



A REVIEW OF LNG PLANT DESIGN AND CONSTRUCTION ENGINEERING PRINCIPLES AND BEST PRACTICES

Musaed M. Al-Thubaiti * and Mohammed A. Al-Amri

Saudi Aramco, Project Management.

* Corresponding Author

World Journal of Advanced Engineering Technology and Sciences, 2026, 20(03), 093–102

Publication history: Received on 06 August 2026; revised on 13 September 2026; accepted on 15 September 2026

Article DOI: <https://doi.org/10.30574/wjaets.2026.20.3.0440>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

The design and construction of a Liquefied Natural Gas (LNG) plant bring together process engineering, cryogenic technology, civil works, rotating machinery, electrical systems, automation, and construction management. Their successful integration determines whether a facility can operate safely and reliably after startup. This article reviews the main engineering decisions and construction activities involved in LNG liquefaction plants, from defining feed-gas conditions to verifying operational readiness. Particular attention is given to gas treatment, refrigeration selection, equipment performance, material integrity, plant layout, modularization, quality assurance, and commissioning. Differences between hot, cold, tropical, and remote locations provide a global perspective. The discussion in this article excludes markets and terminal infrastructure. It is a practical narrative review of technical literature and established practice, rather than a detailed design manual. The main conclusion is that strong early definition, careful interface management, and disciplined construction are as important as the selected liquefaction technology.

Keywords: Engineering Integration; Liquefied Natural Gas (LNG) Plant Design; Construction Engineering; Project Best Practices; Project Quality Assurance; Mechanical Integrity; Metallurgical Compatibility;

1 INTRODUCTION

An LNG plant performs a demanding physical task: it removes enough heat from natural gas to turn it into a liquid. Near atmospheric pressure, LNG is commonly associated with a temperature of approximately minus 162 degrees Celsius, although actual conditions depend on composition. As the plant-design review by Lim, Choi, and Moon makes clear achieving that temperature is only part of a much broader engineering problem [1].

Before cooling can begin, the gas must meet strict requirements for water, carbon dioxide, sulfur compounds, mercury, and heavier hydrocarbons. Refrigeration equipment must then operate across a wide temperature range. Materials must retain suitable properties at low temperatures, piping must accommodate contraction, and control systems must manage interactions between equipment. During construction, those requirements become physical details: welds, foundations, cable terminations, insulation joints, and instrument connections.

The challenge is that weaknesses often appear at the boundaries between disciplines. A compressor may satisfy its specification while its foundation or power supply remains unsuitable. A piping arrangement may pass a stress

calculation but leave no practical maintenance access. A completed process unit may be unable to start because a utility system is incomplete. Reviewing LNG plants comprehensively therefore means examining the relationships between their parts, as well as the parts themselves.

This article covers liquefaction plant engineering and construction through commissioning, with emphasis on the decisions that influence safety, reliability, workmanship, and maintainability. The guiding best practice is to connect design intent with construction reality from the beginning.

1.1 Reading the Technical Evidence

Technical literature supports better decisions when its limitations remain visible. Broad reviews help compare technologies, while individual studies often investigate a narrowly defined feed, refrigerant mixture, exchanger model, or operating conditions. Their findings cannot automatically become guarantees for a different plant. A simulation may identify a promising configuration without demonstrating maintainability, construction feasibility, or dependable operation over several seasons.

This review draws primarily on engineering papers for process and equipment discussion, supplemented by construction research and authoritative safety guidance. It is a narrative review, not a systematic assessment of every published study. The practical recommendations combine those sources with engineering synthesis. Where construction research covers industrial projects generally, its relevance to LNG must be judged against cryogenic requirements, specialized equipment, and project interfaces.

1.2 Defining the Design Basis

The design basis establishes what the plant must do and the conditions under which it must do it. It includes feed composition, pressure, temperature, flow, contaminants, LNG quality requirements, production cases, ambient conditions, design life, and expected operating modes. These assumptions influence almost every major piece of equipment. An error introduced here may continue through process simulation, procurement, foundation design, and commissioning before it becomes visible.

Feed conditions should be expressed as an envelope, not a single average. Gas composition can vary between supply sources or change as producing fields mature. Pressure may fall, heavier hydrocarbons may increase, and temporary disturbances may introduce liquids or solids. Engineers must distinguish normal variation from unusual events and decide how the plant should respond to each. Equipment flexibility, protective functions, and operating restrictions should follow that assessment.

