Charging Ahead or Running on Fumes? A "EuroTotally Unbiased" Look at Electric, Hydrogen, HVO, and Those Old-School Petrol Cars

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Abstract

In the ever-evolving landscape of automotive propulsion, the race to find the “best” fuel source has become a topic of heated debate, often fueled (pun intended) by passionate enthusiasts, environmentalists, and skeptics alike. This research provides a "EuroTotally Unbiased" look into the world of Electric, Hydrogen Fuel Cell, HVO (Hydrotreated Vegetable Oil), and the good old-fashioned Petrol vehicles. Because, let’s face it, who doesn’t love a good old-fashioned showdown?

Electric vehicles (EVs), championed by brands like Tesla, have surged in popularity, thanks to their zero tailpipe emissions, impressive acceleration, and the allure of silent operation. But are they truly the future, or just a flashy trend? Hydrogen Fuel Cell vehicles promise long ranges and quick refueling times, but with infrastructure challenges and questions about the true environmental impact of hydrogen production, are they just full of hot air?

Then there’s HVO, the lesser-known contender. Produced from renewable sources, HVO promises a reduced carbon footprint compared to traditional diesel. But can it really compete in a world increasingly dominated by battery and hydrogen narratives? And, of course, let’s not forget the old friend, Petrol. With over a century of dominance, Petrol cars have reliability and a vast infrastructure on their side. But with increasing environmental concerns and the rise of alternative fuels, are they becoming the dinosaurs of the automotive world?

The research delves deep into the performance metrics of each propulsion system, analyzing factors such as energy efficiency, total lifecycle emissions, refueling/recharging infrastructure, and cost-effectiveness. It also explores the environmental implications of each fuel source, from the extraction or production phase right through to consumption or utilization in vehicles.

Preliminary findings suggest that while EVs offer significant benefits in urban settings due to their zero tailpipe emissions and lower operating costs, their total environmental impact is heavily influenced by the source of electricity used for charging. Hydrogen, though promising in its quick refueling and potential for clean production, currently faces significant challenges in distribution and storage. HVO, while a cleaner alternative to diesel, still grapples with scalability and feedstock issues. Petrol, despite its widespread use and established infrastructure, faces increasing scrutiny due to its environmental impact and depleting reserves.

In conclusion, this "EuroTotally Unbiased" research cuts through the noise to provide a comprehensive comparison of the pros and cons of each propulsion system. While there is no one-size-fits-all answer, it’s clear that the future of transportation will likely be a mix of these technologies, each finding its niche based on regional needs, infrastructure, and technological advancements. So, whether one is Team Tesla, Hydrogen Hyped, an HVO Hero, or a Petrol Purist, buckle up the road to the future of transportation is bound to be an exciting ride!
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Oliver Bodemer[5]

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Introduction

Background and Motivation

The transition towards sustainable transportation has gained significant momentum in recent years. Electric vehicles (EVs), particularly those championed by brands like Tesla, have emerged as a promising solution to reduce greenhouse gas emissions and local pollutants [3]. However, the adoption of EVs has been slower than anticipated due to various challenges, including range anxiety and inconsistent real-time availability data of charging stations [18].

Hydrogen fuel cell vehicles, which utilize green hydrogen as an energy source, present another compelling alternative. These vehicles offer the advantage of fast refueling and long driving ranges, aligning well with current logistic operation concepts [28]. Moreover, the integration of green hydrogen in transportation can facilitate a more effective synergy between renewable energy sources across different energy sectors [25].

Despite the potential benefits of EVs and hydrogen vehicles, there are still considerable challenges to overcome. For instance, the infrastructure for hydrogen refueling is still in its nascent stages, and there are concerns about the actual environmental impact of hydrogen production. Similarly, while EVs offer significant benefits in urban settings, their broader adoption is contingent on the development of a robust charging infrastructure and the resolution of issues like range anxiety [18].

Objective and Scope of the Study
This study aims to provide a comprehensive comparison of various vehicle propulsion systems, namely electric, hydrogen fuel cell, HVO, diesel, and petrol. The research will delve deep into the physical fundamentals of fuel production for each system, analyze their performance metrics, and evaluate their environmental implications. By doing so, insights into the viability of each propulsion system in the context of a sustainable transportation future can be offered.

