Systematic Analysis and Comparison Between Electric, Fuel and Hybrid Drive Technologies

Yifan Zhai

Shanghai United International School, Wanyuan Campus, Shanghai, 201103, China
1207659@wy.suis.com.cn

Abstract. Against the backdrop of intensifying global climate change and energy crises, the energy transition in the transportation sector has become a global focus. Automotive power system technologies are evolving along diversified pathways, with traditional internal combustion engine vehicles, pure electric vehicles, and hybrid electric vehicles emerging as the primary types. This paper systematically analyzes the driving principles, technical characteristics, and performance differences among these three power systems, comparing them across multiple dimensions such as power output, acceleration performance, high-speed performance, energy replenishment convenience, and environmental impact. The results indicate that pure electric vehicles demonstrate significant advantages in energy efficiency and environmental protection, fuel vehicles remain practical in terms of range and energy replenishment, while hybrid vehicles excel in balancing sustainability and practicality, serving as an ideal transitional solution at this stage. This study provides a basis for consumer decision-making and offers insights for industrial policy formulation. And accelerating the coordinated development of diversified automotive power systems will provide a solid foundation for achieving green transportation and sustainable development goals.

Keywords: Pure electric vehicles, Hybrid electric vehicles, Fuel vehicles, Driving principles, Performance comparison

1 Introduction

With the intensification of global climate change and energy crises, the energy transition in the transportation sector has become a focal point of global attention. As an indispensable means of transportation in modern society, the technological development path of automotive power systems is showing a trend of diversified development. According to the International Energy Agency, global new energy vehicle sales exceeded 14 million units in 2024, marking a 35% year-on-year increase, with China accounting for 60% of the market share [1]. With growing environmental awareness and structural transformations in energy systems, the dominance of traditional fuel vehicles has been disrupted, while alternative power systems such as electric vehicles and hybrid vehicles are gradually becoming crucial components of the market [2]. Based on different power sources and driving methods,

S. Zhang (ed.), *Proceedings of the 2025 International Conference on Electronics, Electrical and Grid Technology (ICEEGT 2025)*, Advances in Engineering Research 292,
https://doi.org/10.2991/978-94-6463-986-5_96

modern vehicles can be primarily categorized into three types: internal combustion engines, pure electric vehicles, and hybrid vehicles, each with unique operational principles and applicable scenarios.

A thorough understanding of the driving principles, technical characteristics, and differences between various automotive powertrains not only enables consumers to make informed purchasing decisions tailored to their specific needs, but it is also critical for understanding the automotive industry's future development direction. This study examines the driving principles, technological aspects, and present development status of three primary powertrain types: internal combustion engines, pure electric vehicles, and hybrid electric vehicles. Comparative studies are conducted on a variety of parameters, including functioning principles, energy efficiency, and environmental impact.

2 Comparative analysis of vehicle power supply modes

As an essential method of transportation in modern civilization, the technological development route of automotive power systems is indicating a trend toward diverse evolution [3]. The dominance of traditional fuel vehicles has been challenged by rising environmental awareness and energy structural transformation, while electric and hybrid electric vehicles have steadily emerged as key market components. Modern automobiles are divided into three groups based on their power sources and driving methods: gasoline-powered cars, pure electric vehicles, and hybrid electric vehicles. Each category has distinct operational concepts and application possibilities.

A thorough understanding of the driving principles, technical features, and differences between various automotive powertrains not only assists consumers in making informed purchasing decisions tailored to their specific needs, but it is also critical for understanding the automotive industry's future development direction. This article thoroughly examines the power drive mechanics of these three types of cars, doing comparative assessments across numerous parameters to give comprehensive and impartial technical references.

2.1 Fuel vehicles

Gas-powered cars use internal combustion engines to generate power by combusting gasoline or diesel. The operating concept involves fuel being ignited and exploded in the engine cylinders, resulting in high-pressure gas that causes piston movement. This linear motion is transformed to rotational motion by the crankshaft, which then sends power to the wheels via transmission components such as clutches, transmissions, and drive shafts, driving the vehicle forward [4].

