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Exploring the Evolution from BS-IV to BS-VI Emission Standards in Automotive Engineering: Comprehensive Review

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Abstract

This paper explores the transformative journey of vehicle technologies in India, transitioning from Bharat Stage-IV (BS-IV) to Bharat Stage-VI (BS-VI) emission standards. The nationwide implementation of BS-IV marked a significant milestone, while the pivotal introduction of on-board diagnostics in all cars became a cornerstone of BS-VI standards. Complex modifications to engine design, equipment, and the integration of exhaust after-treatment devices were undertaken to meet stringent emission regulations. Employing both primary and secondary techniques, the study investigates the reduction of harmful compounds emitted by combustion engines. The growing interest in alternative fuels for gasoline and diesel engines reflects evolving societal demands. The abstract provides a holistic perspective on the environmental impact, performance improvements, and regulatory implications of this technological evolution. Specifically, the highlighted results showcase an 85% reduction in Particulate Matters and an impressive 68% decrease in diesel emissions during the transition from BS-IV to BS-VI, emphasizing the positive outcomes of this standards shift on sustainable and efficient transportation systems.

Keywords: *Barath Stage-IV, Barath Stage-VI, Vehicle Technology, Emissions Standards, Environmental Impact, Performance Improvements.*

INTRODUCTION

The Bharat Stage Emission Standards (BSES), mirroring the European emission norms, were initiated by the Indian government in the year 2000 to regulate the release of air pollutants from motor vehicles. In response to escalating air pollution levels in 2016, the government opted to transition directly from BS-IV to BS-VI emission standards, bypassing the intermediary BS-V norms (IICT Policy Update, 2016). Despite this decision, the full implementation of the BS-VI mandate for vehicular emissions in India was achieved in April 2020.The automotive industry has witnessed a significant transformation with the implementation of BS-IV and subsequently BS-VIemissions standards. These regulatory milestones have propelled advancements in vehicle technology, aiming to address environmental concerns and enhance overall performance. This paper provides a comprehensive exploration of the evolution from BS-IV to BS-VI, examining the impact on emissions, technological innovations, and the regulatory landscape. By delving into the intricacies of these transitions, we aim to shed light on the broader implications for sustainable and efficient vehicle technologies in the contemporary automotive landscape.

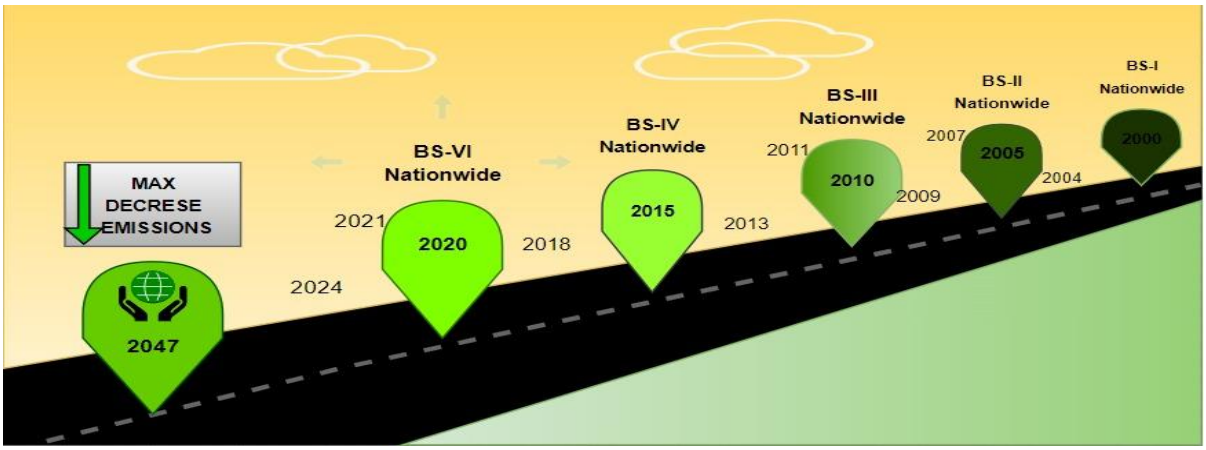


Fig. 1.Roadmap of timeline of incremental implementation of emission standards [16]

On the international stage, various countries and regions have been adopting and implementing stringent emission standards for vehicles, reflecting a global commitment to environmental sustainability. These standards, akin to BS-VIaim to reduce pollutants and improve air quality. Notable examples include the Euro-VI standards in Europe, which share similar objectives with BS-VI, emphasizing advanced emission control technologies and cleaner fuels. The international scenario underscores a collective effort to address

environmental challenges, encouraging the automotive industry worldwide to adopt cleaner and more sustainable practices in vehicle technology.