Literature Review

Historical Overview of Vehicle Propulsion

The history of vehicle propulsion is a testament to human ingenuity and the relentless pursuit of progress. From the earliest horse-drawn carriages to the modern electric vehicles, the means by which we move from one place to another has evolved significantly. The first automobiles, introduced in the late 19th century, were powered by steam engines. However, the steam-powered vehicle was soon overshadowed by the internal combustion engine (ICE), which utilized gasoline or diesel as fuel [33].

The dominance of the ICE began in the early 20th century, with the mass production of automobiles by companies like Ford. The Model T, introduced in 1908, became a symbol of the ICE’s supremacy in the automotive world [15]. For several decades, gasoline and diesel-powered vehicles ruled the roads, with little competition. However, the oil crises of the 1970s prompted a renewed interest in alternative propulsion methods. This period saw the exploration of electric vehicles (EVs), though they remained largely experimental due to technological limitations [53].

The late 20th and early 21st centuries witnessed significant advancements in battery technology, making EVs more viable. Companies like Tesla have played a pivotal role in popularizing electric propulsion, challenging the long-standing dominance of the ICE [45]. Today, hybrid vehicles, which combine ICE and electric propulsion, and fully electric vehicles are becoming increasingly common on roads worldwide.

Recent Advances in Alternative Fuels

Alternative fuels have gained significant attention in recent years due to environmental concerns and the need to reduce dependence on fossil fuels. Biofuels, derived from organic materials, have emerged as a promising alternative to traditional gasoline and diesel. Ethanol, produced from corn or sugarcane, and biodiesel, derived from vegetable oils or animal fats, are among the most common biofuels [11].

Hydrogen is another alternative fuel that has garnered interest. When used in fuel cells, hydrogen can produce electricity to power vehicles, emitting only water vapor as a byproduct [4]. Research is ongoing to address challenges related to hydrogen storage and production.

Natural gas, primarily composed of methane, serves as an alternative fuel for vehicles, offering reduced emissions compared to gasoline or diesel. Compressed natural gas (CNG) and liquefied natural gas (LNG) are the primary forms used in transportation [9].

Electric vehicles (EVs) have seen significant advancements, with improvements in battery technology, charging infrastructure, and vehicle range. The development of fast-charging stations and the reduction in battery costs have contributed to the growing popularity of EVs [37].

Environmental and Economic Impacts

The environmental impact of alternative fuels and propulsion methods is a critical consideration. Biofuels, for instance, can reduce greenhouse gas emissions compared to fossil fuels. However, the cultivation of crops for biofuel production can lead to deforestation and biodiversity loss [47]. The production and use of biofuels also have implications for water resources and air quality [1].

Electric vehicles, while producing zero tailpipe emissions, have environmental impacts associated with battery production and electricity generation. The sourcing of materials for batteries, such as lithium and cobalt, can have environmental and social implications [48]. The benefits of EVs in terms of emissions reduction depend on the source of the electricity used for charging.

The economic impacts of transitioning to alternative fuels and propulsion methods are multifaceted. While there are costs associated with developing new technologies and infrastructure, there are also potential economic benefits. These include job creation in new industries, reduced dependence on oil imports, and potential cost savings for consumers in the long run [12].

Physical Fundamentals of Fuel Production

Electricity Production

Renewable Sources

Wind is caused by the uneven heating of the earth’s surface by the sun. This uneven heating is due to the different absorption rates of the sun’s heat by the earth’s surface, which consists of various types of land and water. Wind turbines utilize the kinetic energy of the wind by using blades, similar to airplane propellers, to generate electricity. As the wind flows over the blades, it creates lift, causing the blades to turn. This turning motion is connected to a drive shaft that turns an electric generator, producing electricity. In 2022, wind turbines contributed to about 10.2% of the total U.S. utility-scale electricity generation.

Another renewable source is biofuel. Biomass can be directly converted into liquid fuels, known as “biofuels,” to meet transportation fuel needs. The most common biofuels are ethanol and biodiesel. Ethanol is an alcohol used as a blending agent with gasoline to increase octane and reduce carbon monoxide and other smog-causing emissions. Biodiesel is a liquid fuel produced from renewable sources like vegetable oils and animal fats. It serves as a cleaner-burning replacement for petroleum-based diesel fuel [6].

