuel trends further away from ideal conditions for combustion to occur, resulting in a decrease in power, torque, and an increase in fuel consumption. In this case, the simulation would be biased towards gasoline resulting in gasoline being the most ideal fuel. As a result, the AFR will be adjusted for each fuel when comparing results.

Figure 25- Graph showing difference between fuel consumption of fuels with adjusted AFR and not (Author, 2024)

Figure 26- Graph showing the difference between torque of fuels with adjusted AFR and not (Author, 2024)

Figure 27- Graph showing difference between power of fuels with adjusted AFR and not (Author, 2024)

## Power

For both indolene and gasoline-ethanol blends, the power produced by the fuel decreases as the ethanol % increases to E70 before then increasing up to a peak at E100. This is the same for both fuels. The general trend for indolene and gasoline follows similar shapes, however, indolene has a shallower curve resulting in indolene producing more power than gasoline when more than 25% ethanol is present, as seen in Figure 28. The largest difference between the gasoline and indolene ethanol blends occurs at E65 with a difference of 1.4kw. Since gasoline creates more power as a base fuel it would be expected to produce more power when mixed with ethanol, however, as previously mentioned this is only the case up to E25. This may be because indolene is chemically more similar to ethanol than gasoline, resulting in more optimal conditions for indolene ethanol fuel blends than gasoline-ethanol blends. Looking at Figure 28 the power created by Indolene ethanol blends becomes unstable between E70 and E85. This may mean that between these ethanol percentages the fuel becomes more volatile, or the simulation is further away from ideal combustion conditions for these specific ethanol contents.

As previous research highlighted, adding ethanol to a fuel blend, under these conditions will not increase the power of the fuel. This is due to ethanol changing the ideal conditions in which the fuel will combust. Without changing the compression ratio or burn temperature conditions within the engine, the extra allowed pressure and octane rating provided by ethanol cannot be taken advantage of resulting in a decrease in power. Further research will be required to determine why this does not occur at high levels of ethanol such as E95 and E100 which both produce high levels of power.

Figure 28- Graph comparing Peak power between Indolene and Gasoline ethanol blends (Author, 2024)

## Fuel Consumption

As seen in Figure 29 the fuel consumption of both indolene ethanol and gasoline-ethanol increases as the ethanol content of the fuel increases. As a result, peak fuel consumption occurs with E100 and the least amount of fuel consumption occurs within base Indolene and gasoline. This is expected since Ethanol is less energy-dense than both Indolene and Gasoline. This mimics previous research highlighted in the literature review. Indolene both having less chemical mass and being less energy-dense than gasoline results in indolene ethanol blends consuming more fuel per hour than equivalent gasoline-ethanol blends, the same occurs with ethanol.

Figure 29- Graph comparing peak fuel consumption between Indolene and Gasoline ethanol blends (Author, 2024)

## CO2 Emissions

Since base Indolene produces more CO2 than gasoline, indolene ethanol blends also produce more than gasoline-ethanol equivalents. Though both ethanol fuel blends follow similar curves (as seen in figure 30) indolene ethanol has peak CO2 emissions when not combined with ethanol, decreasing to a lowest point at E80 before increasing towards E100. Gasoline ethanol, on the other hand, emits the least amount of CO2 between E65 and E70. This is a similar shape and trend as power meaning the fuel consumption is likely related to how much power the fuel can create.

It was initially expected that E100 would produce the least amount of CO2 since the literature states that ethanol produces less CO2 than base fuel. However, within a vehicle that is not set up to use ethanol blend fuels, E100 produced more. It was also expected that as the ethanol content increased the CO2 emissions would continue to decrease however this does not occur. This is likely due to the higher ethanol-content fuel blends requiring more engine modifications for ideal combustion to occur. As a result, as the ethanol content increases past E75 the fuel blend deviates further from ideal conditions, resulting in more CO2 emissions. Alternatively, this may be a result of the power and torque output from these fuel blends also increasing at these percentages.

