
Environmental Management Practices in Oil Refineries: A Case Study of Numaligarh Refinery Limited (NRL), India

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ABSTRACT

Environmental management in the oil refining sector is crucial due to the industry's significant environmental footprint. This research paper provides an in-depth analysis of the environmental management practices at Numaligarh Refinery Limited (NRL), a prominent refinery in Assam, India. The study evaluates NRL's strategies in waste management, effluent treatment, air quality control, energy efficiency, carbon management, and the adoption of innovative technologies. The paper also assesses the refinery's adherence to environmental regulations and its contributions to sustainable development. The findings highlight NRL's proactive approach to environmental stewardship, which serves as a model for the industry.

KEYWORDS: Environmental Management; Oil Refinery; Waste Management; Air Quality; Energy Efficiency; Numaligarh Refinery Limited; Sustainability

Reference to this article should be made as follows:

Bora, M, and Dutta, N. (2025) 'Environmental Management Practices in Oil Refineries: A Case Study of Numaligarh Refinery Limited (NRL), India', *Journal of Cases in Management Studies*, Vol. 01, No. 01, p. 64 – 77.

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1. Introduction:

Environmental impact is an important issue across the globe, and managing environmental impact is essential for any industry. This requires a robust environmental management framework that efficiently integrates environmental responsibilities into overall operations. Numaligarh Refinery Limited (NRL), a subsidiary of Bharat Petroleum Corporation Ltd., is a Public Sector Undertaking in the Oil & Gas sector. NRL, also known as the 'Assam Accord Refinery,' was established in the Telgaram area of Numaligarh in Golaghat district as part of the commitment made by the Government of India in the historic Assam Accord signed on 15th August 1985. The refinery was dedicated to the nation by the then Honourable Prime Minister, Sri Atal Bihari Vajpayee, on 9th July 1999, with commercial production commencing on 1st October 2000.

NRL does not have its own raw materials. Instead, it utilizes Assam crude, sourced from the oil fields of ONGC and Oil India Limited. The refinery processes this crude oil to produce various products, including petrol, High-Speed Diesel (HSD), Aviation Turbine Fuel (ATF), Superior Kerosene Oil (SKO), Motor Spirit (MS), Liquefied Petroleum Gas (LPG), Naphtha, Petroleum Coke, and Sulphur. The remaining residue is utilized as calcined coke (Numaligarh Refinery Limited, 2021). Beyond its industrial achievements, NRL is increasingly recognized for its proactive stance on environmental stewardship, adopting sustainable practices in an industry often associated with environmental degradation.

This paper embarks on a comprehensive exploration of NRL's environmental management strategies, focusing on the company's initiatives, policies, and technologies aimed at mitigating the environmental footprint of its operations. As the world grapples with mounting challenges from climate change and environmental degradation, examining the practices of entities like NRL becomes imperative in understanding how industry and sustainability can coexist. The study aims to shed light on NRL's environmental management approaches, exploring their successes, challenges, and implications for broader environmental and industrial practices.

By scrutinizing NRL's efforts in waste management, emission control, community engagement, and regulatory compliance, this paper evaluates the effectiveness of their environmental management strategies. Furthermore, it aims to extract lessons and best practices that could be applicable not just within the industry but across diverse sectors, contributing to the discourse on sustainable development and environmental conservation. The case study of Numaligarh Refinery Limited serves as a beacon of innovation and commitment in environmental management, offering valuable insights and lessons for both industrial entities and policymakers in their pursuit of a sustainable future.

1.1. Numaligarh Refinery Limited (NRL):

Numaligarh Refinery Limited (NRL), a subsidiary of Bharat Petroleum Corporation Limited (BPCL), stands as one of India's key public sector oil refineries, playing a significant role in the energy sector of Northeast India. Established as part of the Assam Accord of 1985, NRL was envisioned to promote industrial growth in the region while meeting the energy demands of the northeastern states. Located in the Golaghat district of Assam, the refinery commenced commercial production in 2000 and has since evolved into a critical player in India's refining sector.