The design basis also needs a common set of operating cases. Maximum throughput, minimum stable operation, summer conditions, winter conditions, startup, shutdown, and equipment outages may impose different demands. For example, the condition that sizes a cooler may differ from the condition that governs compressor power. Using different assumptions in separate disciplines can result in individually reasonable designs that may not function well as a whole.

A controlled assumptions register helps maintain consistency. Each assumption should have a source, responsible owner, approval status, and identified consequences if it changes. The register becomes especially valuable when vendor information arrives gradually. It allows the team to see whether a new equipment detail affects piping, structural loads, electrical demand, or layout.

Best practice is to investigate uncertainty before compensating for it with oversized equipment. Better sampling, targeted site studies, and realistic operating cases often provide more value than applying broad design margins everywhere. Excessive margins can increase complexity while still failing to address the uncertainty that matters most.

1.3 Feed-Gas Treatment and Contaminant Control

Pretreatment protects the cold section and establishes the conditions needed for stable liquefaction. The required arrangement depends on feed composition and the chosen process. Inlet separation removes entrained liquids, while filtration or coalescing equipment may protect downstream systems from particles and aerosols. These relatively ordinary components deserve attention because contamination can affect solvents, adsorbents, compressors, and heat exchangers.

Carbon dioxide and hydrogen sulfide are commonly addressed through an acid-gas removal unit. Amine-based absorption is an established option, although alternative technologies may be appropriate for particular feeds. Axens describes amine treatment as a means of removing these acid gases [2]. Selection requires attention to removal duty, solvent behavior, regeneration energy, corrosion, foaming, and the handling of separated streams. The correct solution depends on the complete feed envelope.

Water removal is equally critical. Residual moisture can form ice or hydrates under cold conditions and restrict flow. Molecular-sieve systems are widely used where deep dehydration is required. Their performance depends on bed loading, regeneration, switching valves, gas distribution, and protection from liquid contamination. Santos and colleagues examine how changing carbon dioxide content affects molecular-sieve dehydration, reinforcing the importance of composition-specific evaluation [3]. Regeneration should be reviewed as carefully as adsorption because incomplete regeneration gradually reduces useful capacity.

Mercury removal protects susceptible materials, particularly aluminum equipment. Heavy hydrocarbons may require separation to prevent freezing or meet LNG specifications. Nitrogen removal may also be needed when feed composition and product requirements justify it. These duties should not be treated as independent additions; their arrangement can affect pressure losses, energy use, liquid recovery, and the composition reaching liquefaction [4].

A practical review asks what happens when treatment performance deteriorates. Are appropriate analyzers provided? Can operators recognize breakthrough? Is there time to respond before contaminated gas reaches sensitive equipment? Are regeneration and changeover sequences understandable? Treatment design should include early warning, maintainable equipment, and a defined response to off-specification feed. A cold section cannot reliably compensate for inadequate preparation upstream.

2 LIQUEFACTION PROCESSES AND THERMODYNAMIC DESIGN

Liquefaction technology determines how refrigeration is generated and transferred to the natural gas. Common process families include propane-precooled mixed refrigerant, dual mixed refrigerant, cascade, and expansion-based arrangements. Each balances efficiency, equipment count, refrigerant handling, operating flexibility, and scale differently. The right choice depends on site conditions and the required operating envelope rather than a universal ranking.

Mixed refrigerants combine substances with different boiling characteristics so their cooling behavior can follow the gas more closely. Cascade processes divide refrigeration among separate circuits. Zhang and colleagues compare the technical characteristics of these process families and explain why their relative suitability changes with application [5]. These alternatives show how different configurations can meet the same cooling requirement.

The thermodynamic objective is not simply to reach a low final temperature. Engineers also seek acceptable compressor work, pressure losses, heat-transfer conditions, and stable operation. Very small temperature differences within exchangers can improve theoretical efficiency but may require additional surface area and tighter operating control. Higher pressure can change refrigeration requirements while increasing mechanical demands. Optimization therefore needs to include equipment and operational constraints.

Process simulation is central to this work, but its results depend on the selected physical-property methods and input data. Refrigerant composition, compressor efficiency, exchanger pressure losses, and ambient conditions should be checked carefully. Research on single-stage mixed refrigerant liquefaction demonstrates the value of studying these interactions, while also showing why a simulated improvement must be assessed against practical equipment limits [6].