Figure 30- Graph comparing Peak Carbon Dioxide Emissions between Indolene and Gasoline ethanol blends (Author, 2024)

## Torque

As seen in figure 31 the torque produced by the fuel blends follows similar trends seen within power. Much like power, the torque for both indolene and gasoline-ethanol blends are lowest between E65 and E70. Likewise, gasoline blends start with higher torque levels until E25 where Indolene ethanol blends produce more torque than their gasoline ethanol counterparts. Unlike the power, torque produced by indolene ethanol blends are far more stable between E70 and E85, following the general trend far closer. This leads me to believe that the volatility seen from the power is not a result of error within the simulation but more likely a result of the fuel itself. However, further analysis would be required to determine why this occurs.

Figure 31- Graph comparing Peak Torque between Indolene and Gasoline ethanol blends (Author, 2024)

## Overall Analysis

### Defining Analysis Systems

Considering that the performance of each fuel is based on multiple complex parameters that aren’t directly comparable, a system has been created to allocate each fuel a score based on the results for each parameter. These scores will be combined to create an overall score and determine which fuel possesses the most complete performance based on Power, Torque, Fuel consumption, and emissions. The score will be based on the % each fuel blend results are away from an ideal result. For power, the ideal value will be whichever fuel blend has the highest engine power, the same for torque. For CO2 emissions the ideal value will be the lowest, and the same for fuel consumption. Each fuel blend will then be compared to this ideal result, achieving a score within each parameter.

For example, the power for Gasoline E50 is 78.9364 kW. Comparing this to E100’s (Where peak power occurs for Gasoline-Ethanol Blends) 86.8371Kw it can be calculated that E50 produces 9.1% less power than E100. This results in E50 having a Power Rating of 0.909 (E50/E100) compared to E100’s power rating of 1 (E100/E100).

### Gasoline-Ethanol Blend Analysis

The ideal values within gasoline-ethanol blends occur at E100 for power (86.8371Kw) and torque (172.457Nm), E5 for fuel consumption (14.798kg/hr), and E65 for CO2 emissions (2.166 mg/s) shown in Appendix D.

However, the ideal fuel when considering all 4 performance factors is base fuel gasoline even though it does n2t perform best in any single parameter. Though the literature states that ethanol fuel blends should provide overall better performance, without correct tuning of the engine and the correct compression ratio, ethanol within gasoline fuel blends results in an overall decrease in performance. This is the reason higher levels of ethanol are currently not present within pump fuel as most vehicles on the road are not built to dynamically change engine parameters based on the fuel the engine is provided.

One of the main factors resulting in a low total rating for the higher ethanol content blends is fuel consumption. As previously mentioned, the extra ethanol results in more fuel consumption due to ethanol being less energy-dense than gasoline. Considering that the CO2 Emissions are based on how much fuel is consumed, it was decided that a rating should be investigated in which fuel consumption is not considered.

Though doing this does result in higher ethanol content fuel blends having a more comparable total rating, gasoline remains the highest-ranking fuel. E100 increases to the 2nd highest-ranking blend, resulting in E70 becoming the lowest, because of its lower power and Torque when compared to the other fuels. This being the case, removing fuel consumption as a considered factor results in each fuel's total rating being much more comparable to each other, with the largest difference in performance being a 10% decrease.

### Indolene-Ethanol Blend Analysis

In the case of Indolene-ethanol fuel blends the same results apply with E100 still producing more power and torque than any indolene-ethanol blend. However, due to indolene-ethanol blends higher fuel consumption, base indolene has the optimal fuel consumption (14.962), and E70 releases the least amount of CO2 (2.2614) (see Appendix E). When considering fuel consumption, within this application indolene without ethanol provides the best performance results. However, when not considering the fuel consumption the rating of base Indolene drops considerably when compared to indolene ethanol blends. This results in E100 becoming the best-performing fuel. As well as this E80 to E95 provide a higher performance rating than Indolene, Including E5. Though E10 doesn’t provide a higher performance rating, it is very closely matched with base Indolene, resulting in only a 0.3% decrease in performance rating.

Since, as previously mentioned, Indolene is the closest representative for pump fuel, the results shown here are most applicable for road vehicles.