A fuel-powered vehicle's core working process consists of four strokes: intake, compression, power generation, and exhaust. During the intake stroke, the piston lowers while the intake valve opens, allowing the combustible mixture to enter the cylinder. During the compression stroke, the piston rises while compressing the mixture, raising pressure and temperature. The power generating stroke uses spark plug ignition to ignite the compressed gas, resulting in high-temperature, high-pressure gas that propels the piston downward for mechanical work. Finally, during the exhaust stroke, the piston rises as the exhaust valve opens, releasing the combustion gases from the cylinder. This continuous cycle generates and distributes power output [5].

2.2 Pure electric vehicles

Pure electric vehicles run purely on electricity, and their power system consists of a battery pack, motor controller, and traction motor. The driving mechanism operates as follows: The battery pack provides direct current (DC), which is converted to alternating current (AC) by an inverter to power the motor. The torque generated by the motor is then delivered to the wheels via components such as a gearbox and drive shaft, propelling the vehicle forward [6].

Electric vehicles use two power transmission pathways: energy from the battery travels through the controller to the motor, which powers the wheels. When braking, the motor shifts to generator mode, which converts kinetic energy into electrical energy that is stored in the battery. This regenerative braking device can increase a vehicle's range by 15-25% after just one charging.

2.3 Hybrid electric vehicles

Hybrid electric vehicles use two power systems: an internal combustion engine and an electric motor. They can be classified as series, parallel, hybrid, plug-in hybrid (PHEV), range extended hybrid (EREV), or other types based on their construction and operating mode.

The series hybrid system is driven by an internal combustion engine to generate electricity, which is communicated to the battery pack through the control unit, and then powered by the battery pack to the motor, which finally powers the vehicle. In this technology, the internal combustion engine does not directly participate in driving, and always functions in the high efficiency band [7].

A parallel hybrid combines a traditional internal combustion engine system with an electric motor drive system that can either work together or drive the car independently. Typically, the electric motor drives the vehicle at low speeds and starts, but the internal combustion engine drives the car at high speeds or when significant power is required. Hybrid power combines the benefits of serial and parallel structures. The power distribution device allows the power output ratio of the engine and motor to be easily adjusted to ensure maximum efficiency under a variety of working situations.

The EREV is essentially a series hybrid, but with a larger battery capacity and support for external charging. The vehicle uses battery power as the primary driver, and when the battery is low, the internal combustion engine starts to generate electricity to charge the battery, but does not directly participate in driving [8]. The PHEV combines pure electric and hybrid modes, with a large battery capacity, support for external charging, a pure electric range of 50-200 km, and can be switched to hybrid mode when the battery is exhausted.

The hybrid system also has energy recovery function, which converts kinetic energy into electricity and stores it during braking and sliding to improve energy utilization efficiency.

3 Performance comparison analysis

3.1 Power performance

Acceleration performance. Pure electric vehicles: The instantaneous torque characteristics of electric motors give them a substantial advantage in beginning and low-speed acceleration. For example, the Tesla Model S can achieve 0-100 km/h in 2.7 seconds, and the Audi R8 e-tron also achieves 3.5 seconds.

Fuel vehicles: The engine and gearbox combination and modification have a significant impact on the vehicle's acceleration capability. Performance-oriented fuel vehicles, such the Ford Mustang, can accelerate 100 kilometers in approximately 5.45 seconds [9].

Hybrid Vehicles: Acceleration performance depends on the system's combined power and energy management strategies. Some hybrid models prioritize fuel efficiency (e.g., Toyota Prius), while others deliver strong performance like the BYD Tang DM with a combined power output of 580 horsepower and a 0-100 km/h acceleration time of just 4.5 seconds. The Roewe D7 DMH's DMH Super Hybrid System adapts to various driving scenarios and complex road conditions, featuring a 1.5T turbocharged hybrid-specific engine with thermal efficiency exceeding 43% [10].

High speed performance. Pure electric cars: The motor's power output may be constrained at high speeds, and wind resistance rises during high-speed driving, resulting in a markedly higher energy consumption and possibly a less intense power sensation than initially.

Fuel vehicles: Internal combustion engines can usually maintain a high efficiency range at high-speed cruise, with stable power output and reasonably large acceleration capacity in the rear.

