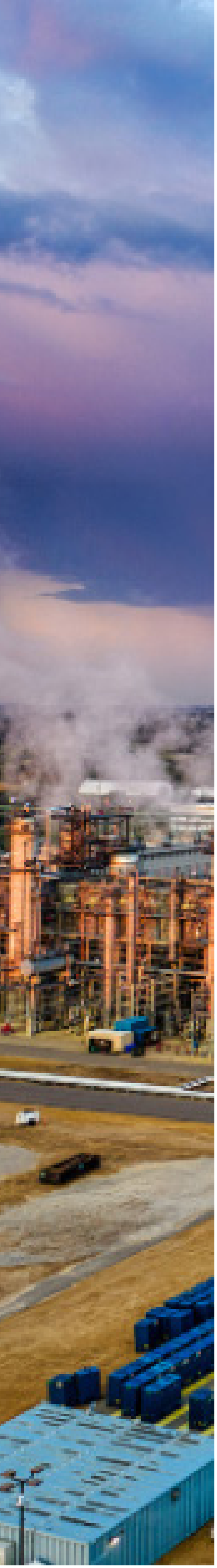
GALLAGHER
Fluid Seals, Inc.

Cryogenic LNG
Seal Design Playbook

Table Of Contents



SECTION 1

Purpose & Scope

This playbook is intended to serve as a practical technical reference for engineers, designers, and reliability professionals responsible for sealing systems in cryogenic LNG service. Its purpose is to address the unique challenges associated with sealing liquefied natural gas and related vapor-phase media at extremely low temperatures, where conventional sealing assumptions often no longer apply.

While many sealing guides discuss cryogenic applications in broad terms, LNG systems present a distinct combination of extreme temperature, light-gas behavior, thermal cycling, and low-pressure operation that requires a more focused approach. This document concentrates specifically on those conditions and the design considerations necessary to achieve reliable, long-term sealing performance in LNG equipment.

The scope of this playbook includes spring-energized seals used in both static and slow-moving dynamic applications commonly found in LNG service, such as valves, pumps, actuators, cold boxes, and transfer equipment.

Topics covered include operating environment characteristics, common failure modes, spring and material selection, gland and hardware considerations, and installation best practices relevant to LNG applications.

The intent is to provide actionable guidance that can be applied during equipment design, seal selection, retrofits, and troubleshooting.

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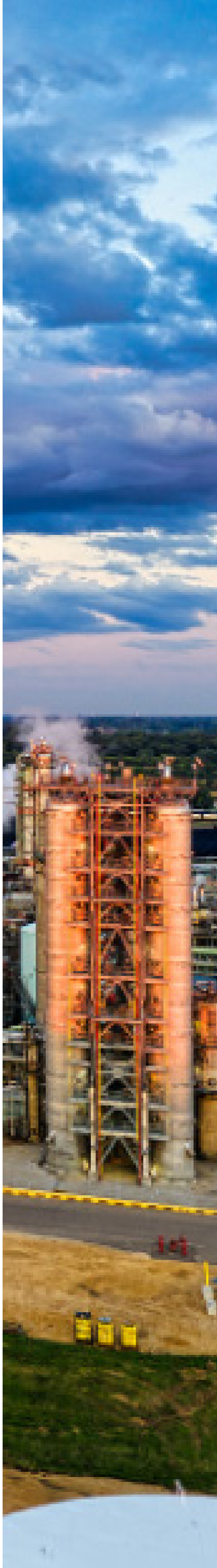


SECTION 2

LNG Operating Environment: What makes it Different

Liquefied Natural Gas (LNG) presents one of the most demanding sealing environments encountered in industrial service. While often grouped under the broader category of "cryogenic applications," LNG service introduces a unique combination of extreme temperature, light-gas behavior, and thermal cycling that exposes the limitations of many conventional sealing approaches.

2.1 Extreme Low Temperatures

LNG is typically handled at temperatures approaching -320°F (-195°C). At these temperatures:

- Elastomeric materials lose elasticity, stiffen, or fracture
- Many plastics experience significant changes in modulus
- Differential thermal contraction between seal materials and metal hardware becomes pronounced

Seals that rely on material resilience alone often lose effective contact force as temperatures drop, resulting in leakage during cooldown or steady-state operation.

