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A Review on : Impact of Corrosion on Fuel Efficiency and Performance in Hydrogen and EVs

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Abstract: The shift from internal combustion engine (ICE) vehicles, which depend on fossil fuels, to other power sources is essential for meeting global climate and public health goals. This paper looks at the environmental and material-specific effects of Battery Electric Vehicles (BEVs) and Hydrogen Fuel Cell Vehicles (HFCVs) compared to traditional ICE vehicles, focusing on the unique issues posed by corrosion. Although the advantages of EVs and HFCVs in cutting tailpipe emissions and greenhouse gases are well-established, the change in energy source greatly affects the corrosive environment a vehicle faces.

This research first highlights the well-known environmental benefits of zero-emission vehicles over fossil-fuel vehicles, discussing lifecycle emissions and air quality improvements. The paper then explores how this transition affects vehicle lifespan and integrity by examining the corrosion mechanisms in BEVs and HFCVs versus ICE vehicles. Important differences arise regarding the types and locations of corrosion. Fossil fuel vehicles mainly suffer from rust due to road salts and the acidic byproducts of fuel combustion. In contrast, EVs and HFCVs create new corrosion pathways, such as galvanic corrosion from multi-material chassis design and the risk of corrosion in high-voltage battery and fuel cell systems.

The findings show that while BEVs and HFCVs remove traditional rust issues, they introduce new and complex corrosion risks that need innovative mitigation strategies. The paper argues that recognizing and managing these new corrosion risks is crucial for ensuring the durability and long-term sustainability of the next generation of transportation. The study concludes by suggesting that ongoing progress in material science, protective coatings, and isolation techniques will be vital for unlocking the full potential of these clean energy vehicles.

Keywords: Hydrogen fuel cell, Electric vehicle, Corrosion, Efficiency, India, Rust, Catalyst degradation, Bipolar plates, Material durability, Green Hydrogen Mission, Sustainable transport

I. INTRODUCTION

India is currently undergoing a significant change in its energy and transportation sectors as it aims to reach its Net Zero emissions target by 2070. Rapid urbanization, increased fuel demand, and severe air pollution in major cities have made the shift to clean mobility a national priority. Hydrogen fuel cell vehicles (HFCVs) and battery electric vehicles (BEVs) are among the most promising technologies driving this change. Both have the potential to greatly reduce greenhouse gas emissions and reliance on imported oil. However, one major challenge that continues to affect the long-term performance and cost-effectiveness of these technologies is corrosion.

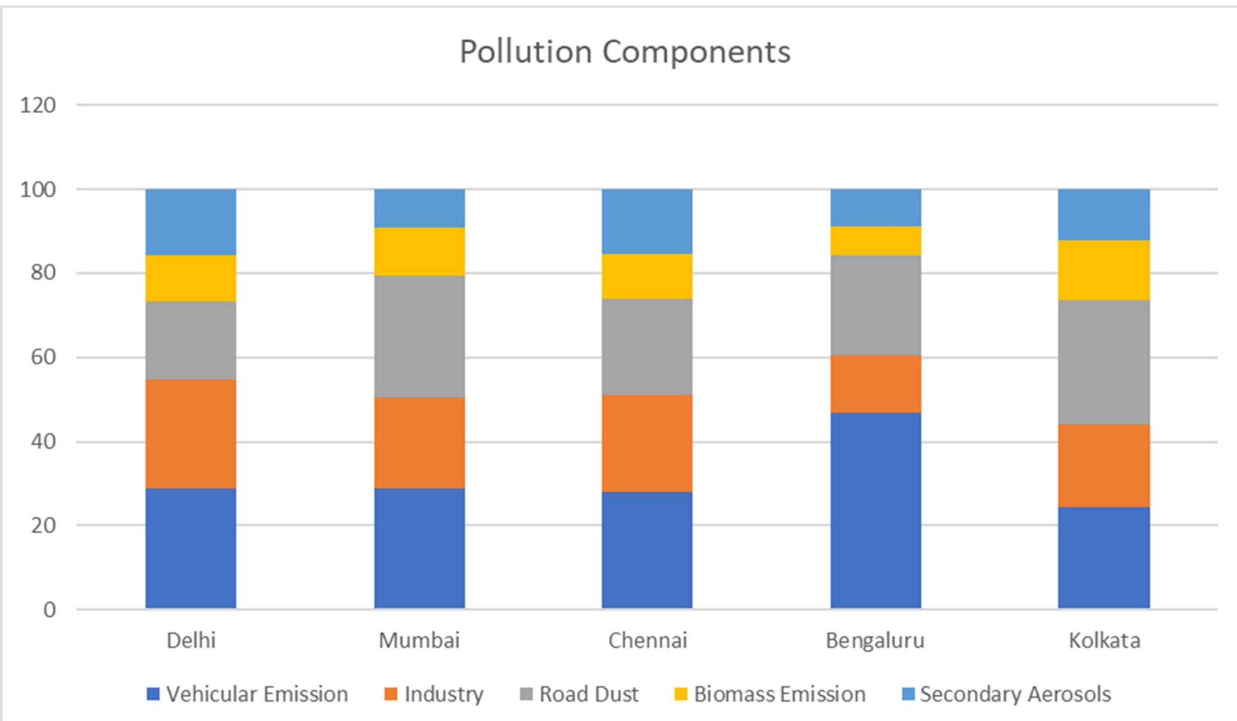
In India, corrosion is a serious issue due to the country's varied climatic conditions, ranging from humid coastal areas to dry, dusty plains. These environments speed up the deterioration of materials used in vehicle parts, especially in hydrogen fuel cells. Components like bipolar plates, catalysts, and current collectors are susceptible to chemical and electrochemical corrosion. This leads to increased resistance, heat generation, and lower stack efficiency. Over time, this decay not only wastes energy but also diminishes the range and power output of hydrogen vehicles. In electric vehicles, corrosion impacts battery terminals, connectors, and cooling systems, which can result in reduced efficiency, short circuits, and higher maintenance costs.

