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Evaluating The Impact Of Bio-CNG And Electric Buses On Chandrapur City's Public Transport System

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ABSTRACT :

This study investigates a sustainable transportation framework to tackle the significant urban issues of traffic congestion, pollution, and transportation efficiency in Chandrapur City. The research provides a comparative analysis of Bio-CNG and Electric (EV) buses, focusing on their environmental impact, cost, and infrastructure requirements. The objective is to determine which technology best meets Chandrapur's public transportation needs. Bio-CNG buses utilize biogas derived from organic waste, offering reduced emissions and compatibility with the existing fuel infrastructure. In contrast, EV buses contribute to zero tailpipe emissions and align with the city's long-term environmental goals, though they require higher initial investments and advanced infrastructure. In addition, this research integrates insights from recent studies on pedestrian bridge planning in rural areas and transit network improvements in Chandrapur's core region to propose a comprehensive approach to urban mobility. Findings suggest that Bio-CNG buses offer a viable, low-cost solution for immediate implementation, while EV buses could provide a sustainable long-term option as infrastructure develops. The study concludes by recommending a phased adoption strategy, starting with Bio-CNG buses and gradually transitioning to EVs. This approach balances immediate feasibility with long-term ecological and economic objectives, providing a sustainable urban transit planning model.

Keywords: Sustainable public transportation, Bio-CNG and Electric buses, urban mobility, Traffic congestion reduction, Pedestrian bridge infrastructure

1. Introduction :

1.1. General

Chandrapur City in Maharashtra has experienced rapid urbanization and industrial growth, leading to significant increases in both population and pollution over the past few decades. With the latest census indicating a population of around 2.5 million, the city has expanded as an industrial and residential hub, putting immense pressure on its transportation network. This has resulted in severe traffic congestion and escalating pollution levels.

Reports from the Maharashtra Pollution Control Board (MPCB) reveal that Chandrapur's air quality has deteriorated due to industrial emissions and vehicular pollution. The air quality index (AQI) frequently surpasses safe levels, with high concentrations of particulate matter (PM10 and PM2.5) largely attributed to the growing number of vehicles. Vehicular emissions significantly contribute to the city's pollution, leading to respiratory health issues among residents and negatively impacting their quality of life.

To address these pressing issues, Chandrapur needs a sustainable and efficient public transportation system that can alleviate traffic congestion and reduce pollution. This study examines two eco-friendly bus options—Bio-CNG and Electric (EV) buses—as potential solutions. Bio-CNG buses utilize biogas from organic waste, providing a renewable fuel source that can reduce emissions and support waste management. EV buses, powered by electricity, eliminate tailpipe emissions entirely, offering a highly sustainable transportation option.

The study also suggests constructing pedestrian bridges in high-traffic areas to ensure safe pedestrian movement and encourage non-motorized transportation. By implementing these strategies, Chandrapur aims to develop an integrated, accessible, and environmentally responsible transportation network that meets both current and future urban demands.



Fig. 1 - Public Transport Bus operated on Bio-CNG



Fig. 2 - Public Transport Bus operated on EV Bus

1.2. Aim

The aim of this project is to design a sustainable public transportation system for Chandrapur City that reduces traffic congestion, minimizes pollution, and enhances accessibility. By evaluating Bio-CNG and EV bus technologies, the study aims to offer a feasible solution for transitioning to an environmentally responsible and economically viable transit system.

1.3. Objectives

1. Reduce Traffic Congestion
2. Minimize Pollution and Promote Eco-Friendly Transport
3. Enhance Pedestrian Safety and Accessibility
4. Simplify Urban Transit and Improve Connectivity
5. Promote Non-Motorized and Sustainable Transportation
6. Reduce Transportation Costs and Improve Cost Efficiency
7. Enhance Urban Aesthetics and Community Appeal
8. Anticipate Future Urban Growth and Connectivity Needs

1.4. Need of Project

The innovative study on incorporating Bio-CNG and Electric (EV) buses and pedestrian infrastructure in Chandrapur City addresses urgent urban challenges such as traffic congestion, air pollution, and insufficient transport options. The extensive use of traditional diesel buses significantly contributes to pollution, adversely affecting air quality and public health. Therefore, a sustainable public transportation system is urgently needed to alleviate traffic, enhance urban air quality, and provide residents with an accessible, efficient, and environmentally friendly alternative to private vehicles.