2.2 Liquid vs. Vapor Phase Sealing

LNG systems commonly alternate between LNG and vapor-phase natural gas, particularly during startup, shutdown, and boil-off conditions.

- LNG has very low viscosity, increasing its tendency to leak through small clearances
- Vapor-phase natural gas behaves as a light gas, readily escaping through micro leak paths
- Seals must maintain tight contact under both liquid and gas conditions, often at low pressure

This dual-phase behavior places a premium on consistent, circumferential contact force rather than pressure-assisted sealing alone.

2.3 Pressure and Thermal Cycling

Unlike steady-state cryogenic storage, many LNG systems experience frequent pressure and temperature cycling, including:

- Cooldown from ambient to cryogenic temperatures
- Partial warmups during maintenance or standby
- Pressure fluctuations driven by boil-off gas management

Each cycle introduces mechanical movement within the gland, seal, and hardware—movement that can relax preload, open leak paths, or accelerate wear if not properly accounted for in the seal design.

Figure 1: A reciprocating pump for LNG use

2.4 Clean Media, Harsh Mechanics

Although LNG itself is relatively clean and non-abrasive, the mechanical environment is unforgiving, as extreme low temperatures reduce material compliance.

Hardware imperfections that are tolerable at ambient temperatures can cause leakage at cryogenic conditions due to material deficiencies. Additionally, even small installation defects can become critical leak paths under these harsh environments.

For these reasons, sealing success in cryogenic environments is governed less by chemical compatibility and more by mechanical stability, preload retention, and thermal compensation

SECTION 3

Common Seal Failure Modes in LNG Service

Most LNG seal failures are not sudden or catastrophic—they are predictable outcomes of mismatched materials, insufficient preload, or incomplete consideration of cryogenic behavior. Understanding these failure modes is essential to selecting the right sealing solution.

3.1 Loss of Seal Contact During Cooldown

As systems transition from ambient to cryogenic temperatures, maintaining seal contact becomes increasingly challenging. PTFE and other polymers stiffen and lose their ability to conform to mating surfaces, while elastomeric energizers shrink and lose preload.

At the same time, metal hardware contracts at a different rate than the seal components. Without a mechanism to actively maintain contact force, these combined effects can cause the seal to pull away from the mating surface, allowing leakage to initiate early in the cooldown process.

3.2 Micro-Leakage in Light Gas Service

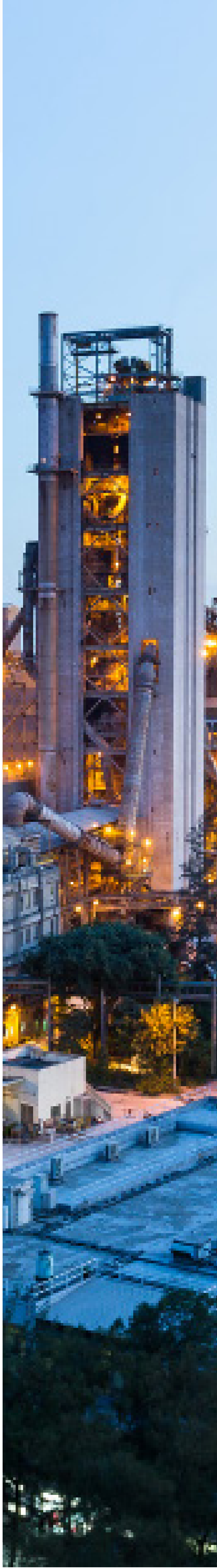
LNG vapor and boil-off gas are particularly unforgiving in sealing applications. Light gases can escape through extremely small clearances, and even well-machined glands may leak if contact pressure is uneven around the seal.