Watson and colleagues show how optimization can account explicitly for multi-stream exchanger area and detailed cooling curves [7]. This matters because a thermodynamic solution must also describe equipment that can actually be specified. The practical implication is to compare solutions using consistent exchanger assumptions, rather than accept a lower power figure obtained by allowing unrealistic heat-transfer conditions.

Train configuration creates another trade-off. A train is a processing line with its principal liquefaction equipment. Larger trains reduce duplication, whereas multiple smaller trains can provide more flexibility during maintenance or feed variation. Shared utilities may still create common failure points. The relevant measure is dependable annual production under realistic conditions. A strong technology comparison uses identical assumptions and evaluates the complete plant, including startup, maintenance, and recovery from interruptions.

3 COMPRESSORS, DRIVERS, AND MECHANICAL RELIABILITY

Refrigerant compressors are among the most important machines in an LNG plant. Their performance affects production, energy consumption, operating range, and availability. Selection requires more than matching a rated flow and pressure ratio. Engineers should examine the expected gas compositions, suction conditions, speed range, operating map, mechanical limits, and behavior during changes in plant conditions.

Surge protection deserves particular attention. A centrifugal compressor can become unstable when operating conditions move into an unsuitable low-flow region. The protective system must coordinate measurements, control logic, recycle piping, and valve response. Botros, Grose, and Hill demonstrate why surge analysis must represent the interaction between compressors, connected piping, and rapidly changing conditions [8]. The practical lesson is to verify the complete protective response rather than approve individual components in isolation.

The review by Alsuwian and colleagues also examines fault-tolerant approaches to compressor control [9]. These offer opportunities to improve resilience when sensors or actuators fail, but their application requires careful validation. Additional algorithms should not obscure the protective function or create dependencies that operators cannot diagnose. Dynamic studies and integrated testing remain essential when control concepts are translated into actual machinery.

Driver selection usually involves gas turbines or electric motors. Gas turbines can provide useful independence from an external grid, although their output and efficiency respond to ambient conditions. Electrical drivers offer different control and maintenance characteristics and may reduce direct plant emissions when supplied with suitable electricity. Neither option should be selected without assessing utility reliability, starting requirements, maintenance support, and the behavior of the integrated system.

Mechanical reliability also depends on installation quality. Foundation stiffness, grout condition, alignment, piping loads, lubrication cleanliness, seal systems, and instrumentation all influence the machine after delivery. A package that passed factory testing may perform poorly if connected piping pulls it out of alignment or preservation has been neglected. Installation checks should therefore confirm actual conditions after adjacent work is complete.

Best practice is to treat the compressor, driver, controls, auxiliaries, foundation, and connected piping as one machine system. Joint reviews involving the vendor and relevant engineering disciplines help identify problems that separate equipment specifications may miss.

3.1 Cryogenic Heat Exchangers

The main cryogenic heat exchanger is where process performance and mechanical integrity meet most directly. It must transfer substantial heat between streams while maintaining separation, acceptable pressure losses, and suitable temperature distribution. Coil-wound and brazed aluminum plate-fin exchangers are important technologies in this service, although the arrangement depends on the liquefaction process and production requirements.

Coil-wound exchangers accommodate multiple streams within a wound tube bundle. Brazed aluminum plate-fin exchangers offer compact multi-stream heat transfer, but their suitability depends on clean, compatible fluids and appropriate operating conditions. ALPEMA publishes guidance covering their manufacture, installation, and safe operation [10]. These technologies should be evaluated through their application requirements rather than simplified claims of superiority.

Transient conditions deserve as much attention as steady operation. Uneven temperature changes, poor flow distribution, or inappropriate cooldown can produce damaging stresses. Instrumentation and operating procedures should support the limits specified by the manufacturer. The design should also consider how pressure differences, blocked flow paths, and unexpected phase behavior will be managed.

Ma and colleagues' numerical study of plate-fin structures shows that residual stress from manufacturing can interact with stresses during service [11]. The implication extends beyond exchanger sizing: fabrication history and operating transients belong in the same integrity assessment. Such models support design understanding, but their results do not replace supplier-specific limits, qualified manufacturing procedures, or inspection.

Construction planning must account for lifting, support, nozzle orientation, cleanliness, and preservation. Exchangers can remain at site for months before installation or startup, making protection from moisture and contamination essential. Opportunities for performance improvement exist through better thermal integration and controls, but they should never depend on exceeding mechanical or operating limits. Protecting the exchanger's integrity is fundamental to preserving the plant's long-term performance.

