

# Comparative Analysis of Traditional and Alternative Engines: Advancements and Impacts on Sustainability

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**Abstract.** Traditional internal combustion engines (ICEs) have accompanied humans for a long time and have developed to contain good performance and high reliability. However, the emissions of traditional engines play a big role in environmental pollution, which goes against the most important tenet of human development—sustainable development. To radically deal with this concern, alternative engines have been invented and developed these years instead of further study of traditional engines. Alternative engines, including hybrid, fuel cell, and electric engines, are designed to convert energies from renewable resources to reduce greenhouse gas (GHG) emissions. Alternative engines are also beneficial for saving costs of fuel because of their higher fuel efficiency, which is a valuable factor for choosing a vehicle with such an engine as the family car. Each kind of alternative engine has its drawbacks, such as the high maintenance rate of hybrid engines, limited driving range of battery electric vehicles (EVs), and possibly high GHG emissions of fuel cells. These are factors for the comparison of engines and should be considered when choosing an engine that is suitable for a specific situation.

**Keywords:** Traditional internal combustion engines, alternative engines, sustainable development.

## 1. Introduction

An engine or a motor is defined as a machine to convert many forms of energy into mechanical energy. In 1853, the first real internal combustion engine (ICE) was invented by Father Eugenio Barsanti and Felice Matteucci, and in 1885, Carl Benz built his Benz Patent Motorcar, which was widely regarded as the first practical modern automobile and the first car that put into series production. From then on, engines have played a pivotal role in human development by powering transportation, industry, and agriculture, thus enhancing efficiency and productivity across various sectors. They have revolutionized manufacturing and farming, enabled reliable energy generation, and improved the quality of daily life. By driving economic growth and technological advancements, engines have become fundamental to modern society, underscoring their importance in our continuous progress and development.

Traditional ICEs, including spark ignition (SI) engines and compression ignition (CI) engines, are still the most popular engines that are used for vehicles today. The spark ignition engine is also called the gasoline engine. As its name suggests, it uses gasoline as a resource and needs a spark plug to ignite the whole system. Compared to the compression ignition engine, the SI engine has higher power output, such that it has quicker acceleration and higher performance. It also has lower emissions, and its combustion process is smoother and quieter, contributing to a better driving experience. Therefore, SI engines are mostly used for passenger vehicles and sports cars.

The compression ignition engine uses diesel oil as a resource, so it is also known as a diesel engine. CI engine ignites the fuel by the high pressure and the high temperature caused by compression instead of using the spark plug. Diesel fuel contains more energy per unit than gasoline, and the CI engine has a higher compression ratio than the SI engine, these allow the CI engine to have higher fuel efficiency and more torque at low RPM. As a result, CI engines are usually used for trucks and buses, which need large power and durability to carry heavy things for long distances.

Although there are many differences between SI engines and CI engines, they are both traditionally ICEs. When compared to alternative engines, their pros and cons can be treated as the same. For

example, both of them have lower fuel efficiency and higher emissions, so they heavily pollute the environment. The usage of traditional engines over a century has produced huge amounts of emissions that went against sustainable development. That is the main reason why alternative engines are designed and considered to replace traditional ones [1].

## 2. Alternative Engine

Alternative engines, which include hybrid, battery electric, and fuel cell electric engines, represent a shift towards more sustainable and environmentally friendly technologies. Unlike traditional ICEs that rely on fossil fuels, these alternatives aim to reduce emissions and dependence on non-renewable resources. As concerns about climate change and resource depletion, the development and adoption of alternative engines are becoming increasingly important in the quest for cleaner and more efficient energy solutions.

The hybrid engine is the most similar to the traditional ICEs among alternative engines. It is a system that combines an ICE with an electric motor. The electric motor has high efficiency at low speed, so a hybrid engine mainly uses an electric motor when the car starts to accelerate. Thus, a hybrid engine has higher fuel efficiency than traditional engines, even though it also has an ICE part [2]. The electric motor also has a special process called regenerative braking, which further enhances fuel efficiency. For traditional vehicles, much kinetic energy is wasted when braking. However, an electric motor, based on Faraday's Law, generates electric energy when the car moves by its inertia without stepping on the gas. The electric motor becomes an electric generator at this moment on which the remaining kinetic energy of the vehicle exerts the force. Then this electric energy is stored back into the battery for the electric motor to use later.

