Battery or engine? Which one is truly more environmentally friendly?

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Research Question:
How does the carbon footprint of an electric vehicle differ from an internal combustion engine vehicle, and which batteries help make that happen?

Abstract:
While electric vehicles (EVs) and traditional cars may look similar on the outside, they are completely different on the inside. EVs are battery-powered, whereas internal combustion engine (ICE) vehicles are powered by fossil fuel combustion. EVs utilize an electric motor powered by a battery, whereas ICE vehicles have a traditional engine that uses gasoline or diesel. EVs produce zero emissions, reducing air pollution, while ICE vehicles emit carbon dioxide and other pollutants, contributing to global warming and air quality issues. Several types of batteries have been used to power EVs since their inception, each with its own strengths and limitations. The most commonly used batteries in EVs are lithium-ion (Li-ion). They have a high energy density and low self-discharge coefficients. High self-discharge coefficients can lead to wasted energy and reduced range. High-energy density batteries provide more range and/or performance for the same size. Sealed lead-acid (SLA) batteries, also used in early EVs, are inexpensive but suffer from low energy density and a shorter lifespan than Li-ion batteries. These limitations make them less suitable for modern EVs that require higher performance and range. Although it may seem like EVs are more environmentally friendly than ICE vehicles on the surface, the use of different types of batteries in EVs plays a crucial role in determining their efficiency and sustainability. As technology continues to evolve, batteries will remain a critical aspect of the future of electric mobility and reducing the carbon footprint of transportation.

Introduction:
To fully appreciate the growing appeal of electric vehicles (EVs), one must first understand the evolution of the personal vehicle and the alternative possibilities available. At the turn of the twentieth century, horse-drawn carriages were still the dominant form of transportation. However, by 1915, consumers readily adopted the newly invented automobile. The traditional automobile has an internal combustion engine (ICE) that requires fossil fuel for power. The engine ignites and burns the fuel, and, and the energy produced from this process is then partially converted into work to move the car. However, this process is not without its disadvantages: loud noises, air pollution, fuel, and heavy maintenance are just some of the reasons why combustion engines will not be viable forever.

To overcome these disadvantages, in the 1830s, researchers began to study EVs. EVs are quiet, easy to drive, and do not produce odorous pollutants. This led to EVs swiftly gaining popularity among city dwellers by the second half of the 19th century [1]. Figure 1 evaluates the differences between these two vehicles. There are a number of similarities and differences between EVs and ICEs. EVs boast increased energy, less maintenance, less fossil fuel dependence, and a lower cost per mile than ICE powered vehicles.