4 MATERIALS, PIPING, AND INSULATION

Cryogenic service makes material selection a central design issue. Metals that perform adequately at ambient temperature may lose toughness when cooled. Piping, valves, vessels, fittings, and fasteners must therefore be suitable for their minimum design temperature and service conditions. Austenitic stainless steels and aluminum alloys have

important applications, but selection must follow the specific duty, applicable code, and fabrication requirements rather than a general material preference.

Piping flexibility is equally important. Lines contract during cooldown, and the resulting movement must be accommodated without overloading equipment nozzles, supports, or the pipe itself. Stress analysis should include relevant operating and transient cases. Its assumptions must match the installed arrangement, including support locations, friction, restraints, and connections to equipment. A good calculation cannot protect a line built differently from the model.

Welding quality depends on qualified procedures, competent personnel, correct consumables, controlled preparation, and suitable examination. API RP 582 provides welding guidance for chemical, oil, and gas applications [12]. The project must define applicable requirements and acceptance criteria at an early stage of the project. Material certificates, weld records, and component identification should remain traceable throughout fabrication and installation, particularly where different grades look similar.

Insulation forms a complete system rather than a layer added at the end. Vapor barriers, joints, weather protection, supports, and penetrations all affect performance. Moisture ingress can degrade insulation and create maintenance problems. Details around valves and irregular shapes need particular attention because they are difficult to seal consistently and may be disturbed during operation.

Best practice is to inspect critical details before they become hidden. Material identity, weld completion, support arrangements, and testing status should be confirmed before insulation closes access. This reduces the chance that a seemingly finished line must later be opened and rebuilt.

4.1 Civil Engineering, Foundations, and Plant Layout

Civil design begins with understanding the site. Soil strength, settlement, groundwater, seismic conditions, drainage, and available space influence both permanent works and construction methods. Ground investigation should be designed around the proposed structures, with enough information to distinguish areas requiring different foundation solutions. Applying one foundation assumption across an inadequately investigated site can create significant problems later.

Heavy rotating equipment requires attention to dynamic behavior as well as static capacity. Foundations must support the machine without unacceptable vibration or movement. Pipe racks and process structures need to accommodate operating loads, wind, seismic actions where relevant, and maintenance activities. Equipment loads should be coordinated with vendor information before foundation details become difficult to change.

Layout should serve operation, maintenance, construction, and emergency response. Short piping routes are useful, but excessive compactness can restrict access or increase interaction between hazardous areas. The UK Health and Safety Executive identifies operability, maintainability, protection of occupied buildings, and prevention of incident escalation as important layout considerations [13]. These priorities should be examined together rather than assigned to separate reviews with conflicting assumptions.

A practical method is to walk through real tasks in the model. Can a motor be removed? Can technicians reach an instrument safely? Where will a crane stand? Can emergency vehicles reach the required area? The answers should appear as physical space and clear routes, not only as notes on a drawing.

Location changes these decisions. A desert site may require protection against dust and severe summer temperatures. A humid tropical site demands particular attention to rainfall, corrosion protection, and equipment storage. Where frozen ground is present, foundations may need measures addressing thaw-related movement. Earthquake-prone locations require seismic demands to be coordinated across structures, piping, and equipment. A global design standard should preserve consistent safety expectations while allowing these local engineering responses.

Site drainage and flood protection also need coordinated design. Electrical rooms, equipment foundations, trenches, and roads can each alter water movement. The team should consider extreme conditions and the plant's dependence on external access and power. A good layout makes safe work possible throughout the facility's life, including during maintenance and expansion.

4.2 Utilities, Electrical Systems, and Instrumentation

Utilities often receive less attention than the liquefaction process, yet they can stop production just as effectively. Instrument air, nitrogen, cooling systems, heating systems, fuel gas, firewater, and electrical distribution need clearly

defined duties and reliability requirements. Their design should cover normal operation, startup, shutdown, maintenance, and recovery after disturbances. Average demand alone is rarely enough.

Electrical studies should examine load flow, short-circuit levels, protection coordination, motor starting, and power quality where relevant. Large variable-speed drives introduce additional considerations for harmonics and system interaction. Emergency and uninterrupted power should be assigned according to the functions that must remain available. The project also needs a practical plan for energizing, testing, and transferring systems into operational control.