In the national scenario, the implementation of BS-IV emission standards in India signifies a crucial step toward mitigating vehicular pollution and aligning with global environmental standards. This transition reflects the nation's commitment to improving air quality and promoting sustainable transportation. The adoption of BS-VI has led to the widespread use of advanced emission control technologies in vehicles, contributing to reduced levels of harmful pollutants. The national scenario emphasizes the importance of regulatory measures to address environmental concerns and enhance the overall quality of the air we breathe.

India's air quality is deteriorating and air pollution-related ailments are rising. The country's population growth has increased demand for light-duty and heavy-duty motorized vehicles. These vehicles emit dangerous PM and other compounds, increasing pollution and harming the ecosystem. Since pollution is rising, the Indian government must impose BS-VI emission norms. The Indian Ministry of Road Transport and Highways released a draft notification for BS-VI emission regulations, while the Ministry of Petroleum and Natural Gas secured nationwide BS-VI fuel supply. The implementation of emission standards nationwide is recommended because staggered implementation in certain cities is not sustainable. For cleaner air, a national fuel standard is essential.

The biggest difference between BS-IV and BS-VI emission regulations is PM, sulfur, and nitrogen oxide traces. BS-IV fuel has five times more sulfur than BS-VI. When adopted in April 2017, BS-IV fuel sulfur levels were 50 ppm, however BS-VI gasoline and diesel sulfur levels are now 10 ppm. PM and NO_x emissions will decrease by 66% and 88%, respectively. In addition, the new BS-VI standards will expand type approval and in-service confirmatory test requirements for light-duty and heavy-duty vehicles to compare laboratory-tested emission performance to real-world driving conditions (IICT Policy Update, 2016).

The oil and automotive industries will struggle with the government's BS-VI changeover. Automobile makers must replace electronic fuel injectors with carburettors, install SCR and DPF, etc. These adjustments will significantly raise BS-VI car prices. Thus, manufacturers must produce affordable BS-VI-compliant vehicles to meet strict emission standards. The oil

sector must also upgrade BS-IV fuel to BS-VI fuel, which is more refined. Lack of incentives may also deter owners of older BS-compliant vehicles from switching to BS-VI. Thus, automobile companies and governments should encourage the majority of the people to transition to eco-friendly vehicles.

People engage in pro-environmental conduct because they care about the environment or believe they can help and found that environmental concerns can encourage environmental behavior. Thus, the sustainability benefits of cleaner fuels may influence consumer behavior toward BS-VI automobiles. Consumer SI can also be examined via planned behavior theory. One of the most important ideas for predicting consumer environmental behavior.Various researches to assess consumer green intention and behavior in several areas of global environmental sustainability. Remanufacturing, green products, electric motoring, bike-sharing, and emission standards-based engine solutions have been highlighted. This conventional and effective approach can anticipate consumers' intention and behavior toward eco-friendly items and techniques.

The automotive and industrial emissions cause air pollution, encouraged India to switch to eco-friendly transportation and renewable sources. Thus, Indian consumers' shift to strict emission-compliant vehicles will reduce air pollution. India has conducted few air pollution studies, but they have not examined consumer switching behavior or intentions from BS-IV to BS-VI automobiles. Their research focused on green supply chain management (GSCM) in the automotive industry, electric and hybrid car purchase, combustion emission control strategies, and the health effects of particulate pollution in Indian cities. No study has examined Indian consumers SI toward BS-VI automobiles. Research on switching behavior will assist decision-makers develop strategies to increase consumer SI for eco-friendly mobility. The study addresses the following research goals.

Currently, there are many customers who are not aware of the strategic changes got in by the government in the sector of automobiles. Also, there are many researchers who have not emphasised on how this change will affect the stakeholders related to this industry. This paper also focuses on Understanding how the fuel specifications for BS-VI is different from that of Euro-VI fuel standards.