Moreover, this research is crucial to enhancing pedestrian safety and mobility in Chandrapur, where busy intersections and a lack of dedicated pedestrian infrastructure pose high risks to pedestrians. Constructing pedestrian bridges and integrating them with key public transportation points can help reduce road accidents and promote non-motorized transportation, aligning with the city's environmental goals.

1.5. Scope of Project

1. Development of a Sustainable Public Transportation Network
2. Design and Construction of Pedestrian Bridges in Key Locations
3. Integration of Transit Infrastructure with Urban Design
4. Use of Sustainable Materials and Eco-Friendly Technologies
5. Adoption of Universal Design Principles for Accessibility
6. Community-Centered Design and Aesthetic Integration
7. Environmental and Traffic Impact Assessments
8. Future-Proofing for Urban Expansion

2. Literature Review :

1. The study titled "A Review on Design of Public Transportation System in Chandrapur City" addresses the pressing necessity for an upgraded urban transport system due to the city's rapid population increase and worsening traffic congestion. The researchers point out that the outdated transportation infrastructure has resulted in elevated pollution levels and inefficient travel options. They propose a new design model, inspired by successful systems in cities such as Nagpur, including the introduction of Star City Buses and a Bus Rapid Transit System (BRTS) to enhance urban travel. By reviewing similar projects and methodologies, they highlight that a well-optimized public transport network could not only improve mobility but also lessen the environmental impact of vehicular pollution. The authors conclude that a meticulously planned public transport network, featuring dedicated bus lanes and alternative fuel vehicles like Bio-CNG buses, could be a viable solution to Chandrapur's transportation issues. They recommend utilizing design software like AutoCAD and Revit for precise route planning, bus bays, and destination points, ensuring an efficient transit flow across the city. The study's results suggest that implementing these infrastructure improvements could ease traffic congestion, reduce pollution, and make transportation more accessible for residents, aligning with the city's urban development goals. (Shende et al., 2018)
2. The research paper titled "Public Transportation System in Chandrapur City" explores the critical challenges of Chandrapur's public transport due to rapid population growth and increased vehicle usage, resulting in traffic congestion and pollution. The authors aim to develop an improved public transport system to address these issues, suggesting a new bus network inspired by successful models in other Indian cities. Key findings highlight high-traffic areas within Chandrapur, such as Jatpura Gate, and emphasize the need for infrastructure solutions like designated bus lanes, enhanced bus stop facilities, and alternative fuel vehicles. They recommend adopting Compressed Natural Gas (CNG) buses to significantly reduce pollution levels while offering a cost-effective alternative to traditional fuels. In conclusion, the authors stress that creating an efficient public transportation system is crucial for mitigating Chandrapur's traffic and environmental issues. They propose a combination of improved route planning, the use of CNG-powered buses, and enhanced infrastructure to boost transportation access and reduce congestion. Their findings underscore that implementing these measures could improve urban mobility, lower transportation costs, and contribute to a cleaner environment for Chandrapur's growing population. This comprehensive strategy underlines the importance of sustainable planning in urban transportation development. (Marve et al., 2018)
3. The research paper titled "Improvement of the Transit Network for the Core Area of Chandrapur City" delves into the transportation challenges in Chandrapur, Maharashtra, particularly within its core area. The authors identify issues such as traffic congestion, insufficient parking, and tax enforcement of traffic regulations, and inadequate infrastructure for pedestrians. Additionally, vendor and shop owner encroachments further diminish road capacity, contributing to congestion and unsafe conditions for all road users. Through various surveys, including traffic volume, road inventory, and parking surveys, the study paints a comprehensive picture of the current situation. The data highlights significant congestion during peak hours and a high demand for parking in commercial areas. In conclusion, the authors suggest several strategies to improve the city's transit network. These recommendations involve road widening, creating pedestrian-only zones in high-density areas, regulating on-street parking, and establishing designated zones for vendors to reduce encroachment. They also propose long-term solutions such as developing multi-level parking structures and encouraging carpooling to decrease private vehicle use. The study underscores that implementing these measures could ease congestion, enhance road safety, and create a more efficient urban environment for Chandrapur's residents and commuters. (Bahade & Chavan, 2022)
4. The research paper titled "Design & Analysis of Multi-Storied Car Parking Building (G+2)" investigates the design of a multi-story car parking facility in Chandrapur, aimed at addressing the growing traffic congestion. The authors elaborate on their design process, utilizing software like AutoCAD for planning and STAAD.PRO for structural analysis. The study focuses on minimizing space usage and enhancing safety by designing floors to accommodate a large number of vehicles and efficiently organizing entry and exit routes. In conclusion, the authors determined that their design is feasible and effective in optimizing parking space, alleviating traffic congestion, and enhancing vehicle safety. Their findings demonstrate the potential of multi-story parking structures to address urban traffic challenges while efficiently using limited space. This research underscores the significance of well-planned parking infrastructure in urban management and highlights the benefits of such solutions for improving urban mobility. (S Jumde, Marve et al., 2020)
5. **S. Kasulkar et. Al. (2023):** The research paper titled "Comprehensive Analysis of Air Pollution Status, Root Causes, and Remedial Solutions for an Industrial Town in Maharashtra, India" provides a thorough examination of air pollution in an industrial town in Maharashtra, India. Through comprehensive data collection and environmental assessment, the authors identify key contributors to air pollution, including industrial emissions, vehicle exhaust, and domestic activities. The findings show alarmingly high levels of pollutants such as Sulphur dioxide (SO₂), Nitrogen dioxide (NO₂), and particulate matter (PM), all of which exceed the permissible limits set by environmental standards. The study