An electric engine is just an electric motor with a battery as a resource. It offers substantial environmental benefits by producing zero tailpipe emissions. As the electricity grid becomes greener in recent years, the overall emissions associated with electric vehicles (EVs) continue to decrease [3]. EVs also present cost savings through zero fuel costs and reduced maintenance due to fewer moving parts. Electric motors, whose efficiency can reach over 70%, are more efficient than ICEs, where efficiency is about 25%-30% for SI engines and 30%-40% for CI engines, converting a higher percentage of energy from the battery into motion. This efficiency translates to lower operational costs and fewer maintenance requirements since EVs do not require oil changes, exhaust system repairs, or other traditional engine maintenance [4]. Performance-wise, electric engines deliver instant torque and quiet operation, providing quick acceleration and a smooth driving experience. This characteristic makes EVs particularly suitable for urban driving, where frequent stops and starts are common.

Fuel cell engine operates by converting hydrogen and oxygen into electricity and provide power output by an electric motor, with water and heat as the only two products. This process results in low chemical, thermal, and also acoustic pollution. Therefore, fuel cell engine is considered the alternative to traditional engines considering its friendly environmental impact [5]. Fuel cells have the flexibility of modularity and siting, allowing them to be used in a variety of applications, from passenger vehicles to heavy-duty trucks and stationary power generation. They require low maintenance due to the absence of moving parts, similar to EVs. Since an electric motor supports a fuel cell vehicle, it also has characteristics of quiet and smooth operation and high efficiency. According to the U.S. Department of Energy, hydrogen fuel cells have the potential to achieve efficiencies of 60% or higher in automotive applications.

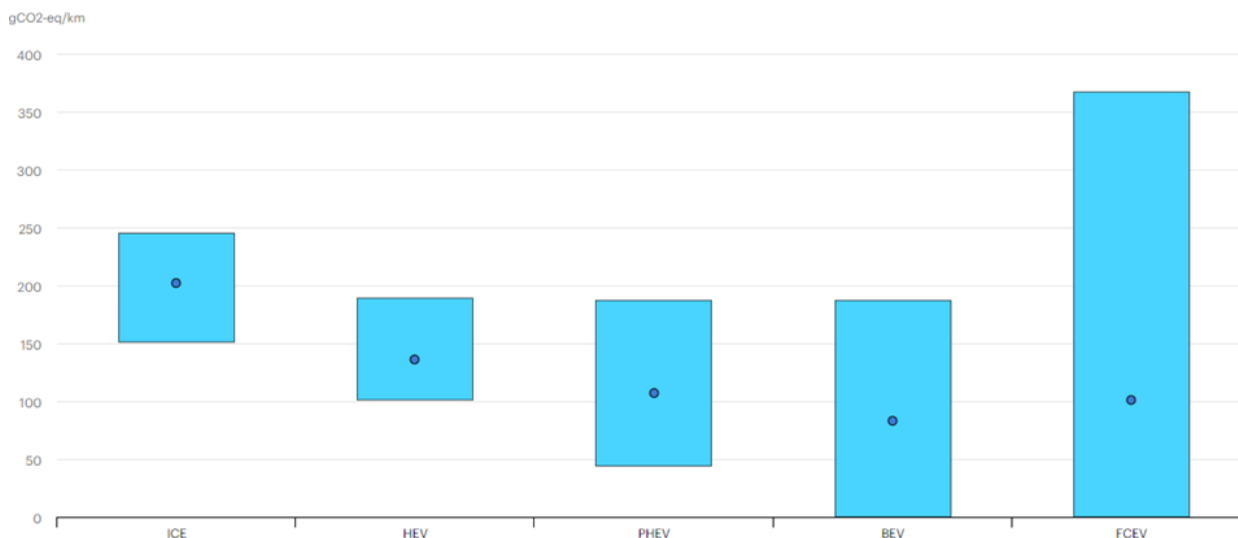
### 3. Comparisons of Each Kind of Engine

Compared to traditional engines, all alternative engines have the advantages of higher energy efficiency, higher fuel efficiency, more friendly environmental impact, as well as quieter and smoother operation. However, each kind of engine has its disadvantages that need to be considered when comparing and applying them [6].

The main characteristic of a hybrid engine is its electric motor, which is responsible for low-speed acceleration. When the vehicle moves at high speed, the ICE starts to work, and the electric motor stops providing power. As a result, on highways, hybrid vehicles do not have significant benefits in fuel efficiency compared to vehicles with traditional engines. Another point is that the hybrid system, including an ICE, an electric motor, and connection components, is much more complex than other kinds of engines. As a result, it needs more frequent maintenance and more cost for this at the same time. Its complexity also makes the hybrid engine larger and heavier, so how to deal with this unwieldy engine becomes a big problem when applying it, especially for small vehicles [7].