### Combined comparison

When comparing both the Indolene and gasoline-ethanol blends using the same system, gasoline-ethanol blends provide more performance than indolene-ethanol equivalents. The ideal values are produced by pure Ethanol for Power and Torque or a gasoline-ethanol blend for fuel consumption and CO2 emission while any fuel blend containing Indolene does not provide ideal values. This is due to Indolene having less carbon and Hydrogen because of added chemicals within the fuel to maintain engine components (See Appendix F).

It is important to note that these results weigh each parameter equally and do not consider the application of the fuel. In real-world scenarios, different vehicles will hold more importance to different performance specifications. For example, a road vehicle will likely need better fuel consumption and less CO2 emissions to stay within regulation while high-performance vehicles will value power and torque more highly.

# Project Management

To achieve the outlined objectives and aims for this project, each event and stage was planned and managed following SMART goals. SMART refers to a set of rules that goals should follow in which they are specific, measurable, achievable, realistic, and time-bound.

To ensure that the goals were specific work breakdown was created, that highlighted the key requirements of the project including what was required to achieve those objectives. These are primarily vague but were used to ensure that each goal set was specific to one of these main objectives/outcomes.

To keep the goals measurable, they all related to a submission date and had clear outcomes. As well as this, the literature review was tackled through different questions that needed to be answered for the project to continue (See Figure 32). This meant the progress of the literature review was measurable as the goal was achieved once the question was answered.

A questionnaire with text

Description automatically generated

Figure 32- Image of literature review questions (Author, 2024)

Setting up meetings with both an academic mentor and the library academic skills team allowed me to ask key questions about the project as well as ensure that the goals that I had set out were achievable and wouldn’t either take too much time or be too ambitious for the project.

A screenshot of a computer

Description automatically generatedFinally, a Gantt chart was used to make goals time-bound and to keep track of the progress of the project as it was ongoing. Though the Gantt chart was set up at the start in a specific way, considering some changes to the project occurred, the Gantt chart changed as the project progressed as can be seen in Figures 33 and 34.

Figure 33- Screenshot of Original Gaant Chart (Author, 2024)

A screenshot of a computer

Description automatically generated

Figure 34- Screenshot of Modified Gaant Chart (Author, 2024)

The primary reason for changes within the Gantt chart occurred because of issues with both deadlines and the use of software.

Since the software being used (Realis Wave 2023.1) was provided by the University, the files that were used to run the software were protected by an admin lock. This meant that the data files couldn’t be directly edited or accessed as they were a part of the software’s operating files. As a result, the data files were copied and moved into a One Drive folder in which the command prompt was able to read and write to the files to create the fuels. Due to the fuels and the data files being stored within cloud-based storage, the files could be accessed by any computer with access to the One Drive.

Due to unforeseen circumstances and University timetabling, the deadlines imposed for the Project proposal, ethics, and risk assessment forms changed from the 1st to the 24th of November and from the 1st to the 17th of November respectively. Though this provided extra time before the deadline, it still affected the beginning of the project resulting in the project not starting until later as the proposal needed to be accepted before the project began. This set back every original goal for the plan by 3 weeks and resulted in a reduction in time allocations to the goals of the project.

# Conclusion

Though many different inroads have been made towards reducing greenhouse gas emissions, global warming remains one of humanity's most imminent threats. Of the many greenhouse gases that contribute to global warming, Carbon dioxide is the most impactful, accounting for 79% of the US greenhouse gases. Carbon Dioxide is primarily released into the atmosphere when fuel combustion occurs within the transportation or power industry, through fossil fuels such as coal and crude oil. It has been known for centuries that bioproducts can be used to create green combustible fuels that can be used to replace both coal and refined crude oil in the form of gasoline. Not only do these biofuels produce less Carbon Dioxide but are also made from renewable resources unlike crude oil and coal which are finite resources, highlighting the importance of biofuels.

One of these biofuels is ethanol which has been included in gasoline and is considered as a replacement for fuel within engines. Research suggests that ethanol produces 44% less carbon dioxide through the acquisition and combustion of the fuel. These results vary depending on what substance is used to create ethanol, the most common of which are sugarcane and corn, produced in Brazil and America respectively, while peas result in the lowest Carbon Dioxide emissions. However, fueling an engine using only ethanol fuel requires specific modifications to conventional road-going engines due to ethanol’s more volatile combustible, and erosive nature.