underscores that rapid industrialization, urbanization, and insufficient pollution control measures have exacerbated air quality, posing significant health and environmental risks to residents. In their conclusion, the authors stress the urgent need for measures to combat air pollution in the town. They suggest stricter enforcement of emission regulations, enhanced air quality monitoring, and the adoption of cleaner technologies in industries. Public awareness programs and the promotion of sustainable transportation options are also recommended to reduce vehicular pollution. The authors conclude that a collaborative effort involving government agencies, industries, and the local community is crucial to addressing the growing air quality crisis and protecting the health and well-being of the population.

6. The research paper titled "Traffic Study and Control System of Chandrapur City" investigates the growing traffic issues in Chandrapur, Maharashtra. The authors highlight problems such as traffic congestion, inadequate parking facilities, and insufficient infrastructure, which together create significant bottlenecks in the city's core areas. By analyzing traffic volume and flow data, the study identifies key congestion points and traffic patterns in Chandrapur, primarily attributed to population growth and urban expansion. In conclusion, the author recommends several strategies to tackle these problems, including enhanced traffic management systems, the development of organized parking areas, and stricter enforcement of traffic regulations. Their findings suggest that combining short-term measures, like optimizing traffic signals, with long-term infrastructure investments, could help alleviate congestion, improve road safety, and streamline urban transit in Chandrapur. This research underscores the necessity of targeted, data-driven approaches to urban traffic management and highlights the importance of proactive city planning. (Shende, n.d.)
7. **A. B. Singh et. Al. (2024):** The research paper "A Review on Pedestrian Bridge Planning: A Multidisciplinary Approach for Rural Connectivity" delves into the planning and design of pedestrian bridges to boost connectivity in rural areas. The authors highlight the critical role of pedestrian bridges in offering secure and dependable passage across water bodies, especially in remote regions where transportation infrastructure is often inadequate. The study explores various factors such as site selection, structural design, environmental impact, and community requirements through an interdisciplinary approach. The authors conclude that well-designed pedestrian bridges can notably enhance accessibility, reduce travel time, and provide a safer route for residents, particularly during monsoon seasons when crossing water bodies becomes hazardous. In their conclusion, the authors advocate for a collaborative effort involving civil engineers, urban planners, local authorities, and the rural community to ensure pedestrian bridges are both functional and sustainable. They recommend using local materials and considering ecological impacts to minimize environmental disruption. The study concludes that thoughtfully planned pedestrian bridges not only improve rural connectivity but also contribute to the social and economic well-being of rural communities by enhancing access to essential services and fostering regional development.

