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# Green Buffer Stock Hub (GBSH): A Regional Industrial Support Framework for Resilient Oil and Gas Supply Chains Under Energy Transition

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## Abstract

The oil and gas industry faces increasing operational risk due to long spare-parts lead times, import dependency, logistics disruptions, inventory inefficiencies, and rising sustainability pressure under the global energy transition. These challenges are especially significant in developing industrial regions such as Indonesia, where critical components are often sourced from distant suppliers and maintenance operations are highly sensitive to delay. This study introduces the Green Buffer Stock Hub (GBSH), a proposed industrial support framework developed for resilient and sustainable oil and gas supply chains that integrates strategic regional inventory, reverse engineering, additive manufacturing, and digital logistics coordination to improve logistics stability and operational continuity. A conceptual qualitative methodology was applied using industrial supply chain analysis, comparative operational evaluation, and regional applicability assessment for Indonesia, with potential expansion toward Timor-Leste. The findings suggest that localized industrial support ecosystems can improve emergency responsiveness, reduce supply chain vulnerability, and support sustainability objectives simultaneously. Under energy transition conditions, the framework also supports lower transportation intensity, better inventory efficiency, and adaptability to gradual changes in fossil-fuel demand, within an integrated and scalable industrial support model.

## Keywords
Supply Chain Resilience, Oil and Gas Logistics, Additive Manufacturing, Reverse Engineering, Sustainable Supply Chains.

## 1. Introduction
Global oil and gas supply chains continue to face significant operational challenges associated with import dependency, transportation disruptions, long procurement cycles, and unstable global logistics conditions. These risks became more visible after recent international supply-chain disruptions, particularly for maintenance-intensive industries that rely on rapid availability of critical spare parts. For example, centralized storage of critical components is not always an ideal solution for the following reasons: it fixes up capital and contributes to their deterioration or loss of availability, especially for expensive components such as turbines.

The situation is especially challenging in developing industrial regions such as Indonesia, where many specialized components are still sourced from overseas suppliers through centralized procurement systems. In operational regions including Balikpapan and offshore production zones, delayed spare-parts delivery can directly affect maintenance schedules, operational continuity, and shutdown risk.

At the same time, industrial operators are under increasing pressure to improve sustainability performance, reduce transportation-related emissions, and strengthen supply-chain resilience under energy-transition policies. Recent

advances in additive manufacturing, reverse engineering, and digital logistics coordination provide new opportunities for localized industrial support systems capable of reducing dependence on long international supply chains.
This study introduces the (GBSH) framework, a proposed industrial support framework integrating strategic regional inventory, reverse engineering capability, additive manufacturing support, and coordinated logistics management. The GBSH is designed to improve operational responsiveness, reduce downtime exposure, and support more sustainable industrial logistics practices.

Indonesia continues to face logistical and geographical challenges in supporting upstream oil and gas operations due to the archipelagic nature of the country and dependency on imported industrial components. Figure 1.

The geographical complexity of Indonesia, expanding industrial activity, and strategic importance within Southeast Asian energy and logistics networks. Particular attention is given to industrial regions such as Surabaya and East Kalimantan, where logistics accessibility and operational proximity create different industrial support advantages.