Hydrogen production through electrolysis is also a promising renewable method. Electrolysis uses electricity to
split water into hydrogen and oxygen. This process takes place in an electrolyzer, which can be powered by renewable energy sources, ensuring a carbon-free hydrogen production [55].

Wind is caused by the uneven heating of the earth’s surface by the sun. The kinetic energy $E_k$ of the wind can be represented by the equation:

$$ E_k = \frac{1}{2} m v^2 $$

where $m$ is the mass of the air and $v$ is its velocity. Wind turbines utilize this kinetic energy to generate electricity.

Biofuels, such as ethanol, can be represented by the combustion equation:

$$ C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O $$

indicating the conversion of ethanol and oxygen into carbon dioxide and water [6].

For hydrogen production through electrolysis, the basic equation is:

$$ 2H_2O \rightarrow 2H_2 + O_2 $$

representing the splitting of water into hydrogen and oxygen [55].

**Non-renewable Sources**

Electricity generation from non-renewable sources primarily involves the combustion of fossil fuels. The most common non-renewable sources are coal, natural gas, and nuclear energy. When fossil fuels are burned, they release carbon dioxide and other greenhouse gases, which contribute to global warming. On the other hand, nuclear energy uses nuclear reactions to generate heat, which is then used to produce steam that drives a turbine to produce electricity. While nuclear energy does not emit greenhouse gases during electricity generation, there are concerns related to nuclear waste disposal and the potential risks of nuclear accidents.

For coal combustion, the basic equation is:

$$ C + O_2 \rightarrow CO_2 $$

indicating the conversion of carbon in coal and oxygen into carbon dioxide.

For natural gas, primarily methane, the combustion equation is:

$$ CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O $$

Nuclear energy relies on nuclear fission reactions, where a heavy nucleus splits into two or more smaller nuclei, releasing energy.

**Hydrogen Production**

**Electrolysis**

Electrolysis is a method of producing hydrogen by passing an electric current through water. When a sufficient voltage is applied between two electrodes immersed in water, it causes the water to split into its basic elements: hydrogen and oxygen. The overall reaction for the electrolysis of water is given by:

$$ 2H_2O(l) \rightarrow 2H_2(g) + O_2(g) $$

This method is particularly attractive because it produces pure hydrogen without any carbon emissions. However, the efficiency of electrolysis is heavily dependent on the source of electricity. If the electricity comes from renewable sources like wind or solar, the carbon footprint is minimal. On the other hand, if the electricity is derived from coal or other non-renewable sources, the environmental benefits are reduced [49].

**Steam Methane Reforming**

Steam Methane Reforming (SMR) is the most common method of producing commercial bulk hydrogen. Natural gas, which is primarily methane, is reacted with steam to produce hydrogen. The process occurs in multiple stages:

1. The first step involves the reaction of methane with steam to produce carbon monoxide and hydrogen:

$$ CH_4 + H_2O \rightarrow CO + 3H_2 $$

2. In subsequent reactions, carbon monoxide reacts with steam to produce carbon dioxide and more hydrogen:

$$ CO + H_2O \rightarrow CO_2 + H_2 $$

Although SMR is efficient and well-established, it does produce carbon dioxide as a byproduct, which raises concerns about its environmental impact. However, if carbon capture and storage technologies are employed, the carbon dioxide can be captured and stored or utilized, thereby reducing the environmental impact [50].

**HVO (Hydrotreated Vegetable Oil) Production**

**Feedstock Sources**

HVO is produced from triglycerides, which are sourced from various vegetable oils and animal fats. Common feedstocks include rapeseed oil, soybean oil, palm oil, and used cooking oil. The choice of feedstock can influence the properties of the final HVO product and its sustainability profile. For instance, using waste feedstocks like used cooking oil can enhance the environmental benefits of HVO. HVO, also known as renewable diesel, is produced from a variety of feedstocks. These feedstocks primarily include:

- Vegetable oils: Such as rapeseed oil, soybean oil, and palm oil.
- Animal fats: Including tallow and fish oil.
- Waste and residues: Like used cooking oil (UCO) and trap grease.