With India's National Green Hydrogen Mission and rising investments in local EV manufacturing, understanding and addressing corrosion is crucial for ensuring reliability and affordability. Research on better corrosion-resistant materials, protective coatings, and effective maintenance strategies can greatly improve the durability of clean-energy vehicles used in Indian conditions.

This paper aims to examine how corrosion affects the efficiency and performance of hydrogen fuel cells and electric vehicles in India. It reviews existing research, compares data on material degradation, and looks into potential solutions suited to India's environmental and economic context. The findings can help create strong, long-lasting, and sustainable vehicle technologies that align with India's green mobility goals.

The below chart represents the components of pollution in air caused by various factors. The Indian transport sector contributes to 7.4% of national CO2 emission (GoI. 2015).

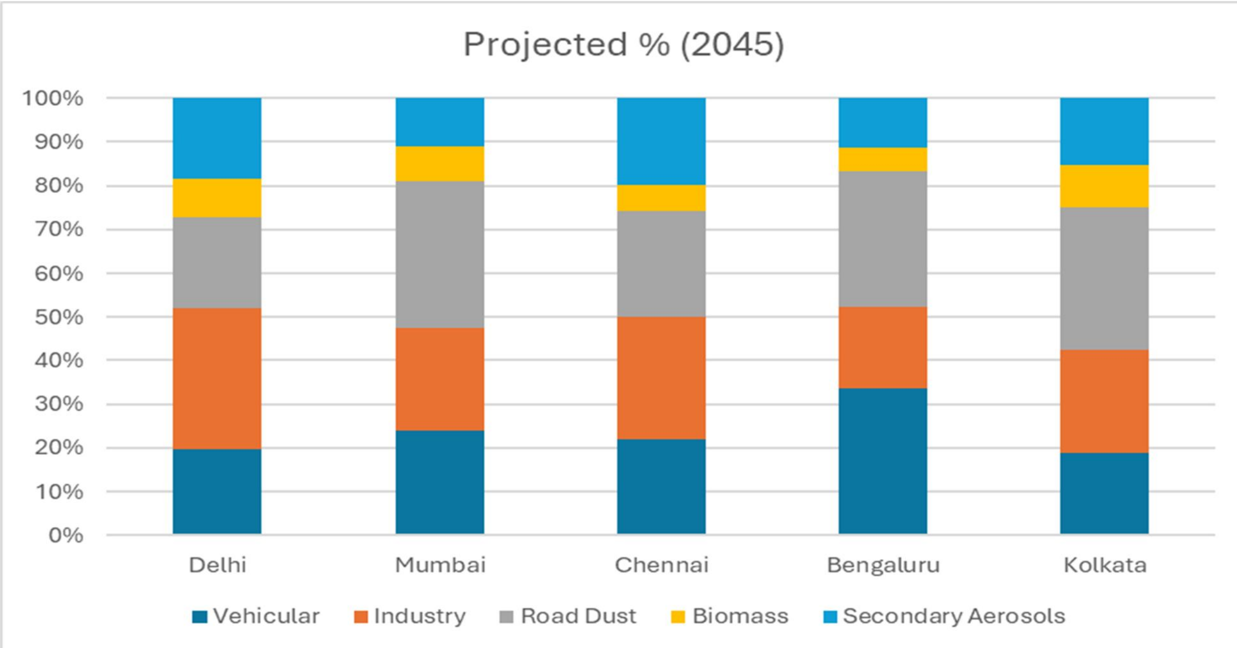
CITY	VEHICULAR EMISSION (%)	INDUSTRY (%)	ROAD DUST (%)	BIOMASS EMISSION (%)	SECONDARY AEROSOLS (%)
DELHI	*20-41*	*20-35*	*10-30*	*5-20*	*10-25*
MUMBAI	*25-35*	*15-30*	*20-40*	*10-15*	*5-15*
CHENNAI	*20-35*	*15-30*	*15-30*	*5-15*	*10-20*
BENGALURU	*40-56*	*10-20*	*20-30*	*5-12*	*5-15*
KOLKATA	*20-30*	*15-25*	*20-40*	*10-20*	*10-15*