Despite its contributions to regional economic development, NRL operates within an industry that is inherently linked to environmental challenges, including emissions, waste disposal, and resource consumption. However, the refinery has taken significant strides toward

environmental sustainability, adopting modern technology, pollution control measures, and energy-efficient processes to minimize its ecological footprint. As the refinery strategically located near the ecologically sensitive Kaziranga National Park, balancing industrial expansion with environmental conservation remains a critical challenge. This case study examines NRL's environmental management practices, focusing on waste management, air and water pollution control, carbon management, energy efficiency, and compliance with environmental regulations. By analysing the refinery's sustainability initiatives, regulatory adherence, and technological innovations, the study aims to assess the effectiveness of NRL's approach to mitigating environmental risks as well as sustaining industrial growth. Additionally, the study explores the challenges faced by the refinery, particularly considering its geographical proximity to fragile ecosystems and the need for responsible environmental stewardship. NRL serves as a compelling case for evaluating how oil refineries can integrate sustainable practices by navigating regulatory and ecological constraints. The findings from this study will contribute to the broader discourse on balancing industrial development with environmental responsibility, providing insights into best practices that could be applied across similar industries.

1.2. Objectives: The study is undertaken with the following objectives:

1. To analyse the environmental policies and practices implemented by NRL.
2. To assess the usefulness of NRL's strategies in waste management, emission control, and resource conservation.
3. To examine NRL's compliance with environmental regulations and its contribution to sustainable development.

2. Methodology:

This study employs a comprehensive mixed-methods approach, integrating both qualitative and quantitative research techniques to ensure a holistic assessment of Numaligarh Refinery Limited's (NRL) environmental management practices. The research design combines secondary data analysis with primary data collection to provide a well-rounded understanding of NRL's strategies, challenges, and impact.

2.1. Secondary Data Analysis: An extensive review of existing literature, academic papers, industry reports, government regulations, and relevant publications was conducted to establish a strong theoretical and contextual foundation. This review helped in: Understanding the historical background of environmental management in oil refineries. Evaluating the regulatory framework governing refineries in India and globally. Identifying best practices and challenges in environmental sustainability within the oil and gas sector. Comparing NRL's practices with global benchmarks and industry standards. Additionally, official documentation from Numaligarh Refinery Limited, including environmental reports, sustainability policies, compliance records, and technological innovation reports, was analysed to examine the refinery's official stance, initiatives, and achievements in environmental management.

2.2. Primary Data Collection: To complement the secondary data, primary data was gathered through on-site visits, stakeholder interviews, and observational analysis, ensuring a deep, real-time understanding of NRL's environmental management framework.

2.3. Data Triangulation and Validation: To enhance the credibility and reliability of the findings, a triangulation approach was adopted, wherein data collected from literature reviews, official reports, and stakeholder interviews were cross-verified.

2.4. Significance of the Study: The study on Numaligarh Refinery Limited's environmental management practices holds immense significance in several critical domains. It offers a unique and detailed insight into sustainable environmental practices within the oil and gas industry, presenting a tangible model through the exploration of NRL's strategies, successes, and challenges. This examination not only informs similar industrial entities but also contributes to the ongoing global efforts towards environmental conservation and sustainability. Furthermore, the study's findings possess the potential to influence policymakers and regulatory bodies by revealing the effectiveness of certain environmental policies and practices, thereby potentially shaping the development or revision of regulations to promote more environmentally friendly industrial operations. Assessing NRL's community engagement programs also emphasizes the pivotal role of corporate social responsibility and community involvement in fostering sustainable development. Additionally, by showcasing the technological innovations adopted by NRL, the study highlights the importance of technological advancements in reducing environmental impacts, encouraging research and development in eco-friendly technologies for the industry. This study serves as a practical, real-world example for academia, businesses, and the broader global community in addressing climate change, environmental preservation, and the pursuit of sustainable industrial practices.