The choice of feedstock can influence the properties of the final HVO product and its sustainability profile. For instance, using waste and residues can lead to a lower carbon footprint compared to virgin vegetable oils [40].
Production Process
The production of HVO involves the hydrotreatment of triglycerides. In this process, the feedstock is exposed to hydrogen in the presence of a catalyst, typically at high temperatures and pressures. The oxygen in the triglycerides is removed and replaced with hydrogen, resulting in the formation of paraffinic hydrocarbons. The primary reactions can be represented as:

$$\text{Triglyceride} + 3H_2 \rightarrow 3\text{Alkane} + \text{Glycerol}$$

The resulting product is free of oxygen and sulfur, making it a high-quality renewable diesel with properties similar to fossil diesel. The glycerol byproduct can be further processed or used in other industries.

The production of HVO involves the hydrotreating of triglycerides, which are the main components of fats and oils. The process can be summarized as follows:

1) **Pre-treatment**: The feedstock is cleaned to remove impurities and pre-treated to eliminate free fatty acids.
2) **Hydrogenation**: The cleaned feedstock is then exposed to hydrogen in the presence of a catalyst at elevated temperatures and pressures. This process breaks down the triglycerides into straight-chain hydrocarbons.
3) **Fractionation**: The hydrocarbons are then fractionated or distilled to produce different cuts, similar to conventional refining. This results in the production of renewable diesel, jet fuel, and other products.
4) **Post-treatment**: Any remaining impurities are removed, and the final HVO product is stabilized for storage and transport.

The HVO production process does not produce glycerol as a by-product, unlike biodiesel production. This makes HVO a drop-in fuel that can be used in existing diesel engines without modifications [31].

Diesel Production
Crude Oil Refining
Diesel fuel is one of the products derived from crude oil. During the refining process, the viscous dark thick crude oil is turned into the much lighter diesel fuel. Crude oil is a naturally occurring liquid that can be refined into various fuels and other petroleum-based products. It is through the process of distillation that crude oil transforms into different fuels and petroleum-based products. At the molecular level, crude oil is composed of various kinds of hydrocarbons (chains of hydrogen and carbon). The hydrocarbon chains in crude oil come in various lengths, with longer hydrocarbon chains having a higher boiling point than those of shorter lengths. Distillation leverages the differences in boiling points to separate the various distillates from crude oil [51].

Additives and Enhancements
Once the basic diesel fuel is produced, it often undergoes further treatment with additives to enhance its properties. Additives can improve the fuel’s performance, increase its storage life, and make it more environmentally friendly.

Common additives include cetane boosters to improve combustion, antioxidants to prevent gum formation, and lubricity agents to protect the fuel system components. Additionally, to reduce emissions, ultra-low sulfur diesel (ULSD) is produced by removing most of the sulfur from the diesel fuel [51].

Gasoline Production
Distillation and Refining
Gasoline is a primary product derived from crude oil refining. The refining process begins with distillation, where crude oil is heated and separated into various components based on their boiling points. Modern separation involves pipining crude oil through hot furnaces, leading to the formation of vapors that are discharged into distillation units. These units separate the petroleum components, called fractions, according to their boiling points. Light fractions, including gasoline, rise to the top of the distillation tower, where they condense back into liquids. After distillation, the gasoline fraction can undergo further refining processes, such as cracking, to break down larger hydrocarbon molecules into smaller ones, enhancing the gasoline yield [52].

Octane Boosters and Additives
The octane rating of gasoline measures its resistance to knocking or pinging during combustion. To enhance this rating, octane boosters are added. Common octane boosters include Tetraethyl lead (historically used but declined due to environmental concerns), Methyl tertiary-butyl ether (MTBE), and Ethanol. Apart from octane boosters, gasoline also contains other additives to improve its performance, stability, and environmental impact. These can include detergents to keep engines clean, corrosion inhibitors to protect engine components, and stabilizers to maintain fuel quality during storage [19].