Basic principles of BS-IV:

The basic principle of BS-IV is to regulate vehicular emissions by setting specific limits on pollutants such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). BS-IV standards focus on improving air quality by introducing advanced emission control technologies in vehicles, such as catalytic converters and more efficient engine designs. These measures aim to reduce the environmental impact of vehicle emissions and enhance overall air quality.

Basic principles of BS-VI:

The fundamental principle of BS-VI is to establish even more stringent standards for vehicular emissions compared to BS-IV. BS-VI aims to significantly reduce harmful pollutants, including nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and hydrocarbons (HC). The key approach involves the implementation of advanced emission control technologies, such as selective catalytic reduction (SCR) and improved fuel quality. BS-VI standards emphasize a substantial reduction in emissions to address environmental concerns and enhance air quality, reflecting a commitment to more sustainable and cleaner vehicle technologies.

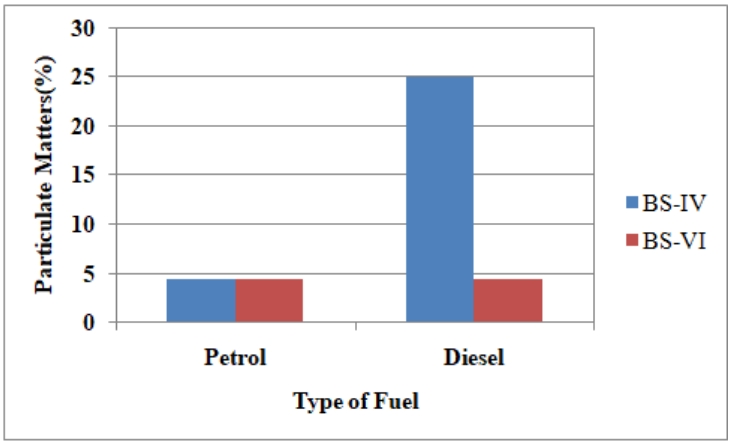
METHODOLOGYAND HIGHLIGHTS OF BS-IV AND BS-VI TECHNOLOGY

The transition from BS-IVto BS-VI technology signifies a pivotal advancement in automotive engineering. BS-VI standards mandate stringent emission norms, resulting in significantly lower levels of harmful pollutants emitted by vehicles. Key highlights include the adoption of advanced emission control technologies such as Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF), ensuring cleaner air and improved public health. Additionally, BS-VI vehicles exhibit enhanced fuel efficiency and performance attributes, marking a significant stride towards sustainable and eco-friendly transportation systems.

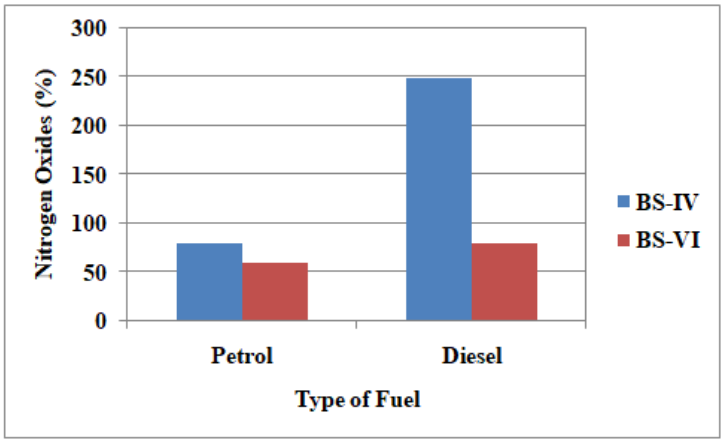
Transitioning from BS4 to BS6 signifies a significant decrease in emissions. To comprehend the harmful nature of emissions, it's essential to identify the noxious gases expelled from the exhaust – the menacing trio of carbon monoxide (CO), unburnt hydrocarbons (HC), and

oxides of nitrogen (NOx). Additionally, particulate matter (PM), a microscopic amalgamation of unburned elements, is present.

PM lingers in the air and poses a carcinogenic threat if inhaled excessively. Any unchecked combustion of fossil fuels releases this perilous combination. The sole method to diminish these emissions is by optimizing the combustion process for completeness. In theory, complete combustion yields only water (H2O), carbon dioxide (CO2), and nitrogen (N2) – all naturally occurring, non-toxic elements. However, CO2 contributes significantly to global warming. Although achieving 100 percent combustion is unattainable, engines that come closest to this ideal exhibit the lowest emissions. BS6 standards mandate a substantial emissions reduction, with the required technology varying between petrol and diesel engines due to their distinct emissions profiles.