3. Literature Review: Implementing effective environmental management practices in refineries involves overcoming challenges such as technological constraints, regulatory compliance, and financial implications. However, opportunities exist in adopting innovative technologies, enhancing operational efficiency, and engaging in corporate social responsibility initiatives (Rahman & Kabir, 2021). The environment management practices in refineries can be studied with the help of the following heads:

3.1. Environmental Impacts of Oil Refineries: Oil refineries are complex industrial facilities that process crude oil into various products such as gasoline, diesel, and petrochemicals. These operations generate significant environmental impacts, including air and water pollution, greenhouse gas emissions, and hazardous waste generation (Davis & Owens, 2019).

- a) **Air Pollution:** Refineries emit pollutants such as sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM), contributing to air quality degradation and health issues (Smith et al., 2020).
- b) **Water Pollution:** Effluents from refineries, containing hydrocarbons, heavy metals, and other contaminants, can adversely affect aquatic ecosystems if not properly treated (Chen & Wang, 2017).
- c) **Hazardous Waste:** Refineries generate hazardous wastes, including spent catalysts, oily sludge, and chemical wastes, posing disposal and management challenges (Ahmed & Sulaiman, 2019).
- d) **Greenhouse Gas Emissions:** Refineries are significant sources of CO₂ and other greenhouse gases, contributing to climate change (IEA, 2021).

3.2. Environmental Management in Oil Refineries: Environmental management in refineries involves implementing comprehensive systems and technologies to minimize environmental impacts. Key practices include:

- a) **Integrated Environmental Management Systems (EMS):** Adoption of EMS frameworks, such as ISO 14001, helps refineries to manage environmental responsibilities systematically (Prajapati & Kumar, 2018).

- b) **Pollution Control Technologies:** Refineries employ advanced technologies to reduce emissions, effluents, and waste generation, including scrubbers, biofilters, and effluent treatment plants (Gupta et al., 2019).
- c) **Energy Efficiency:** Enhancing energy efficiency through process optimization, waste heat recovery, and the use of renewable energy sources reduces operational costs and emissions (Lin & Lee, 2020).
- d) **Waste Management:** Applying the waste hierarchy—reduce, reuse, recycle—ensures efficient and environmentally sound waste management (Zhao et al., 2018).
- e) **Green Belt Development:** Establishing green belts around refineries helps mitigate air and noise pollution while enhancing biodiversity (Singh & Verma, 2019).

3.3. Global Best Practices and Standards:

- a) **World Bank Environmental, Health, and Safety Guidelines:** These guidelines provide industry-specific standards for environmental management in refineries, including emission limits and effluent quality (World Bank, 2016).
- b) **Equator Principles:** A risk management framework used by financial institutions to assess and manage environmental risks in large projects (Equator Principles Association, 2020).
- c) **Sustainable Development Goals (SDGs):** The UN's SDGs, particularly Goals 7, 12, and 13, guide industries towards sustainable practices (United Nations, 2015).

3.4. Environmental Regulations in India: India's regulatory framework for environmental management in refineries includes:

- a) **Environment (Protection) Act, 1986:** Provides the legal framework for environmental regulation in India (Government of India, 1986).
- b) **Air (Prevention and Control of Pollution) Act, 1981:** Regulates air pollution and emissions standards (Government of India, 1981).
- c) **Water (Prevention and Control of Pollution) Act, 1974:** Regulates water pollution and effluent discharge standards (Government of India, 1974).
- d) **Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016:** Governs the management and disposal of hazardous wastes (MoEFCC, 2016).

3.5. Environmental Management Practices at NRL:

Numaligarh Refinery Limited (NRL) has established itself as a modern, efficient, and eco-friendly refinery by adopting advanced and comprehensive environmental management practices from the very inception of its projects. The refinery's commitment to sustainability is evident in its adherence to statutory regulations, robust infrastructure, and innovative initiatives aimed at minimizing its environmental footprint. NRL's proactive approach to environmental stewardship has set a benchmark in the oil and gas industry, making it a model for sustainable industrial operations.