3. Methodology :

1. **Data Collection:** This step involves gathering relevant data on traffic volume, emission levels, and operational costs from transportation and environmental agencies in Chandrapur. This data provides the necessary baseline information for the study.
2. **Cost Analysis:** This involves comparing the initial and ongoing operational costs of Bio-CNG and EV buses. The analysis will cover aspects like the purchase price, maintenance expenses, and infrastructure requirements such as refueling stations for Bio-CNG buses and charging stations for EV buses.
3. **Environmental Impact Assessment:** This step calculates the potential reductions in emissions that could be achieved by using Bio-CNG and EV buses instead of traditional diesel buses. It includes an analysis of pollutants like CO₂, NO_x, and particulate matter.
4. **Infrastructure and Feasibility Analysis:** This involves evaluating the practicality of setting up the necessary infrastructure for Bio-CNG and EV buses. It considers the availability of resources, space for refueling and charging stations, and the technical feasibility of integrating these infrastructures into the existing transportation network.
5. **User Needs Assessment:** Conducting surveys and gathering feedback from the public to understand their preferences, needs, and perceptions regarding public transportation. This step aims to ensure that the proposed solutions align with user expectations and increase public transit uptake.

4. Environmental Impact and Cost Analysis :

4.1. Environmental Impact

Bio-CNG buses offer a sustainable alternative to traditional diesel buses by significantly lowering emissions of carbon dioxide (CO₂) and particulate matter. They utilize methane derived from organic waste, which not only reduces the environmental impact of waste management but also prevents the release of methane—a highly potent greenhouse gas—into the atmosphere. While Bio-CNG buses do emit some pollutants during combustion, these emissions are considerably lower than those of diesel buses. This technology provides a practical solution for cities like Chandrapur to address air quality challenges while supporting renewable energy use through local biogas production.

On the other hand, EV buses provide unparalleled environmental benefits by eliminating tailpipe emissions. They contribute directly to improved local air quality, reducing respiratory health risks for residents. The environmental advantages of EV buses are maximized when they are charged using renewable energy sources such as wind or solar power. By integrating clean energy into the charging infrastructure, EV buses can achieve a near-zero emission lifecycle, making them an essential part of long-term urban sustainability strategies. This positions EV buses as a future-proof solution for cities aiming to achieve net-zero carbon goals.

4.2. Cost Analysis

Cost Comparison in ticket fares, traveling costs, and fuel costs for Bio-CNG and EV buses would depend on specific data points, such as:

- Fuel/Energy Costs:** Average cost per kg of Bio-CNG versus cost per kWh of electricity for EV buses in Chandrapur.
- Operational Efficiency:** Kilometers per kg for Bio-CNG buses versus kilometers per kWh for EV buses.
- Ticket Fares:** Estimated ticket fare adjustments based on operational and maintenance costs.

Table No. 1 - Analysis of various Cost Factors

Cost Factor	Bio-CNG Buses	EV Buses	Remarks
Fuel Cost per km	₹8 per km (₹60/kg, 7.5 km/kg)	₹4 per km (₹8/kWh, 2 km/kWh)	EV buses have lower energy costs.
Maintenance Cost per km	₹3 per km	₹1.5 per km	EV buses have fewer moving parts.
Ticket Fare (estimated)	₹15 for a 5 km trip	₹12 for a 5 km trip	Lower operational costs reduce EV fares.
Range per refill/charge	300 km per refill	150-200 km per full charge	Bio-CNG has better range and refueling speed.
Refueling/Charging Time	10-15 minutes	2-4 hours (or 30 min with fast charge)	EV buses need more time for recharging.

Observations:

- Fuel Costs:** EV buses are cheaper to operate due to lower electricity costs compared to Bio-CNG.
- Maintenance Costs:** EV buses incur lower maintenance costs, translating into potential long-term savings.
- Ticket Fares:** EV buses could offer lower fares over time, but Bio-CNG buses might maintain competitive pricing initially due to lower setup costs.
- Range and Refueling Time:** Bio-CNG buses are advantageous for longer routes with quick refueling needs, whereas EV buses are suitable for shorter routes with accessible charging infrastructure.