(a) Particulate Matters



(b) Nitrogen Oxides Emission

Fig.2 Comparative of Emission controlling with BS-IV and BS-VI Standards

The above Fig.2 (a) graphs illustrates the values of petrol and diesel emissions for both BS-IV and BS-VI standards, with an additional context of a percentage value, presumably representing a reduction or improvement. In terms of petrol emissions, both BS-IV and BS-VI exhibit identical values at 4.5. This suggests a consistent emission level for petrol between the two standards. The associated percentage value of 85% does not seem to directly impact petrol emissions in this case. On the other hand, focusing on diesel emissions, there is a noticeable contrast. For BS-IV, the diesel emission value is 25, indicating a higher level of emissions. However, with the transition to BS-VI, there is a substantial reduction in diesel emissions, dropping to 4.5. The percentage value of 85% now gains significance, possibly representing an 85% reduction in diesel emissions when transitioning from BS-IV to BS-VI.

The Fig.2 (b) presented graph depicts the values of petrol and diesel emissions for both BS-IV and BS-VI standards, along with associated percentage values, presumably indicating a reduction or improvement. In terms of petrol emissions, there is a noticeable change from BS-IV to BS-VI. For BS-IV, the petrol emission value is 80, and with the transition to BS-VI, there is a reduction to 60.

The accompanying percentage value of 25% implies a 25% decrease in petrol emissions when upgrading from BS-IV to the more advanced BS-VI standard. Shifting attention to diesel emissions, a significant transformation is evident. In the BS-IV scenario, the diesel emission value stands at 250, indicating a relatively high level of emissions. However, with the adoption of BS-VI standards, there is a substantial reduction to 80. The associated percentage value of 68% signifies an impressive 68% decrease in diesel emissions during the transition from BS-IV to BS-VI.

Highlights of BS-IV Technology:

BS-IV emission standards marked a notable advancement in automobiles, enhancing engine performance with electronic fuel injection and variable valve timing. Mandating lower pollutant levels, BS-IV contributed to environmental improvement. Advanced exhaust after-treatment systems and common rail diesel tech further reduced emissions, emphasizing cleaner engine technologies and efficient fuel management.

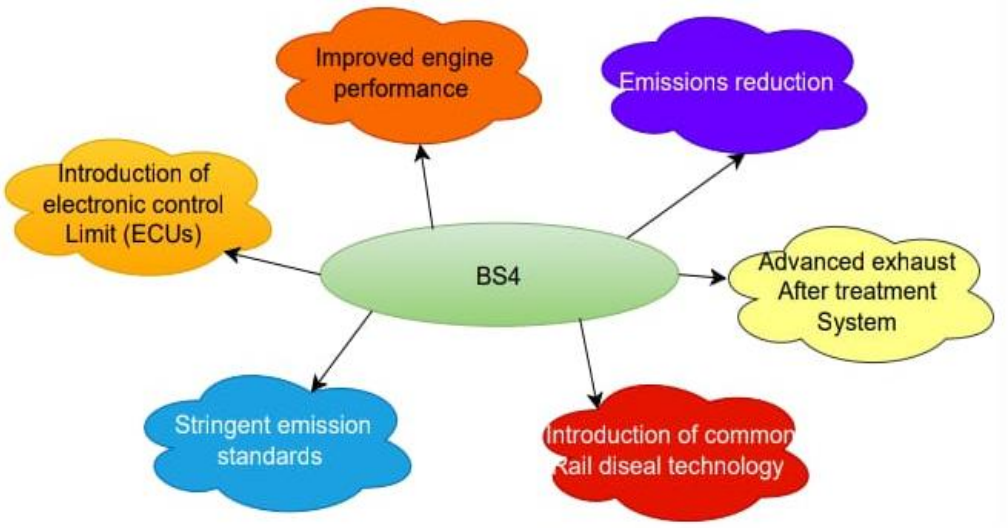


Fig.3: A Schematic Representation of Highlights of BS-IV Technology

- **Improved Engine Performance:** BS-IV vehicles often feature more advanced engine designs, including electronic fuel injection systems and variable valve timing, resulting in better fuel efficiency and power output compared to earlier generations.