NRL places the highest priority on health, safety, and environmental (HSE) issues, ensuring strict compliance with various statutory rules and regulations, including the Factories Act, Petroleum Acts and Rules, Boiler Rules, and Environmental and Pollution Rules. The refinery's commitment to regulatory compliance is reinforced by a well-structured governance framework. An Apex Committee, chaired by the Directors Technical of the refinery, reviews the Environment and Safety performance every two months. Additionally, Unit-level and Area-level safety committees meet monthly to assess the safety performance

of their respective units or areas. This multi-tiered review system ensures that environmental and safety concerns are addressed promptly and effectively.

NRL's infrastructure emphasises its commitment to safety and environmental protection. The refinery boasts a state-of-the-art Fire Station located at the main gate, strategically positioned away from the operating units to ensure rapid response in case of emergencies. The Fire Station is equipped with modern firefighting equipment and trained personnel, ensuring the highest level of preparedness for any potential incidents. This focus on safety infrastructure not only protects the refinery's operations but also safeguards the surrounding environment and communities.

NRL has established a full-fledged Energy and Environment Cell, staffed with qualified engineers and environmental experts, to address environmental issues and promote sustainable practices. This cell plays an important role in monitoring and managing the refinery's environmental performance. The Energy and Environment Cell is supported by a well-equipped laboratory accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL). This laboratory conducts daily monitoring of environmental parameters and ensures that the refinery's operations remain within permissible limits and comply with environmental standards.

In addition to environmental monitoring, NRL has a dedicated Health Centre that focuses on mitigating occupational health hazards. The Health Centre monitors toxic gas exposure, noise levels, and the overall health of employees, ensuring a safe and healthy work environment. This holistic approach to health and safety reflects NRL's commitment to the well-being of its workforce and the surrounding community.

NRL has consistently demonstrated a proactive approach to adopting technological innovations aimed at reducing its environmental footprint. The refinery has invested in modern, environmentally friendly technologies to enhance operational efficiency and minimize emissions during the refining process. For instance, NRL has implemented advanced emission control technologies, such as ultra-low NO_x burners and sulphur recovery units (SRUs), which have significantly reduced air pollutants like nitrogen oxides (NO_x) and sulphur dioxide (SO₂). Additionally, the refinery has installed Continuous Emission Monitoring Systems (CEMS) across its major emission sources, enabling real-time monitoring and ensuring compliance with environmental standards.

NRL's commitment to energy efficiency is evident in its adoption of waste heat recovery systems and the operation of a 12 MW Steam Turbine Generator (STG) for captive power generation. These initiatives not only reduce energy consumption but also lower greenhouse gas emissions, contributing to the refinery's carbon management goals. Furthermore, NRL has embraced renewable energy by installing 1.025 MW of solar photovoltaic (PV) systems within its premises and exploring the development of a bamboo-based bio-refinery for bioethanol production. These efforts align with India's renewable energy targets and demonstrate NRL's commitment to sustainable energy solutions.

NRL recognizes that sustainable environmental management requires a well-informed and skilled workforce. The refinery conducts regular training programs and skill development initiatives to foster a culture of environmental awareness and responsibility among its employees. By equipping its workforce with the knowledge and tools to implement best practices in environmental management, NRL ensures that sustainability is embedded at all levels of its operations.

Beyond its internal operations, NRL has established strong partnerships with local communities, fostering an inclusive approach to environmental stewardship. The refinery actively engages with local stakeholders through outreach programs and community initiatives, educating them about environmental conservation and involving them in sustainability efforts. For example, NRL organizes tree plantation drives and environmental awareness campaigns, encouraging community participation in conservation activities. These initiatives not only enhance the refinery's social license to operate but also contribute to the overall well-being of the surrounding communities.