Graph 1: Percentage Pollution according to 2018 Census

The above graph is a pictorial representation of the pollution components in air of different metropolitan cities (the data has been modified for convenience of understanding). We observe that a major component of pollution in all these cities is vehicular emission. The Government of India has been implementing various policies in minimizing vehicular pollution. These include improvements in internal combustion engine technology, inclusion of alternative fuels like hydrogen, biofuels, etc. the best way for achieving emission reduction is by decarbonizing the transport sector by switching to EVs and hydrogen fuel vehicles.

The data shows that vehicle pollution is the main cause of poor air quality in these cities. To tackle this issue, the Government of India has started actions like improving engine technology, promoting alternative fuels such as hydrogen and biofuels, and encouraging the use of electric and hydrogen fuel vehicles. These steps aim to reduce emissions in the transport sector.



Graph 2: Predicted Percentage Pollution for 2045

The projected distribution shows significant declines in both vehicle and industrial emissions across cities. These changes align with India's efforts to:

- Expand electric vehicle infrastructure
- Deploy hydrogen fuel cell buses, trucks, and rail systems
- Implement green energy incentives under the National Green Hydrogen Mission

A. Hydrogen Fuel Cell & Material Durability Factors

Hydrogen fuel cell systems, especially Proton Exchange Membrane Fuel Cells (PEMFCs), are expected to become prominent by 2045. Their success largely depends on:

- Catalyst degradation behavior over long operating cycles
- Corrosion resistance of bipolar plates
- Overall material durability under humid, high-temperature fuel cell condition.

Better materials engineering reduces lifecycle emissions and improves system reliability. This contributes indirectly to lower pollution from industry and vehicles in the projected model.

B. Reduction in Vehicle Emission Percentage

The shift to electric vehicles and hydrogen-based mobility directly reduces combustion-related pollutants like NO_x, PM, and CO. This change is strongly supported by:

- Rapid electrification targets
- Improvements in battery technology
- Cleaner charging from renewable energy sources
- Deployment of hydrogen-powered heavy transport

C. Effects of Corrosion in Hydrogen Fuel Cells Under Indian Operating Condition

Hydrogen fuel cell vehicles (HFCVs), especially those with Proton Exchange Membrane Fuel Cells (PEMFCs), depend on the durability of key parts like bipolar plates, catalysts, current collectors, and membrane assemblies. India's varied environment features high humidity, coastal salinity, extreme temperatures, and high levels of particulate matter. These factors increase corrosion and wear in these parts. This degradation affects energy efficiency, reduces the lifespan of fuel cells, and impacts overall vehicle performance, as noted in the paper's abstract.