- **Emission Reduction:** BS-IV standards mandate lower levels of harmful pollutants such as nitrogen oxides (NOx), particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO) compared to previous emission norms, leading to reduced environmental impact and better air quality.

- **Advanced Exhaust After-Treatment Systems:** BS-IV vehicles are equipped with advanced exhaust after-treatment systems, such as catalytic converters and diesel particulate filters (DPF), which help further reduce emissions by treating exhaust gases before they are released into the atmosphere.

- **Introduction of Common Rail Diesel Technology:** BS-IV implementation saw the introduction of common rail diesel technology in many vehicles, improving fuel efficiency, reducing emissions, and enhancing overall engine performance.

- **Stringent Emission Standards:** BS-IV emission standards represent a significant step forward in emission control compared to earlier norms, driving the development and adoption of cleaner engine technologies and fuel formulations.

- **Introduction of Electronic Control Units (ECUs):** BS-IV vehicles often incorporate electronic control units to manage engine functions more efficiently, leading to smoother operation, better fuel economy, and reduced emissions.

Highlights of BS-VI technology:

BS-VI emission standards signify a crucial shift towards cleaner vehicles, significantly reducing pollutants for improved air quality. With advanced engine designs, sophisticated exhaust after-treatment systems, lower sulfur content fuels, and On-Board Diagnostics (OBD-II), BS-VI sets stringent standards, driving the development of eco-friendly and efficient engine technologies for a sustainable automotive future.

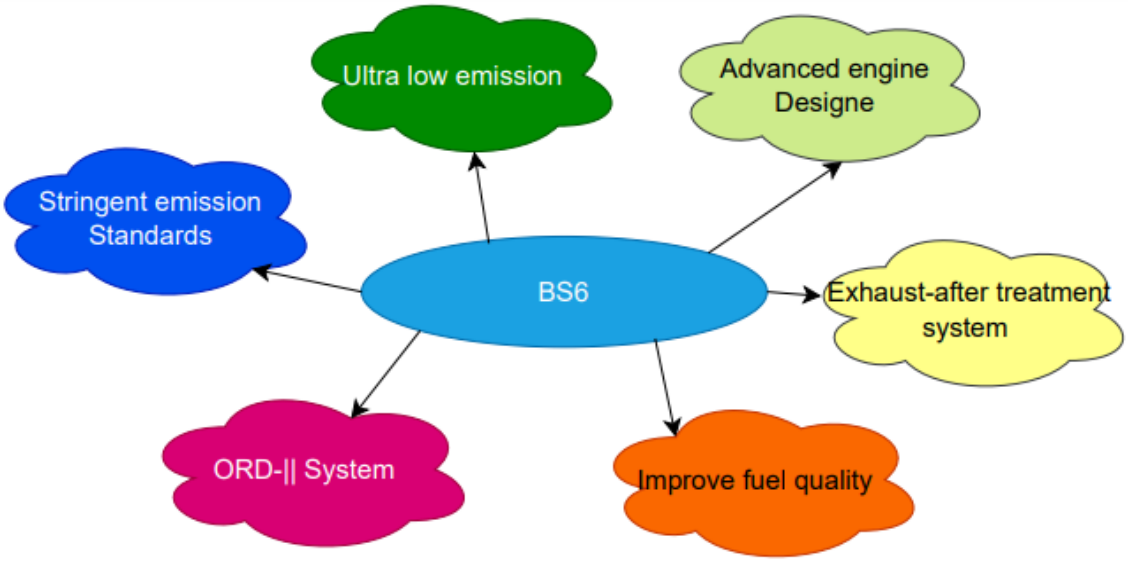


Fig.4: A Schematic Representation of Barath Stage-VI

- **Ultra-Low Emissions:** BS-VI vehicles produce significantly lower levels of harmful pollutants such as nitrogen oxides (NOx), particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO) compared to BS-IV vehicles, leading to cleaner air quality and reduced environmental impact.

- **Advanced Engine Design:** BS-VI engines are equipped with advanced technologies such as direct fuel injection, turbocharging, and optimized combustion processes to achieve higher efficiency and lower emissions.

- **Exhaust After-Treatment Systems:** BS-VI vehicles feature advanced exhaust after-treatment systems, including selective catalytic reduction (SCR) systems and diesel particulate filters (DPF), which further reduce harmful emissions by treating exhaust gases before they are released into the atmosphere.