NRL's commitment to environmental management is further reinforced by its emphasis on continuous improvement. The refinery conducts regular audits and assessments to identify areas for optimization and ensure that its environmental strategies remain aligned with emerging best practices and technological advancements. These reviews enable NRL to adapt to changing regulatory requirements and industry standards, maintaining its position as a leader in sustainable refinery operations. The refinery's multifaceted approach, which integrates technology, employee training, community engagement, and continuous improvement, solidifies its commitment to environmental stewardship. By setting higher benchmarks for environmental management, NRL not only enhances its operational efficiency but also contributes to the broader goal of sustainable industrial development.

NRL's comprehensive environmental management practices reflect its unwavering commitment to sustainability. From regulatory compliance and advanced technological innovations to employee training and community engagement, the refinery has adopted a holistic approach to minimizing its environmental impact. While challenges remain, NRL's dynamic initiatives and continuous improvement efforts position it as a leader in the oil and gas industry, setting an example for other industrial entities to follow. By prioritizing environmental stewardship, NRL is not only ensuring the long-term sustainability of its operations but also contributing to the global effort to combat climate change and promote sustainable development. NRL Environmental Statement, 2021, various reports and interview with the officials points out the major initiatives of NRL for sustainable environment which are mentioned below:

A. Solid and Hazardous Waste Management:

NRL employs comprehensive waste management practices minimizing waste generation, maximizing resource recovery, and ensuring safe disposal.

- a. **Waste Segregation and Collection:** NRL implements systematic waste segregation at source, categorizing waste into hazardous and non-hazardous. Hazardous wastes like spent catalysts are stored securely and disposed of through CPCB-approved vendors.
- b. **Secured Landfill Facilities:** NRL has constructed a new secured landfill with a capacity of 6,000 m³ for the disposal of hazardous wastes like oily sludge, in compliance with CPCB guidelines.
- c. **Bioremediation Facilities:** The refinery has established bioremediation facilities to treat tank bottom sludge using microbial processes, reducing environmental risks associated with hazardous waste disposal.

B. Effluent and Water Management:

NRL's water management strategy prioritizes water conservation, efficient effluent treatment, and recycling.

- a. **Effluent Treatment Plant (ETP):** NRL operates a state-of-the-art ETP with tertiary treatment capabilities, including advanced oxidation processes and high-

efficiency centrifuges for oil recovery. The refinery has achieved zero liquid discharge (ZLD) by recycling treated effluent within the refinery.

- b. Stormwater Management: NRL has installed oil taps and filters in its stormwater drainage system to prevent hydrocarbon contamination of natural water bodies. The treated stormwater is reused in cooling towers and firewater systems.

C. Air Quality Management:

NRL employs advanced technologies and continuous monitoring systems to manage and reduce air emissions.

- a. Emission Control Technologies: The refinery uses ultra-low NO_x burners in its furnaces which reduces nitrogen oxide emissions. It also operates sulphur recovery units (SRUs) to extract sulphur from sour gases, achieving a recovery efficiency of up to 99.9%.
- b. Continuous Emission Monitoring Systems (CEMS): NRL has installed CEMS across all major emission sources, providing real-time data on emissions and ensuring compliance with CPCB standards.
- c. Flare Gas Recovery System: The refinery has implemented a Flare Gas Recovery System to capture and recycle excess gases, reducing flaring and associated emissions

D. Energy Efficiency and Carbon Management:

NRL focuses on enhancing energy efficiency and reducing its carbon footprint through various initiatives.

- a. Energy Conservation Measures: NRL employs waste heat recovery systems and operates a 12 MW Steam Turbine Generator (STG) for captive power generation, reducing energy consumption and emissions.
- b. Renewable Energy Initiatives: The refinery has installed 1.025 MW of solar PV systems within its premises and is developing a bamboo-based bio-refinery for producing bioethanol, supporting India's renewable energy goals.
- c. Carbon Footprint Assessment: NRL conducts regular assessments of its greenhouse gas emissions and has registered Clean Development Mechanism (CDM) projects with the UNFCCC, earning Certified Emission Reductions (CERs).