1) Corrosion of Bipolar Plates

Bipolar plates distribute reactant gases, remove heat, and conduct electrons. In India's humid and coastal areas such as Mumbai, Chennai, and Kochi, stainless steel and graphite composite plates experience faster corrosion due to:
- Chloride ions in coastal air, causing pitting corrosion
- High humidity, which increases electrolyte formation
- An acidic PEMFC environment

This results in higher interfacial contact resistance (ICR), lower cell voltage, and decreased overall efficiency.

2) Catalyst Layer Corrosion and Degradation

Platinum-based catalysts dissolve and clump together over time. In cities with high air pollution and particulate matter, impurities like SO_2 and NO_x contaminate the catalyst surface and lower its electrochemical activity. High temperatures during extended driving also speed up carbon support corrosion, causing catalyst detachment.

3) Corrosion in Gas Diffusion Layers (GDL) and Current Collectors

Materials such as carbon cloth and carbon paper break down under oxidative conditions. Corrosion leads to:
- Decreased water management efficiency
- Reduced proton conductivity
- Increased mass transport losses

Copper and aluminum current collectors corrode when exposed to moisture, especially in assemblies with different materials.

4) Hydrogen Storage and Pipeline Corrosion

India's emerging hydrogen infrastructure brings risks such as:
- Hydrogen embrittlement in steel cylinders
- Stress corrosion cracking in pipelines
- Surface oxidation in humid areas

These issues affect the reliability of hydrogen fueling networks, which has implications for vehicle safety and maintenance schedules.

D. Impact of Corrosion on Fuel Cell Efficiency and Vehicle Performance

Corrosion-related material damage directly lowers voltage output, increases heat generation, and affects system durability. The paper points out that Indian climate conditions hasten the damage of catalysts, plates, and connectors, resulting in reduced stack efficiency and thermal instability.

1) Reduced Electrochemical Efficiency

Corrosion raises electron transfer resistance, lowering the effective power output of each cell. Over time, this results in:
- Lower fuel economy
- Reduced driving range
- More hydrogen consumption per kilometer

2) Heat Imbalance and Higher Cooling Load

Localized corrosion creates hotspots in the cell stack. To manage these thermal differences, the cooling system must work harder, consuming more auxiliary power and reducing overall efficiency.

3) Increased Maintenance and Lifecycle Cost

Components need replacing more often. Bipolar plates and catalysts, which are two of the costliest fuel cell parts, can account for nearly 60% of PEMFC system costs in many commercial designs. Corrosion speeds up their wear.

E. Corrosion in Electric Vehicles (Comparative Insight)

While the primary focus is on hydrogen fuel cells, electric vehicles (EVs) also face corrosion issues in India, particularly in battery terminals, high-voltage connectors, electronic control units, and liquid cooling circuits. It is observed that corrosion in EVs can lead to reduced efficiency, short circuits, and higher operational costs.

F. Mitigation Strategies Suitable for Indian Conditions

1) Corrosion-Resistant Coatings

- Titanium nitride, chromium carbide, and graphene coatings for bipolar plates
- Atomic Layer Deposition (ALD) for catalyst supports
- Hydrophobic layers for GDL materials

2) Improved Water and Thermal Management

Managing humidity levels within PEMFCs helps reduce unwanted electrolyte formation that speeds up corrosion. Better cooling systems are necessary for India's extreme weather.

3) Air Filtration and Impurity Control

High-efficiency particulate filters (HEPA-level) and gas-phase purifiers can limit catalyst poisoning from SO_2, NO_x, and PM-laden air in Indian cities.

4) Material Innovation for Indian Infrastructure

Hydrogen pipelines and storage tanks should use:
- Embrittlement-resistant alloys
- Smart coatings
- Real-time corrosion sensors

These measures will improve safety and reliability in future hydrogen networks.

Corrosion is one of the biggest challenges impacting the performance, cost, and safety of hydrogen fuel cell vehicles in India. While both EVs and HFCVs help reduce tailpipe emissions and assist cities in meeting pollution reduction targets, creating a mobility system that resists corrosion needs significant advancements in material science and designs that suit specific climate conditions.