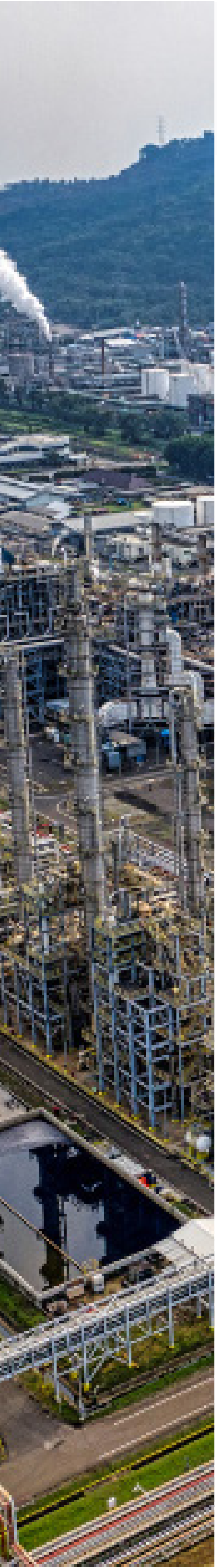
In addition, gas permeation is often mistaken for leakage, which can mask the presence of true seal failure. In many cases, leakage is not caused by gross damage to the seal, but by localized loss of contact pressure at specific points around the circumference.

3.3 Thermal Cycling Fatigue

Repeated thermal cycling introduces cumulative damage to sealing systems over time. Each cycle can contribute to a gradual loss of preload, progressive relaxation in elastomer-energized designs, and the development of wear patterns that only become apparent after multiple temperature excursions.

As a result, seals that perform acceptably during initial commissioning may begin to leak months later as the effects of thermal cycling accumulate.





3.4 Installation Damage Revealed at Cryogenic Temperatures

Minor installation defects—such as nicks, edge damage, or distortion—may remain undetected under ambient conditions. At cryogenic temperatures, however, stiffer seal materials can no longer “heal” over these imperfections.

Damaged areas become preferential leak paths, and leakage often appears only after cooldown, complicating both detection and troubleshooting efforts.

Most LNG seal failures originate before the system ever reaches steady-state operation, either during design or installation.

3.5 Gas Decompression and Rapid Depressurization Effects

The rate of depressurization can have a direct impact on seal integrity. Rapid pressure release can create transient pressure differentials across the seal that exceed its ability to respond, particularly at cryogenic temperatures where materials are stiff and less compliant.

If pressure is released too quickly, gas trapped within gland volumes or behind seal lips may not equalize at the same rate as the surrounding system. In severe cases, this imbalance can lead to cracking or structural damage in polymer seal jackets that are already operating near their lower temperature limits. For LNG service, controlled and gradual decompression is essential.

SECTION 4

Why Spring-Energized Seals Are Used in LNG

The defining challenge of LNG sealing is maintaining reliable contact force at cryogenic temperatures, independent of pressure and material elasticity. This is the core reason spring-energized seals are widely used in LNG service.

4.1 Contact Force Independent of Temperature

Spring-energized seals incorporate a metal energizer that provides continuous mechanical loading to the seal lips. Unlike elastomeric energizers, metal springs:

- Do not lose elasticity at cryogenic temperatures
- Maintain load across wide temperature ranges
- Compensate for material stiffening and thermal contraction

This ensures that sealing contact is preserved during cooldown, steady-state operation, and thermal cycling.

4.2 Compensation for Tolerance and Movement

In LNG equipment, perfect hardware alignment and tight tolerances cannot always be guaranteed. Spring-energized seal designs help compensate for these real-world conditions by accommodating gland tolerance variation, minor misalignment, and wear over time.

The spring continuously adjusts to maintain contact pressure, reducing sensitivity to small dimensional changes that would otherwise result in leakage.