Hybrid Electric Vehicles: In situations involving fast driving, hybrid systems may be powered wholly or mostly by the engine. This setup solves the energy consumption issues of fully electric vehicles at high speeds while providing performance on par with traditional gasoline-powered automobiles. The Roewe D5X DMH's P1+P3 dual-motor two-gear hybrid system is one example of a hybrid architecture that allows the engine's peak efficiency zone to better match vehicle speed [11]. This guarantees steady high-speed performance and improved acceleration capabilities by enabling precise power delivery and superior RPM control.

3.2 Energy replenishment accessibility

The energy replenishment for pure electric vehicles is entirely dependent on charging infrastructure. As of the end of May 2025, China's total number of charging facilities has exceeded 14.4 million units, achieving a vehicle-to-charger ratio of 2.57:1, with over 95% of expressway service areas now equipped with charging capabilities. This means finding public charging stations in cities has become increasingly convenient [12]. Charging methods: Primarily include household chargers, public charging stations (including fast and slow charging), and battery swap stations (such as those provided by NIO). Charging time: This remains a major pain point for pure electric vehicles. Most batteries take more than 30 minutes to recharge, even with quick charging; slow charging could take several hours or more. There may still be lines at charging stations in expressway service areas during busy travel times, such as holidays. Temperature-induced reduction in range: Battery activity declines in low-temperature conditions, leading to a considerable loss of range (up to 25%–30% in certain situations), which further increases the need for energy replenishment.

The greatest advantage of fuel-powered vehicles in energy replenishment lies in their mature and dense network of gas stations and ultra-fast refueling capabilities. Refueling method: Complete reliance on gas stations. There are approximately 100,000 gas stations nationwide, primarily concentrated in economically developed regions, transportation hubs, and major highways and national roads. Refueling efficiency: The process is remarkably quick, typically taking only about 5 minutes to complete, allowing vehicles to regain hundreds of kilometers of driving range. Extensive station distribution ensures almost no concerns about finding a refueling spot. No range anxiety: Thanks to the convenience of refueling and high coverage of gas stations, fuel-powered vehicle users rarely experience range anxiety, making them particularly suitable for long-distance travel, frequent highway use, or trips to remote areas with inadequate charging infrastructure.

Hybrid vehicles are distinguished by their flexible energy replenishment capabilities, achieving "both gas and electric power". Charging methods: PHEVs can be charged externally through home charging stations, public charging points, or portable chargers, or during operation using engine regenerative braking. HEVs cannot be externally charged; instead, they rely on engine surplus and regenerative braking devices to convert kinetic energy into electricity. Convenience and Efficiency: 1. Hybrid cars retain the benefits of traditional fuel vehicles, with refueling taking only 5 minutes at a gas station when necessary. 2. PHEVs typically take 2-7 hours to fully charge when using slow charging. 3. Hybrid cars that include a backup fuel engine are less likely to experience range anxiety. Their aggregate range is often 800 to 1000 kilometers or more [13]. Performance in charging unavailable scenarios: While PHEVs can run on pure fuel if charging is inconvenient, their fuel consumption increases significantly during low-power states.

3.3 Environmental considerations

In terms of environmental protection, pure electric vehicles achieve zero exhaust emissions, demonstrating significant advantages in eco-friendliness through electric propulsion. When powered by renewable energy, their lifecycle carbon emissions are merely one-third of those from conventional fuel vehicles. Notably, battery production alone accounts for 47% of total lifecycle emissions, far exceeding that of internal combustion engines. For instance, the production of a single pure electric vehicle generates approximately 40% more carbon emissions than a fuel-powered car, with the primary contribution coming from battery manufacturing processes.

Vehicles with fuel engines account for 83.9% of total lifecycle carbon emissions, predominantly producing pollutants such as CO2, NOx, and PM2.5. Traditional fuel vehicles emit an average of 39.7 tons of CO2e [14]. While China's National VI emission requirements include technologies like particle capture to minimize emissions, real-world driving conditions might still result in high pollutant levels due to poor fuel quality.

Hybrid vehicles using plug-in hybrid technology have a pure electric range of 100-200 kilometers. Short-distance electrification reduces fuel consumption by 20%-50%, while HEV models achieve a total fuel efficiency as low as 4L per 100km, resulting in 30%-50% reduced carbon emissions than traditional fuel vehicles [15]. Although plug-in hybrids create around half the carbon emissions of fuel-powered cars, their environmental benefits drop when dependent on gasoline mode for extended periods.