G. Long-Term Implications

- Higher reliability for hydrogen buses, trucks, and rail systems
- Lower lifecycle emissions due to less frequent material replacement
- Greater public trust in new green technologies
- Supporting India's National Green Hydrogen Mission

II. RESULT & CONCLUSION

Corrosion is a key factor in the future success of hydrogen fuel cell vehicles and electric mobility in India. If material degradation related to India's climate and pollution is not addressed, the benefits of clean mobility in terms of cost and efficiency cannot be fully realized. However, progress in materials engineering, coatings, and system design can significantly improve durability. With smart investments and dedicated research and development, India can tackle corrosion issues and speed up the transition to sustainable, zero-emission mobility.

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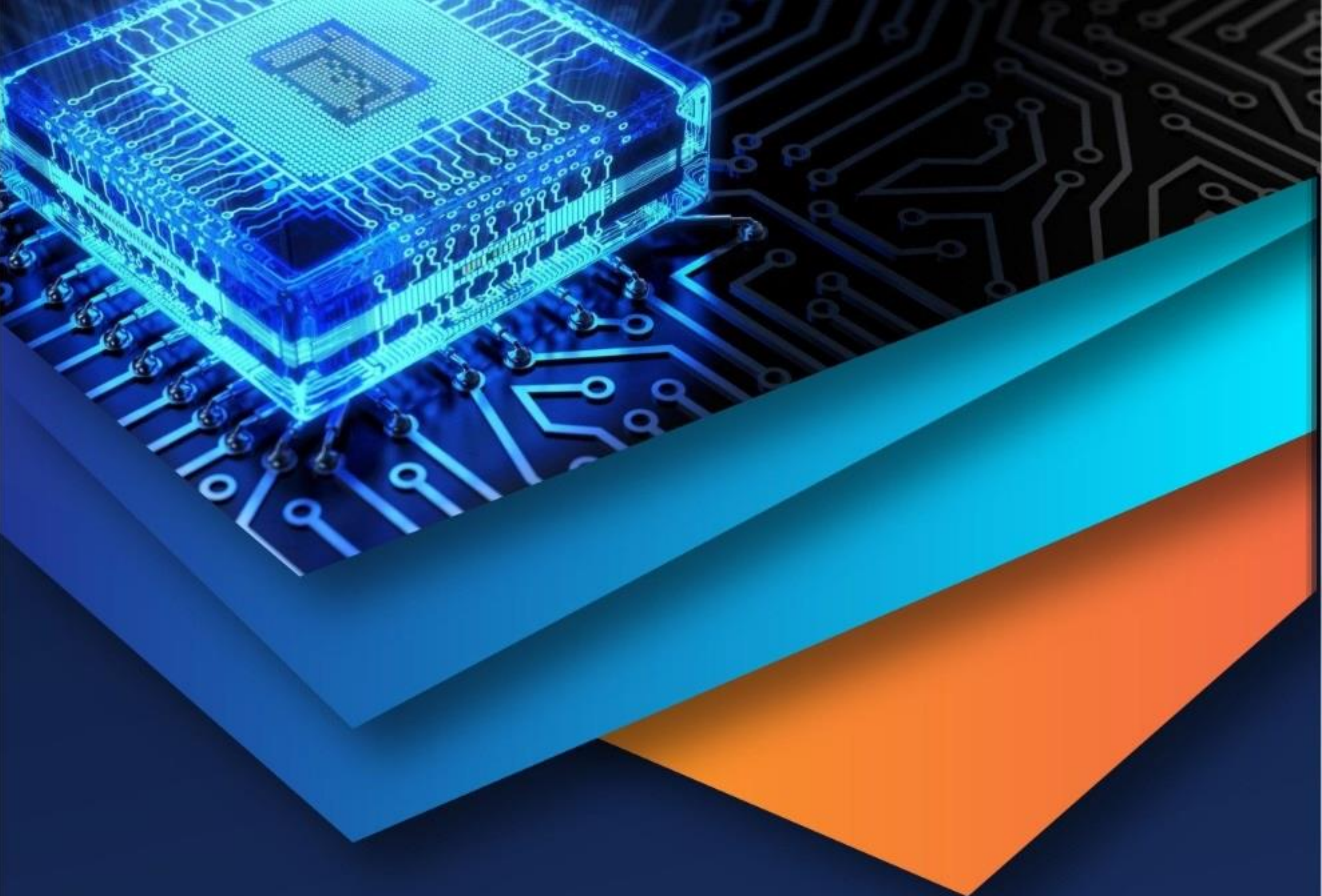

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