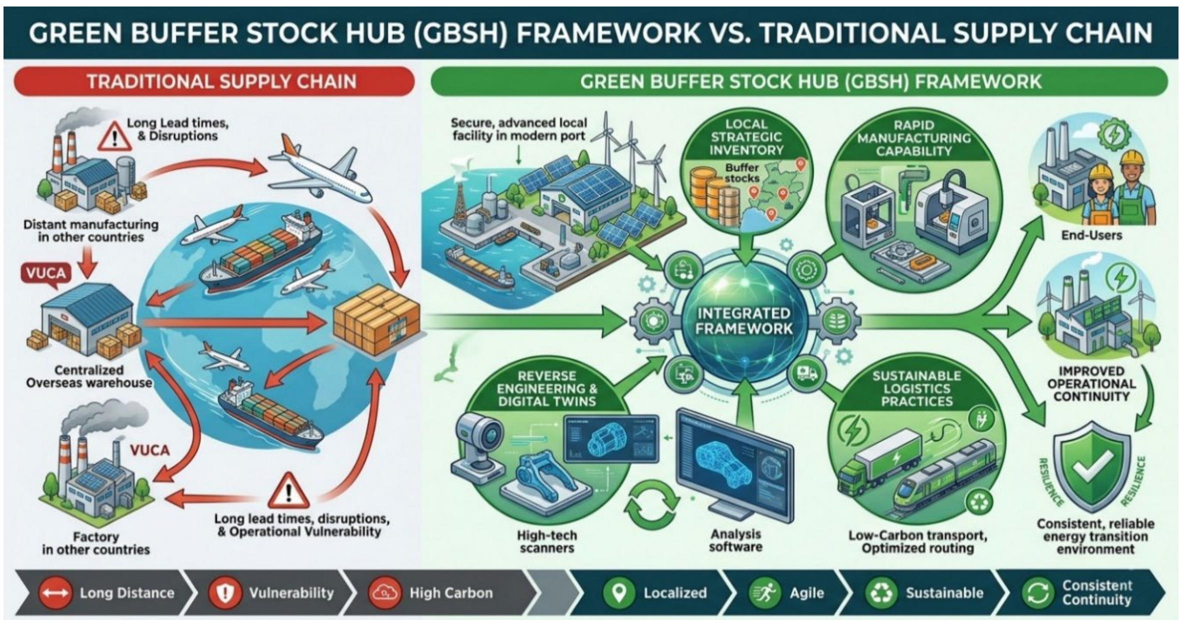


Figure 1. Traditional supply chain versus GBSH localized support model

As global energy systems move toward lower-carbon industrial strategies, oil and gas operators are increasingly required to reduce transportation intensity, and optimize maintenance operations. The proposed regionalized support structure contributes to these objectives by reducing long-distance spare-parts transportation, improving inventory efficiency, supporting localized manufacturing capability, and decreasing operational downtime exposure. In addition, the framework may help industrial operators adapt to future scenarios involving fluctuating fossil-fuel demand, supply-chain instability, and gradual industrial diversification under energy transition policies.

### 1.1 Objectives

This research aims to develop and evaluate a regional industrial support framework capable of improving logistics stability and operational continuity within oil and gas industries under energy transition conditions. The specific objectives are to identify the major operational and logistics challenges affecting oil and gas supply chains, analyze the limitations of traditional centralized procurement systems, develop the GBSH Framework, evaluate its operational and environmental advantages, and assess the contribution of regional industrial support systems toward resilient and sustainable supply chain operations.

## 2. Literature Review

Supply-chain resilience has become a major research priority following large-scale global disruptions affecting transportation systems, procurement networks, and industrial operations. Christopher and Peck (2004) emphasized that resilient supply chains require flexibility, visibility, and rapid recovery capability, while Ivanov and Dolgui (2021) highlighted the importance of decentralized and digitally connected operational systems under disruption conditions. Several studies reported that global transportation disruptions and supplier delays can significantly increase operational downtime and maintenance risk in industrial supply chains (Queiroz et al. 2022; Ghadge et al. 2020).

Recent studies further emphasized the growing importance of adaptive and resilient supply-chain capabilities under uncertain global conditions. Kaneberg et al. (2025) highlighted the role of dynamic operational capabilities in improving industrial resilience, while Wufron and Judijanto (2024) discussed mitigation strategies for logistics disruption and supply-chain instability. Rumapea et al. (2025) additionally demonstrated the increasing integration of reverse engineering and additive manufacturing technologies within industrial component development processes.
Ford and Despeisse (2016) concluded that additive manufacturing contributes to sustainability by reducing transportation demand and inventory dependency. Knofius et al. (2021) showed that additive manufacturing can improve spare-parts supply effectiveness and reduce lead-time dependency in low-volume industrial systems. In addition, López and Vila (2021) demonstrated that reverse engineering combined with additive manufacturing can support reconstruction of obsolete or unavailable industrial components.

Recent industrial standards such as API 20S and emerging digital twin applications further support the practical relevance of additive manufacturing and regional operational synchronization in oil and gas systems. Industry 4.0 technologies have also accelerated development of digitally integrated manufacturing ecosystems combining predictive maintenance, inventory visibility, and decentralized production capability (Zhong et al. 2017; Kusiak 2018).

Sustainable logistics has become another important factor influencing industrial supply-chain transformation. Recent studies emphasized that reducing transportation intensity and improving inventory efficiency are essential for lowering environmental impact and improving operational sustainability (Hariyani et al. 2024; Holgado et al. 2024).
Digital twin technologies may further enhance the GBSH framework through predictive maintenance, inventory simulation, and operational synchronization (Tao et al., 2022).

