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Green Manufacturing Practices and its Effects on the Operational Efficiency and Environmental Sustainability of an Aerospace Manufacturing Company

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***Abstract*—** This study examines the effects of green manufacturing practices on operational efficiency and environmental sustainability within an aerospace manufacturing company. Given the capital-intensive and environmentally sensitive nature of the aerospace industry, sustainable practices are increasingly vital for competitiveness, regulatory compliance, and environmental responsibility. The research focuses on operational efficiency in manufacturing costs, productivity, and resource utilization, alongside environmental sustainability indicators, including waste reduction, pollution control, and climate change mitigation. A quantitative research design was employed using a structured survey questionnaire administered to regular employees. Data were measured using a semantic differential scale and analyzed to examine the relationship between green manufacturing practices and performance outcomes. The findings indicate that adopting green manufacturing practices reduces operational costs, improves productivity, and increases resource efficiency. Additionally, these practices significantly contribute to minimizing waste, enhancing pollution management, and supporting climate change mitigation efforts. The study concludes that integrating green manufacturing practices offers dual benefits by improving operational performance while advancing environmental sustainability. The results provide practical insights for aerospace industry practitioners, managers, and policymakers seeking to balance efficiency with sustainable development goals.

***Keywords*—** Aerospace Manufacturing, Environmental Sustainability, Green Manufacturing Practices, Operational Efficiency, Productivity, Waste Reduction.

1. INTRODUCTION

Environmental sustainability has become a critical global concern as industries confront escalating challenges related to climate change, pollution, and resource depletion. These pressures have compelled manufacturing organizations to adopt environmentally responsible practices to ensure regulatory compliance, operational resilience, and long-term competitiveness (Hariram et al., 2023). The aerospace industry is under heightened scrutiny due to its complex manufacturing processes, high energy consumption, and substantial carbon emissions. As a result, aerospace manufacturers are increasingly required to align operational performance with global sustainability objectives while maintaining strict safety and quality standards.

Green manufacturing has emerged as a strategic approach to addressing these challenges by reducing environmental impact while enhancing operational efficiency through energy conservation, waste reduction, pollution prevention, and optimized resource utilization (Abualfaraa et al., 2020; Sezen & Cankaya, 2013). In the aerospace sector, the adoption of green manufacturing practices is driven not only by regulatory requirements but also by the need to control manufacturing costs, improve productivity, and reduce emissions without compromising product quality or competitiveness (Lin, 2013; Ribeiro et al., 2022). Recent studies suggest that integrating green manufacturing with lean production systems and digital technologies can further improve process efficiency and environmental performance, positioning sustainability as a source of operational advantage rather than a constraint (Boumsisse et al., 2025; Fiorello et al., 2023).

Despite growing interest in sustainable manufacturing, empirical evidence on the impact of green manufacturing practices within aerospace manufacturing environments remains limited. Aerospace companies operate in highly regulated

settings where safety, quality, and environmental compliance are non-negotiable, implementing sustainability initiatives both complex and essential. A clearer understanding of how green manufacturing practices influence manufacturing costs, productivity, and resource utilization is necessary to support informed engineering and managerial decision-making. Moreover, external stakeholders, including regulators, customers, investors, and government agencies, are increasingly evaluating aerospace firms based on environmental performance and Environmental, Social, and Governance (ESG) criteria, reinforcing sustainability as a strategic and competitive imperative (Hami et al., 2015).

This study addresses this research gap by examining the effects of green manufacturing practices on operational efficiency and environmental sustainability in an aerospace manufacturing company. Although the company has implemented informal initiatives, such as waste segregation and wastewater recycling, the absence of a formal sustainability framework has led to inconsistent implementation.

1.1 Conceptual Framework

Rooted in Green Industry and Green Economy Theory, this framework explains how green manufacturing practices can simultaneously enhance operational efficiency and environmental sustainability. It emphasizes that industries can remain economically competitive while being environmentally responsible by improving resource efficiency, reducing pollution, and adopting cleaner production methods (UNIDO, 2011).

In this study, practices such as energy conservation, waste reduction, and recycling are expected to lower production costs, optimize resource use, and improve productivity, while also reducing emissions and environmental impact. Overall, the framework highlights a synergistic "win–win" relationship in which improved operational efficiency supports sustainability outcomes and strengthens long-term organizational resilience.