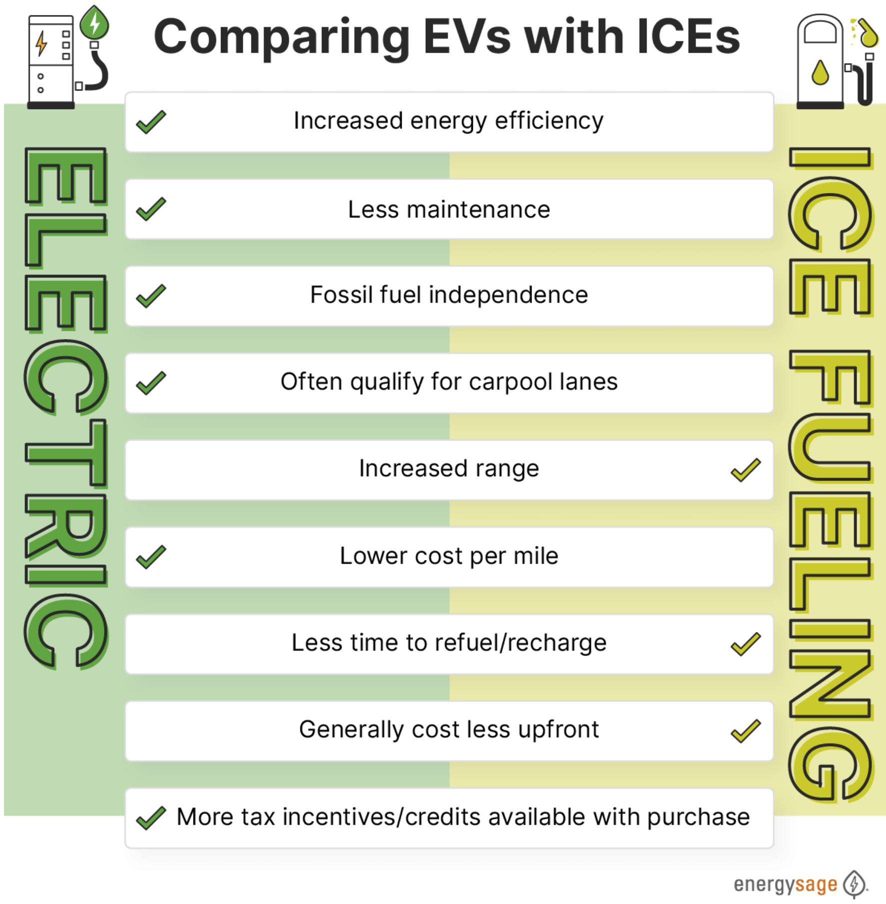

Figure 1 - The advantages of EVs over ICEs. Based on the image, buying an EV has more benefits.
Source: Adapted from [4]

Today, EVs are becoming more popular. One of their main benefits is the absence of greenhouse gases emissions, like carbon dioxide and methane, due to the lack of an ICE. Figure 2 presents a graph comparing EVs vs ICEs and their effects on global warming emissions. Driving an EV over a gas-powered car reduces carbon emissions by about 52% over the lifecycle of a car and 57% for trucks. Blue represents the amount of CO_2 released per mile from manufacturing the battery of an EV, orange represents the amount of CO_2 released per mile by the manufacturing of the vehicle (excluding the battery), and gray represents the amount of CO_2 released per mile by vehicle over its lifespan.