Despite growing research in supply-chain resilience, additive manufacturing, and sustainable logistics, limited studies have proposed an integrated framework combining strategic regional inventory, reverse engineering, additive manufacturing, and localized logistics coordination specifically for oil and gas industries in developing industrial regions. Therefore, this study addresses an important research gap through development of the (GBSH) Framework.
Table 1. shows that previous studies often addressed supply-chain resilience, inventory optimization, or manufacturing flexibility separately.

Table 1. Summary of major supply chain challenges in oil and gas operations

| Research Area | Key Findings | Research Gap |
|---|---|---|
| logistics stability | Focus on flexibility and disruption management | Limited focus on oil and gas spare-parts systems |
| Inventory management | Improved efficiency through digitalization | Weak integration with local manufacturing |
| Additive manufacturing | Reduces lead times and waste | Limited industrial ecosystem integration |
| Sustainable logistics | Supports emission reduction | Limited application in heavy industry |
| Industry 4.0 | Enhances operational visibility | Lack of integrated regional support models |
| Oil and gas logistics | High dependency on imports | Lack of decentralized industrial support |

However, limited research proposed a unified industrial support framework integrating these functions within one regional operational model for oil and gas industries.

## 3. Methods

This study adopts a conceptual qualitative engineering approach supported by comparative operational analysis to develop and evaluate the proposed Green Buffer Stock Hub (GBSH) framework as a regional industrial support model for oil and gas supply chains operating under energy transition conditions.

The research methodology was developed through literature review, industrial observations, operational insights, and comparative analysis of traditional supply chain limitations, including long spare-parts lead times, import dependency, logistics disruptions, inventory inefficiencies, transportation dependency, and downtime exposure. The framework development logic was also aligned with selected Lean Six Sigma DMAIC principles to support systematic problem identification, operational analysis, process improvement, and continuous predictive control.

The proposed GBSH framework integrates strategic regional inventory, reverse engineering, additive manufacturing, predictive planning, and digital logistics coordination into a shared regional support structure serving multiple industrial operators. Unlike conventional warehousing systems, where critical spare parts may remain unused for long periods while locking significant capital, the proposed framework introduces a collaborative predictive inventory model designed to improve spare-parts readiness, reduce downtime exposure, decrease transportation dependency, and support more sustainable logistics operations.

A comparative operational analysis was conducted between traditional supply chain systems and the proposed GBSH framework using key operational indicators including lead time, inventory burden, operational responsiveness, transportation dependency, and downtime exposure, as illustrated in Figure 2. The comparative evaluation used scenario-based engineering estimates appropriate for early-stage conceptual framework assessment where full industrial implementation data are not yet available.

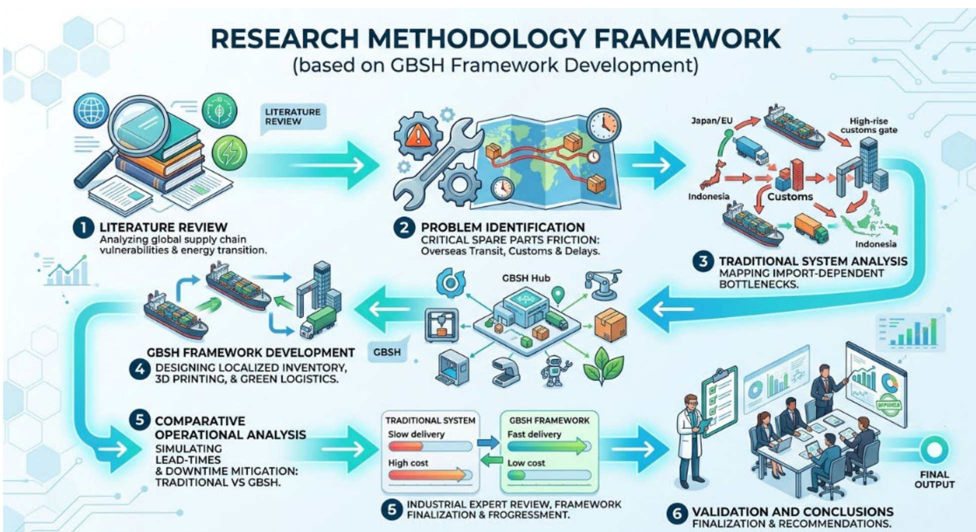


Figure 2. Research methodology model

The operational improvement percentage was calculated using the following equations:

$$\text{Improvement Percentage} = \frac{Traditional\,Value - GBSH\,Value}{Traditional\,Value} \times 100$$

Environmental Cost=Transportation Impact+Storage Impact+Material Waste

The environmental assessment considered transportation impact, storage burden, and material waste associated with emergency logistics and long-term inventory storage. The selected methodology supports systematic comparison between conventional and proposed operational models while providing a foundation for future quantitative validation, Digital Twin simulation, and industrial pilot implementation. The values presented in this study are indicative engineering estimates used for comparative framework evaluation.