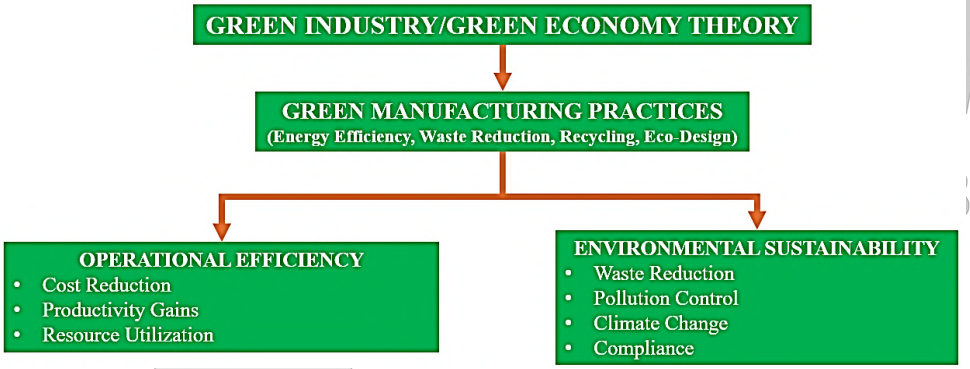

Figure 1: *Conceptual Framework of the Study*

2. METHODOLOGY

This study employs a quantitative research design grounded in Green Industry Theory to examine the relationship between green manufacturing practices, operational efficiency, and environmental sustainability in an aerospace manufacturing company. Data was collected using a structured questionnaire administered to regular employees from key departments within the organization. Stratified random sampling was applied to ensure adequate representation across departments and functional areas. The questionnaire measured the extent of green manufacturing practices such as energy efficiency, waste reduction, and recycling alongside operational efficiency indicators, including manufacturing cost, productivity, and resource utilization, as well as environmental sustainability outcomes.

Descriptive statistics were used to assess the level of implementation of green manufacturing practices, while inferential statistical techniques were applied to analyze the strength and direction of

relationships among green practices, operational efficiency, and environmental sustainability. The study was conducted in a large aerospace manufacturing company with established production systems and accessible performance records, providing a suitable setting for evaluating the measurable impacts of green manufacturing initiatives.

2.1 Population and Sampling

This study employed a probability sampling approach to select respondents with direct involvement in or sufficient knowledge of green manufacturing practices, operational processes, and environmental initiatives within the company. Stratified random sampling was used to ensure proportional representation from key departments involved in manufacturing operations, sustainability programs, and plant management, drawn from a total workforce of approximately 1,500 employees.

The required sample size was determined using Slovin's formula with a 5% margin of error, resulting in 316 respondents. This sampling strategy supports a robust quantitative assessment of the relationships between green manufacturing practices, operational performance, and environmental sustainability, while enhancing the validity and reliability of the study's findings.

2.2 Research Instrument

Data were collected using a structured quantitative questionnaire designed to assess the implementation of green manufacturing practices and their effects on operational efficiency and environmental sustainability in an aerospace manufacturing company.

The instrument employed a semantic differential scale ranging from 0 to 5, allowing respondents to rate statements using opposing descriptors (e.g., strongly disagree to strongly agree). The questionnaire consisted of two sections: Part I measured the perceived impact of green manufacturing practices on operational efficiency, including manufacturing cost, productivity, and resource utilization; Part II evaluated environmental sustainability outcomes, focusing on waste reduction, pollution control, and climate change mitigation.

Content validity was established through review by a Subject Matter Expert and a Statistician. Reliability was tested in a pilot study involving 30 respondents, and internal consistency was assessed using Cronbach's alpha, yielding an overall result of 0.90, which exceeded the commonly accepted threshold of 0.70.

Mean scores were used to assess the extent of practice implementation, while correlation coefficients were used to determine the strength of relationships among green manufacturing practices, operational efficiency, and environmental sustainability.

2.3 Data Gathering

This study employed a quantitative data gathering procedure to examine the effects of green manufacturing practices on operational efficiency and environmental sustainability in an aerospace manufacturing company.

The process began with a comprehensive review of related literature to establish a theoretical foundation and identify relevant variables. A structured survey questionnaire was then developed and distributed to selected employees to collect data on green manufacturing practices, operational performance, and environmental outcomes.