Electric engine faces challenges such as range anxiety due to limited driving range compared to traditional vehicles. The availability of charging infrastructure is still developing, although it is rapidly expanding in many regions. Public charging stations, home charging solutions, and workplace chargers are becoming more common, but they are not yet as ubiquitous as gasoline stations [8]. The charging time is also much longer than refilling the fuel, where fast chargers can replenish an EV's battery to 80% in about 30 minutes and standard home chargers take even several hours to charge a battery fully. There is a good solution to deal with such a challenge, which NIO EVs have used in China: All models of NIO EVs use the same size and specification of batteries, then the company builds thousands of stations in most areas of China which have prepared full-charged batteries for the coming EVs. There are artificial intelligence robots in these stations that are connected to the computers inside EVs. Once the driver parks the EV in an NIO charging station and speaks to its computer: "Switch the battery." the robot will immediately take the battery out of the EV and then put in a full-charged battery to replace that. This method effectively solves the problem of long charging time and limited driving range for EVs to travel long distances.

Fuel cell engines are theoretically beneficial to the environment, as mentioned above, but in real life, they cannot ideally perform as expected. Fuel cell engine has high fuel costs where the production, storage, and distribution of hydrogen remain significant challenges. Hydrogen is typically produced from natural gas, which involves carbon emissions, although green hydrogen production methods using renewable energy are being developed these years. Inappropriate use of fuels, such as fossil fuel-derived hydrogen, which will emit CO<sub>2</sub> as they remain, can negate the environmental benefits of fuel cells [9]. To realize their full potential, fuel cells must be integrated into a broader strategy that includes renewable energy sources and efficient hydrogen production methods. Another consideration is the durability and longevity of fuel cell systems. The current generation of fuel cells has a limited lifespan, typically around 5,000-10,000 hours of operation, which can be a barrier for commercial applications. Fuel cell vehicles are also expensive to manufacture due to the high cost of fuel cell stacks and hydrogen storage systems, and the lack of widespread hydrogen refueling infrastructure further limits their adoption.



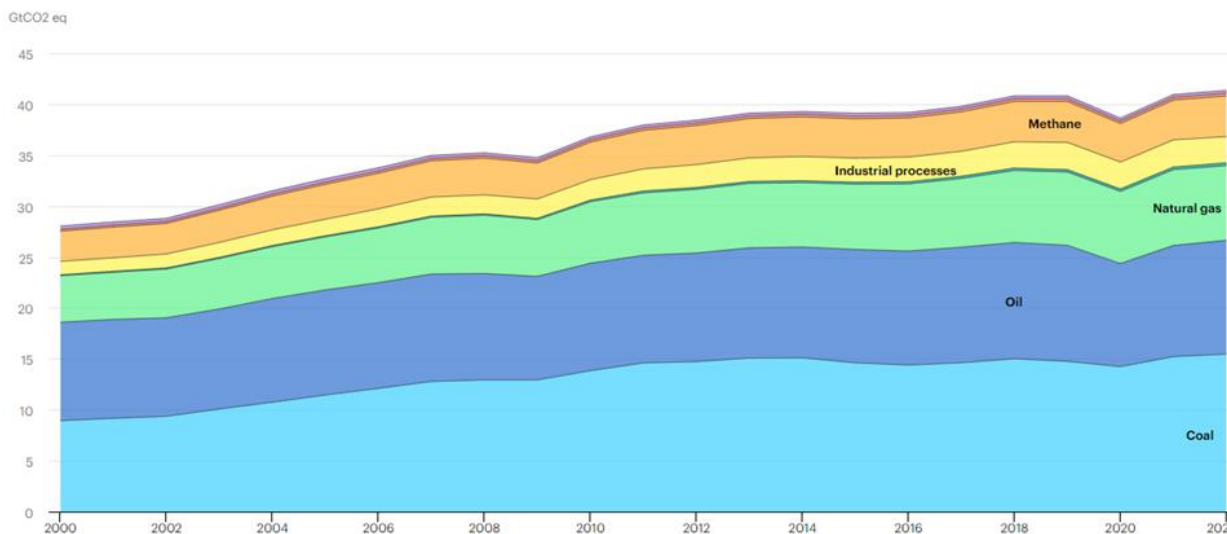
**Fig. 1** Well-to-Wheel greenhouse gas emissions of each engine, reproduced from the website: <https://www.iea.org/data-and-statistics/charts/well-to-wheels-greenhouse-gas-emissions-for-cars-by-powertrains>