Since this is the case, ethanol has been included in current pump fuel to create new blends known as E5 (5% Ethanol) and E10 (10% Ethanol). The idea behind this is to incorporate the positive aspects of ethanol while avoiding its volatile nature. Within the UK this resulted in a reduction of 2% in total emissions. As well as this, ethanol is said to be able to produce more power and torque than conventional fuel due to being more combustible and able to withstand higher compression ratios. The extra power, torque, and reduced emissions come at the cost of fuel consumption, as ethanol has a lower energy density than conventional fuel.

Since the amount of fuel required increases when ethanol is blended with conventional fuel and the fact that current engines are not designed in a way to take advantage of ethanol's increased combustibility, an experiment was conducted to find what amount of ethanol within fuel would provide the best performance based on these factors. It was determined before the experiment that since fuel consists of many different chemicals, Realis Waves’ Indolene is a better chemical representation than pure gasoline. Since this is the case, both gasoline and indolene ethanol blends were included in the experiment.

Results showed that on the selected engine (2.0L, inline 4 cylinders) E100 or pure ethanol provided the best power (86.8371Kw) and torque (172.457Nm). However, in the case of gasoline-ethanol blends, the lowest average fuel consumption occurred at E5 (14.798kg/hr) and the lowest average carbon dioxide emissions occurred at E65 (2.166mg/s). The spread of results concluded that pure gasoline provided the best total rating when comparing power, torque, fuel consumption, and carbon dioxide emissions combined against other fuel blends.

In the case of Indolene ethanol blends, pure indolene provides the best average fuel consumption (14.962kg/hr) while E70 results in the lowest average CO2 emissions (2.2614mg/s). Resembling gasoline-ethanol blends, indolene provides the best total rating when comparing all 4 parameters, however, if fuel consumption is not a considered factor, then E100, E95, E90, E85, E80, and E5 all perform better than base indolene with E100 providing the highest performance.

These results show that current road-going engines are unable to utilize the effects of ethanol within fuel without modification to increase compression ratios and engine combustion conditions. As a result, increasing ethanol content within fuel is overall not beneficial within these conditions. The experiment considers all performance parameters where in real-world applications some vehicles may be biased towards high power and torque, namely track vehicles, while road vehicles are likely to have reduced carbon emissions as a priority.

As well as this, results are for a specific engine under specific parameters. Ethanol may have a greater impact on an engine's performance under different conditions. For example, if the injection is direct or if a turbo was included as a part of the intake. These parameters are likely the reason for the disparity between results and current research as this experiment focuses on an engine that is not ideally set up in a way to utilise ethanol. These results could be used for any form of internal combustion engine to minimize emissions while maximizing power.

Overall, the report covers the aims and objectives laid out, researching the production of ethanol, the effects on combustion and a vehicle, covering areas of production, other biofuels and effectively creating fuels and gathering results through simulation.

# Recommendations

It is recommended that the study continues further to test these fuel blends under each fuel blend's complete ideal conditions including testing different forms of injection, compression ratios, burn temperatures and injection duration. This will result in a comprehensive result as to which ethanol fuel blend provides the best performance without either blend having a potentially biased limiting factor which is a clear limitation of the current research.

It is suggested that research will need to be conducted further into both indolene’s and ethanols' ideal combustion conditions and how each increment change of ethanol within a fuel blend may affect those conditions. The findings will then need to be verified through simulation before results are extracted. This can be done by comparing the results of a single blend under multiple different conditions to ensure that theoretical and calculated ideal conditions provide the best performance.

Finally, it is suggested that the results from the simulation be verified through real-life applications. This is because the engine used for the simulation has no real-world counterpart to compare or verify simulation results.