The following table illustrates the cost dynamics, highlighting how Bio-CNG buses are an economical short-term solution, while EV buses are better suited for long-term sustainability.

Table No. 2 - Cost Analysis of Bio-CNG and EV Buses

Cost Component	Bio-CNG Buses	EV Buses
Initial Purchase Cost	Lower initial cost due to conventional engine technology.	Higher due to advanced battery and electric systems.
Infrastructure Cost	Moderate cost for establishing refueling stations.	High cost for installing charging stations, especially fast chargers.
Fuel/Charging Costs	Low fuel costs, especially if biogas is locally produced.	Lower electricity costs; further reduced with renewable energy sources.
Maintenance Costs	Moderate, as engine components are similar to diesel buses.	Low, due to fewer moving parts and no combustion engine.
Lifecycle Costs	Competitive, with long-term benefits from local fuel sourcing.	Higher initially but reduced significantly over time with savings in fuel and maintenance.
Scalability	High, as existing gas supply networks can be adapted.	Challenging initially due to dependence on grid upgrades and charging infrastructure.
Economic Sustainability	Promotes a circular economy using waste-derived biogas.	Long-term savings with advancements in battery technology.

Key Insights:

- Bio-CNG Buses:** Offer immediate cost advantages with moderate infrastructure needs and the ability to use locally sourced biogas, making them suitable for quick deployment.
- EV Buses:** Involve higher upfront investment but provide significant savings in the long run due to lower maintenance and operational costs, particularly when paired with renewable energy sources.

The cost comparison between Bio-CNG and EV buses reveals distinct advantages for each. Bio-CNG buses are relatively affordable in terms of upfront costs for vehicle procurement and infrastructure. The setup of Bio-CNG fueling stations is cost-effective and can be optimized by using locally available organic waste, thereby creating a circular economy. Additionally, the operational costs of Bio-CNG buses remain competitive due to the low price of biogas compared to conventional fuels, making them a financially viable option for immediate implementation.

In contrast, EV buses involve higher initial expenses due to advanced battery technology and the need for a robust charging infrastructure. However, these costs are offset in the long run by significantly lower maintenance and operational expenses. EV buses have fewer mechanical components, leading to reduced wear and tear and minimal servicing requirements. Furthermore, advancements in battery technology are expected to improve energy

density and reduce costs over time, enhancing the financial feasibility of EV buses. When evaluated over their lifecycle, EV buses present a strong case for long-term cost efficiency and environmental sustainability.

5. Range, Feasibility, and Transit Network Integration :

5.1. Range and Feasibility

Bio-CNG buses excel in range and operational efficiency, making them highly suitable for routes with high passenger demand and continuous service requirements. Their quick refueling capabilities ensure minimal downtime, enabling seamless operation throughout the day. These attributes make Bio-CNG buses particularly effective for long-distance and high-frequency routes, where reliability and range are critical. Moreover, the infrastructure required for Bio-CNG refueling is relatively straightforward to establish, especially in areas with access to biogas production facilities. This ensures the rapid scalability and feasibility of Bio-CNG buses for Chandrapur's transit needs.

In contrast, EV buses face challenges related to range and charging durations. Limited battery capacity often necessitates frequent charging, particularly on long routes. Charging times, even with fast-charging technologies, can disrupt operations if not strategically managed. These limitations make EV buses better suited for urban routes with accessible charging points at terminals or transit hubs. However, technological advancements in battery efficiency and charging speed are expected to mitigate these challenges in the future. Strategic deployment, such as operating EV buses on fixed, shorter routes with high commuter density, can optimize their use while minimizing operational disruptions.

5.2. Integration with Chandrapur's Transit Network

Seamless integration of Bio-CNG and EV buses into Chandrapur's transit system requires careful planning and investment. Strategic route planning is essential to align the operational strengths of each technology with the city's transit needs. Bio-CNG buses can dominate high-demand, long-distance routes, while EV buses are deployed on shorter, urban routes with charging infrastructure at designated endpoints. This division ensures optimal performance and reliability for both bus types, enhancing the overall effectiveness of the transit system.