## 4. Data Collection

The data used in this research were collected from academic, industrial, and operational sources to support the development and evaluation of the proposed GBSH framework. The data collection process focused on identifying operational challenges affecting oil and gas supply chains, particularly in developing industrial regions with high dependency on imported spare parts and centralized procurement systems.

In particular, warehouse cost estimates were developed for Surabaya and Kalimantan using market-based observations to support the evaluation of regional storage feasibility. In addition, an expert interview with experienced industrial engineers and academics provided practical insights regarding spare-parts availability, storage risks, downtime exposure, and the role of reverse engineering and additive manufacturing in addressing hard-to-source industrial components. Additional practical insights were obtained through discussions with maintenance personnel, procurement engineers, and industrial operators familiar with oil and gas activities in Indonesia. These additional data sources complemented the academic literature and operational observations by linking the conceptual framework to realistic industrial conditions.

### 4.1 Academic Literature Sources

Academic data were collected from journal articles, conference proceedings, and industrial engineering publications related to supply chain resilience, spare-parts logistics, additive manufacturing, reverse engineering, Industry 4.0 systems, sustainable industrial logistics, and inventory optimization. The literature review included both foundational and recent publications to ensure theoretical consistency and alignment with current industrial developments. Recent publications from 2020 to 2025 were emphasized due to the rapid evolution of supply chain disruption research following major global logistics crises. The sources were primarily used to identify major operational challenges, evaluate existing industrial solutions, analyze decentralized manufacturing concepts, support development of the GBSH framework, and compare traditional and regional industrial support models.


Figure 3. Regional industrial supply chain structure in Indonesia

### 4.2 Industrial and Technical Reports

Industrial data were additionally obtained from technical reports, logistics studies, manufacturing case studies, and publications issued by Indonesia's Ministry of Energy and Mineral Resources and SKK Migas (2024).

The traditional industrial supply chain structure in Indonesia and highlights the multiple delay points.
The collected reports focused on spare parts procurement delays, equipment downtime, import dependency, transportation bottlenecks, inventory holding costs, maintenance responsiveness, and regional logistics limitations. Industrial observations from Indonesia were particularly important due to the geographical complexity of the country and the dependence of industrial operators on imported equipment and centralized suppliers. Special focus was given to industrial regions including Balikpapan, Surabaya, East Kalimantan, and offshore operational zones. Figure 3. These regions represent major industrial hubs supporting oil, gas, mining, and energy activities.

### 4.3 Operational Observations

Data were also collected incorporated operational observations related to industrial logistics and spare parts management practices. These observations included long procurement lead times, emergency maintenance delays, storage degradation risks, high transportation dependency, difficulties obtaining specialized industrial components, and limited regional engineering capability. Additional observations were derived from discussions with industrial professionals involved in oil and gas operations, logistics support, maintenance systems, and industrial manufacturing environments. Many observations have been shown the vulnerability of industrial operators to international shipping disruptions and long supplier response times, particularly for critical equipment and specialized pipe components.

### 4.4 Comparative Supply Chain Data

Comparative operational data were developed to evaluate the potential performance improvements associated with the proposed GBSH framework. The comparative analysis included estimated operational indicators such as spare-parts lead time, emergency response duration, inventory holding cost, downtime exposure, transportation dependency, and environmental logistics impact. The values were estimated based on literature findings, industrial observations, and operational patterns commonly observed in maintenance-intensive industries, as shown in Table 2. The comparative data were used to support operational evaluation based analysis of the proposed framework.

Table 2. Comparative operational indicators used in the study

| Operational Indicator | Traditional System | Proposed GBSH Framework |
|---|---|---|
| Spare-part lead time | 30–120 days | 3–14 days |
| Emergency response | Several weeks | Less than one week |
| Inventory dependency | Centralized | Regionalized |
| Transportation distance | International | Local/regional |
| Downtime exposure | High | Reduced |
| Manufacturing flexibility | Limited | Improved |

### 4.5 Expert and Industrial Insights

Additional qualitative insights were collected through technical discussions with industrial professionals. These insights contributed significantly to the development of the practical operational structure of the GBSH framework and supported the industrial relevance of the proposed model.