Comparative Analysis of Common Cars with Different Propulsions

Introduction to the Vehicle Comparison
In the quest for sustainable transportation, various technologies and fuel sources have emerged, each with its own set of advantages and challenges. This comparison aims to shed light on four distinct vehicles, representing different approaches to achieving eco-friendly mobility:

- **Tesla Model 3 Long Range (2023)**: Representing the forefront of electric vehicle (EV) technology, the Tesla Model 3 has become synonymous with performance, range, and sustainability. As battery technology advances, EVs like the Model 3 continue to push the boundaries of what’s possible in electric mobility [41].
- **Mercedes C 300 d 4MATIC (W 205)**: A testament to the versatility of diesel engines, this vehicle can run on both conventional diesel and HVO (Hydrotreated Vegetable Oil), a renewable diesel alternative. It showcases how traditional engines can be adapted for a more sustainable future [32].
- **Mercedes C 400 4MATIC (W 205)**: As a conventional gasoline-powered vehicle, the C 400 offers a benchmark
against which alternative fuel vehicles can be compared. Its performance and efficiency provide a standard for understanding the trade-offs and benefits of newer technologies [39].

- **Hyundai Nexo**: Pioneering the hydrogen fuel cell technology, the Nexo offers a glimpse into a future where hydrogen powers our vehicles. With quick refueling times and zero emissions, hydrogen vehicles like the Nexo challenge the dominance of battery-electric vehicles [16].

Each of these vehicles, while catering to a similar market segment, offers a unique perspective on the future of transportation. This comparison will delve into their respective strengths, weaknesses, and the potential each holds for a sustainable future.

### Electric Vehicles

**Performance and Efficiency**

Electric vehicles (EVs) are known for their instant torque and rapid acceleration, thanks to the direct connection between the electric motor and the wheels. The Tesla Model 3, in particular, has garnered attention for its impressive performance metrics.

The energy consumption of the Tesla Model 3 Performance is approximately 16.5 kWh/100 km[46]. This means that for every 100 kilometers, the car uses 16.5 kilowatt-hours of electricity. To put this into perspective, consider the energy equivalence in terms of gasoline. One gallon of gasoline contains about 33.6 kWh of energy. Thus, the Tesla Model 3’s energy consumption is equivalent to a gasoline car achieving more than 200 miles per gallon or 85 km per liter or 1.18 l/100 km, showcasing the efficiency of electric propulsion. To compare the consumption with gasoline in the metric system it is calculated, that thay:

1 gal. \(\approx 3.78541\) l

33.6 kWh/3.78541 \(\approx 8.87619\) kWh

The efficiency of an EV is not just about its energy consumption but also about how it uses that energy. Regenerative braking is a significant feature in EVs, where the electric motor runs in reverse during braking to generate electricity, converting what would otherwise be wasted energy into useful power. This process can recover as much as 60% of the energy used during acceleration.

**Environmental Impact**

The environmental impact of an EV is multifaceted. On the one hand, EVs produce zero tailpipe emissions, which means they don’t emit harmful pollutants like nitrogen oxides or particulates that can harm human health and the environment. The Tesla Model 3, for instance, emits 0g/km of CO2 during operation [46].

However, the environmental footprint of an EV also depends on the source of the electricity it uses. If the electricity comes from renewable sources, the carbon footprint is minimal. But if it’s derived from coal or other non-renewable sources, the benefits diminish. Still, even on a coal-heavy grid, EVs tend to produce fewer emissions than their gasoline counterparts over their lifecycle.

Another environmental consideration is the production and disposal of batteries. Mining the materials for batteries, especially lithium, can have environmental consequences. However, advancements in recycling technologies and the potential for second-life applications of EV batteries in energy storage solutions can mitigate some of these impacts.

### Hydrogen Fuel Cell Vehicles

**Performance and Efficiency**

Hydrogen fuel cell vehicles (FCVs) utilize hydrogen gas to produce electricity, which then powers an electric motor to propel the vehicle. The Hyundai Nexo is a notable example of a commercial FCV.

The Hyundai Nexo’s fuel cell stack can produce a maximum power output of 95 kW. Its hydrogen consumption rate is approximately 0.95 kg/100 km [22].

Given the energy content of hydrogen is typically around 33.3 kWh/kg for gaseous hydrogen, the efficiency for a specific driving scenario can be represented as:

\[
\eta = \frac{\text{Hydrogen consumed (kg)} \times \text{Energy content of hydrogen (kWh/kg)}}{\text{Power output (kW)} \times \text{Driving duration (h)}}
\]

For instance, if the Hyundai Nexo is driven for 1 hour at its maximum power output, the efficiency is:

\[
\eta = \frac{0.95\text{kg/100km} \times 33.3\text{kWh/kg} \times 100\text{km/h}}{95\text{kW} \times 1\text{h}} \approx 33.3\%
\]

However, real-world efficiency can vary based on driving conditions, speed, and other factors.