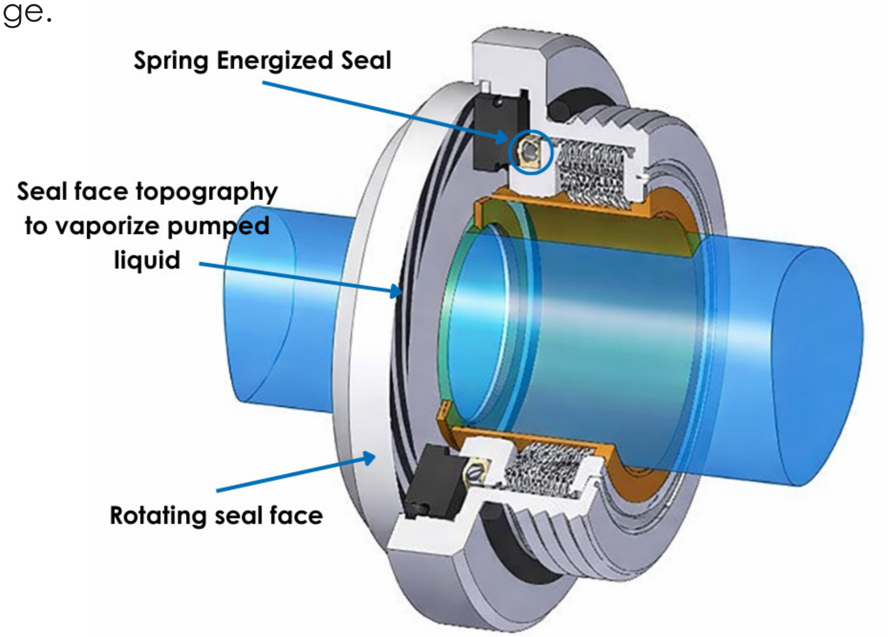


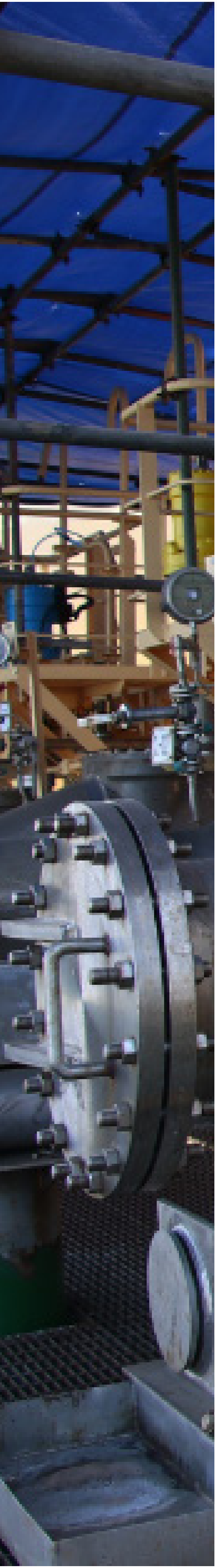
Figure 2: A Spring Energized Seal installed on an LNG pump

4.3 Low-Pressure and Vacuum Sealing Capability

Many LNG sealing conditions involve low differential pressures, particularly during startup or in vapor service.

Spring-energized seals do not rely on system pressure to activate sealing, allowing them to provide effective performance even at zero or near-zero pressure.

This makes them well suited for vacuum and light-gas environments and particularly effective during non-steady-state LNG operation.



4.4 Comparison to Alternative Cryogenic Sealing Approaches

While other sealing technologies are used in cryogenic service, each has limitations in LNG applications:

- Elastomer-energized seals: lose preload and resilience at cryogenic temperatures
- Metal C-rings or E-rings: require very high seating loads and extremely precise hardware
- Graphite packing: limited gas tightness and potential for leakage under cycling

Spring-energized seals offer a balance of compliance, preload retention, and adaptability that aligns well with LNG operating realities.

SECTION 5

Spring Selection for LNG Applications

The performance of a spring-energized seal in LNG service is driven as much by spring design as by seal jacket material. At cryogenic temperatures, the spring becomes the primary source of sealing energy, responsible for maintaining contact force as polymers stiffen and hardware contracts.

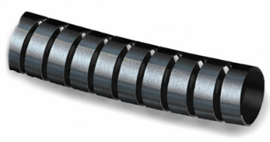
5.1 Why Helical Springs Are Common in LNG Service

Helical springs are widely used in LNG applications due to their ability to deliver high, uniform circumferential load across the seal lip. This uniformity is particularly valuable in cryogenic environments, where localized loss of contact can quickly lead to gas leakage.