## 5. Results and Discussion

The results indicate that the proposed GBSH framework can improve operational responsiveness, reduce supply chain vulnerability, and support sustainability objectives within oil and gas supply chains. Traditional procurement systems remain highly dependent on international suppliers, centralized inventory structures, and long transportation cycles, increasing operational risk during logistics disruption and import delays.

It also addresses these problems through integration of regional strategic inventory, reverse engineering capability, additive manufacturing support, and digital logistics coordination. Field-derived industrial observations and expert interview insights further confirmed that downtime losses associated with critical industrial equipment may significantly exceed the value of the spare part itself.

The warehouse cost comparison between Surabaya and Kalimantan also demonstrated that regional warehousing economics play an important role in industrial support strategy. Surabaya offers lower storage cost and stronger logistics infrastructure, while Kalimantan provides operational proximity to oil, gas, and mining activities.
The presented operational estimates are intended for comparative engineering evaluation rather than statistically validated industrial performance measurements.

## 5.1 Numerical Results

The numerical analysis compared traditional procurement systems with the proposed GBSH framework using operational performance indicators including lead time, downtime exposure, inventory holding cost, transportation dependency, and manufacturing flexibility. Table 3. provides a rough comparative operational assessment based on industry observations, literature findings, and expert-based assumptions.

Table 3. Comparative operational performance analysis

| Operational Indicator | Traditional Procurement Model | Proposed GBSH Framework | Estimated Operational Impact |
|---|---|---|---|
| Spare-part lead time | 30–120 days depending on international supplier availability, customs clearance, and shipping conditions | 3–14 days through regional inventory availability, reverse engineering, and additive manufacturing support | Lead-time reduction estimated at approximately 80–90 % |
| Emergency maintenance response | Several weeks due to centralized procurement and transportation dependency | Less than one week through territorial industrial support capability | Faster operational recovery and reduced shutdown duration |
| Downtime exposure cost | Up to USD 500,000 per critical operational interruption based on industrial interview observations | Significantly reduced through rapid local replacement capability | Downtime exposure reduction estimated at around 80 % |
| Inventory holding structure | Large centralized inventory with high capital lock-in and storage burden | Strategic regional inventory with distributed support hubs | Lower storage burden and improved inventory flexibility |
| Inventory holding cost | Approximately USD 1.2 million annually for centralized industrial stock systems | Approximately USD 700,000 annually through optimized regional allocation | Estimated cost reduction of 40 % |
| Storage environment dependency | High dependency on climate-controlled storage for long-term preservation of sensitive components | Reduced dependency through lower storage duration and regional rotation | Reduced storage degradation risk |
| Storage cost in Surabaya | USD 0.007–0.010 per kg per month equivalent for dry warehouse storage | Regional hub optimization reduces total storage exposure | Lower logistics and warehousing cost |
| Storage cost in Kalimantan | USD 0.009–0.012 per kg per month equivalent because of limited warehouse infrastructure | National support minimizes excessive stock accumulation | Improved regional operational efficiency |
| Transportation dependency | Heavy reliance on international shipping and centralized ports | Regionalized logistics and manufacturing support | Reduced transportation vulnerability |

| | | | |
|---|---|---|---|
| Manufacturing flexibility | Fully dependent on external suppliers and OEM schedules | Reverse engineering and additive manufacturing capability available locally | Improved responsiveness for non-critical |
| industrial responsiveness | Vulnerable to global shipping disruption, import restrictions, and supplier delays | Distributed support structure with decentralized operational capability | Higher resilience under disruption conditions |
| Sustainability performance | High transportation-related environmental impact | Reduced long-distance logistics activity and optimized inventory | Improved environmental performance |

The comparative results indicate that the proposed GBSH framework can significantly improve operational responsiveness and reduce logistics vulnerability compared with traditional centralized procurement systems. The largest operational improvement was observed in spare-parts lead time reduction, mainly because of localized inventory positioning and additive manufacturing support capability. The results also suggest that decentralized industrial support structures may reduce downtime exposure and improve maintenance continuity during logistics disruption conditions.

The warehouse cost comparison demonstrates that regional logistics strategy plays an important role in industrial support planning. Surabaya provides lower storage cost and stronger logistics infrastructure, while Kalimantan offers operational proximity advantages for oil, gas, and mining activities. These differences support the concept of distributed industrial support hubs rather than dependence on a single centralized inventory location.