Collected responses were analyzed using statistical techniques, including inferential analysis, to identify relationships among the study variables.

Data quality and validity were ensured through careful verification of responses, triangulation of sources, and strict adherence to confidentiality and anonymity requirements.

The data analyzed were subsequently interpreted to determine the impacts, benefits, and challenges associated with implementing green manufacturing practices within the aerospace manufacturing context.

2.4 Data Analysis

Table 1: *Data Analysis Plan*

Objectives	Source of Data	Type of Data	Data Analysis
Find out the degree to which green manufacturing practices affect the operational efficiency of an aerospace manufacturing company in the following aspects: **Manufacturing cost** **Productivity** **Available resource utilization**	Survey Questionnaire Part I	Quantitative Data (Nominal)	Descriptive Analysis (Mean)
Find out the degree to which green manufacturing practices affect the environmental sustainability of an aerospace manufacturing company in the following aspects: **Waste reduction** **Pollution control** **Climate change**	Survey Questionnaire Part II	Quantitative Data (Nominal)	Descriptive Analysis (Mean)
Establish the relationship between green manufacturing practices adoption, environmental sustainability, and operational efficiency of an aerospace manufacturing company.	Results of Survey Questionnaire Part I and Part II	Quantitative Data (Nominal)	Inferential Statistics (Correlation Analysis)
Generate operational and strategic action plans that will help in the successful implementation of green manufacturing practices in an aerospace manufacturing company that will positively affect the environment, overall manufacturing cost, productivity, and efficient use of available resources	Results of Survey Questionnaire Part I and Part II	Quantitative Data (Nominal)	Descriptive Analysis (Mean) Inferential Statistics (Correlation Analysis)

2.5 Research Locale

The study will be conducted at a leading aerospace manufacturing company known for its innovative aircraft components and global production capabilities. Selected for its efficient processes and extensive data on key efficiency indicators, the company specializes in aircraft interiors. The primary objective is to explore the impact of green manufacturing practices on operational efficiency, including productivity, cost savings, resource management, and environmental sustainability. The research aims to provide insights into the relationship between sustainable practices and overall operational performance.

3. RESULTS AND DISCUSSION

The survey involved 316 respondents from various departments of the aerospace manufacturing company, providing a comprehensive view of employee perceptions regarding the impact of green manufacturing practices on operational efficiency and environmental sustainability. Results indicate that green manufacturing initiatives are perceived to positively influence key operational efficiency indicators, including manufacturing cost, productivity, and resource utilization, while also supporting environmental sustainability through improved waste management, pollution control, and climate change mitigation. The structured questionnaire enabled systematic assessment of these dimensions,

demonstrating that the adoption of environmentally responsible practices contributes to both improved operational performance and enhanced sustainability outcomes in the aerospace manufacturing context.

3.1 Effects on Operational Efficiency

The findings indicate that employees strongly perceive green manufacturing practices as effective in reducing manufacturing costs and enhancing operational sustainability. Practices such as waste reduction, energy efficiency improvements, and optimized resource utilization were viewed as contributing to significant cost savings, while compliance with environmental regulations and avoidance of penalties further strengthened financial performance. These results align with prior studies showing that green and lean initiatives improve economic outcomes by minimizing waste and improving process efficiency (Abualfaraa et al., 2020; Ribeiro et al., 2022; D'Angelo et al., 2023). Although earlier research cautioned that initial investments in green technologies may increase short-term costs, the present findings suggest that the organization has surpassed this phase, with long-term benefits outweighing initial expenditures. Overall, the results support the view that sustained adoption of green manufacturing enables cost efficiency, long-term savings, regulatory compliance, and enhanced corporate reputation.

3.2 Effects on Productivity

The findings indicate that green manufacturing practices significantly enhance productivity in the aerospace manufacturing company by streamlining workflows, reducing downtime, and improving overall operational efficiency. Employees perceived that environmentally sustainable practices foster a high-performance culture while increasing engagement and motivation, as they feel part of an organization committed to environmental responsibility. These results are consistent with previous studies showing that the integration of lean, green, and digital technologies improves productivity and operational efficiency (Fiorello et al., 2023). Overall, the findings suggest that environmental sustainability and productivity are complementary, and that embedding green practices into daily operations can enhance output, improve employee morale, reduce energy consumption, and support long-term organizational success.