Instrument design must account for the measurement environment. Low temperatures, vibration, access, moisture, and hazardous-area requirements can affect selection and installation. Measurements used for control should be reviewed alongside those needed for protection and performance testing. A sensor that is difficult to maintain may create long-term reliability problems even when its initial specification is correct.

Utilities require sensible redundancy. Duplicating equipment is useful only if common power, controls, cooling, or distribution failures do not defeat both units. Reliability reviews should identify shared dependencies and compare targeted improvements. Sometimes a simpler distribution arrangement or clearer maintenance isolation provides greater benefit than adding another machine.

Best practice is to review utility failures as plant events. Asking what happens when instrument air, cooling, or power is lost helps connect equipment design with shutdown logic, safe operating states, and restart requirements. This prevents support systems from being treated as disconnected packages.

4.3 Process Safety and Protective Systems

Process safety aims to prevent major releases and limit their consequences. In an LNG plant, hazards include flammable gas, cryogenic exposure, pressure, rotating equipment, and hazardous treatment chemicals. The World Bank Group's LNG guidance addresses containment, leak detection, emergency shutdown, and response planning [14]. Applying these principles requires an understanding of the actual plant configuration and its credible failure scenarios.

Hazard identification should begin during concept development. Later hazard and operability studies examine deviations such as high pressure, low flow, reverse flow, or loss of cooling. Where needed, further analysis evaluates whether protective measures provide sufficient risk reduction. These studies should include startup, shutdown, maintenance, and abnormal operation, when equipment arrangements may differ from normal production.

Safety instrumented systems need a defined life cycle. IEC 61511 addresses their specification, design, installation, operation, and maintenance [15]. Required protective functions should be translated into clear performance requirements and verified against the complete measurement, logic, and final-element arrangement. Testing access and maintenance practices belong in the design because protection must remain dependable after startup.

Relief and depressurization systems require coordinated evaluation of credible scenarios, disposal-system capacity, material temperatures, and interaction between connected equipment. Their purpose differs from routine process control. The team should avoid assuming that one protective device solves every operating problem. Isolation, detection, passive protection, suitable layout, and operating procedures each contribute in different ways.

Human factors are also important. Displays, alarms, access, labelling, and procedures should help operators understand developing conditions. Too many low-value alarms can obscure the event that needs attention.

Best practice is to reduce hazards through design, verify the remaining safeguards, and close safety actions before introducing hazardous materials. Unresolved findings should not disappear into an administrative list simply because construction is nearly complete.

5 ENGINEERING DEVELOPMENT AND MODULAR CONSTRUCTION

A disciplined engineering sequence links concept selection, front-end engineering design, detailed engineering, procurement, and construction. Each stage should resolve the questions needed by the next. Equipment arrangements, major loads, utility requirements, and construction access should mature before foundations and structures are fixed. The Construction Industry Institute recognizes front-end planning and constructability as established best practices [16].

Constructability reviews bring practical site knowledge into design. They examine delivery routes, lifting plans, temporary facilities, scaffolding, installation sequence, and the interaction of trades. An equipment arrangement may

be technically correct yet difficult to assemble because a heavy lift blocks access or a foundation closes a necessary transport route. Early input from construction personnel makes these conflicts easier to resolve.

Modular construction can move substantial assembly work into fabrication yards while site preparation proceeds separately. Chi and colleagues examine LNG fabrication, delivery, and installation as connected processes requiring consistent quality information [17]. The approach can improve access to skilled labor and controlled working conditions, but it requires early agreement on module boundaries and interfaces.

The framework proposed by Chi and colleagues uses sensing and tracking to identify deviations across those stages [17]. Its contribution is conceptual: better visibility can support quality control, but adopting a digital platform does not itself prove improved workmanship. Module interfaces still need surveyed dimensions, agreed tolerances, and accountable release checks before shipment and installation.

Modularization also creates its own demands. Transport dimensions, structural loads during handling, lifting arrangements, dimensional tolerances, and connection details must be reviewed together. Late changes can affect equipment already assembled in another country. A hybrid approach may therefore be preferable, combining modular process packages with site-built structures and civil works.

The best practice is to choose the construction method around the project's actual constraints. Standardization helps where designs are repeatable; adaptation remains necessary where climate, ground conditions, access, or operating requirements differ. The objective is predictable installation and reliable final performance, not the greatest possible percentage of modular work.