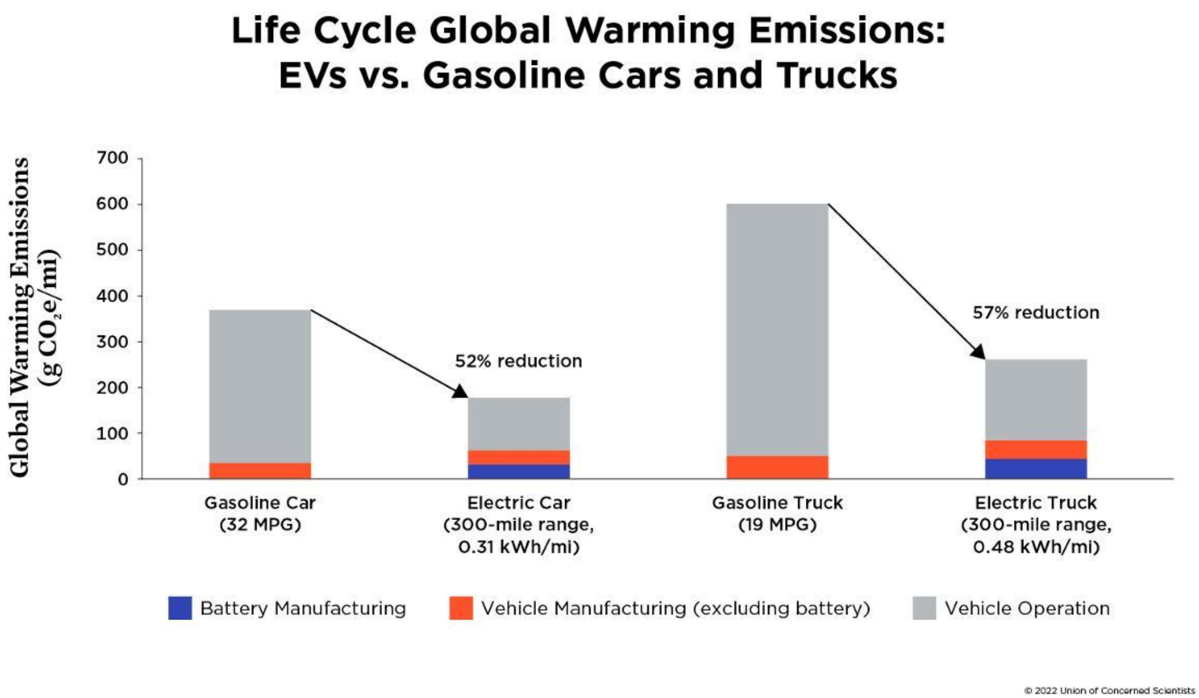

Figure 2 - The graph shows the total CO_2 emissions of gas-powered cars and trucks in gCO_2e/mi (grams of carbon dioxide equivalents per mile). The different colors of each bar represent the amount of CO_2 that is produced by a specific part of the vehicle. Source: Adapted from [18]

Due to the lack of complicated transmissions, exhaust systems, and other standard engine parts, like pistons, crankshafts, and camshafts, EVs have fewer maintenance requirements. The decreased maintenance requirements result in consumers spending less money on service and parts [2].

Table 1: Maintenance costs per mile and over 45,000 miles for two ICE vehicles and their respective electric counterparts [3].

Car make/model	Maintenance costs per mile	Maintenance costs per mile for 45,000 miles
Hyundai Kona:	$0.0984 per mile	$4,428
Hyundai Kona Electric	$0.0794 per mile	$3,573
Ford F-150	$0.0933 per mile	$4,199
Ford F-150 Lightning	$0.0794 per mile	$3,573

Additionally, unlike gas cars, EVs are powered by a rechargeable battery instead of an engine. The electricity required to charge the battery in an EV is relatively cheap. In comparison, the average ICE vehicle costs almost three times as much per year to refuel [4]. Another advantage of EVs is that they are inherently safer than ICE-powered vehicles due to their low center of gravity. In most commercial ICE-powered vehicles, the engine is near the top and front of the car, as shown in Figure 3. A front-engined car that is front-wheel drive improves traction by putting more weight over the wheels that move the vehicle. It is also more power efficient as less energy is wasted due to the short distance between the engine and wheels [5].

Figure 3 - A schematic that depicts that the engine is located in the front of the car for ICE vehicles. In most ICE-powered vehicles, the engine is placed at the front of the car. This allows the engine to be easily accessed and leads to better traction.
Source: Adapted from [19]

In EVs, the battery is located at the bottom of the car, closer to the ground mainly to evenly distribute the weight of the battery pack itself and to allow for a lower center of gravity which leads to better handling [6].

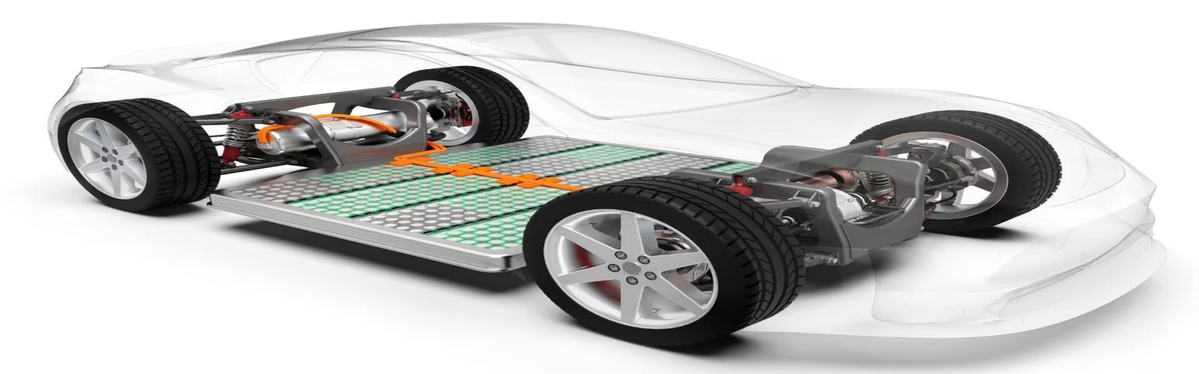

Figure 4 - The battery for an EV is located at the bottom of the car.
Source: Adapted from [20]