To compare the consumption of 0.95 kg/100 km, it would be equally

\[
33.3\text{kWh} \times 0.95 = 31.635\text{kWh}
\]

Environmental Impact

The primary environmental advantage of FCVs like the Hyundai Nexo is that they emit only water vapor as a byproduct, making them a zero-emission vehicle at the tailpipe.

The Hyundai Nexo is often marketed as an environmentally friendly vehicle. For instance, Hyundai Motor UK claimed that if 10,000 of its cars were on the road, the carbon emission reduction would be equivalent to planting 60,000 trees. However, the Advertising Standards Authority (ASA) found that while the car does filter incoming air, it still releases pollutants from tire and brake wear. It’s essential to consider the entire lifecycle of the vehicle, from production to disposal, when evaluating its environmental impact [54].

### HVO Vehicles

**Performance and Efficiency**

Vehicles powered by HVO (Hydrotreated Vegetable Oil) typically offer performance characteristics similar to those of conventional diesel vehicles. The Mercedes C 300 d 4MATIC (W 205), as a representative of luxury diesel sedans, is expected to deliver robust
performance, especially in terms of torque, which is a hallmark of diesel engines.

HVO, being a renewable diesel, has a high cetane number, which can lead to improved combustion efficiency and potentially better engine performance compared to conventional diesel. The energy content of HVO is also comparable to that of regular diesel, ensuring that vehicles using HVO don’t suffer from reduced range or performance.

Given the characteristics of HVO and its combustion properties, the Mercedes C 300 d 4MATIC (W 205) is expected to have a thermal efficiency in the upper range of typical diesel engine efficiencies.

Environmental Impact
One of the primary advantages of HVO is its environmental profile. Being derived from renewable sources, HVO can significantly reduce greenhouse gas emissions compared to conventional diesel. When combusted, HVO produces fewer particulates and other pollutants, making it a cleaner alternative. The Mercedes C 300 d 4MATIC (W 205), when powered by HVO, can be expected to have a reduced carbon footprint and lower tailpipe emissions compared to using conventional diesel [36].

Diesel Vehicles
Performance and Efficiency
Diesel engines are known for their high torque and fuel efficiency. The Mercedes C 300 d 4MATIC (W 205), being a representative of luxury diesel sedans, is designed to deliver robust performance, especially in terms of torque and fuel economy.

The efficiency of a diesel engine is often represented as thermal efficiency. Thermal efficiency ($\eta$) is calculated by comparing the useful work done by the engine to the energy content of the fuel consumed.

For diesel engines, typical thermal efficiencies range from 30% to 40%. This means that only about 30% to 40% of the energy in the diesel fuel is converted into useful work, while the rest is lost as heat.

Environmental Impact
While diesel engines are efficient, they have been under scrutiny for their environmental impact. Diesel combustion produces nitrogen oxides (NOx) and particulate matter, both of which have adverse effects on air quality and human health. The Mercedes C 300 d 4MATIC (W 205) and other modern diesel vehicles are equipped with advanced emission control systems to reduce these pollutants. However, the overall environmental impact depends on factors like driving conditions, maintenance, and the quality of the diesel fuel used [14].

Gasoline Vehicles
Performance and Efficiency
Gasoline engines, also known as Otto engines, have been the dominant power source for passenger cars for over a century. The efficiency of a gasoline engine depends on many factors, including engine design, fuel quality, and operating conditions. On average, the thermal efficiency of modern gasoline engines is about 20% to 30%. This means that only 20% to 30% of the energy stored in gasoline is converted into usable mechanical energy, while the rest is lost as heat.

Environmental Impact
Gasoline engines emit a range of pollutants, including carbon dioxide (CO2), nitrogen oxides (NOx), and volatile organic compounds (VOCs). CO2 is a greenhouse gas that contributes to global warming. Nitrogen oxides and VOCs can promote the formation of ground-level ozone, which is harmful to health and contributes to the formation of smog. However, modern gasoline engines are equipped with exhaust aftertreatment systems that significantly reduce the emissions of these pollutants. Nevertheless, CO2 emissions remain a central concern as they are directly linked to fuel consumption.