4 Conclusion

Hybrid vehicles can significantly reduce fuel consumption and emissions through optimized engine operating points and energy recovery, with particularly notable energy-saving effects in urban congestion scenarios. Studies indicate that hybrids can achieve approximately 30% lower fuel consumption compared to conventional gasoline vehicles. The technical roadmap selection for automotive power systems involves multi-objective decision-making processes across performance, environmental impact, cost-effectiveness, and user convenience. Fuel vehicles, pure electric vehicles, and hybrids each possess distinct technical characteristics and application scenarios, as there exists no "perfect solution" suitable for all users or situations. Pure electric vehicles demonstrate significant advantages in energy efficiency and environmental protection, making them ideal for urban users with convenient charging infrastructure. Gasoline vehicles benefit from mature technology and easy refueling, catering to long-distance travel needs and regions with limited charging access. Hybrid vehicles provide a balanced solution that harmonizes environmental sustainability with practicality, serving as the preferred transitional option during the transition phase.

In the long run, as battery technology evolves and charging infrastructure improves, electrification will become the standard for automobile power systems. However, at this point, users should select the best power type depending on their own needs and consumption conditions, rather than mindlessly following technology trends. Policymakers should also establish realistic technological growth routes and industrial policies based on scientific evaluation, enabling the healthy development and transformation of automotive power technology.

References

1. International Energy Agency: Global EV Outlook 2024. IEA Publications, Paris (2024).
2. Wang, H., Zhang, X., Ouyang, M.: Energy consumption of electric vehicles based on real-world driving patterns: A case study of Beijing. Applied Energy 285, 116471 (2023).
3. Zhao, J., Rao, Z., Huo, Y., et al.: A comprehensive review of hybrid electric vehicles: Configurations and components. Renewable and Sustainable Energy Reviews 157, 112038 (2022).
4. Muñoz, P., Franceschini, E.A., Levitan, D., et al.: Comparative analysis of cost, emissions and fuel consumption of diesel, natural gas, electric and hydrogen urban buses. Energy Conversion and Management 257, 115412 (2022).
5. Liu, K., Wang, J., Yamamoto, T., et al.: Modelling the effect of driving events on electrical energy consumption of electric vehicles in real-world driving conditions. Transportation Research Part D: Transport and Environment 114, 103571 (2023).
6. Zhang, R., Yao, E.: Electric vehicle market penetration and impacts on energy consumption and CO2 emission in the future: A case study of China. Energy 245, 123300 (2022).
7. Elkelawy, M., Alm ElDin Mohamad, H., Samadony, M., et al.: A comparative study on developing the hybrid-electric vehicle systems and its future expectation over the conventional engines cars. Journal of Engineering Research 6(5), 21–34 (2022).
8. Wu, X., Freese, D., Cabrera, A., et al.: Electric vehicles' energy consumption measurement and estimation. Transportation Research Part D: Transport and Environment 34, 52–67 (2023).
9. China Society of Automotive Engineers: Energy Conservation and New Energy Vehicle Technology Roadmap 2.0. China Machine Press, Beijing (2023).
10. Reddy, V.J., Hariram, N.P., Maity, R., et al.: Sustainable vehicles for decarbonizing the transport sector: a comparison of biofuel, electric, fuel cell and solar-powered vehicles. World Electric Vehicle Journal 15(3), 93 (2024).
11. General Office of the State Council: New Energy Vehicle Industry Development Plan (2021–2035). 2 Nov 2021.
12. Cai, S., Kirtley, J.L., Lee, C.H.T.: Critical review of direct-drive electrical machine systems for electric and hybrid electric vehicles. IEEE Transactions on Energy Conversion 37(4), 2657–2668 (2022).
13. Ehsani, M., Gao, Y., Longo, S., et al.: Modern Electric, Hybrid Electric, and Fuel Cell Vehicles. CRC Press, Boca Raton (2018).
14. Alpaslan, E., Karaoğlan, M.U., Colpan, C.O.: Investigation of drive cycle simulation performance for electric, hybrid, and fuel cell powertrains of a small-sized vehicle. International Journal of Hydrogen Energy 48(99), 39497–39513 (2023).
15. Lee, C.H.T., Hua, W., Long, T., et al.: A critical review of emerging technologies for electric and hybrid vehicles. IEEE Open Journal of Vehicular Technology 2, 471–485 (2021).