Infrastructure investments must focus on creating shared fueling and charging facilities at key transit hubs. This approach optimizes resource use and simplifies operational logistics. Additionally, dedicated bus lanes and traffic management measures can further enhance the efficiency of public transit, encouraging more residents to shift from private vehicles to public transportation. By integrating these buses into a cohesive network, Chandrapur can improve mobility, reduce congestion, and achieve significant environmental gains. This comprehensive strategy ensures a sustainable and user-friendly transit system that supports the city's long-term development goals.

6. Comparative Analysis of Bio-CNG And EV Buses :

The comparative study of Bio-CNG and electric (EV) buses for Chandrapur's transit network examines the advantages and drawbacks of each type based on environmental impact, costs, infrastructure requirements, range, and integration feasibility.

1. Environmental Impact:

Bio-CNG buses significantly lower CO₂ emissions and particulate matter compared to traditional diesel buses. Although not entirely emission-free, they provide a greener alternative by utilizing methane from organic waste, which would otherwise contribute to greenhouse gases if released. On the other hand, EV buses produce zero tailpipe emissions, greatly improving local air quality. Their environmental benefits are further maximized if the electricity used for charging comes from renewable sources like solar or wind power, ensuring the buses remain emission-free throughout their lifecycle.

2. Cost and Infrastructure:

Bio-CNG buses entail lower initial and operational costs, with moderate infrastructure needs for fuelling stations. Producing Bio-CNG locally from organic waste establishes a closed-loop system, promoting a circular economy. Conversely, EV buses have higher upfront costs for both the vehicles and the required charging infrastructure, especially if fast-charging stations are needed. However, over time, EV buses can offer significant savings due to lower maintenance costs and advances in battery technology, which are anticipated to enhance energy density and reduce costs.

3. Range and Feasibility:

Bio-CNG buses offer advantages in range and refueling speed, providing ample operational capacity for high-demand routes. Their quick refueling capability makes them ideal for continuous, high-frequency service without significant downtime. In contrast, EV buses generally have a shorter range and require longer charging times, potentially limiting their use to routes where charging infrastructure is readily accessible, such as urban routes with charging stations at designated endpoints. This limitation can be addressed with strategic deployment, although it poses logistical challenges for high-demand or longer routes.

4. Integration with Chandrapur's Transit Network:

Both Bio-CNG and EV buses have the potential to significantly reduce private vehicle usage if well-integrated into Chandrapur's public transit system. Through strategic route planning, dedicated lanes, and traffic management measures, Bio-CNG and EV buses could provide reliable, eco-friendly public transport options. Successful integration requires infrastructure investments that accommodate both types of buses and support shared charging and fuelling stations at transit hubs. These options can enhance overall mobility, reduce congestion, and improve air quality in the region, contributing to a more sustainable and efficient transit system in Chandrapur.

7. Results and Discussion :

1. Traffic Congestion Reduction:

The introduction of Bio-CNG and EV buses, along with strategically placed pedestrian bridges, has the potential to significantly reduce traffic congestion. By promoting public transportation and safe pedestrian pathways, residents are encouraged to shift from private vehicles, thereby alleviating road congestion.

2. Pollution Reduction and Environmental Impact:

Bio-CNG buses help to moderate emissions by using renewable biogas, while EV buses eliminate tailpipe emissions. These environmental benefits are further enhanced by eco-friendly pedestrian bridges, which incorporate solar-powered lighting and green elements, thereby reducing the city's carbon footprint and supporting sustainable urban development.

3. Improved Pedestrian Safety and Accessibility:

The placement of pedestrian bridges in high-traffic areas provides safe crossings and reduces the likelihood of accidents. Additionally, the inclusion of universal design features ensures that these bridges are accessible to all residents, including the elderly and people with disabilities.

4. Enhanced Connectivity and User-Friendly Transit System:

The integration of Bio-CNG and EV buses with a network of pedestrian bridges creates an accessible and interconnected transit system, simplifying movement across the city. This improves overall accessibility to major zones, including residential, commercial, and transit hubs, providing a seamless experience for public transit users and pedestrians.