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# Appendix

## Appendix A

A screenshot of a computer

Description automatically generated

## Appendix B

A screenshot of a computer screen

Description automatically generated

## Appendix C

A screenshot of a computer

Description automatically generated

A screenshot of a video game

Description automatically generated

A screenshot of a video game

Description automatically generated

## Appendix D

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Fuel Type** | **Peak Power** | **Power Ranking** | **Peak Torque** | **Torque Rating** | **Average FC** | **FC Rating** | **Average CO2** | **CO2 Rating** | | **Total Rating** | **Total Rating - FC Rating** |
| Gasoline | 86.1912 | 0.9926 | 172.437 | 0.9999 | 15.019 | 0.985 | 2.352 | 0.9207 |  | 3.8983514 | 2.913123166 |
| E5 | 85.1346 | 0.9804 | 170.394 | 0.988 | 14.798 | 1 | 2.389 | 0.9066 |  | 3.8750743 | 2.87507429 |
| E10 | 84.4557 | 0.9726 | 168.78 | 0.9787 | 14.918 | 0.992 | 2.362 | 0.9169 |  | 3.860109 | 2.868164846 |
| E15 | 83.4776 | 0.9613 | 167.205 | 0.9695 | 15.046 | 0.984 | 2.334 | 0.9276 |  | 3.842018 | 2.858504342 |
| E20 | 82.8061 | 0.9536 | 165.661 | 0.9606 | 15.189 | 0.974 | 2.309 | 0.9377 |  | 3.8261464 | 2.851922043 |
| E25 | 82.0784 | 0.9452 | 164.198 | 0.9521 | 15.344 | 0.964 | 2.285 | 0.9478 |  | 3.8095112 | 2.845101243 |
| E30 | 81.2852 | 0.9361 | 162.84 | 0.9442 | 15.515 | 0.954 | 2.262 | 0.9575 |  | 3.791573 | 2.837823045 |
| E35 | 80.6653 | 0.9289 | 161.507 | 0.9365 | 15.707 | 0.942 | 2.241 | 0.9665 |  | 3.7740557 | 2.831939476 |
| E40 | 80.1287 | 0.9227 | 160.351 | 0.9298 | 15.921 | 0.929 | 2.222 | 0.9748 |  | 3.7568114 | 2.827366172 |
| E45 | 79.5277 | 0.9158 | 159.163 | 0.9229 | 16.154 | 0.916 | 2.204 | 0.9827 |  | 3.7374972 | 2.821486047 |
| E50 | 78.9364 | 0.909 | 158.092 | 0.9167 | 16.426 | 0.901 | 2.189 | 0.9891 |  | 3.7156904 | 2.814822245 |
| E55 | 78.5116 | 0.9041 | 157.274 | 0.912 | 16.73 | 0.885 | 2.178 | 0.9944 |  | 3.6950081 | 2.810498604 |
| E60 | 78.377 | 0.9026 | 156.596 | 0.908 | 17.078 | 0.866 | 2.17 | 0.9981 |  | 3.6752207 | 2.808754733 |
| E65 | 78.135 | 0.8998 | 156.257 | 0.9061 | 17.477 | 0.847 | 2.166 | 1 |  | 3.652532 | 2.805850178 |
| E70 | 78.1188 | 0.8996 | 156.344 | 0.9066 | 17.943 | 0.825 | 2.167 | 0.9993 |  | 3.6302192 | 2.805515274 |
| E75 | 78.4222 | 0.9031 | 156.847 | 0.9095 | 18.491 | 0.8 | 2.176 | 0.9954 |  | 3.6082868 | 2.808013343 |
| E80 | 79.0427 | 0.9102 | 158.062 | 0.9165 | 19.148 | 0.773 | 2.193 | 0.9874 |  | 3.5870166 | 2.814212371 |
| E85 | 80.1757 | 0.9233 | 159.841 | 0.9268 | 19.938 | 0.742 | 2.221 | 0.9751 |  | 3.5674046 | 2.82521317 |
| E90 | 81.5431 | 0.939 | 162.696 | 0.9434 | 20.928 | 0.707 | 2.266 | 0.9559 |  | 3.5453869 | 2.838327526 |
| E95 | 83.7544 | 0.9645 | 166.892 | 0.9677 | 22.181 | 0.667 | 2.332 | 0.9287 |  | 3.5280723 | 2.86094729 |
| E100 | 86.8371 | 1 | 172.457 | 1 | 23.824 | 0.621 | 2.429 | 0.8915 |  | 3.5126461 | 2.891524103 |