The increased mass beneath the EV decreases the probability of the car tipping over [7]. Soon enough, batteries will deliver the same amount of performance in a smaller and lighter size, thereby eliminating the fear of EVs being too heavy. Traffic safety is especially important: according to a 2011 study published by the National Bureau of Economic Research, the "baseline fatality probability" increases 47% for every 1,000 additional pounds in the vehicle, and the fatality risk is even higher if the striking vehicle is an SUV, pickup truck, or minivan [8]. Researchers are already experimenting with structural batteries; batteries that are built into the the structure of the car itself, rather than packed into the floor of the vehicle [9]. Since the area of the battery is larger, there is more power to drive the car without changing the overall footprint of the vehicle. This increased driving range is a departure from the constraints of gas-powered engines and represents a significant step toward attaining sustainable and efficient transportation.

Background:
Lithium-ion (Li-ion) and sealed lead-acid (SLA) batteries are the two most commonly used battery types for the majority of electric vehicles. In order to assess the performance of these chemicals in different EV batteries, there are a number of standard metrics used by manufacturers and researchers. One of these standards is weight. Compared to an SLA battery, a Li-ion battery weighs more than a lead-acid battery [10].

Another commonly used metric is battery cycles, which can predict the lifespan of a battery. A battery with a 500-cycle lifespan can last 500 charging cycles. A charge cycle is measured as a battery going from fully charged to dead. The projected number of charge cycles can never guarantee how long a battery will survive. This is because other factors, such as the temperature the battery is subjected to and how well it is maintained, come into play [11]. Most Li-ion batteries must be operated within 15–35°C (59–95°F) [12] while most SLA batteries operate at 25°C (77°F); every 8°C (15°F) rise in temperature will cut an SLA battery’s life in half [13].

Discussion:
While EV batteries are still being optimized, they have already been employed in the commercial market. A common issue with Li-ion batteries is that, unlike mechanical engines, they undergo chemical aging. This means that after 12-15 years, drivers will have to replace their battery, regardless of how well they were maintained. In the future, however, there may be higher-energy-density batteries that can hold more charge for the same size. To address the issue of chemical aging, EVs frequently come with warranties that cover a specific number of years or miles [14]. These warranties can alleviate concerns about battery replacement expenses during the first few years of ownership.

All batteries are subject to battery safety assessments and certification processes to ensure that they work safely in both normal and extreme settings. For example, off-roading and extremely hot or cold environments are some situations in which researchers and manufacturers test EVs before they begin mass production. These assessments test the battery under fluctuating temperatures, repetitive charging and discharging, and a full range of driving cycles [15].

Implementing battery technology into other industries improves grid stability, decreases dependency on fossil fuels, and promotes a more sustainable and resilient energy ecology. Batteries play a key role in the larger landscape of energy storage [16]. They make it easier to integrate renewable energy sources like solar and wind into the grid. This allows for the capture and storage of excess energy produced during peak production times for later use. Solar-panels can also be built into the roof of the car which charges the car whilst it's driving for free [17].

Conclusion:

To appreciate the rise of electric vehicles, one must grasp the evolution of personal transportation from horse-drawn carriages to early automobiles with internal combustion engines. EVs rely on rechargeable batteries instead of traditional engines. This offers cost-effective charging compared to the significantly higher annual refueling expenses of ICE vehicles. Additionally, EVs' enhanced safety is attributed to their low center of gravity, where the battery is positioned at the bottom of the vehicle. In contrast, in many ICE-powered cars, the engine is situated towards the top and front of the vehicle. A standard metric such as weight is used to compare battery chemistries in EVs. Li-ion batteries are typically heavier, leading to enhanced vehicle stability and safety in accidents. EV batteries currently face issues such as chemical aging, thus necessitating replacement after 12-15 years regardless of maintenance. Warranties are often issued to address these concerns. Manufacturers offer warranties covering a set number of years or miles to alleviate early replacement concerns, and future advancements in higher-energy-density batteries are expected to surpass the longevity and range of gas engines. The integration of battery technology into various industries also enhances grid stability, reduces reliance on fossil fuels, and fosters a more sustainable and robust energy ecosystem.

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