3.3 Effects on Resource Utilization

The findings indicate that green manufacturing practices significantly improve resource utilization in the aerospace manufacturing company by promoting efficient use of raw materials, energy, and water while minimizing waste throughout the production process. Employees perceived that sustainable initiatives support better planning and resource allocation, leading to enhanced operational efficiency and improved environmental performance. These results are consistent with prior studies highlighting the role of green practices and advanced technologies in optimizing resource use and reducing waste (Boumsisse et al., 2025; Hariram et al., 2023). Although earlier research noted challenges in balancing resource optimization with environmental goals (Sezen & Cankaya, 2013), the present findings suggest a strong integration of both aspects. Overall, effective resource utilization contributes to lower operational costs, reduced environmental impact, and increased stakeholder confidence, reinforcing green manufacturing as a key driver of sustainable organizational value.

3.4 Effects on Waste Reduction

The findings indicate that green manufacturing practices significantly reduce waste in the aerospace manufacturing company by optimizing material use, improving production planning, and enhancing waste management efficiency. Employees perceive these initiatives as effective in minimizing scrap and byproducts and in fostering active engagement in sustainability efforts, reflecting a strong organizational culture of environmental stewardship. These results align with previous research, showing that sustainable manufacturing and employee-driven green innovations contribute to both waste reduction and improved operational performance (Hami et al., 2015, 2016) and support UNIDO's emphasis on cleaner production for sustainable industrial development (2010, 2011). Overall, the study demonstrates that adopting green manufacturing not only advances environmental conservation but also enhances

operational efficiency, delivers cost savings, and benefits stakeholders, including local communities and regulators, through cleaner and more sustainable production practices.

3.5 Effects on Pollution Control

The findings indicate that green manufacturing practices play a critical role in enhancing pollution control within the aerospace manufacturing company. Employees perceive that sustainable initiatives such as emission reduction, cleaner technologies, energy efficiency, and eco-friendly waste disposal contribute to a safer workplace and a lower ecological footprint, while fostering greater environmental responsibility among staff. These results align with prior studies highlighting the importance of proactive green leadership, environmental policies, and green supply chain management in minimizing pollution and promoting sustainable operations (Wang & Yang, 2025; Kharat et al., 2025).

Overall, the study demonstrates that effective pollution control through green manufacturing not only ensures regulatory compliance but also strengthens stakeholder trust and reinforces a corporate culture of environmental stewardship.

3.6 Effects on Climate Change

The findings indicate that green manufacturing practices help address climate change at the aerospace manufacturing company, though employees perceive their impact as moderate. Sustainable initiatives such as energy conservation, renewable energy use, waste reduction, and pollution control help lower the company's carbon footprint and improve production processes, but there is room to strengthen implementation and visibility.

These results align with previous studies that emphasize the role of green manufacturing, innovation, and green finance in reducing industrial emissions while maintaining productivity (Shantanu et al., 2025; Uche et al., 2025).

Despite challenges in adopting renewable energy in resource-intensive industries (Lin, 2013; UNIDO, 2011), the study shows growing momentum and employee engagement in climate-positive practices. Overall, the findings suggest that expanding green initiatives can enhance organizational resilience, strengthen environmental stewardship, and support alignment with global climate action and the UN Sustainable Development Goals.

3.7 Relationship Between Operational Efficiency and Environmental Sustainability

The correlation analysis demonstrates a moderately strong and statistically significant positive relationship between operational efficiency and environmental sustainability in the aerospace manufacturing company ($r = 0.561$, $p < 0.01$), indicating that efficiency improvements are closely associated with better sustainability outcomes.

Among the operational variables, productivity showed the strongest correlation with environmental sustainability ($r = 0.578$), followed by resource utilization ($r = 0.540$) and manufacturing cost ($r = 0.461$), suggesting that leaner, more productive processes and efficient resource use generate more immediate environmental benefits than cost-focused initiatives alone.

These findings align with Green Industry Theory and prior studies, which emphasize that integrating lean and green practices enhances both operational and environmental performance.

The results support the study's conceptual framework, confirming that efficiency-driven improvements, particularly in productivity and resource optimization, naturally reduce waste, pollution, and environmental impact.

