

A CASE STUDY ON THE TECHNICAL FEASIBILITY OF FABRICATING A 700-BAR PRESSURE VESSEL USING THE DESIGN-BY-ANALYSIS (DBA) APPROACH AT PT PLN (PERSERO)

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Abstract

Green-hydrogen deployment requires storage vessels capable of sustaining very high pressure while maintaining structural integrity and manufacturability. This study evaluates the technical feasibility of manufacturing a Type II hydrogen pressure vessel at PT PLN (Persero) PUSHARLIS using a Design-by-Analysis approach supported by finite element analysis. The study integrates engineering standards, material screening, workshop observations, design calculations, ANSYS simulation, manufacturing review, and hydrostatic-test planning. The proposed vessel uses an AISI 4130 steel liner with a 49 mm wall and a 14 mm composite hoop-wrapping layer under a 70 MPa (700 bar) internal pressure. Simulation produced a maximum von Mises stress of 381.75 MPa, below the 1,186 MPa yield strength adopted for the liner, with a minimum safety factor of approximately 3.05. The hydrostatic-test scheme uses 910 barg, equivalent to 1.3 times the design pressure. Local ASTM A36 can support prototype manufacturing-process development, but its lower strength makes it unsuitable for long-term high-pressure hydrogen storage. The results indicate a feasible domestic manufacturing pathway provided that high-pressure code qualification, material compatibility, testing capability, and quality assurance are strengthened.

Keywords: Design-by-Analysis; Finite Element Analysis; Hydrogen Storage; PLN PUSHARLIS; Pressure Vessel.

INTRODUCTION

Decarbonization commitments have placed green hydrogen among the strategic options for reducing emissions in industrial, transportation, and electricity applications. In the source engineering report, hydrogen is also positioned as an energy-storage medium that can support renewable-energy integration and Indonesia's Net Zero Emission target for 2060. The main engineering challenge is that gaseous hydrogen has low volumetric energy density at atmospheric conditions; practical storage therefore relies on compression, commonly in the range of 35-70 MPa. At the upper end of this range, storage-vessel design becomes a safety-critical problem because high pressure, cyclic loading, hydrogen-material interaction, and manufacturing defects can combine to accelerate failure mechanisms (Li et al., 2024; Marini et al., 2025).

PT PLN (Persero) Pusat Pemeliharaan Ketenagalistrikan (PUSHARLIS) is responsible for maintenance-related manufacturing, reverse engineering, repair, and production of electricity-system components. The engineering-practice report documents a feasibility study performed at the Production and Workshop II unit in Jakarta, where manufacturing capability, pressure-vessel certification experience, design software, welding expertise, quality control, and testing facilities can be developed toward emerging hydrogen applications. The strategic question is not merely whether a pressure vessel can be fabricated, but whether the entire engineering chain—from design basis and material selection to analysis, manufacturing, inspection, and pressure testing—can satisfy the risk profile of hydrogen service.

High-pressure hydrogen introduces a particular material-integrity concern because hydrogen atoms may diffuse into metallic microstructures and contribute to embrittlement, reduced ductility, crack initiation, and accelerated fatigue-crack growth. These effects are especially important at welded regions and other stress-concentration zones. The report therefore treats material selection as a central design variable and distinguishes between readily available structural steels and higher-performance alloys intended for severe pressure service. Recent literature similarly emphasizes that material compatibility and welded-joint integrity are decisive for hydrogen storage safety (Elsheikh et al., 2026).

The engineering approach adopted in the study is Design-by-Analysis (DbA), supported by finite element analysis (FEA). Instead of relying only on simplified design formulas, DbA evaluates the stress field and structural response of the modeled vessel under defined loads and constraints. FEA is particularly useful for identifying local stress concentration around geometrical transitions such as the cylindrical-to-dome region, supports, and nozzles, while also enabling evaluation of the effect of composite reinforcement. Numerical analysis has been widely applied to metallic-lined and composite pressure vessels because the load-sharing behavior of different layers cannot always be represented adequately by a single closed-form equation (Kabir, 2000; Digwijaya et al., 2026).

Accordingly, this study addresses three engineering questions derived from the practice report: how to obtain an technically optimized high-pressure vessel design using Design-by-Analysis; how prototype manufacturing can be implemented while controlling service-life and safety risks; and how the manufacturing quality of PLN PUSHARLIS can be evaluated against the stringent requirements associated with pressure-vessel production. The contribution of the study lies in connecting high-pressure hydrogen design, local material availability, FEA-based structural verification, workshop manufacturing readiness, and hydrostatic-test preparation within one Indonesian industrial case.