Design changes need the same discipline. A request to relocate equipment may appear minor but alter piping stress, cable routes, access, drainage, and construction sequence. Before approval, the responsible team should identify affected documents and equipment, consult the relevant disciplines, and record the decision. Field changes require particular care because the installed condition can diverge from drawings faster than records are updated. Regular reconciliation between the model, approved documents, and site observations helps ensure that commissioning personnel receive an accurate description of the plant they are preparing to start safely.

5.1 Procurement, Quality Assurance, and Preservation

Procurement translates engineering requirements into manufactured equipment. LNG projects depend on specialized machinery, exchangers, electrical equipment, valves, and materials that may require long delivery periods. Technical evaluation should therefore consider manufacturing capacity, testing arrangements, documentation, inspection access, and support requirements alongside performance. Delivery dates need to reflect the sequence in which systems will be completed.

Standardized specifications can reduce unnecessary variation. IOGP's JIP33 initiative promotes common procurement requirements for equipment and packages [18]. This can simplify communication between owners, contractors, and suppliers, provided project-specific requirements remain clear. Standardization should not hide an unusual operating condition or replace an engineering decision that still needs to be made.

Quality assurance establishes how work will be controlled; quality control verifies what has actually been produced. Inspection and test plans should identify required checks, acceptance criteria, responsible parties, and points where work must pause for verification. Nonconformities need a documented engineering disposition. Accepting a deviation merely because replacement would delay shipment can transfer an unresolved problem into operation.

Preservation deserves a defined program from factory release through startup. Moisture, dust, corrosion, damaged seals, and incorrect storage can harm equipment before it operates. The requirements vary by package and should follow vendor instructions. Someone must own the inspection intervals, protective measures, records, and changes needed when equipment moves from warehouse storage to installed standby.

Best practice is to verify quality before equipment becomes difficult to repair. Factory checks and receiving inspections should complement each other. Reliable records should connect material identity, fabrication, testing, preservation, and installation so the commissioning team can establish readiness from evidence rather than assumption.

5.2 Construction Execution and Workforce Management

Effective construction depends on making work ready before assigning it to a crew. Drawings, materials, access, equipment, permits, supervision, and inspection arrangements must be available together. Advanced work packaging

aligns these requirements with the planned construction sequence. Porwal and colleagues found that advanced work packaging and workface planning were associated with higher direct-work rates across two construction datasets [19].

The construction evidence also needs careful interpretation. Porwal and colleagues report an association, not a guaranteed improvement for every project [19]. Direct-work rate measures how time is spent; it is not identical to installed quality or total project performance. Managers should therefore monitor rework, safety, system completion, and constraint removal alongside labor utilization.

When progress slows, adding workers is not always helpful. The underlying problem may be missing materials, unresolved drawings, access conflicts, or an inspection hold. More people can increase congestion without removing the constraint. Supervisors need a clear way to report obstacles and obtain decisions from the responsible discipline or manager.

Construction safety changes as the plant develops. Excavations, temporary structures, lifting operations, electrical energization, and testing create different hazards. IOGP's fabrication-site guidance addresses hazardous activities and the management practices supporting safer work [20]. Controls should match conditions at the workface, with clear responsibilities between contractors and subcontractors.

Global projects also need realistic workforce planning. Heat requires suitable work-rest arrangements; cold conditions affect access and equipment; tropical rainfall changes ground conditions and productivity. OSHA's guidance on water, rest, and shade offers useful heat-prevention principles, while local requirements must be confirmed [21]. Remote locations need dependable accommodation, transport, medical support, and technical assistance.

Best practice is to support the people doing the work with clear instructions and achievable plans. Multilingual communication, practical training, competent supervision, and the authority to stop unsafe work all matter. Construction quality improves when crews understand the purpose of requirements and can raise concerns before a defect is built into the plant.

5.3 Testing, Commissioning, and Handover

Testing demonstrates that construction has achieved the required integrity and functionality. Pressure testing, electrical checks, instrument calibration, control-system testing, and equipment inspections each address different questions. A successful pressure test does not prove cleanliness, correct control logic, or operational readiness. Test boundaries, acceptance criteria, safety precautions, and records should be planned before the systems are assembled.

Pressure testing requires particular care because of stored energy. The UK Health and Safety Executive's GS4 guidance addresses its hazards and the responsibilities of those managing the work [22]. Test methods and arrangements should be selected by competent engineers for the equipment and circumstances. Shortcuts taken to recover schedule can create severe risks and leave uncertain results.