Methodology
Data Collection
In automotive research, data collection is a pivotal step that ensures the accuracy and reliability of the study’s findings. Various methods can be employed, including:

- Surveys and Questionnaires: These are often used to gather information on consumer preferences, driving habits, and perceptions about different vehicle technologies.
- Experimental Data: This involves controlled experiments, often in a lab setting, to test specific vehicle components or full vehicles under standardized conditions.
- Field Tests: Real-world testing of vehicles to gather data on performance, efficiency, and other parameters in various driving conditions.
- Database Analysis: Analyzing existing databases, such as vehicle registration, accident reports, and fuel consumption records, can provide valuable insights.

Analytical Techniques
Once data is collected, it needs to be analyzed to derive meaningful insights. Some of the common analytical techniques in automotive research include:

- Statistical Analysis: Using tools like regression analysis, hypothesis testing, and variance analysis to identify patterns and relationships in the data.
- Simulation: Computer-based models can simulate vehicle performance, traffic scenarios, or even predict future trends based on current data.
- Comparative Analysis: Comparing data from different vehicle models, technologies, or even countries to identify best practices or areas of improvement.

Assumptions and Limitations
Every research study comes with its set of assumptions and limitations. In the context of automotive research, some potential assumptions might include:

- Assuming that driving conditions (like road quality, traffic density, and weather conditions) remain constant during field tests.
- Assuming that drivers’ behavior does not change significantly over time.

Limitations could be:

- Limited sample size for surveys or experiments, which might not be representative of the larger population.
- Potential biases in data collection methods.
- The rapidly evolving nature of automotive technology might make some findings obsolete in a short span.

Results and Discussion
Key Findings
The automotive industry has been undergoing a propulsion system electrification revolution, aiming to improve energy efficiency and
reduce dependence on fossil fuels [57]. Electric vehicles (EVs), such as the Tesla Model 3 Long Range, have shown significant advancements in energy consumption and battery degradation management. The use of Q-learning strategies in EVs has been found to slow down battery degradation by 13-20% and increase the vehicle range by 1.5-2% compared to vehicles without ultracapacitors [57].

On the other hand, vehicles like the Mercedes C 300 d 4MATIC and Mercedes C 200 4MATIC, which rely on diesel and gasoline respectively, have their own sets of advantages and challenges. The energy-optimal design and control of transmissions in electric vehicles can lead to a reduction in energy consumption by 3% and 2.5% compared to fixed-gear transmission and continuously variable transmission, respectively [21].

Hydrogen fuel cell vehicles, represented by the Hyundai Nexo, present a different set of dynamics. While they offer the promise of zero-emission driving, their efficiency and performance metrics differ from traditional EVs and internal combustion engine vehicles.

- **Electric Vehicles (Tesla Model 3 Long Range):** Electric vehicles, particularly the Tesla Model 3 Long Range, have shown significant advancements in battery technology, allowing for extended ranges and faster charging times. The energy efficiency of EVs is notably higher than traditional combustion engines, with the Tesla Model 3 boasting an impressive energy consumption rate [43].

- **Hydrogen Fuel Cell Vehicles (Hyundai Nexo):** Hydrogen vehicles like the Hyundai Nexo offer a promising alternative to traditional fuels. They produce zero emissions at the tailpipe, with water being the only byproduct. However, the efficiency of converting electricity to hydrogen and back to electricity in the vehicle is currently lower than directly using electricity in EVs [7].

- **HVO Vehicles (Mercedes C 300 d 4MATIC):** HVO, or Hydrotreated Vegetable Oil, is a renewable diesel fuel. The Mercedes C 300 d 4MATIC, when powered by HVO, can reduce greenhouse gas emissions significantly compared to conventional diesel. However, the availability and production scale of HVO currently limit its widespread adoption [36].

- **Petrol Vehicles (Mercedes C 200 4MATIC):** Traditional gasoline engines, as seen in the Mercedes C 200 4MATIC, have undergone numerous refinements over the years to improve their efficiency. However, in terms of emissions and overall energy efficiency, they still lag behind their electric and hydrogen counterparts [38].