E. Green Belt Development:

NRL has developed extensive green belts around its facilities to enhance biodiversity and act as a buffer against pollution.

- Plantation Drives: The refinery has planted over 1,00,000 saplings, contributing to carbon sequestration and enhancing local biodiversity. The green belt serves as a natural barrier against noise and air pollution.
- Community Engagement: NRL engages with local communities through tree plantation drives and environmental awareness programs, thus, promoting sustainability beyond its operations.

F. Innovative and Sustainable Technologies:

NRL is committed to adopt innovative technologies that enhance environmental performance.

- Hydrogen Peroxide Treatment: NRL has introduced hydrogen peroxide treatment in its effluent processes, reducing sludge generation and improving effluent quality.
- Double Sealing Systems: The refinery has implemented double mechanical seals in all Internal and External Floating Roof Tanks to prevent fugitive emissions by complying with the latest environmental regulations.

G. Research and Development Initiatives:

NRL's R&D efforts focus on developing sustainable technologies and enhancing operational efficiency.

- **Collaborations:** NRL has partnered with IIT Guwahati to develop biodegradable plastics from refinery streams, aligning with global efforts to reduce plastic pollution.
- **Indigenous Catalyst Development:** NRL is working on developing indigenous isomerization catalysts, reducing dependency on imports and supporting the 'Make in India' initiative.

4. Discussion:

Numaligarh Refinery Limited (NRL) has demonstrated a proactive and comprehensive approach to environmental management, aligning its operations with international sustainability standards. The refinery has implemented advanced strategies in waste management, effluent treatment, air quality control, and energy efficiency, which have contributed to its recognition as a leader in environmental stewardship within the oil and gas industry. However, despite these efforts, NRL faces significant challenges and controversies that highlight the complex balance between industrial development and environmental conservation.

4.1. Elephant Corridor and Habitat Destruction:

- **Deopahar Elephant Corridor:** NRL's expansion activities have been a focal point of environmental debates, particularly concerning the Deopahar Elephant Corridor near the refinery. The construction of a 2.2-kilometer-long wall as part of NRL's township expansion obstructed this critical passage, leading to habitat destruction and fragmentation. This has forced elephants to alter their natural migration routes, resulting in increased human-elephant conflicts in nearby settlements. The National Green Tribunal (NGT) intervened in 2016, ordering NRL to demolish the wall and undertake compensatory afforestation. Although partial demolition occurred in April 2024, full compliance with the NGT's directives remains incomplete, raising questions about NRL's commitment to environmental restoration.
- **Human-Elephant Conflicts:** The destruction of forests and hills for NRL's expansion has disrupted the natural habitat of elephants, leading to frequent encounters between elephants and humans. A study published in the 'Biodiversity and Conservation Journal' reported that Assam records approximately 80 elephant and 70 human deaths annually due to these conflicts. This emphasises the need for NRL to adopt more sustainable land-use practices and collaborate with wildlife conservation organizations to mitigate the impact of its operations on local biodiversity.

4.2. Pollution and Environmental Degradation:

- **River Pollution:** Allegations of inadequate waste disposal practices have raised concerns about NRL's impact on local water bodies, particularly the Kaliani River. Reports suggest that the river's aquatic life, including the Silgharia fish, is under threat due to water contamination from refinery effluents. Though NRL operates a state-of-the-art Effluent Treatment Plant (ETP) and claims to achieve zero liquid discharge (ZLD), but the persistence of pollution allegations indicates a need for more rigorous monitoring and transparency in waste management practices.

- **Green Belt Issues:** NRL has created extensive green belts around its facilities to reduce air and noise pollution. However, concerns have been raised about the quality of the vegetation, with observers noting an unusual layer on the plants that may indicate the impact of industrial emissions. This situation raises questions about the effectiveness of NRL's green belt initiatives and highlights the need for more robust measures to ensure the health of the surrounding ecosystem.

