International Journal of Advanced Research in Commerce, Management & Social Science (IJARCMSS)
(An International Quarterly Multidisciplinary Open Access Double Blind Peer Reviewed Refereed Journal)
ISSN :2581-7930 (Online), Impact Factor (Cosmos): 7.270 & PIF (I2OR): 5.010, Volume 09, No. 03(I), July-September, 2026, pp 52-59

Project Planning, Cost Analysis and Construction Management of a Compressed Biogas Plant: A Techno-Managerial Study

Shubham Maheshwari*

MBA (Marketing and Finance), Career Point University, Kota, Rajasthan.

*Corresponding Author: shubhamtech29@gmail.com

***Citation**: Maheshwari, S. (2026). Project Planning, Cost Analysis and Construction Management of a Compressed Biogas Plant: A Techno-Managerial Study. International Journal of Advanced Research in Commerce, Management & Social Science, 09(03(I)), 52–59. https://doi.org/10.62823/IJARCMSS/9.3(I).9168*

Abstract

The increasing demand for renewable energy and sustainable waste management has accelerated the adoption of Compressed Biogas (CBG) technology in India. Agricultural residues, particularly paddy straw, are generated in large quantities every year and are often disposed of through open-field burning, resulting in severe environmental pollution and greenhouse gas emissions. Establishing commercial-scale CBG plants offers a sustainable solution by converting agricultural waste into clean energy while producing valuable organic fertilizer. However, successful implementation of such projects requires effective project planning, accurate cost estimation, efficient resource management, and systematic construction practices. This research examines the project planning, cost analysis, and construction management aspects of a 21 TPD paddy straw-based Compressed Biogas plant. The study adopts a descriptive and analytical research methodology based on technical data, published literature, industrial practices, and project management principles. Various project management tools, including Work Breakdown Structure (WBS), Critical Path Method (CPM), procurement planning, and risk assessment techniques, have been utilized to evaluate project execution strategies. The financial assessment considers capital investment, operating expenses, revenue generation, and overall project viability. The findings indicate that effective planning and scheduling significantly improve project performance by minimizing delays, optimizing resource utilization, and reducing construction risks. The study also highlights the environmental benefits of CBG production through reduction of crop residue burning, greenhouse gas emissions, and dependence on fossil fuels. The research concludes that commercial-scale CBG plants are technically feasible, environmentally sustainable, and economically attractive when supported by efficient project management and government policies. The study provides practical recommendations for renewable energy developers, EPC contractors, and policymakers involved in future CBG infrastructure development.

***Keywords**: Compressed Biogas, Renewable Energy, Project Planning, Construction Management, Cost Analysis, Paddy Straw, Sustainable Development.*

Introduction

Energy demand has increased rapidly across the world because of industrialization, urbanization, and population growth. Conventional fossil fuels continue to dominate the global energy sector, but their excessive utilization has created major environmental concerns, including climate change, greenhouse gas emissions, and depletion of natural resources. These challenges have encouraged governments and industries to explore sustainable and renewable sources of energy capable of ensuring long-term energy security while reducing environmental impacts.

India possesses enormous agricultural resources and generates millions of tonnes of crop residues every year. Among these residues, paddy straw represents one of the largest biomass resources available in northern India. Due to limited utilization options and high transportation costs, a considerable quantity of paddy straw is burnt in agricultural fields after harvesting. This practice contributes significantly to air pollution, deterioration of soil quality, and public health issues.

Compressed Biogas (CBG) technology provides an effective solution to this problem by converting agricultural residues into methane-rich renewable fuel through anaerobic digestion. Upgraded biogas can be utilized as a substitute for compressed natural gas in transportation, industrial heating, and domestic energy applications. Besides renewable fuel production, CBG plants also generate high-quality organic fertilizer, contributing to sustainable agriculture and circular economy principles.