LITERATURE REVIEW

High-Pressure Hydrogen Storage and Vessel Architecture

Compressed gaseous hydrogen storage has developed through several vessel architectures. Metallic Type I vessels rely on a metal wall as the primary load-bearing structure, whereas Type II vessels use a metallic liner reinforced by composite wrapping over the cylindrical portion. Type III and Type IV vessels increase the share of composite reinforcement and reduce metallic mass. Composite pressure vessels are attractive because high-strength fibres can provide a high strength-to-weight ratio and reduce the mass penalty associated with thick metallic walls (Air et al., 2023). The source report selects a Type II concept as a practical intermediate pathway because it retains a metallic liner that is familiar to the existing manufacturing environment while using hoop-wrapped composite reinforcement to carry part of the circumferential load.

Earlier research on filament-wound pressure vessels shows that winding architecture, dome geometry, and the distribution of reinforcement strongly affect structural efficiency (Liang et al., 2002; Park et al., 2002). Load sharing between a metallic liner and an external composite layer is also important because the liner contributes sealing and structural support while the composite can reduce the stress transmitted to the metal (Kabir, 2000). These principles are reflected in the present design, which combines a 49 mm AISI 4130 liner with a 14 mm composite layer over the cylindrical region.

Material Compatibility, Codes, and Failure Risk

Hydrogen storage design must address not only static strength but also resistance to hydrogen-assisted degradation. The practice report compares carbon steel, low-alloy steel, austenitic stainless steel, and tool steel. Carbon steel is attractive because of cost and local availability, but the report classifies it as comparatively vulnerable to hydrogen embrittlement for severe high-pressure service. AISI 4130, a chromium-molybdenum low-alloy steel, is selected for the theoretical liner because of its high strength and better suitability for high-pressure cylindrical applications. Austenitic stainless steel offers strong hydrogen compatibility but can require a heavier section for equivalent pressure capacity, while highly brittle tool steels are not considered appropriate for the pressure-retaining structure.

The report uses the ASME Boiler and Pressure Vessel Code as its main design and manufacturing framework. In its adopted interpretation, Section VIII Division 1 supports conventional pressure-vessel design and hydrostatic-test procedures, while Division 3 is treated as the relevant framework for very-high-pressure service requiring more rigorous fracture-mechanics and fatigue evaluation. The study also recognizes that high-pressure hydrogen implementation depends on material certification, welding procedure qualification, non-destructive examination, and control of heat-affected regions. This aligns with recent studies emphasizing that hydrogen embrittlement and fatigue behavior must be considered together with conventional strength criteria (Marini et al., 2025; Elsheikh et al., 2026).

Design-by-Analysis, FEA, and Manufacturing Readiness

Finite element analysis provides a numerical means of examining stress, strain, deformation, and safety margin across complex vessel geometry. Applied engineering studies use FEA to evaluate pressure vessels under

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internal pressure and to identify critical areas that require geometric or material refinement (Imron, 2025). More recent hydrogen-vessel studies extend this approach to temperature variation, composite material behavior, and failure criteria (Digwijaya et al., 2026). The practice report follows this logic by modeling the Type II vessel in ANSYS, defining material properties, generating a finite element mesh, applying 70 MPa internal pressure, constraining the support regions, and evaluating von Mises stress and factor of safety.

Manufacturing feasibility is equally important because a numerically acceptable design cannot be implemented without appropriate forming, welding, heat treatment, inspection, and testing capabilities. Reviews of advanced composite pressure vessels identify manufacturing-process control as one of the principal challenges in scaling hydrogen-storage technology (Khan & Kumar, 2025; Mehrabianbardar et al., 2025). This study therefore treats workshop readiness, available materials, production sequence, quality control, and hydrostatic testing as integral elements of technical feasibility rather than as post-design activities. The literature gap addressed is the lack of an integrated case linking DbA, local workshop readiness, and a concrete domestic prototype pathway within PLN's manufacturing ecosystem.

METHOD

This work is an applied, descriptive-evaluative engineering case study conducted at the PT PLN (Persero) PUSHARLIS Production and Workshop II facility in Jakarta from January to May 2026. The study combines analytical design, numerical simulation, comparative review of standards and materials, field observation, and evaluation of manufacturing readiness. Primary data consist of observations of workshop equipment and production flow, discussions with welding and quality-control personnel, and internal equipment information. Secondary data include engineering standards, material specifications, technical reports, and published research cited in the source document.