**Interpretation and Implications**

The transition to cleaner and more efficient propulsion systems is evident. EVs, with their rapid advancements in battery technology and energy management systems, are at the forefront of this transition. The ability to manage battery degradation and improve vehicle range makes them a viable option for the future [57].

However, traditional gasoline and diesel vehicles, represented by the Mercedes models, are not to be discounted. With advancements in transmission design and control, these vehicles can achieve comparable energy efficiencies [21]. The choice of propulsion system, therefore, depends on various factors, including regional incentives, infrastructure availability, and individual driving patterns.

Hydrogen fuel cell vehicles, though in their nascent stages, offer a promising future, especially in regions where hydrogen production and infrastructure are being developed.

In conclusion, the automotive industry is at a crossroads, with multiple viable propulsion systems available. The choice of system would depend on a combination of technological advancements, infrastructure development, and policy decisions.

The transition to sustainable transportation is multifaceted, with each propulsion method offering its unique advantages and challenges. Electric vehicles, represented by the Tesla Model 3, are at the forefront of this transition, offering high efficiency and reducing greenhouse gas emissions. However, the environmental impact of battery production and electricity generation must be considered [10].

Hydrogen vehicles, like the Hyundai Nexo, provide a clean alternative but face challenges in production, storage, and distribution of hydrogen. The energy-intensive process of producing hydrogen currently limits its environmental benefits [55].

HVO, as seen with the Mercedes C 300 d 4MATIC, offers a bridge between traditional diesel and renewable fuels. While it significantly reduces emissions, its production scale and feedstock sources are potential challenges [31].

Lastly, while petrol vehicles, such as the Mercedes C 200 4MATIC, have been the mainstay for decades, their environmental impact in terms of emissions is a growing concern. Advancements in fuel efficiency and emission control technologies have mitigated, but not eliminated, these concerns [30].

**Conclusion**

**Summary of Findings**

The automotive industry is in the midst of a transformative phase, with a clear shift towards sustainable and efficient propulsion systems. Electric vehicles (EVs), such as the Tesla Model 3 Long Range, have emerged as frontrunners in this transition, offering impressive energy efficiencies and reduced emissions [42]. The advancements in battery technology and energy management systems have significantly improved the range and performance of EVs.

Hydrogen fuel cell vehicles, like the Hyundai Nexo, while still in their early stages, present a promising alternative to traditional internal combustion engines. Their zero-emission driving capability and potential for rapid refueling make them an attractive option for future transportation [26].

Vehicles relying on diesel and gasoline, represented by the Mercedes C 300 d 4MATIC and Mercedes C 200 4MATIC respectively, continue to hold a significant market share. The introduction of HVO as a cleaner alternative to traditional diesel has the potential to reduce the environmental impact of diesel vehicles [56].

**Recommendations and Future Directions**

1) **Investment in Infrastructure:** For EVs and hydrogen vehicles to become mainstream, significant investments in charging and refueling infrastructure are essential. Governments and private entities should collaborate to expand this infrastructure [27].

2) **Research and Development:** Continued R&D in battery technology, hydrogen production, and HVO can lead to further improvements in efficiency, range, and sustainability [17].

3) **Policy Incentives:** Governments should provide incentives for consumers to adopt cleaner transportation options. This could include tax breaks, rebates, and subsidies for EVs, hydrogen vehicles, and vehicles using HVO [29].

4) **Public Awareness:** Raising public awareness about the benefits of sustainable transportation options can drive consumer demand and accelerate the transition to cleaner propulsion systems [8].

In the long run, a combination of these propulsion systems, tailored to specific regional needs and infrastructure, will likely dominate.
the automotive landscape. The focus should be on adopting a holistic approach, considering environmental, economic, and societal factors.

References
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54. “When the hydrogen-powered Hyundai Nexo car was launched in the UK in the spring of 2019, it was described as so beautifully clean that it purifies the air as it goes. Hyundai Motor UK claimed that if 10,000 of its cars were on the road, carbon emission reduction would be equivalent to planting 60,000 trees.” Web Source. [Online]. Available: https://www.link-to-source.com/.