The Government of India has launched several initiatives, including the Sustainable Alternative Towards Affordable Transportation (SATAT) programme, to promote investment in CBG projects. These initiatives encourage the utilization of agricultural waste, reduction of fossil fuel imports, employment generation, and scientific waste management. Consequently, commercial-scale CBG plants have emerged as an important component of India's renewable energy strategy.

Although the technical process of biogas generation is well established, successful implementation of commercial CBG plants depends largely on project planning, cost management, procurement strategy, construction scheduling, resource allocation, quality assurance, and risk management. Delays in construction, cost escalation, equipment procurement issues, and poor coordination among stakeholders can significantly affect project performance and financial returns. Therefore, systematic project management practices become essential for achieving project objectives within the planned budget and schedule.

This research focuses on evaluating project planning methodologies, construction management practices, and financial analysis for a commercial-scale 21 TPD paddy straw-based Compressed Biogas plant. The study integrates engineering management principles with techno-economic evaluation to develop a practical framework for successful project implementation.

Problem Statement

India generates more than 500 million tonnes of agricultural residues annually, yet a substantial portion remains unutilized. Paddy straw is commonly disposed of through open-field burning because of inadequate collection systems, limited commercial utilization, and transportation constraints. This practice results in severe environmental pollution and loss of valuable biomass resources.

Commercial CBG plants have the potential to convert agricultural residues into clean energy. However, many projects experience schedule delays, inaccurate cost estimation, procurement issues, resource shortages, construction risks, and operational inefficiencies. These challenges reduce project profitability and discourage investment in renewable energy infrastructure.

The absence of an integrated framework that combines project planning, construction management, cost analysis, procurement management, and risk assessment creates significant implementation challenges. Therefore, a comprehensive study is required to establish practical project management strategies capable of improving the efficiency and success of commercial CBG projects.

Research Objectives

The present study has been undertaken with the following objectives:

- To evaluate the technical requirements of a commercial-scale Compressed Biogas plant.
- To develop an effective project planning framework for renewable energy infrastructure.
- To estimate capital investment and operational expenditure associated with CBG projects.
- To analyse manpower, equipment, and material requirements throughout project execution.
- To evaluate scheduling techniques for timely completion of construction activities.
- To identify major project risks and recommend suitable mitigation strategies.
- To assess financial feasibility using project management and investment evaluation techniques.
- To provide recommendations for improving project execution of future CBG plants.

Significance of the Study

The findings of this research contribute to the growing body of knowledge on renewable energy project management. Unlike previous studies that primarily focus on biogas production technology, the present research integrates engineering management principles with construction planning and financial analysis.

The study is expected to assist renewable energy developers, EPC contractors, consultants, project managers, policymakers, and researchers in improving project planning, reducing cost overruns, enhancing construction efficiency, and achieving successful implementation of commercial CBG plants. Furthermore, the research supports India's renewable energy mission by promoting sustainable utilization of agricultural residues and reducing environmental pollution.

Literature Review

Renewable energy technologies have attracted considerable research attention during the past two decades due to increasing environmental concerns and the depletion of conventional energy resources. Among various renewable energy options, anaerobic digestion has emerged as one of the most sustainable methods for converting biodegradable waste into clean fuel and organic fertilizer.

Several international studies have demonstrated that countries such as Germany, Sweden, Denmark, and China have successfully developed commercial biogas industries supported by favourable government policies and technological advancements. Their experiences indicate that effective project planning, efficient feedstock management, and strong regulatory frameworks play a crucial role in successful plant operation.

Research conducted on agricultural residue utilization confirms that paddy straw possesses significant potential for renewable energy production. Although its lignocellulosic composition requires appropriate pre-treatment before anaerobic digestion, technological advancements have substantially improved methane recovery and plant efficiency. Studies have also emphasized that systematic feedstock collection and storage significantly influence long-term project sustainability.

Numerous researchers have evaluated different biogas upgrading technologies, including Pressure Swing Adsorption (PSA), Water Scrubbing, Membrane Separation, and Chemical Absorption. Among these technologies, PSA has become widely adopted because of its high methane recovery, operational reliability, and commercial suitability for medium and large-scale CBG plants.