Overall, the findings reinforce the view that green manufacturing practices enable organizations to achieve operational excellence while advancing environmental responsibility, providing a strong empirical basis for developing operational and strategic action plans that promote sustainable competitiveness in the aerospace manufacturing sector.

3.8 Action Plan Focusing on Low Scores

Table 2: *Proposed Action Plan*

Recommendation / Action Item	Proposed Action or Strategy	Responsible Personnel	Success Indicator / Performance Metric
1. Establish a Formal Green Manufacturing Policy	Develop a company-wide sustainability policy covering waste reduction, energy efficiency, pollution control, and climate mitigation.	Senior Management; Sustainability Committee	• Policy approved and implemented • 100% employee awareness of policy within 6 months
2. Strengthen Climate Change Mitigation Efforts	Create a Climate Action Roadmap outlining carbon reduction targets, renewable energy use, and energy management programs.	Environmental, Safety, and Sustainability (EHS) Team; Facilities Engineering	• Documented roadmap • Annual % reduction in energy usage • Annual carbon footprint report published
3. Enhance Employee Engagement in Climate-Positive Practices	Conduct climate literacy workshops and introduce employee-driven initiatives such as energy-saving campaigns and climate pledges.	HR Learning & Development; Department Supervisors; EHS Team	• At least 80% employee participation in climate training • Reduction in energy waste incidents • Increase in employee self-reported climate-positive behaviors
4. Improve Visibility of Environmental Performance	Install dashboards displaying real-time energy use, emissions data, and waste metrics in production areas.	EHS Team; IT Department; Production Managers	• Dashboards are operational in all major departments • Monthly environmental performance reports shared with all staff
5. Optimize Resource Utilization Processes	Implement resource planning tools and conduct audits to identify material inefficiencies and energy leaks.	Operations Manager; Process Engineers; Quality Assurance	• 10–15% reduction in material waste • Verified improvements in process efficiency through audits
6. Expand Waste Reduction Programs	Strengthen waste segregation systems, increase recycling points, and provide refresher training on proper disposal.	EHS Team; Housekeeping; All Department Heads	• Higher waste segregation accuracy (≥90%) • Increased recycling volume year-over-year

7. Implement Cleaner and Safer Pollution Control Measures	Adopt cleaner production technologies and improve chemical handling protocols.	Manufacturing Engineering; EHS; Procurement	• Reduction in harmful chemical outputs • Zero pollution-related violations or penalties
8. Integrate Digital Tools for Green Practices	Use digital monitoring systems (Industry 4.0/5.0 tools) for tracking machine energy use and equipment performance.	Digital Transformation Team; Facilities Engineering	• Improved machine efficiency metrics • Decrease in unplanned downtime or breakdowns
9. Strengthen Employee Motivation and Green Culture	Launch recognition programs such as the "Green Champion Award" for departments demonstrating excellent sustainability practices.	HR; Supervisors; Corporate Communications	• Increased employee participation in sustainability initiatives • improvement in survey scores on sustainability culture
10. Conduct Regular Environmental Audits and Compliance Checks	Schedule quarterly sustainability audits and ensure corrective actions are completed promptly.	Internal Audit Team; EHS Committee	• 100% audit completion • Reduction in non-conformities and corrective action delays
11. Foster Collaboration with External Stakeholders	Partner with local government, industry groups, and suppliers to strengthen the green supply chain and climate initiatives.	Senior Management; Supply Chain Department	• Participation in at least 2–3 sustainability networks • Supplier compliance rate with green requirements
12. Institutionalize a Continuous Improvement System for Green Manufacturing	Establish a feedback and suggestion platform for employees to propose sustainability ideas and innovations.	HR; EHS; Kaizen/Lean Team	• Number of approved employee suggestions • Implementation rate of sustainability improvement projects

3.9 Action Plan Reinforcing High Scores

Table 3: *Proposed Action Plan*

Recommendation / Action Item	**Proposed Action or Strategy**	**Responsible Personnel**	**Success Indicator / Performance Metric**
Waste Reduction	• Standardize existing waste segregation and scrap-reduction practices into formal SOPs.	EHS Department Production Managers	• Reduction in monthly scrap volume • ≥ 90% audit