5. Cost Efficiency and Economic Benefits:

Bio-CNG buses offer immediate cost efficiency due to lower fuel costs, while EV buses promise long-term savings on maintenance and operational costs. Pedestrian bridges, built with durable, low-maintenance materials, also demonstrate long-term cost-effectiveness, reducing future infrastructure expenses for the city.

6. Enhanced Urban Aesthetics and Community Engagement:

The aesthetic design of pedestrian bridges aligns with the cultural identity of Chandrapur, enhancing the urban landscape and making the bridges more than just functional structures. This approach fosters community engagement, as well-designed public infrastructure becomes part of the city's character and appeal.

7. Preparedness for Future Growth:

The scalable and adaptable design of the public transportation system and pedestrian bridges addresses the anticipated population growth and increasing transportation demand in Chandrapur. This forward-thinking approach ensures that the city can handle future urban expansion without compromising accessibility or connectivity.

8. Conclusion :

This study demonstrates that integrating Bio-CNG and EV buses with strategically placed pedestrian bridges presents a viable and sustainable solution to Chandrapur's urban transportation challenges. Key conclusions from this analysis include:

1. Phased Implementation Approach is Optimal:

Introducing Bio-CNG buses in the short term addresses immediate congestion and emission concerns, while a gradual transition to EV buses aligns with Chandrapur's long-term sustainability goals. This phased approach balances current feasibility with future environmental impact.

2. Pedestrian Bridges are Essential for Safety and Connectivity:

Strategically placed pedestrian bridges significantly enhance urban connectivity, reduce traffic-related accidents, and promote non-motorized transportation, aligning with the city's goals for accessibility and safety.

3. Cost-efficiency and Environmental Sustainability Coexist:

Bio-CNG buses provide immediate cost savings, while EV buses offer long-term financial and environmental benefits. The cost-effective, low-maintenance design of pedestrian bridges further reinforces the financial viability of sustainable infrastructure.

4. Public Transportation and Pedestrian Infrastructure must be interconnected:

An integrated network of buses and pedestrian bridges enhances public transit usage and accessibility, supporting a citywide movement toward non-motorized and public transportation options.

5. Aesthetic and Community-Focused Design Strengthens Public Engagement:

Designing pedestrian bridges that align with Chandrapur's cultural identity and enhance urban aesthetics fosters a sense of community ownership and engagement, encouraging usage and positive perceptions of public infrastructure.

6. Long-Term Urban Planning is Key:

By creating scalable, adaptable infrastructure that anticipates population growth, Chandrapur is better positioned to address future transportation demands, reducing the likelihood of congestion and infrastructure strain as the city expands.

In conclusion, Chandrapur City's public transportation system and pedestrian infrastructure can achieve sustainability, cost-efficiency, and enhanced urban liability through the combined use of Bio-CNG and EV buses and pedestrian bridges. This integrated approach not only meets current transportation needs but also supports Chandrapur's vision for a greener, more accessible urban future.

9. Future Scope :

The future scope of this research lies in the continued advancement and adoption of sustainable transportation technologies, along with integrating complementary infrastructure to address growing urban mobility demands. One significant area of future development is the evolution of battery technology for EV buses, which can enhance energy storage capacity, reduce charging times, and increase operational range. With advancements in renewable energy integration, the environmental impact of EV buses can be further minimized, ensuring their lifecycle remains emission-free. Simultaneously, innovations in biogas production and storage can optimize Bio-CNG operations, enabling the use of more efficient and scalable fueling systems. These advancements will make both Bio-CNG and EV buses more versatile, further aligning with Chandrapur's urban growth and sustainability goals.

In addition, future studies could focus on hybrid approaches, combining Bio-CNG and EV technologies to create multi-fuel systems that maximize efficiency and environmental benefits. Integration with smart city initiatives, such as real-time data collection, intelligent traffic management, and dynamic route optimization, will enhance the operational efficiency of public transit systems. Further exploration into public-private partnerships could accelerate infrastructure development for both Bio-CNG and EV systems, reducing financial constraints. As Chandrapur's urban landscape evolves, these initiatives will not only address immediate transportation challenges but also position the city as a model for sustainable and forward-thinking urban planning.

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