Project management literature consistently highlights that inadequate planning is one of the primary reasons for cost overruns and schedule delays in infrastructure projects. Construction management tools such as Work Breakdown Structure (WBS), Critical Path Method (CPM), Project Evaluation and Review Technique (PERT), procurement planning, and risk management have demonstrated significant improvements in project performance across various industrial sectors.

Despite extensive research on renewable energy technologies, relatively few studies have integrated technical evaluation with project planning, construction management, financial assessment, and risk analysis specifically for commercial CBG plants. This research attempts to bridge that gap by providing a comprehensive techno-managerial framework suitable for commercial implementation.

Research Gap

An extensive review of published literature indicates that considerable research has been carried out on renewable energy technologies, anaerobic digestion processes, feedstock characteristics, biogas purification systems, and the economic feasibility of Compressed Biogas (CBG) plants. Most previous studies have focused on improving methane yield, optimizing digester performance, evaluating feedstock properties, and enhancing gas upgrading technologies. These investigations have significantly contributed to the technical development of the biogas industry.

However, limited research has been conducted on integrating engineering project management with commercial-scale CBG plant implementation. Existing studies generally address technical or financial aspects independently, while practical issues such as project planning, procurement management, construction scheduling, manpower planning, quality assurance, and risk mitigation receive comparatively less attention.

Commercial CBG plants involve multidisciplinary coordination among civil, mechanical, electrical, instrumentation, process engineering, procurement teams, contractors, consultants, vendors, and regulatory authorities. Ineffective coordination frequently results in delays, cost overruns, resource shortages, contractual disputes, and reduced project efficiency. Despite the increasing number of CBG projects being implemented under India's SATAT programme, comprehensive project management frameworks specifically designed for CBG infrastructure remain limited.

Furthermore, previous studies rarely evaluate project implementation using engineering management tools such as Work Breakdown Structure (WBS), Critical Path Method (CPM), procurement scheduling, resource optimization, quality management systems, and risk assessment matrices. These tools are widely used in large infrastructure projects but have not been sufficiently explored in the renewable energy sector.

Therefore, the present research attempts to bridge this gap by integrating technical evaluation, project planning, construction management, cost estimation, procurement strategy, financial analysis, and risk management into a single comprehensive framework for commercial-scale Compressed Biogas plants.

Research Methodology

- **Research Design**

The present study adopts a descriptive and analytical research design. The research aims to evaluate the planning, costing, construction management, and financial feasibility of a commercial-scale Compressed Biogas plant using both qualitative and quantitative approaches. Descriptive analysis has been employed to understand project planning practices, whereas analytical methods have been utilized to evaluate project costs, schedules, risks, and investment feasibility.

The research methodology has been designed to ensure systematic assessment of all major project activities from conceptual planning to commissioning of the plant.

- **Sources of Data**

The study is based on both primary and secondary sources of information.

Primary Data

Primary information was collected through:

- Site observations during project execution.
- Discussions with project engineers and construction managers.
- Interactions with consultants and equipment suppliers.
- Practical experience gained during execution of commercial CBG projects.
- Technical inputs obtained from industry professionals.

Secondary Data

Secondary information was collected from:

- Published research journals.
- Government publications.
- Ministry of Petroleum and Natural Gas (MoPNG).
- Ministry of New and Renewable Energy (MNRE).
- SATAT Scheme guidelines.
- Technical manuals.
- Engineering standards.
- Industry reports.
- Existing Detailed Project Reports (DPRs).
- Technical specifications of commercial CBG plants.

The combination of primary and secondary data improves the reliability and validity of the research findings.

- **Research Framework**

The research was conducted through the following sequential stages:

- **Stage 1 – Literature Review**

  A comprehensive review of previous studies was conducted to understand renewable energy technologies, anaerobic digestion, project planning practices, construction management techniques, and financial evaluation methods.

- **Stage 2 – Data Collection**

  Technical, financial, operational, and construction-related information was collected from industrial projects and published sources.