Fig. 1 shows the comparison of well-to-wheel CO<sub>2</sub> emissions of each kind of engine, where the bars indicate the range of emissions from possible maxima to minima, and the points refer to the world average value. A well-to-wheel analysis considers the entire lifecycle of the vehicle, including upstream emissions (fuel production and distribution), operational emissions (driving), and downstream emissions (maintenance and end-of-life disposal). As expected, alternative engines all have a lower range and average value of GHG emissions. However, it should be noticed that fuel cell engine has a large range, where sometimes it may produce very high emissions, even higher than traditional engines. The reason that has been mentioned above is the inappropriate usage of fuels like fossil fuel-derived hydrogen. This process mainly indicates methane reforming (SMR) or coal gasification. These two reactions have similar paths to generate CO<sub>2</sub>. For example, in SMR, natural gas (methane) reacts with steam under high pressure to produce hydrogen, carbon monoxide (CO), and a small amount of CO<sub>2</sub>. The carbon monoxide then reacts with steam in a water-gas shift reaction to produce additional hydrogen and CO<sub>2</sub>. As a result, fuel cells are not as stable as other kinds of engines in the aspect of resources and emissions.

Electric resources purely support battery electric vehicles, so they do not have tailpipe emissions, meaning that they do not emit GMGs or other pollutants while being driven. That is why the minimum limit of BEV in Figure 1 can reach 0. However, it also has a maximum limit that is almost the same as a hybrid engine, which is mainly caused by the production of batteries. Lithium-ion batteries are the best selection for EVs because of their large capacity and high stability, where the production of them is energy-intensive. Mining, refining, and processing raw materials such as lithium, cobalt, and nickel require significant energy, often sourced from fossil fuels [10].

#### 4. Development of Engines Based on Resources and Requirements in the Future

According to the data collected by the International Energy Agency (IEA), today, the remaining fossil fuel resources are still sufficient, such that the choice of engines does not have to depend on resources. However, the requirement for less emissions and better environmental protection stimulates the continuous development of alternative engines. According to Fig. 2, oil, natural gas, and methane, which are resources for traditional ICEs, hybrid, and fuel cell engines, have been increasing from 2000 to 2022. They occupy a large percentage of GMG-related energies, so vehicles with those engines still contribute a lot to air pollution. Therefore, for better sustainable development, battery EVs are the most appropriate alternative rather than other kinds of engines.



**Fig. 2** Global energy-related greenhouse gas emissions, 2000-2022, reproduced from the website: <https://www.iea.org/data-and-statistics/charts/global-energy-related-greenhouse-gas-emissions-2000-2022>

## 5. Conclusion

Engines have been one of the cores of human development since it was invented, which are closely related to many aspects such as industry innovation, transportation, and even the life quality of all individuals. The ongoing evolution of engine technologies always focuses on improving the balance of performance, efficiency, as well as environmental impact. Traditional ICEs have powered human development for over a century but are now recognized for their substantial contributions to GHG emissions and environmental pollution. In response, alternative engines—hybrid, battery electric, and fuel cell engines—aim to reduce emissions and reliance on non-renewable resources. Hybrid engines offer improved fuel efficiency and lower emissions, particularly in urban driving scenarios. Battery EVs make reformation by using electric motors to totally replace ICEs, which is the only kind of engine with zero tailpipe emissions. Fuel cell engines are designed to generate electric energy as their energy supply through chemical reactions of hydrogen and oxygen, which are clean and renewable resources. However, challenges such as limited driving range, long charging times, and hydrogen production issues remain, which are the goals for research of engineering, materials and resources in the future.

Despite sufficient fossil fuel resources, the need to mitigate climate change and reduce air pollution necessitates a shift towards sustainable energy solutions. Battery EVs, with their potential for zero tailpipe emissions and decreasing lifecycle emissions, are the most promising option for replacing traditional engines. They are also the most appropriate choice for driving in urban areas because of their extremely low cost for energy supply. Continuous innovation and supportive infrastructure development are essential for ensuring that alternative engines not only replace traditional ICEs but also contribute to a cleaner, more sustainable future.

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