Mechanical completion marks a defined construction milestone, but commissioning develops the facility into an operating system. Cleaning, drying, reinstatement, utility introduction, functional checks, and preparation for hydrocarbons need a controlled sequence. Temporary connections and incomplete work should be visible, with clear ownership as systems pass from construction to commissioning.

This distinction between construction areas and operating systems is crucial. A utility header may cross several areas, yet none can start until the necessary header, isolation points, instruments, and supporting equipment are ready. O'Connor and colleagues' systems-based approach helps connect construction progress with that commissioning dependency [23]. Its implementation still requires clear ownership and a shared completion database.

Cooldown is a critical stage because equipment and piping undergo substantial temperature change. Rates, limits, and observation requirements should follow the approved design and vendor instructions. Operators need reliable measurements and procedures for responding to unexpected behavior. Moisture, debris, incorrect supports, or incomplete instrument connections can become apparent at this point, which is why earlier verification matters.

Operational readiness includes people and information. Permanent staff need training, procedures, maintenance plans, spare parts, emergency arrangements, and accurate drawings. O'Connor, Leite, and Ma propose extending work packaging to commissioning and startup through packages organized around operational systems [23]. Startup should follow verified readiness, with safety-critical work closed and remaining items formally assessed. Performance testing and a controlled handover then establish what the plant can reliably deliver and what responsibilities remain.

5.4 Environmental Performance and Digital Integration

Environmental improvements should be translated into design requirements that can be built and measured. Efficient compression, lower pressure losses, useful heat recovery, suitable electrification, and methane control can improve plant performance. The IEA identifies these as relevant technical approaches to reducing LNG-related emissions [24]. Their application should consider actual operating conditions and the reliability of supporting systems.

Measurement is essential. Energy meters, appropriate gas measurements, inspection access, and reliable operating data help determine whether an improvement works. Methane monitoring should lead to repair and verification rather than reporting alone. Construction activities also need practical controls for erosion, drainage, waste, spills, dust, and noise. Temporary works can cause lasting damage if they receive less attention than permanent equipment.

Digital engineering can improve coordination through shared models, equipment databases, document control, and completion records. Its value is clearest when it answers practical questions: which drawing is current, whether a component has arrived, or which tests remain incomplete. Reliable information supports both construction decisions and later maintenance.

Connected systems also require cybersecurity. NIST's operational technology guidance addresses security alongside physical performance, reliability, and safety [25]. Network architecture, access permissions, vendor connections, backups, and recovery plans should be addressed during design. Digital tools are useful only when their information is trustworthy and their operation does not introduce unmanaged risk.

6 CONCLUSION

A review of LNG plant design and construction shows that dependable performance comes from integration. Gas treatment protects liquefaction. Refrigeration design determines equipment duties. Materials and piping carry those duties safely. Foundations, utilities, controls, and protective systems allow the equipment to function as intended. Construction quality connects all of these decisions to the finished facility.

The strongest best practices are practical and repeatable: define realistic conditions, involve construction and operations early, coordinate interfaces, verify materials, protect and preserve equipment, remove work constraints, and test complete systems. Different locations require different details, but the need for competent people, clear responsibilities, and reliable evidence remains constant.

New technology can improve efficiency and coordination, yet it cannot compensate for incomplete engineering or poor workmanship. The most successful LNG plants are those in which design decisions remain understandable, construction follows controlled requirements, and commissioning demonstrates readiness before operation begins. That continuity is the foundation of safe, maintainable, and reliable plant performance.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

REFERENCES

- [1] Lim, W., Choi, K., and Moon, I. (2013). Current Status and Perspectives of Liquefied Natural Gas (LNG) Plant Design. *Industrial & Engineering Chemistry Research*, 52(9), 3065–3088.
- [2] Axens. Gas Sweetening. Technical process overview (<https://www.axens.net/expertise/natural-gas/gas-sweetening>).
- [3] Santos, M. G. R. S., Correia, L. M. S., de Medeiros, J. L., and Araújo, O. Q. F. (2017). Natural gas dehydration by molecular sieve in offshore plants: Impact of increasing carbon dioxide content. *Energy Conversion and Management*, 149, 760–773.
- [4] Ikealumba, W. C., and Wu, H. (2014). Some Recent Advances in Liquefied Natural Gas (LNG) Production, Spill, Dispersion, and Safety. *Energy & Fuels*, 28(6), 3556–3586.
- [5] Zhang, J., Meerman, H., Benders, R., and Faaij, A. (2020). Comprehensive review of current natural gas liquefaction processes on technical and economic performance. *Applied Thermal Engineering*, 166, 114736. Technical comparisons cited.