Surabaya showed lower storage cost and stronger logistics infrastructure, while Kalimantan offered better operational proximity to industrial sites.
The findings indicate that Surabaya provides a more cost-efficient environment for centralized strategic inventory, while Kalimantan offers operational advantages because of its proximity to industrial sites.
The operational improvement percentage was calculated using the following equation:
Improvement Percentage = ((Traditional Value − GBSH Value) / Traditional Value) × 100
For spare-part lead time reduction: Improvement Percentage $= \frac{90-10}{90} \times 100 = 88.9\%$
For downtime exposure reduction: Improvement Percentage $= \frac{500000-80000}{500000} \times 100 = 84\%$
The numerical values used in the comparative analysis are indicative engineering estimates.

## 5.2 Graphical Results

The graphical analysis further illustrates the operational differences between traditional procurement systems and the proposed GBSH framework. Figure 4. compares spare parts lead time between traditional supply chains and the GBSH framework, showing significant reduction in procurement duration through regional support capability.

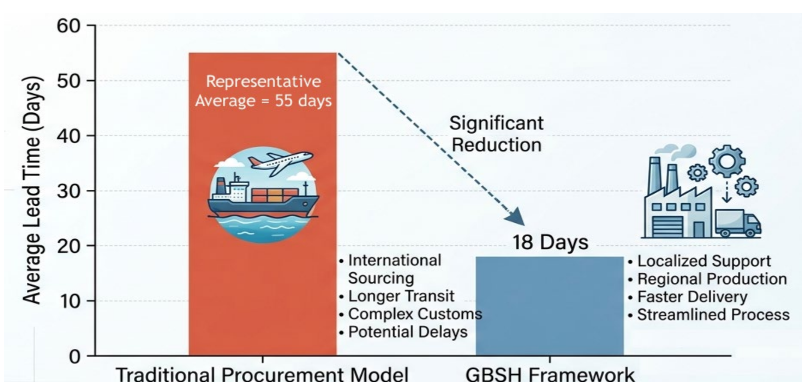


Figure 4. Lead-time comparison between traditional supply chains and GBSH framework

Figure 5. illustrates the evolution of the GBSH framework from traditional independent inventory systems toward a predictive shared regional hub supported by Digital Twin technologies. The proposed model integrates predictive maintenance, coordinated logistics response, shared strategic inventory, and Industry 4.0 digital monitoring to improve operational readiness, reduce downtime exposure, optimize capital utilization, and decrease transportation-related environmental impact.