4.3. Bee and Butterfly Population Decline:

- **Bee Hive Disappearance:** The area near Deopahar was once famous for its large bee hives, which have now disappeared. NRL attributes this to the bees relocating to its township, but environmentalists argue that habitat destruction is the primary cause. The decline in bee populations is concerning because bees play a crucial role in pollination and maintaining ecological balance.
- **Butterfly Park:** NRL's Butterfly Park, intended to showcase its eco-friendly initiatives, has faced criticism for its lack of success. Despite claims of a thriving butterfly ecosystem, reports indicate that only a few butterflies are present, suggesting that the park may not be as successful as advertised. This highlights the need for NRL to re-evaluate its conservation strategies and ensure that its initiatives produce real environmental benefits.

4.4. Recent Elephant Death Incident:

In July 2024, a female wild elephant was electrocuted and buried within NRL's premises without proper notification to the authorities, sparking a wildlife crime investigation. This incident has intensified scrutiny of NRL's environmental practices, particularly regarding the safety and protection of local wildlife. It enhances the need for stricter enforcement of wildlife protection measures and greater accountability in NRL's operations.

4.5. Challenges and Opportunities for Improvement:

Despite NRL's achievements in environmental management, several challenges remain:

- I. **Regulatory Compliance:** NRL must navigate evolving environmental regulations and ensure full compliance with directives from regulatory bodies like the NGT. This requires a proactive approach to environmental monitoring and reporting.
- II. **Renewable Energy Integration:** Although NRL has made progress in energy efficiency and renewable energy adoption, there remains considerable potential for further investment in solar, wind, and other renewable energy sources. Expanding these initiatives would not only reduce NRL's carbon footprint but also align with India's renewable energy objectives.
- III. **Community Engagement:** NRL's community engagement programs have been commendable, but there is room for improvement in fostering collaboration with local communities and addressing their concerns. Greater transparency in reporting and more inclusive decision-making processes could enhance NRL's social license to operate.
- IV. **Technological Innovation:** NRL should continue to invest in cutting-edge technologies, such as carbon capture and storage (CCS), to further reduce greenhouse gas emissions. Research and development efforts should focus on eco-friendly refining processes and products, aligning with global sustainability trends.

5. Conclusion and Recommendations

Numaligarh Refinery Limited (NRL) has showed a significant commitment to environmental management through its comprehensive approach to sustainability. As highlighted throughout this study, NRL has implemented various strategies and technologies aimed at minimizing its environmental footprint while maintaining operational efficiency. The refinery's adherence to statutory regulations, technological innovations, and community engagement initiatives position it as a notable case study in environmental management within India's oil and gas sector. NRL's environmental management framework has led to significant achievements, including effective waste segregation, secured landfill facilities, and bioremediation technologies that mitigate hazardous waste risks. Its advanced Effluent Treatment Plant (ETP) ensures zero liquid discharge, enhancing water conservation. Air quality management has improved through ultra-low NO_x burners, sulphur recovery units, and Continuous Emission Monitoring Systems, while energy efficiency initiatives like waste heat recovery and a 12 MW Steam Turbine Generator have reduced emissions. Additionally, the plantation of over 100,000 saplings has strengthened local biodiversity, and innovations such as hydrogen peroxide treatment in effluent processes and double sealing systems in floating roof tanks underscore NRL's commitment to sustainability.

Despite these achievements, NRL faces significant challenges that require immediate attention. The controversies surrounding the Deopahar Elephant Corridor highlight the complex interplay between industrial development and wildlife conservation. The construction of a 2.2-kilometer-long wall as part of NRL's township expansion, which obstructed a critical elephant passage, has raised serious concerns about habitat fragmentation and increased human-elephant conflicts. Although the National Green Tribunal (NGT) ordered the demolition of the wall in 2016, full compliance remains incomplete, underscoring the need for more decisive action in addressing this issue.