## Appendix E

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fuel Type | Peak Power | Power Rating | Peak Torque | Torque Rating | Average FC | FC Rating | CO2 Average | CO2 Rating | | Total Rating | Total Rating – FC Rating |
| Indolene | 84.3677 | 0.97156 | 168.895 | 0.9793 | 14.962 | 1 | 2.5242 | 0.8959 |  | 3.8468 | 2.846773 |
| E5 | 84.4548 | 0.97257 | 169.025 | 0.9801 | 15.2387 | 0.9818 | 2.52 | 0.8974 |  | 3.8319 | 2.850034 |
| E10 | 83.7915 | 0.96493 | 167.73 | 0.9726 | 15.3697 | 0.9735 | 2.4899 | 0.9082 |  | 3.8192 | 2.845723 |
| E15 | 83.3036 | 0.95931 | 166.589 | 0.966 | 15.5268 | 0.9636 | 2.464 | 0.9178 |  | 3.8067 | 2.843047 |
| E20 | 82.562 | 0.95077 | 165.281 | 0.9584 | 15.6707 | 0.9548 | 2.4343 | 0.929 |  | 3.7929 | 2.838135 |
| E25 | 82.0863 | 0.94529 | 164.149 | 0.9518 | 15.8435 | 0.9444 | 2.4083 | 0.939 |  | 3.7805 | 2.836104 |
| E30 | 81.5473 | 0.93908 | 163.452 | 0.9478 | 16.0323 | 0.9332 | 2.3836 | 0.9487 |  | 3.7688 | 2.835589 |
| E35 | 80.9675 | 0.93241 | 162.022 | 0.9395 | 16.2343 | 0.9216 | 2.3592 | 0.9585 |  | 3.752 | 2.830413 |
| E40 | 80.7089 | 0.92943 | 161.12 | 0.9343 | 16.4612 | 0.9089 | 2.3376 | 0.9674 |  | 3.74 | 2.831075 |
| E45 | 80.362 | 0.92543 | 160.403 | 0.9301 | 16.7159 | 0.8951 | 2.3182 | 0.9755 |  | 3.7261 | 2.831028 |
| E50 | 80.0043 | 0.92131 | 159.754 | 0.9263 | 16.9966 | 0.8803 | 2.3004 | 0.983 |  | 3.711 | 2.830671 |
| E55 | 79.6292 | 0.917 | 159.21 | 0.9232 | 17.3107 | 0.8643 | 2.2853 | 0.9895 |  | 3.694 | 2.829711 |
| E60 | 79.478 | 0.91525 | 158.818 | 0.9209 | 17.6687 | 0.8468 | 2.2737 | 0.9946 |  | 3.6776 | 2.830743 |
| E65 | 79.517 | 0.9157 | 158.731 | 0.9204 | 18.07 | 0.828 | 2.265 | 0.9984 |  | 3.6625 | 2.834496 |
| E70 | 79.4765 | 0.91524 | 158.95 | 0.9217 | 18.535 | 0.8072 | 2.2614 | 1 |  | 3.6441 | 2.836915 |
| E75 | 79.8196 | 0.91919 | 159.514 | 0.9249 | 19.0708 | 0.7846 | 2.2629 | 0.9993 |  | 3.628 | 2.843434 |
| E80 | 80.1876 | 0.92343 | 160.459 | 0.9304 | 19.6257 | 0.7624 | 2.2639 | 0.9989 |  | 3.6151 | 2.852742 |
| E85 | 81.5143 | 0.9387 | 162.312 | 0.9412 | 20.4456 | 0.7318 | 2.2899 | 0.9875 |  | 3.5992 | 2.867405 |
| E90 | 82.7233 | 0.95263 | 164.814 | 0.9557 | 21.3431 | 0.701 | 2.3192 | 0.9751 |  | 3.5844 | 2.883384 |
| E95 | 84.5978 | 0.97421 | 168.39 | 0.9764 | 22.4449 | 0.6666 | 2.3643 | 0.9565 |  | 3.5737 | 2.907095 |
| E100 | 86.8371 | 1 | 172.457 | 1 | 23.8238 | 0.628 | 2.4291 | 0.931 |  | 3.559 | 2.930956 |