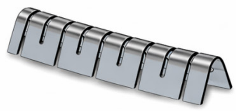
Key advantages of helical springs in LNG service include:

- Consistent sealing force from ambient down to cryogenic temperatures
- Strong performance at low pressure and vacuum conditions
- Excellent compensation for thermal contraction and tolerance variation

For static and low-motion LNG applications, helical springs often provide the most robust sealing solution.



Helical Spring



Cantilever Spring

Canted Coil Spring

5.2 Cantilever and Canted-Coil Springs in LNG Applications

In LNG applications involving slow dynamic motion or intermittent cycling—such as valve stems or actuators—alternative spring types may be more appropriate than traditional helical designs.

Cantilever and canted-coil springs offer lower friction, improved tolerance to misalignment and eccentricity, and more forgiving performance in dynamic or oscillating service.

However, these designs typically generate lower unit loads than helical springs and must be carefully selected to ensure adequate contact force is maintained at cryogenic temperatures.

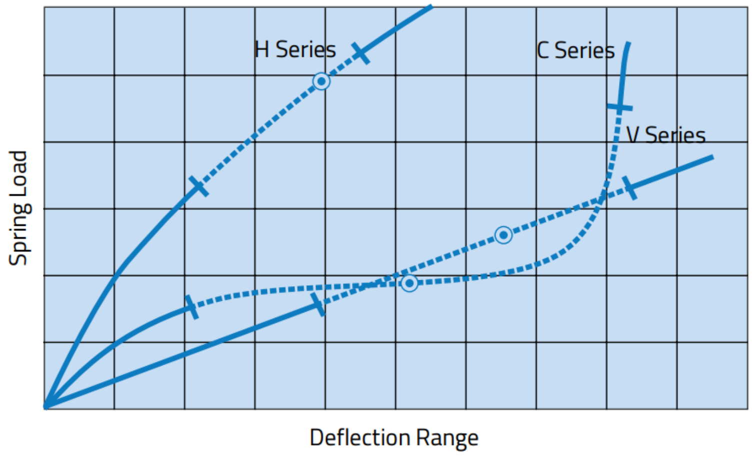
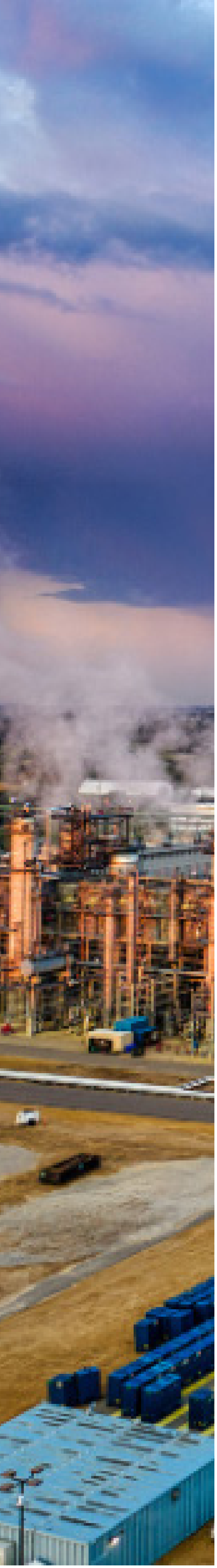


Figure 4: Spring load versus deflection demonstrated in Helical (H Series), Canted Coil (C Series), and Cantilever (V Series) springs.

5.3 Spring Load Considerations at Cryogenic Temperatures

Spring load selection in LNG service requires balancing two competing demands:

1. Sufficient preload to maintain sealing contact as PTFE stiffens
2. Controlled contact pressure to avoid excessive wear or friction



At cryogenic temperatures, polymer seal jackets become much harder, less flexible, and less able to stretch. Springs must be sized to overcome this stiffness increase while still accommodating wear, gland variation, and thermal cycling.

SECTION 6

Seal Jacket Material Selection for LNG

Material selection for LNG seals is often misunderstood as the primary determinant of performance. In reality, jacket material plays a supporting role, enabling the spring to function effectively under cryogenic conditions.