The workflow consists of six stages: problem identification; literature and code review; collection of technical data; technical-feasibility analysis and simulation; evaluation of manufacturing and safety; and formulation of conclusions and recommendations. The main independent variable is working pressure, the principal dependent variable is wall thickness, and geometric dimensions are treated as controlled parameters. Design and structural evaluation use CAD-related modeling, ANSYS Workbench, and the pressure-vessel analysis context described in the source report, while spreadsheet calculations support analytical checks.

The selected configuration is a Type II vessel with a cylindrical body and hemispherical ends. The theoretical liner material is AISI 4130 with a 49 mm wall, reinforced by a 14 mm composite hoop-wrapping layer over the cylindrical section. Internal pressure is set to 70 MPa (700 bar). The ANSYS model uses automatic meshing with a nominal element size of 7 mm; the source report records 158,179 elements and 380,117 nodes. Internal pressure is applied normally to the internal surfaces and increased through a ramped load, while fixed supports are defined at the vessel support-ring regions. Structural response is evaluated from von Mises stress distribution and factor of safety.

Table 1. Principal design and simulation parameters

Parameter	Value	Engineering role
Vessel concept	Type II	Metal liner with composite hoop reinforcement
Liner material	AISI 4130	Primary pressure-retaining metallic liner
Liner thickness	49 mm	Based on the source design for 700 bar
Composite thickness	14 mm	Additional cylindrical reinforcement
Internal pressure	70 MPa (700 bar)	Primary design load
Mesh size	7 mm	Automatic ANSYS mesh
Elements / nodes	158,179 / 380,117	Numerical discretization
Hydrostatic test pressure	910 barg	1.3×700 barg in the source test scheme

RESULTS AND DISCUSSION

Material Selection and Design Configuration

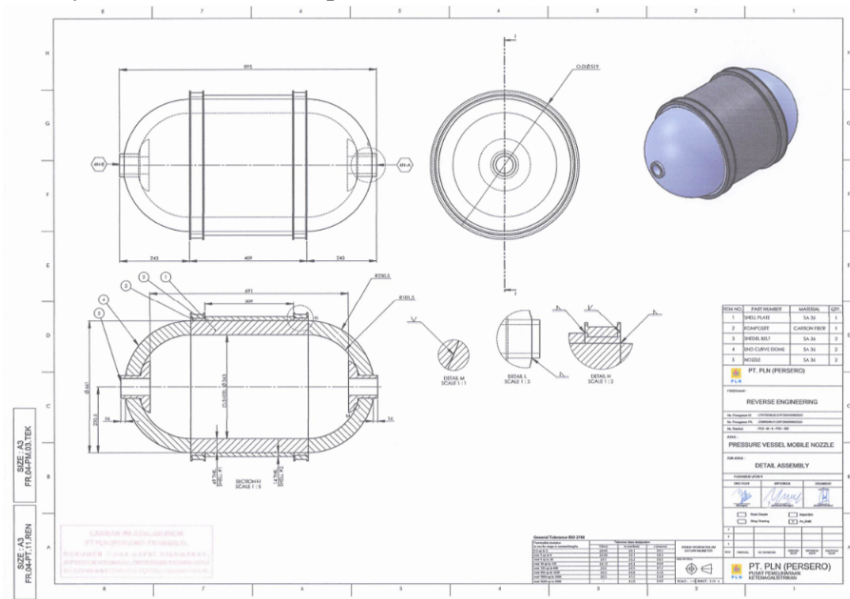
The material screening shows a clear trade-off between local availability and suitability for hydrogen service. ASTM A36 is readily available in the domestic market and can be formed and welded using familiar processes, but the source study does not regard it as an acceptable long-term pressure-retaining material for 700 bar hydrogen storage. AISI 4130 is preferred for the analytical design because its adopted yield strength of 1,186 MPa and ultimate tensile strength of 1,289 MPa provide substantially greater structural margin. The report also notes that AISI 4130 is less readily available domestically, creating a supply-chain constraint for local industrialization.

For prototype process development, ASTM A36 is used as a practical substitute to demonstrate geometry, forming, welding, assembly, and quality-control flow. This distinction is important: the prototype can validate manufacturing capability without being treated as proof that A36 is suitable for long-duration high-pressure hydrogen containment. In engineering terms, the local prototype is therefore a manufacturing-readiness demonstrator, whereas the 700 bar operational design requires a code-appropriate material system with verified hydrogen compatibility.