	• Implement real-time waste monitoring dashboards. • Conduct monthly 5S Green audit cycles.	Quality Assurance	compliance rating • Increased accuracy in waste segregation
Productivity	• Integrate digital tools (predictive maintenance, performance dashboards). • Strengthen lean-green Kaizen activities.	Industrial Engineers IT Department Training and Development	• Reduced machine downtime • Improved cycle time productivity • Higher digital tool adoption rate
Resource Utilization	• Establish resource-use KPIs for energy, materials, and water. • Train employees on resource-efficient equipment operation. • Conduct weekly reviews of resource consumption trends.	Energy Management Team Production Supervisors Facilities Engineering	• Lower energy use per production unit • Higher material efficiency ratio • Reduced water and utility consumption
Pollution Control	• Introduce continuous emission and effluent monitoring systems. • Replace hazardous materials with safer alternatives where feasible. • Conduct quarterly environmental compliance audits.	EHS Department Facilities & Engineering Chemical Management Team	• Zero violations or environmental citations • Decline in harmful substance usage • Improved air and water quality test results
Employee Engagement in Green Initiatives	• Launch a "Green Champions" program per department. • Establish recognition awards for sustainability contributions.	HR Department Department Managers Communications Office	• Increased participation rate in sustainability activities • Higher employee engagement scores • More employee-led green initiatives
Overall High Operational Efficiency (Cost, Productivity, Resources)	• Institutionalize high-performing practices into a unified Green Manufacturing Policy. • Conduct semi-annual sustainability audits and continuous improvement cycles. • Integrate successful green processes into onboarding and job training programs.	EHS Department Quality Assurance Operations Leadership	• Policy implementation across all departments • Improvement in cost-efficiency metrics • Higher audit compliance and sustained performance levels

4. RESEARCH IMPLICATIONS

4.1 Summary of Findings

The study concludes that green manufacturing practices offer dual benefits, enhancing both environmental sustainability and operational performance. By implementing eco-friendly processes, aerospace manufacturing companies can reduce costs, improve productivity, optimize resource

use, and achieve better environmental outcomes. The findings highlight that sustainability and operational excellence are closely linked, demonstrating that adopting green practices is not only environmentally responsible but also a strategic approach for long-term business success and competitive advantage.

4.2 Conclusion

This study demonstrates that green manufacturing practices significantly enhance both operational efficiency and environmental sustainability in aerospace manufacturing, showing that these goals are mutually reinforcing rather than conflicting. By combining lean and eco-friendly strategies, companies can boost productivity, optimize resource use, reduce material waste, save energy, and comply with environmental regulations, all while fostering a culture of employee engagement and sustainability (Abualfaraa et al., 2020; Fiorello et al., 2023; Boumsisse et al., 2025; D'Angelo et al., 2023; Ribeiro et al., 2022). The findings highlight that sustainable cost management not only lowers financial and operational risks but also strengthens competitiveness, brand image, and alignment with global standards (Lin, 2013; Wang & Yang, 2025; UNIDO, 2011). Furthermore, green manufacturing supports corporate social responsibility and long-term industry viability by promoting cleaner operations and positive societal impact (Hami et al., 2016; Uche et al., 2025). Overall, the study underscores that adopting green practices is a strategic, value-creating approach that drives operational excellence, environmental stewardship, and lasting competitive advantage in aerospace manufacturing.

4.3 Recommendations

Based on the study's findings, several recommendations are proposed to strengthen green manufacturing practices and enhance both operational efficiency and environmental sustainability in aerospace manufacturing. For management, continued investment in green technologies and sustainable cost-management policies is essential to optimize productivity while aligning with environmental goals. For employees, fostering a culture of environmental responsibility through training, awareness programs, and active participation in waste reduction and pollution control initiatives is recommended. For policymakers and industry leaders, supporting incentives for green manufacturing, promoting collaboration between industries and local governments, and advancing climate change mitigation programs can accelerate sector-wide sustainability efforts. For future researchers, expanding the study to multiple companies or industries will improve generalizability, while comparative analyses between large and small-to-medium enterprises can reveal implementation differences. Engaging stakeholders for access to internal environmental data, using anonymous digital surveys, and employing mixed-method approaches, including interviews and observations, can enrich data quality and provide deeper insights into factors affecting green manufacturing success, including innovation, employee engagement, and supply chain sustainability.

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