6.1 Behavior of PTFE at Cryogenic Temperatures

PTFE and PTFE-based compounds are commonly used in LNG sealing applications due to their excellent chemical compatibility and low friction. At cryogenic temperatures, however, the material modulus increases significantly, reducing compliance and diminishing the ability of the seal to conform to surface imperfections.

These changes reinforce the need for adequate spring preload to maintain reliable sealing contact under LNG operating conditions.

6.2 Common Materials Used in LNG Spring-Energized Seals

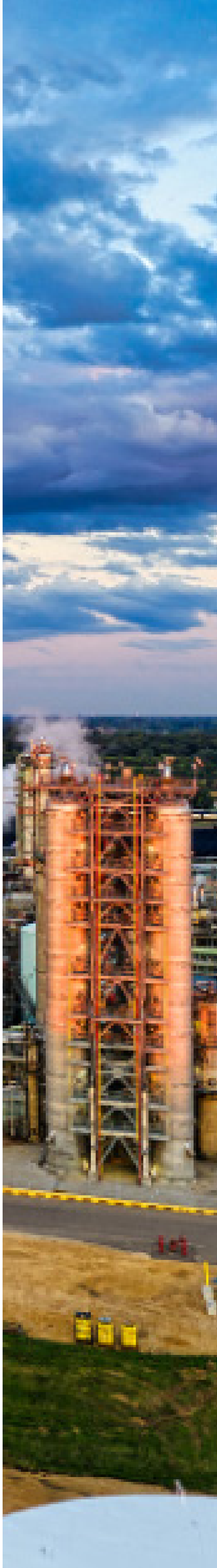
Typical jacket materials for LNG service include:

- Modified virgin PTFE compounds optimized for cryogenic stability
- Low-permeation PTFE blends for vapor-phase sealing
- PCTFE for applications requiring improved dimensional stability

Filled PTFE compounds may be used selectively, but filler selection must account for brittleness and thermal behavior at cryogenic temperatures.

6.3 Permeation, Shrinkage, and Dimensional Stability

While LNG leakage is often blamed on permeation, most field failures are caused by mechanical leakage paths rather than true molecular diffusion.



That makes dimensional stability a critical factor in seal performance.

Thermal shrinkage must be accounted for in both seal and gland design, excessive cold flow can undermine long-term sealing integrity, and maintaining uniform contact pressure is essential to minimizing leak paths in light-gas service.

SECTION 7

Gland Design for Cryogenic LNG Sealing

Even the most robust spring-energized seal will fail if installed in an improperly designed gland. LNG service magnifies the effects of poor gland geometry, surface defects, and thermal mismatch.

7.1 Designing Glands for Cold Conditions

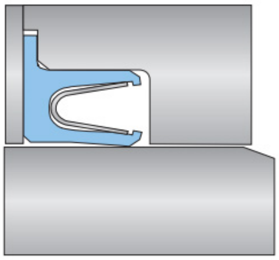
Glands should be designed based on cryogenic dimensions, not room-temperature measurements. As temperatures drop, metal hardware contracts. This causes clearance change, meaning seal interference can increase or disappear.

Different hardware materials contract at different rates when exposed to LNG temperatures. Stainless steels, aluminum alloys, and nickel-based alloys each behave differently, affecting gland dimensions and seal loading.

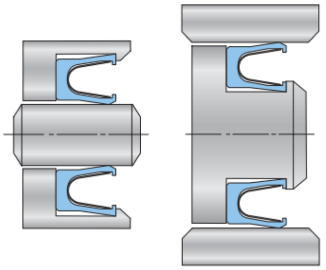
For this reason, designers must account for material specific contraction rates and avoid mixed-material gland assemblies when possible. The chosen material should ensure the seal can accommodate dimensional changes without losing its preload.

7.2 Preferred Gland Styles for LNG Applications

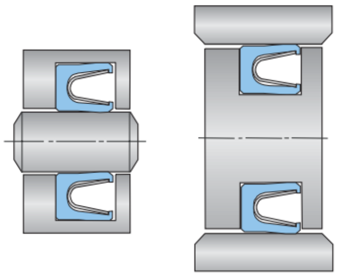
Certain gland configurations are better suited to cryogenic service. Lead-in chamfers and edge breaks are essential to prevent installation damage that may only become apparent at cryogenic temperatures.