Table 2. Material alternatives evaluated in the source study

Material group	Representative material	Main advantage	Key limitation for this case
Carbon steel	ASTM A36	High local availability and ease of fabrication	Lower strength and poor suitability for long-term 700 bar hydrogen service
Low-alloy steel	AISI 4130	High strength and favorable high-pressure design margin	Limited domestic availability; requires strict material and process control
Austenitic stainless steel	SS 316L	Strong hydrogen compatibility and toughness	Heavier section and limited availability in the source assessment
Composite reinforcement	Carbon-fibre based	High strength-to-weight ratio; load sharing with liner	Requires controlled winding, inspection, and qualification

The final concept adopts a cylindrical vessel with hemispherical ends, a 49 mm AISI 4130 liner, and 14 mm composite reinforcement over the cylindrical section. This arrangement is consistent with the Type II load-sharing concept discussed in the literature, where the metallic liner maintains the vessel boundary while the composite layer reduces the stress carried by the metal in the hoop direction.



Source: Engineering drawing in the practice report / PLN PUSHARLIS data (2026).

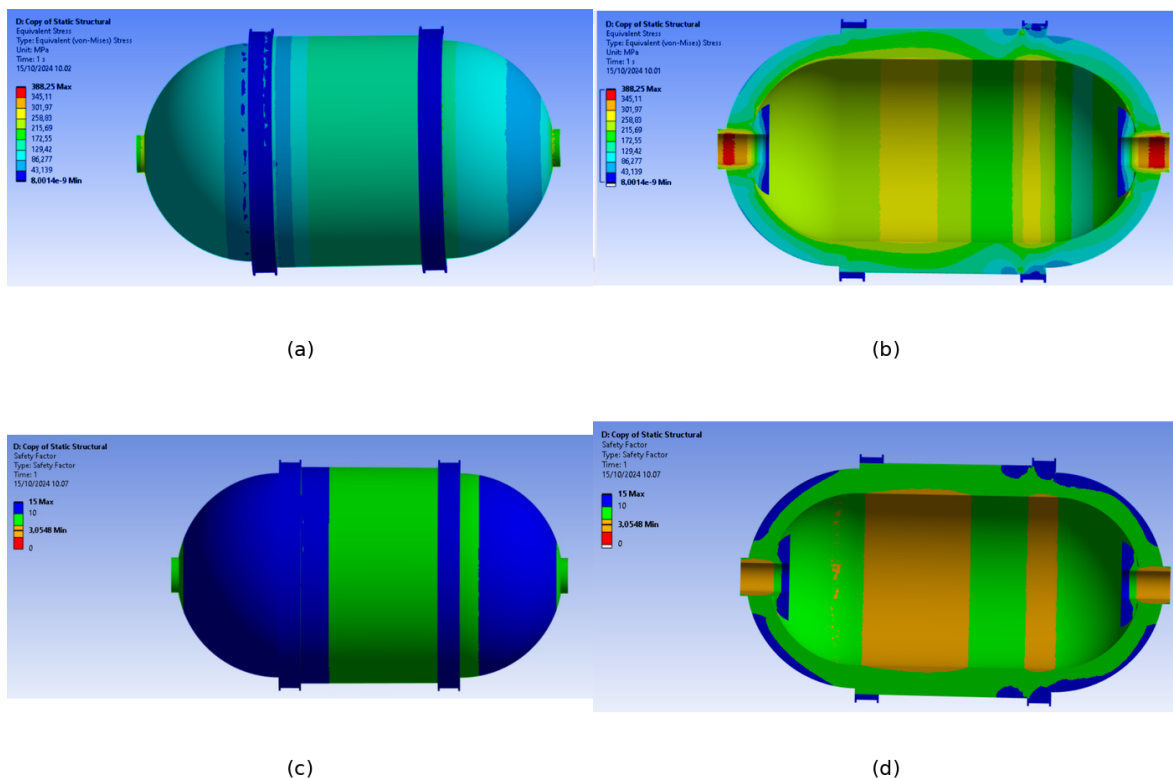
Figure 1. Engineering drawing of the 700 bar hydrogen-vessel concept

Finite Element Simulation and Structural Margin

The ANSYS model applies 70 MPa internal pressure over the internal vessel surfaces. The pressure is defined normal to the surface and introduced as a ramped load, while the support-ring regions are constrained to reproduce the fixed-support condition described in the engineering report. The resulting stress field is not uniform: the highest stresses occur around geometry transitions, especially near the dome-to-cylinder junction and support regions. These locations are expected to be more critical because load paths change locally and the structure experiences geometric discontinuity.