- **Improved Fuel Quality:** BS-VI fuel standards mandate lower sulfur content, which helps improve the efficiency of exhaust after-treatment systems and reduces emissions. This cleaner fuel also contributes to better engine performance and longevity.

- **OBD-II Systems:** BS-VI vehicles are equipped with On-Board Diagnostics (OBD-II) systems that monitor various engine parameters and emission control systems in real-time, enabling early detection of faults and ensuring compliance with emission standards throughout the vehicle's lifespan.

- **Stringent Emission Standards:** BS-VI emission standards are more stringent than their predecessors, requiring vehicles to meet lower emission limits for pollutants such as NOx, PM, HC, and CO, thus driving the development of cleaner and more efficient engine technologies.

FUTURE SCOPE

The future scope of Bharat Stage Emission Standards (BSES), particularly in comparison to BS-VI, involves a continued commitment to addressing environmental concerns and advancing technological innovations in the automotive sector. Here are some aspects of the future scope:

Fig.5 Expected aspects of the future scope in Bharat Stage Emission Standards

Stricter Standards (BS-VII and Beyond): The government is likely to introduce even more stringent emission standards, such as BS-VII and beyond, in the future. These standards will aim to further reduce pollutant levels, emphasizing the need for cleaner and more fuel-efficient vehicles.

Alternative Fuels and Electric Vehicles (EVs): The future of emission standards will likely see an increased focus on promoting alternative fuels and electric vehicles. Governments may incentivize the production and adoption of electric and hybrid vehicles to minimize the reliance on traditional internal combustion engines.

Technology Advancements: With each iteration of emission standards, there will be a push for technological advancements in vehicle design and engine efficiency. Manufacturers will continue to invest in research and development to meet or exceed the emission norms while improving overall vehicle performance.

Global Alignment: As the automotive industry becomes more interconnected globally, future emission standards in India may align closely with international norms. This alignment could facilitate the export and import of vehicles, creating a more standardized approach to emissions control.

Monitoring and Enforcement: Future regulations may involve more robust monitoring and enforcement mechanisms to ensure that vehicles on the road comply with the prescribed emission standards. This could include stricter testing procedures and increased penalties for non-compliance.

Public Awareness and Education: Governments may focus on increasing public awareness about the environmental impact of vehicular emissions. Education campaigns could encourage responsible driving habits, vehicle maintenance, and the adoption of eco-friendly transportation options.

Collaboration with Industry: Governments and regulatory bodies may collaborate more closely with the automotive industry to encourage the development of green technologies and sustainable practices. This collaboration could lead to the creation of a more eco-friendly and technologically advanced automotive landscape.

CONCLUSIONS

The evolution of vehicle technologies from Bharat Stage-IV (BS-IV) to Bharat Stage-VI (BS-VI) emission standards in India signifies a significant stride towards environmentally sustainable and efficient transportation systems. The mandatory implementation of on-board diagnostics in BS-VI standards and the comprehensive modifications to engine design, equipment, and exhaust treatment devices have played pivotal roles in meeting and surpassing stringent emission regulations. The study emphasizes the dual application of primary and secondary techniques to reduce harmful combustion engine emissions.

The results, highlighting an 85% reduction in Particulate Matters and an impressive 68% decrease in diesel emissions during the transition, underscore the positive environmental impact of adopting BS-VI standards. These findings contribute valuable insights into the broader landscape of environmental responsibility, performance enhancements, and regulatory compliance within the automotive industry, reinforcing the need for continued advancements in pursuit of sustainable and cleaner transportation solutions.

- The transition from BS-IV to BS-VI signifies a move towards more rigorous emission standards, reflecting a commitment to reducing harmful pollutants emitted by vehicles.

- BS-VI necessitates the integration of advanced emission control systems and the use of ultra-low sulfur fuel, driving innovation in engine design and promoting the adoption of cleaner fuels.

- The evolution from BS-IV to BS-VI reflects a strong dedication to addressing environmental challenges and enhancing air quality, contributing to a healthier environment for all.

- The phased implementation and continuous monitoring through on-board diagnostics demonstrate a comprehensive strategy to mitigate the environmental impact of vehicular emissions.

- Overall, the transition to BS-VI technology marks a significant stride towards a more sustainable future by curbing air pollution, fostering innovation, and promoting cleaner transportation solutions.

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