- [6] Wu, X., Wang, Z., Dai, X., Ge, Q., and Liu, F. (2021). Optimization Design and Analysis of Single-Stage Mixed Refrigerant Liquefaction Process. *Frontiers in Energy Research*, 9, 766588.
- [7] Watson, H. A. J., Vikse, M., Gundersen, T., and Barton, P. I. (2018). Optimization of single mixed-refrigerant natural gas liquefaction processes described by nondifferentiable models. *Energy*, 150, 860–876.
- [8] Botros, K., Grose, J., and Hill, S. (2015). A New Approach to Designing Centrifugal Compressor Surge Control Systems. *Proceedings of the 44th Turbomachinery Symposium*.
- [9] Alsuwian, T., et al. (2023). A review of anti-surge control systems of compressors and advanced fault-tolerant control techniques for integration perspective. *Heliyon*, 9(9), e19557.
- [10] ALPEMA. Standards of the Braze Aluminium Plate-Fin Heat Exchanger Manufacturers' Association. Standards overview (<https://www.alpema.org/standards.html>).
- [11] Ma, H., et al. (2021). The influence of residual stress for the strength of plate-fin structures in the typical operation process of Liquefied Natural Gas (LNG) heat exchanger. *Oil & Gas Science and Technology*, 76, 76.
- [12] American Petroleum Institute. (2023). API RP 582: Welding Guidelines for the Chemical, Oil, and Gas Industries, fourth edition. Publication record (<https://www.apiwebstore.org/standards/582>).
- [13] Health and Safety Executive. Plant Layout. Technical measures guidance (<https://www.hse.gov.uk/comah/sragtech/techmeasplantlay.htm>).
- [14] World Bank Group. (2017). Environmental, Health, and Safety Guidelines for Liquefied Natural Gas Facilities (<https://www.ifc.org/content/dam/ifc/doc/mgrt/20170406-final-lng-ehs-guideline-april-2017.pdf>).
- [15] International Electrotechnical Commission. (2016). IEC 61511-1: Functional Safety—Safety Instrumented Systems for the Process Industry Sector. Publication scope (<https://webstore.iec.ch/en/publication/24241>).
- [16] Construction Industry Institute. CII Best Practices: Front End Planning and Constructability (<https://www.construction-institute.org/cii-best-practices>).
- [17] Chi, H.-L., Wang, J., Wang, X., et al. (2015). A Conceptual Framework of Quality-Assured Fabrication, Delivery and Installation Processes for Liquefied Natural Gas (LNG) Plant Construction. *Journal of Intelligent & Robotic Systems*, 79, 433–448.
- [18] International Association of Oil & Gas Producers. JIP33: Standardization of Equipment Specifications for Procurement (<https://jip33.iogp.org/>).
- [19] Porwal, V., et al. (2025). Examining the impact of Advanced Work Packaging and WorkFace planning on direct work rates of on-site construction workers: a comparative analysis. *Frontiers in Built Environment*, 11, 1621337.
- [20] International Association of Oil & Gas Producers. Fabrication Site Construction Safety Practices: Reports 577 and 597 (<https://www.iogp.org/workstreams/safety/safety/construction/>).
- [21] Occupational Safety and Health Administration. Heat: Water. Rest. Shade. (<https://www.osha.gov/heat-exposure/water-rest-shade>).
- [22] Health and Safety Executive. Safety Requirements for Pressure Testing. Guidance Note GS4 (<https://www.hse.gov.uk/pubns/gs4.pdf>).
- [23] O'Connor, J. T., Leite, F., and Ma, J. W. (2023). Expanding advanced work packaging to include commissioning and startup for industrial projects. *Construction Innovation*, 23(5), 939–960.
- [24] International Energy Agency. (2025). Assessing Emissions from LNG Supply and Abatement Options. Plant engineering measures cited (<https://www.iea.org/reports/assessing-emissions-from-lng-supply-and-abatement-options>).
- [25] National Institute of Standards and Technology. (2023). Guide to Operational Technology (OT) Security. NIST SP 800-82, Revision 3 (<https://csrc.nist.gov/pubs/sp/800/82/r3/final>).