The maximum reported von Mises stress is 381.75 MPa. Compared with the adopted AISI 4130 yield strength of 1,186 MPa, this value remains within the elastic range and leaves substantial margin before yielding. The source model also reports a minimum safety factor of approximately 3.0548, while large regions of the vessel exhibit much higher values. The composite layer contributes to more even stress distribution and reduces the stress transferred to the metallic liner, illustrating the structural benefit of the Type II concept.

These results demonstrate numerical feasibility for the modeled static pressure case, but they should not be interpreted as a complete qualification for hydrogen service. The practice report itself recommends further assessment of fatigue, fracture mechanics, material variation, wall-thickness sensitivity, destructive and non-destructive testing, and code qualification. Such follow-up is particularly important because hydrogen service introduces degradation mechanisms that are not represented by a simple static von Mises comparison.



Source: ANSYS simulation results in the practice report (2026).

Figure 2. Structural simulation results: (a-b) von Mises stress and (c-d) safety-factor distribution

Table 3. Key structural-analysis and test-design results

Indicator	Reported result	Interpretation in this study
Maximum von Mises stress	381.75 MPa	Below adopted AISI 4130 yield strength
AISI 4130 yield strength	1,186 MPa	Reference limit used by the model
Minimum safety factor	≈ 3.05	Static structural margin under 700 bar load
Composite UTS	2,860 MPa	High-strength external reinforcement
Hydrostatic test pressure	910 barg	1.3 times 700 barg in the test scheme
Acceptance criteria	No leakage, abnormal deformation, or pressure drop	Basis for hydrostatic-test evaluation

Manufacturing Feasibility, Quality Control, and Hydrostatic Testing

The manufacturing sequence evaluated in the report includes cylinder forming, preparation of seamless or rolled cylindrical sections, dome forming, welding, heat treatment, quality control, and pressure testing. For a welded configuration, joint preparation and welding quality are critical because weld defects can become crack-initiation sites under repeated high-pressure cycling. The source report identifies GTAW/TIG as a high-quality welding option and emphasizes cleaning, staged welding, post-weld heat treatment where required, and non-destructive examination as part of the quality-assurance chain.

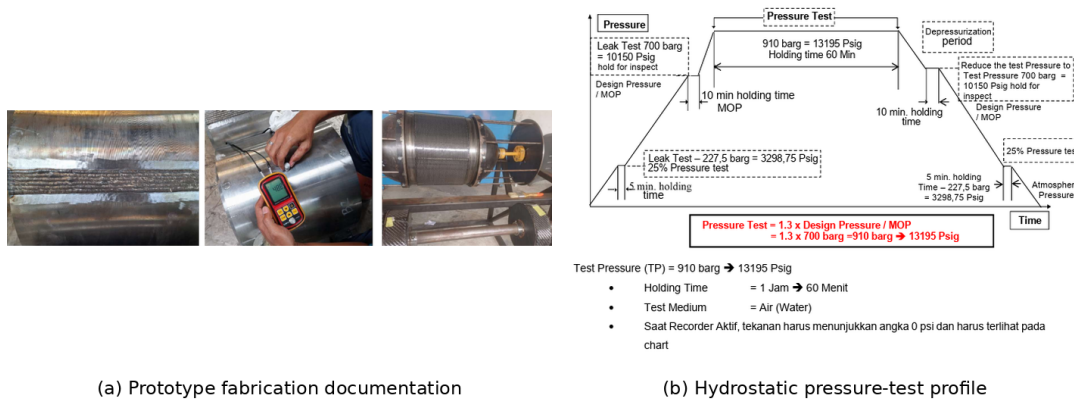
Workshop feasibility is supported by PLN PUSHARLIS experience in pressure-vessel-related manufacturing and its existing ASME certification context. Nevertheless, high-pressure hydrogen introduces stricter requirements than ordinary pressure-vessel fabrication. The report therefore recommends strengthening capability toward the qualification framework required for very-high-pressure service, including material traceability, advanced inspection, fatigue and fracture assessment, and the relevant ASME high-pressure authorization before full-scale operational deployment.