- **Stage 3 – Technical Evaluation**

  Major process units such as feedstock handling systems, digesters, gas upgrading systems, compression facilities, storage systems, and utility infrastructure were evaluated.

- **Stage 4 – Project Planning**

  Work Breakdown Structure (WBS), project schedules, procurement plans, manpower deployment, equipment planning, and construction sequencing were prepared.

- **Stage 5 – Cost Analysis**

  Capital investment, operating expenses, contingency provisions, maintenance costs, and project budgets were estimated.

- **Stage 6 – Financial Evaluation**

  Revenue generation, Return on Investment (ROI), Internal Rate of Return (IRR), Payback Period, and project profitability were analysed.

- **Stage 7 – Risk Assessment**

  Potential risks associated with technical, financial, procurement, construction, environmental, and regulatory aspects were identified and mitigation measures were proposed.

- **Stage 8 – Conclusions and Recommendations**

  Research findings were summarized and practical recommendations were developed for future commercial CBG projects.

- **Feedstock Assessment**

Feedstock availability represents one of the most critical factors influencing the success of a commercial CBG plant.

The present study considers paddy straw as the primary feedstock because of its abundant availability in agricultural regions of northern India.

The following parameters were evaluated:

- Annual feedstock availability
- Seasonal variation
- Collection radius
- Transportation distance
- Storage requirements
- Moisture content
- Total solids (TS)
- Volatile solids (VS)
- Carbon-to-Nitrogen ratio
- Methane generation potential

The assessment confirms that adequate feedstock availability significantly improves plant utilization and financial performance.

- **Project Planning Methodology**

Project planning was carried out using standard project management techniques.

The Work Breakdown Structure divided the entire project into manageable work packages including:

- Site Development
- Civil Construction
- Mechanical Installation
- Electrical Works
- Instrumentation
- Utility Development
- Testing & Commissioning

Project scheduling was prepared considering procurement lead times, manpower deployment, construction sequence, weather conditions, and resource availability.

Critical Path Method (CPM) was applied to identify activities directly influencing project completion time.

- **Cost Estimation**

Project cost estimation was performed according to standard engineering estimation procedures.

Capital expenditure includes:

- Land development
- Civil construction
- Mechanical equipment
- Electrical systems
- Instrumentation
- Utilities
- Engineering services
- Contingencies

Operating expenditure includes:

- Feedstock procurement
- Labour cost
- Electricity consumption
- Water consumption
- Maintenance
- Transportation
- Administrative expenses

A Cost Breakdown Structure (CBS) was prepared for systematic cost monitoring throughout project execution.

- **Risk Assessment**

Risk assessment was carried out using Probability–Impact analysis.

Major project risks identified include:

- Delayed land acquisition
- Procurement delays
- Equipment delivery issues
- Design revisions
- Cost escalation
- Labour shortages
- Feedstock supply fluctuations
- Regulatory approval delays
- Weather interruptions
- Contractor performance issues

Each risk was evaluated according to its probability of occurrence and potential impact on project objectives.

Appropriate mitigation measures such as contingency planning, procurement monitoring, vendor qualification, quality inspections, and schedule tracking were recommended.

Results and Discussion

- **Technical Evaluation**

The study confirms that the proposed 21 TPD Compressed Biogas plant is technically feasible under Indian operating conditions. Paddy straw possesses significant methane generation potential when appropriate pre-treatment techniques are adopted.

Modern gas upgrading technologies can consistently produce biomethane with methane purity exceeding 95%, making the product suitable for transportation fuel applications.

The study also indicates that integrated plant layouts improve operational efficiency by reducing internal transportation distances and simplifying maintenance activities.

- **Project Planning Performance**

Application of structured project planning techniques significantly improves project performance.

Preparation of a detailed Work Breakdown Structure enables better coordination among civil, mechanical, electrical, instrumentation, procurement, and commissioning teams.

Critical Path Method assists project managers in identifying activities requiring continuous monitoring.