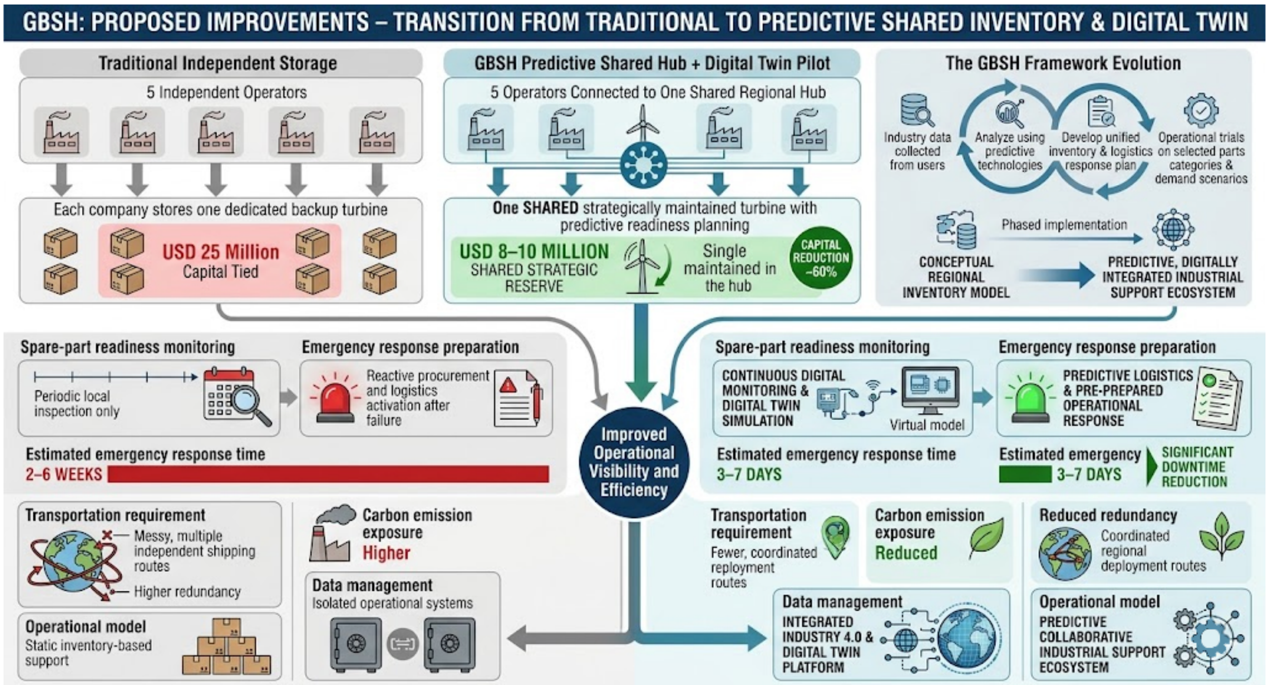


Figure 5. Transition from traditional inventory systems toward the predictive shared GBSH and Digital Twin framework

## 5.3 Proposed Improvements

The GBSH framework is not intended to replace traditional procurement systems immediately, but rather is designed for phased industrial implementation beginning with pilot operational scenarios and selected spare-parts categories. At each stage, operational data collected from participating industrial operators can be analyzed using predictive technologies to support coordinated inventory preparation, logistics readiness, and maintenance planning. The framework may also operate as an independent third-party regional industrial support platform serving multiple operators through shared predictive inventory, coordinated logistics, reverse engineering capability, and localized additive manufacturing support. This collaborative structure may improve resource utilization, reduce duplicate strategic inventory, lower capital lock-in, and enhance regional operational resilience.

The proposed pilot scenario demonstrates how the GBSH framework could evolve from a conceptual regional inventory model into a predictive and digitally integrated industrial support ecosystem. In addition, the Digital Twin approach may enable simulation of spare-parts demand, logistics response, inventory readiness, and maintenance scenarios before large-scale industrial implementation. The numerical values presented in Table 5. are indicative engineering estimates intended to support comparative operational evaluation.

Table 5. Predictive Shared Inventory and Digital Twin Pilot Model in GBSH VS Traditional Storage

| Operational Parameter | Traditional Independent Storage | GBSH Predictive Shared Hub + Digital Twin Pilot | Estimated Operational Effect |
|---|---|---|---|
| Number of participating companies | 5 independent operators | 5 operators connected to one shared regional hub | Shared operational ecosystem |

| | | | |
|---|---|---|---|
| Critical spare-part strategy | Each company stores one dedicated backup turbine | One shared strategically maintained turbine with predictive readiness planning | Reduced duplicate inventory |
| Estimated capital tied in backup assets | USD 25 million (5 × USD 5 million turbines) | USD 8–10 million shared strategic reserve | Capital reduction approximately 60% |
| Spare-part readiness monitoring | Periodic local inspection only | Continuous digital monitoring and predictive maintenance simulation | Improved operational reliability |
| Risk of non-ready stored equipment | Moderate to high due to long idle storage periods | Reduced through centralized maintenance and digital readiness tracking | Lower startup failure probability |
| Emergency response preparation | Reactive procurement and logistics activation after failure | Predictive logistics and pre-prepared operational response | Faster deployment capability |
| Estimated emergency response time | 2–6 weeks | 3–7 days | Significant downtime reduction |
| Transportation requirement | Multiple independent emergency shipments | Coordinated regional deployment | Reduced logistics redundancy |
| Carbon emission exposure | Higher because of duplicated storage and emergency transportation | Reduced through shared inventory and optimized logistics | Improved environmental sustainability |
| Inventory carrying cost | Individually borne by each operator | Distributed among participating operators | Lower cost burden per company |
| Data management approach | Isolated operational systems | Integrated Industry 4.0 and Digital Twin platform | Improved operational visibility |
| Operational model | Static inventory-based support | Predictive collaborative industrial support ecosystem | Higher resilience and flexibility |

### 5.4 Validation

The proposed GBSH framework was validated through literature consistency, comparative operational analysis, field-derived industrial observations, and expert-based practical assessment. The validation results indicate that the framework is both theoretically grounded and operationally feasible for oil and gas supply chains operating under long lead times and logistics uncertainty.

The model is consistent with previous studies emphasizing decentralized and digitally integrated supply chain resilience strategies (Christopher and Peck 2004; Ivanov and Dolgui 2021; Zhong et al. 2017). Field observations and expert interview insights further confirmed the operational relevance of regional inventory systems, reverse engineering, and additive manufacturing for reducing downtime exposure and improving maintenance responsiveness. Overall, the validation results indicate that the proposed GBSH framework provides a realistic and scalable industrial support model capable of improving operational continuity, reducing supply chain vulnerability, and supporting sustainable industrial logistics.