The hydrostatic-test plan uses fresh water and a test pressure of 910 barg, calculated as 1.3 times the 700 barg operating/design pressure used in the study. Pressure is increased progressively, held for the specified period, and monitored with calibrated pressure instruments and a chart recorder. The acceptance criteria are the absence of leakage, abnormal deformation, and pressure loss. The report also emphasizes controlled depressurization, restricted test zones, personal protective equipment, and safety coordination because even hydrostatic testing at this pressure represents a significant stored-energy hazard.

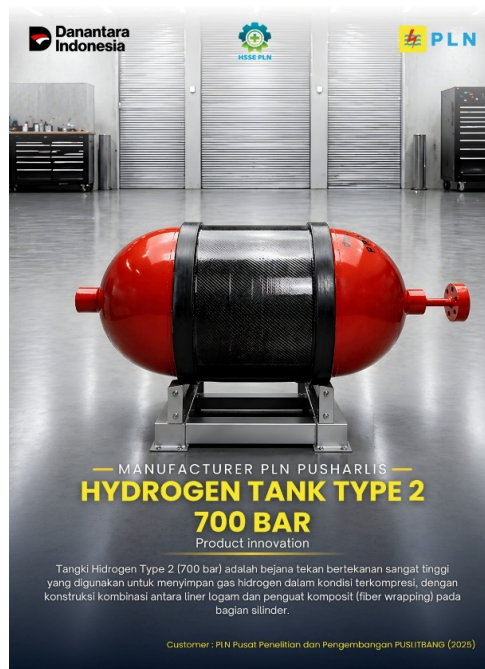
The prototype produced in the local workshop demonstrates that geometry formation, welding, assembly, and quality-control sequencing can be executed domestically. The engineering value of the prototype lies in validating the manufacturing route and exposing capability gaps before committing to an operational hydrogen-storage product. The gap between a successful prototype and a qualified hydrogen vessel remains material- and code-dependent: the study explicitly cautions that ASTM A36, although useful for process demonstration, has substantially lower yield strength than AISI 4130 and should not be used as the long-term 700 bar hydrogen-storage material.

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Source: PLN PUSHARLIS manufacturing and pressure-test documentation in the practice report (2026).
Figure 3. Prototype manufacturing documentation and the hydrostatic pressure-test profile



Source: PLN PUSHARLIS prototype documentation in the practice report (2026).
Figure 4. Hydrogen Type II 700 bar pressure-vessel prototype produced by PLN

Implications for Domestic Hydrogen-Manufacturing Capability

The case indicates that PLN PUSHARLIS has a credible foundation for entering the hydrogen-storage manufacturing ecosystem because the unit already combines design, manufacturing, welding, quality-control, and pressure-vessel experience. The main barriers are not limited to workshop equipment. They include domestic availability of hydrogen-compatible materials, qualification of high-pressure design methods, specialized testing capability, and the need to establish a repeatable supply and inspection chain. Consequently, industrial readiness should be treated as a system capability rather than as a single fabrication achievement.

The recommended development pathway is incremental. First, the 700 bar design should be refined through wall-thickness and material sensitivity studies, fatigue and fracture-mechanics assessment, and code-based design review. Second, prototype manufacturing should progress toward Type III and Type IV concepts where full composite reinforcement can reduce mass. Third, destructive and non-destructive tests should simulate actual service conditions. Finally, collaboration with PLN off-takers and research units is necessary to connect technical qualification with a sustainable demand base. This pathway directly supports the source report's objective of reducing import dependence while maintaining professional engineering ethics, safety, governance, and technical accountability.

CONCLUSION

The technical-feasibility study shows that a Type II high-pressure hydrogen vessel can be developed as a domestic manufacturing pathway at PLN PUSHARLIS when design analysis, material selection, manufacturing control, and testing are treated as one integrated engineering system. The modeled configuration uses a 49 mm AISI 4130 liner with 14 mm composite hoop reinforcement at 700 bar. ANSYS analysis reports a maximum von Mises stress of 381.75 MPa and a minimum safety factor of about 3.05, indicating adequate static structural margin relative to the adopted material properties. The 910 barg hydrostatic-test scheme provides a practical verification stage for leakage and deformation control. Local ASTM A36 is useful for demonstrating prototype fabrication processes but, according to the source study, is not appropriate for long-term 700 bar hydrogen containment because of its substantially lower strength and hydrogen-service limitations. Full industrial implementation therefore requires high-pressure code qualification, hydrogen-compatible material supply, advanced inspection, fatigue and fracture assessment, and continued pilot testing. These steps can position PLN PUSHARLIS to support Indonesia's hydrogen infrastructure while strengthening domestic engineering capability and reducing dependence on imported pressure-vessel technology.

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