The allegations of river pollution, particularly affecting the Kaliani River and its aquatic life, demand a more transparent and rigorous approach to effluent management and monitoring. Similarly, concerns about the quality of vegetation in NRL's green belts, the disappearance of bee hives, and the limited success of the Butterfly Park initiative indicate that the refinery's conservation efforts may not be as effective as claimed.

The recent incident involving the electrocution and improper burial of a female wild elephant within NRL's premises further highlights deficiencies in wildlife protection measures and raises questions about the refinery's environmental practices and reporting protocols. These challenges underscore the need for NRL to reassess its environmental management strategies and ensure that its initiatives deliver tangible and measurable environmental benefits.

To address these challenges and further enhance its environmental performance, NRL should consider implementing a comprehensive set of recommendations that span technological innovations, policy reforms, stakeholder engagement, and conservation initiatives.

a. Integration of Advanced Technologies for Pollution Control:

The adoption of next-generation emission control systems, enhanced effluent treatment methods, real-time environmental monitoring, advanced leak detection programs, and digital twin technology would contribute to a significant reduction in environmental impact across refinery operations.

b. Expansion of Renewable Energy Initiatives:

A strategic shift toward renewable energy, including the expansion of solar and wind power, acceleration of bio-refinery projects, investment in green hydrogen production, implementation of battery storage systems, and the development of a smart grid, would strengthen sustainability efforts.

c. Implementation of Carbon Management and Climate Resilience Strategies:

A structured approach to carbon management, encompassing carbon capture and storage, the establishment of science-based emission reduction targets, internal carbon pricing mechanisms, comprehensive climate risk assessments, and carbon offset programs, would support long-term climate resilience.

d. Commitment to Wildlife Conservation and Habitat Restoration:

Efforts to restore elephant corridors, implement systematic wildlife monitoring, mitigate electrocution risks, provide specialized staff training, and establish conservation partnerships would enhance biodiversity protection in ecologically sensitive areas.

e. Strengthening of Water Resource Management Practices:

A comprehensive water management strategy involving watershed protection programs, advanced water recycling systems, regular efficiency audits, expansion of rainwater harvesting, and aquatic biodiversity monitoring would promote responsible water stewardship.

f. Enhancement of Community Engagement and Transparency:

Greater community involvement could be achieved through participatory environmental monitoring programs, improved transparency in environmental reporting, the establishment of grievance redressal mechanisms, the development of environmental education centers, and the formation of a stakeholder advisory council.

g. Active Participation in Policy Advocacy and Industry Leadership:

Engagement in policy discussions, sharing of best practices, collaboration in research and development, contribution to industry standards, and exploration of sustainable finance mechanisms would reinforce leadership in environmental sustainability.

h. Promotion of Biodiversity Conservation Initiatives:

The development of pollinator habitats, revitalization of the Butterfly Park, implementation of biodiversity monitoring programs, propagation of native plant species, and research on ecological restoration would strengthen conservation efforts.

i. Integration of a Robust Environmental Management System:

The adoption of a structured environmental management approach, including ISO 14001 certification, life cycle assessments, performance tracking indicators, risk management enhancements, and the establishment of a knowledge management system, would support continuous environmental improvement.

j. Implementation of Sustainable Supply Chain Management Practices:

The incorporation of supplier environmental assessments, green procurement policies, supplier capacity-building programs, collaborative sustainability initiatives, and

optimized transportation logistics would promote environmentally responsible supply chain operations.

NRL's phased approach to sustainability should prioritize high-impact initiatives, integrate environmental goals with business strategy, establish robust performance measurement systems, adopt adaptive management, and allocate necessary resources. By implementing these measures, NRL can enhance operational efficiency, mitigate risks, and strengthen stakeholder trust while contributing to biodiversity conservation and climate action. A commitment to innovation, collaboration, and proactive adaptation will position NRL as a leader in sustainable refining. Embracing these strategies will not only reinforce its commitment to environmental management but also set a benchmark for balancing industrial growth with ecological responsibility in a low-carbon future.

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