## Appendix F

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fuel Type | Peak Power | Power Ranking | Peak Torque | Torque Rating | Average FC | FC Rating | Average CO2 | CO2 Rating | Total Rating | Total Rating - FC Rating |
| Gasoline | 86.19122 | 0.992563 | 172.4367 | 0.999882 | 15.01937 | 0.985228 | 2.352154 | 0.920679 | 3.898351 | 2.913123 |
| Gasoline E5 | 85.13461 | 0.980395 | 170.3941 | 0.988038 | 14.79751 | 1 | 2.388571 | 0.906642 | 3.875074 | 2.875074 |
| Gasoline E10 | 84.4557 | 0.972577 | 168.7798 | 0.978677 | 14.91769 | 0.991944 | 2.36182 | 0.916911 | 3.860109 | 2.868165 |
| Gasoline E15 | 83.47756 | 0.961313 | 167.2052 | 0.969547 | 15.04556 | 0.983514 | 2.33449 | 0.927645 | 3.842018 | 2.858504 |
| Gasoline E20 | 82.80607 | 0.95358 | 165.661 | 0.960592 | 15.18902 | 0.974224 | 2.309335 | 0.93775 | 3.826146 | 2.851922 |
| Gasoline E25 | 82.07844 | 0.9452 | 164.1978 | 0.952108 | 15.34359 | 0.96441 | 2.284865 | 0.947793 | 3.809511 | 2.845101 |
| Gasoline E30 | 81.28519 | 0.936066 | 162.8405 | 0.944238 | 15.51509 | 0.95375 | 2.261654 | 0.95752 | 3.791573 | 2.837823 |
| Gasoline E35 | 80.66534 | 0.928927 | 161.5067 | 0.936504 | 15.70667 | 0.942116 | 2.240621 | 0.966508 | 3.774056 | 2.831939 |
| Gasoline E40 | 80.12867 | 0.922747 | 160.3513 | 0.929804 | 15.9208 | 0.929445 | 2.221528 | 0.974815 | 3.756811 | 2.827366 |
| Gasoline E45 | 79.52773 | 0.915827 | 159.1632 | 0.922915 | 16.15429 | 0.916011 | 2.203603 | 0.982744 | 3.737497 | 2.821486 |
| Gasoline E50 | 78.93645 | 0.909018 | 158.0921 | 0.916704 | 16.42583 | 0.900868 | 2.189443 | 0.9891 | 3.71569 | 2.814822 |
| Gasoline E55 | 78.51164 | 0.904126 | 157.274 | 0.91196 | 16.72963 | 0.884509 | 2.177747 | 0.994413 | 3.695008 | 2.810499 |
| Gasoline E60 | 78.37701 | 0.902575 | 156.5965 | 0.908032 | 17.07801 | 0.866466 | 2.169598 | 0.998148 | 3.675221 | 2.808755 |
| Gasoline E65 | 78.13498 | 0.899788 | 156.2568 | 0.906062 | 17.47706 | 0.846682 | 2.165579 | 1 | 3.652532 | 2.80585 |
| Gasoline E70 | 78.11877 | 0.899602 | 156.3442 | 0.906569 | 17.94282 | 0.824704 | 2.166998 | 0.999345 | 3.630219 | 2.805515 |
| Gasoline E75 | 78.42224 | 0.903096 | 156.8469 | 0.909483 | 18.49057 | 0.800273 | 2.175513 | 0.995433 | 3.608287 | 2.808013 |
| Gasoline E80 | 79.04267 | 0.910241 | 158.0617 | 0.916528 | 19.14782 | 0.772804 | 2.193117 | 0.987444 | 3.587017 | 2.814212 |
| Gasoline E85 | 80.17574 | 0.923289 | 159.8414 | 0.926847 | 19.9376 | 0.742191 | 2.220932 | 0.975076 | 3.567405 | 2.825213 |
| Gasoline E90 | 81.54314 | 0.939036 | 162.6961 | 0.9434 | 20.92825 | 0.707059 | 2.265508 | 0.955891 | 3.545387 | 2.838328 |
| Gasoline E95 | 83.75441 | 0.964501 | 166.8921 | 0.967731 | 22.18102 | 0.667125 | 2.3318 | 0.928716 | 3.528072 | 2.860947 |