The validation process also demonstrated consistency between the proposed model and current industrial trends toward decentralized manufacturing, resilient logistics systems, and sustainability-oriented supply-chain management.

### 5.5 Research Limitations

This study is primarily based on conceptual framework development, comparative operational analysis, industrial observations, and expert insights rather than full-scale industrial implementation. Therefore, the numerical values and operational estimates presented should be interpreted as indicative engineering estimates intended to support comparative evaluation of the proposed GBSH framework rather than fully validated industrial measurements. Since the framework is currently at an early conceptual and comparative assessment stage, the study does not include full statistical hypothesis testing or large-scale industrial datasets. Instead, comparative scenario analysis, operational observations, and expert-based evaluations were used to assess potential operational impacts. In addition, the research focuses mainly on Indonesian industrial conditions and may require regional adaptation for application in other countries or industrial sectors. Future research may include quantitative simulation, statistical validation, and pilot-scale Digital Twin implementation using real industrial operational data.

### 5.6 Future Work
A practical future direction for the GBSH framework is the development of a Digital Twin pilot module focused on predictive spare-parts management and shared regional inventory. The proposed pilot would simulate demand forecasting, logistics response, inventory readiness, and maintenance scenarios using operational data collected from multiple industrial operators. This approach could support early-stage operational validation of the framework under realistic disruption conditions before full-scale industrial implementation.

## 6. Conclusion
This study proposes the Green Buffer Stock Hub (GBSH) as a sustainable industrial support framework for resilient oil and gas supply chains operating under energy transition conditions. It also addressed the major operational challenges observed in developing industrial regions, including long spare-parts lead times, import dependency, logistics disruptions, centralized inventory limitations, and high downtime exposure. The comparative analysis showed that conventional procurement systems remain vulnerable to global shipping instability and supplier delays, while the proposed model provides a more resilient and responsive alternative through localized support capability.
The results demonstrated that integrating strategic regional inventory, reverse engineering, additive manufacturing, and digital logistics coordination can significantly improve operational performance. The proposed model reduced lead-time exposure, improved emergency response capability, lowered inventory burden, and strengthened regional manufacturing flexibility.

The study addressed its main research objectives and demonstrated the potential applicability of the proposed model, identified the main supply chain challenges affecting oil and gas operations, analyzed the limitations of traditional centralized procurement systems, developed the GBSH framework, evaluated its operational and environmental advantages, and demonstrated its potential contribution to resilient and sustainable supply chain operations.

The main contribution of this research is the development of an integrated model that connects inventory management, rapid manufacturing, logistics coordination, and sustainability within one regional industrial support framework. Unlike traditional approaches that treat these functions separately, GBSH combines them into a unified and scalable system suitable for maintenance-intensive industries.

The findings suggest that near-site industrial support ecosystems can provide a practical pathway toward more resilient, efficient, and sustainable oil and gas supply chains. Future research should focus on quantitative simulation, economic feasibility analysis, pilot implementation, and certification requirements for industrial additive manufacturing applications.

One of the most important advantages of the proposed Green Buffer Stock Hub (GBSH) framework is its ability to predict future demand before failures escalate.

The proposed framework contributes to the industrial engineering and process management literature by integrating decentralized inventory systems, additive manufacturing support, reverse engineering capability, and regional logistics coordination into a unified operating model that focuses on flexibility. The proposed GBSH framework model may also provide future application potential for mining, energy infrastructure, offshore maintenance, and other maintenance-intensive industrial sectors facing long procurement cycles and logistics uncertainty.

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## Biography

Molham Maihoub is a consulting mechanical engineer with more than 30 years of experience in engineering, industrial development, and technical consulting across Syria, Lebanon, and Southeast Asia. He obtained the Consulting Engineer qualification in Mechanical Power Engineering from the Syrian Engineers Syndicate in 2017. And is currently pursuing a Master's degree in Infrastructure and Environmental Engineering in Bali, Indonesia. His research interests include industrial logistics, sustainable supply chains, additive manufacturing, reverse engineering, and operational resilience. His professional interests also include circular-economy practices and sustainable reuse engineering, including transforming discarded and underutilized materials into functional products and technical solutions. He also has a talent for generating innovative ideas, as well as creative abilities in problem-solving and finding practical solutions in complex operating conditions.