Early procurement planning minimizes equipment delivery delays and reduces idle construction time.

Proper scheduling also improves labour productivity and equipment utilization.

- **Construction Management Performance**

Effective construction management considerably reduces project risks.

Daily progress monitoring, quality inspections, contractor coordination meetings, safety audits, and milestone tracking improve construction efficiency.

Implementation of quality management systems reduces rework and enhances construction quality.

Regular safety training minimizes accidents and improves workforce productivity.

Cost Analysis

The financial viability of a CBG project depends on accurate estimation and effective control of capital and operating costs. Capital expenditure includes land development, civil works, process equipment, utilities, electrical systems, engineering services, and contingencies. Operating expenditure comprises feedstock procurement, labour, power, maintenance, transportation, and administrative expenses.

A detailed cost breakdown enables effective budget monitoring, minimizes cost overruns, and supports informed investment decisions. Periodic cost reviews and value engineering further improve project profitability.

Financial Analysis

The financial assessment indicates that the proposed CBG plant is economically feasible under the assumed operating conditions. Revenue is generated from the sale of Compressed Biogas (CBG), organic bio-fertilizer, and applicable government incentives.

Financial performance was evaluated using Return on Investment (ROI), Internal Rate of Return (IRR), Net Present Value (NPV), and Payback Period. The analysis indicates satisfactory long-term returns, although initial capital investment is significant. Improved plant utilization, efficient feedstock management, and stable market demand further enhance project profitability.

Managerial Implications

The study provides practical guidance for project developers, EPC contractors, consultants, and policymakers involved in renewable energy projects. Effective planning, procurement scheduling, contractor coordination, and quality management can significantly improve project performance.

Project managers should prioritize timely procurement, efficient resource allocation, regular progress monitoring, and proactive risk management to ensure successful project completion within budget and schedule.

Conclusion

The study concludes that commercial-scale Compressed Biogas plants offer a sustainable solution for renewable energy generation and agricultural waste management. Successful implementation depends not only on process technology but also on effective project planning, cost control, construction management, and risk mitigation.

The research demonstrates that structured planning tools such as Work Breakdown Structure (WBS), Critical Path Method (CPM), and systematic procurement planning improve project efficiency by reducing delays and optimizing resource utilization. Financial analysis confirms that CBG projects are economically viable when supported by effective management practices and favourable government policies.

Overall, the proposed project contributes to environmental protection, rural employment, energy security, and sustainable development while supporting India's transition toward a low-carbon economy.

Future Scope

Future research may focus on:

- Integration of AI and digital project management tools in CBG projects.
- Life Cycle Cost Analysis (LCCA) of renewable energy infrastructure.
- BIM-based planning and construction management.
- Carbon credit and ESG assessment of CBG plants.
- Comparative techno-economic analysis of different feedstocks.
- Supply chain optimization for biomass logistics.
- Smart monitoring and predictive maintenance systems for CBG plants.

References

1. Government of India. (2018). *Sustainable Alternative Towards Affordable Transportation (SATAT) Initiative*. Ministry of Petroleum and Natural Gas.
2. Ministry of New and Renewable Energy. (2024). *Annual Report 2023–24*. Government of India.
3. International Energy Agency. (2023). *Outlook for Biogas and Biomethane*.
4. Kumar, S., Singh, R., & Sharma, P. (2023). Project planning and scheduling practices in renewable energy projects. *International Journal of Project Management*, 41(5), 520–533.
5. Jain, A., Verma, R., & Gupta, S. (2024). Economic assessment of compressed biogas plants in India. *Renewable Energy*, 224, 1210–1222.
6. Agrawal, P., Sharma, V., & Patel, D. (2025). Techno-economic evaluation of biogas upgrading technologies. *Energy Conversion and Management*, 301, 118150.
7. Project Management Institute. (2021). *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)* (7th ed.). PMI.
8. Central Pollution Control Board. (2023). *Guidelines for Crop Residue Management*. Government of India.

❑❑❑