| Indolene | 84.36769 | 0.971563 | 168.8945 | 0.979342 | 14.962 | 0.989007 | 2.524212 | 0.857923 | 3.797834 | 2.808828 |
| Indolene E5 | 84.4548 | 0.972566 | 169.0246 | 0.980096 | 15.23875 | 0.971045 | 2.519981 | 0.859363 | 3.783071 | 2.812026 |
| Indolene E10 | 83.79154 | 0.964928 | 167.7304 | 0.972592 | 15.36974 | 0.962769 | 2.489928 | 0.869735 | 3.770025 | 2.807256 |
| Indolene E15 | 83.30356 | 0.959309 | 166.5889 | 0.965973 | 15.52684 | 0.953028 | 2.463984 | 0.878893 | 3.757202 | 2.804175 |
| Indolene E20 | 82.562 | 0.950769 | 165.2813 | 0.958391 | 15.67072 | 0.944278 | 2.434253 | 0.889628 | 3.743065 | 2.798788 |
| Indolene E25 | 82.0863 | 0.945291 | 164.1492 | 0.951826 | 15.84353 | 0.933978 | 2.408298 | 0.899215 | 3.730311 | 2.796333 |
| Indolene E30 | 81.54732 | 0.939084 | 163.4518 | 0.947782 | 16.03231 | 0.922981 | 2.383583 | 0.908539 | 3.718387 | 2.795406 |
| Indolene E35 | 80.96751 | 0.932407 | 162.0219 | 0.939491 | 16.23432 | 0.911496 | 2.359233 | 0.917917 | 3.70131 | 2.789815 |
| Indolene E40 | 80.70889 | 0.929429 | 161.1202 | 0.934262 | 16.46116 | 0.898935 | 2.337605 | 0.926409 | 3.689036 | 2.790101 |
| Indolene E45 | 80.36204 | 0.925435 | 160.4032 | 0.930105 | 16.71591 | 0.885235 | 2.318182 | 0.934171 | 3.674946 | 2.789711 |
| Indolene E50 | 80.00426 | 0.921315 | 159.7538 | 0.926339 | 16.99659 | 0.870617 | 2.300427 | 0.941381 | 3.659652 | 2.789035 |
| Indolene E55 | 79.62917 | 0.916995 | 159.2099 | 0.923185 | 17.31073 | 0.854817 | 2.285286 | 0.947618 | 3.642616 | 2.787799 |
| Indolene E60 | 79.47801 | 0.915254 | 158.8183 | 0.920915 | 17.66869 | 0.837499 | 2.273696 | 0.952449 | 3.626117 | 2.788618 |
| Indolene E65 | 79.51701 | 0.915704 | 158.7313 | 0.92041 | 18.06996 | 0.818901 | 2.265023 | 0.956096 | 3.611111 | 2.79221 |
| Indolene E70 | 79.47653 | 0.915237 | 158.9498 | 0.921677 | 18.53501 | 0.798355 | 2.261359 | 0.957645 | 3.592914 | 2.794559 |
| Indolene E75 | 79.81963 | 0.919189 | 159.5139 | 0.924948 | 19.07078 | 0.775926 | 2.26295 | 0.956972 | 3.577034 | 2.801108 |
| Indolene E80 | 80.18755 | 0.923425 | 160.4592 | 0.93043 | 19.62572 | 0.753986 | 2.263878 | 0.956579 | 3.56442 | 2.810434 |
| Indolene E85 | 81.51429 | 0.938704 | 162.3118 | 0.941172 | 20.44556 | 0.723752 | 2.289917 | 0.945702 | 3.54933 | 2.825578 |
| Indolene E90 | 82.72325 | 0.952626 | 164.8138 | 0.95568 | 21.34314 | 0.693315 | 2.319157 | 0.933778 | 3.535399 | 2.842084 |
| Indolene E95 | 84.59785 | 0.974214 | 168.3896 | 0.976414 | 22.44487 | 0.659283 | 2.364283 | 0.915956 | 3.525866 | 2.866584 |
| E100 | 86.83707 | 1 | 172.4571 | 1 | 23.82384 | 0.621122 | 2.429071 | 0.891525 | 3.512647 | 2.891525 |