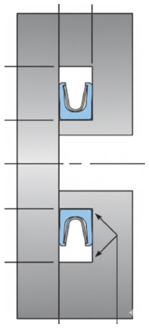
Split (or two piece) glands facilitate installation and inspection



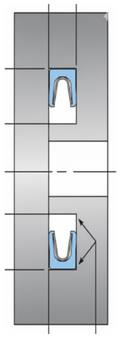
Stepped glands help manage thermal contraction



Solid glands may limit assembly tolerance and increase risk during cooldown



Extgernal glands allow larger gland volumes for better lubrication



Internal glands permit better protection of the seal from external damage

7.3 Gland Surface Finish and Geometry

Small imperfections that are acceptable at ambient conditions can become dominant leak paths in LNG service. Proper gland geometry and surface finish are critical to achieving gas-tight sealing.

A well-designed seal cannot compensate for a poorly designed gland—especially at cryogenic temperatures.

SECTION 8

Surface Finish & Hardware Requirements for LNG Service

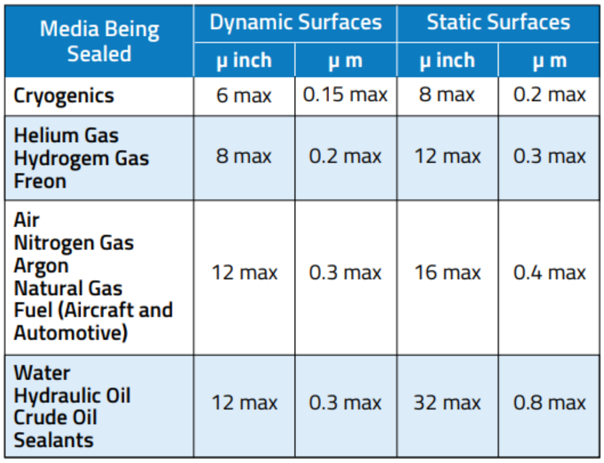
In LNG applications, sealing performance is often limited not by the seal itself, but by the condition and geometry of the mating hardware. Cryogenic temperatures amplify the impact of surface imperfections, making surface finish and hardware preparation critical to achieving gas-tight sealing.

8.1 Surface Finish Requirements for LNG and Light Gas Sealing

LNG and natural gas vapor can escape through microscopic leak paths, making surface finish requirements significantly more stringent.

Vapor-phase sealing generally demands smoother surface finishes than liquid-only service. Directional machining marks should also be avoided, as they can form continuous leak paths.

At cryogenic temperatures, reduced seal conformability further exacerbates these issues, since the seal can no longer “flow” into surface valleys as it might under ambient conditions.



Media Being Sealed	Dynamic Surfaces		Static Surfaces	
	μ inch	μ m	μ inch	μ m
Cryogenics	6 max	0.15 max	8 max	0.2 max
Helium Gas **Hydrogem Gas** **Freon**	8 max	0.2 max	12 max	0.3 max
Air **Nitrogen Gas** **Argon** **Natural Gas** **Fuel (Aircraft and Automotive)**	12 max	0.3 max	16 max	0.4 max
Water **Hydraulic Oil** **Crude Oil** **Sealants**	12 max	0.3 max	32 max	0.8 max

Figure 4: Surface Roughness

8.2 Surface Hardness and Material Pairing

Cryogenic operation alters material behavior:

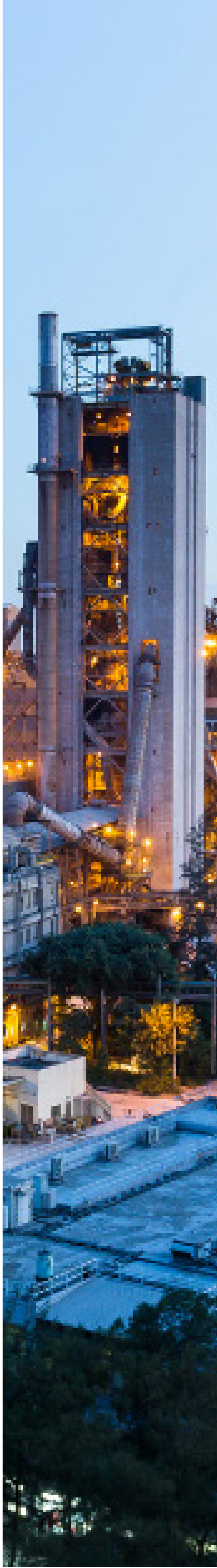
- Metals may become harder and less forgiving
- Galling risk increases in sliding interfaces
- Wear patterns change due to reduced lubrication

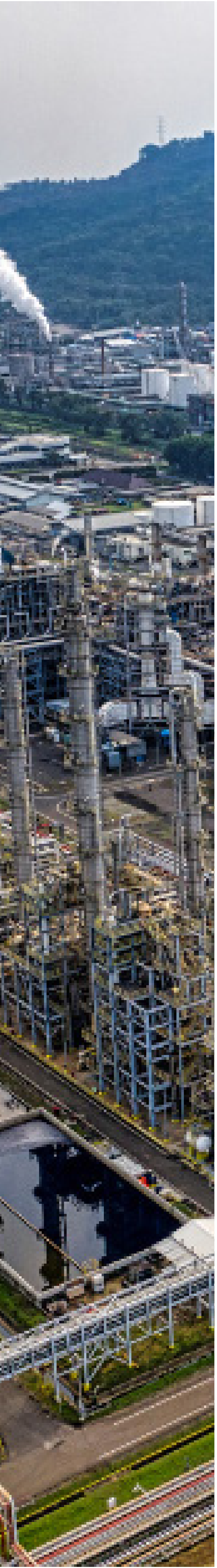
Hardware hardness should be sufficient to resist wear without introducing brittleness. Material pairings should be evaluated to minimize galling, particularly in dynamic LNG applications.

8.3 Flatness, Roundness, and Geometry Control

Geometric deviations that may be acceptable at ambient temperatures can become critical sealing failures under cryogenic conditions.

Particular attention should be paid to shaft roundness and concentricity between mating components in dynamic applications and face flatness in static face-seal designs, as even small geometric errors can lead to uneven seal contact pressure and subsequent leakage at LNG operating temperatures.





SECTION 9

Static vs. Dynamic LNG Sealing Considerations

While LNG systems contain both static and dynamic seals, the distinction between the two is often less clear than in ambient-temperature equipment. Many LNG components experience long static dwell periods punctuated by infrequent motion.

9.1 Static LNG Sealing Applications

Common static LNG sealing locations include:

- Valve body seals
- Flange interfaces
- Instrumentation ports
- Cold box penetrations

In these applications, the primary challenge is maintaining sealing contact during cooldown and through thermal cycling. Spring-energized seals are particularly effective here due to their ability to seal independently of system pressure.

9.2 Slow Dynamic and Intermittent Motion Applications

Dynamic LNG seals are typically characterized by low surface speeds, intermittent motion rather than continuous rotation, and long static dwell times at cryogenic temperatures.

Common examples include valve stems, actuator rods, and indexing mechanisms. In these applications, seals must strike a careful balance between low friction during periods of motion and high sealing force during extended static conditions.

9.3 Implications for Seal Design

Because most LNG “dynamic” seals spend the majority of their service life in a static state, seal design priorities differ from those of conventional rotating or continuously moving applications.

The primary challenge becomes maintaining sufficient preload during long cryogenic dwell periods, while still minimizing stick-slip when motion does occur.

Equally important is ensuring that the seal can reestablish consistent contact and sealing performance after extended static exposure at low temperature. The key design takeaway is that LNG sealing success depends far more on long-term preload retention and stability than on traditional dynamic wear considerations.

SECTION 10

Installation & Commissioning for LNG Seals

Proper installation and commissioning practices are essential to achieving reliable sealing in LNG service. Errors introduced during installation may not become apparent until the system is cooled down, making early-stage diligence critical.

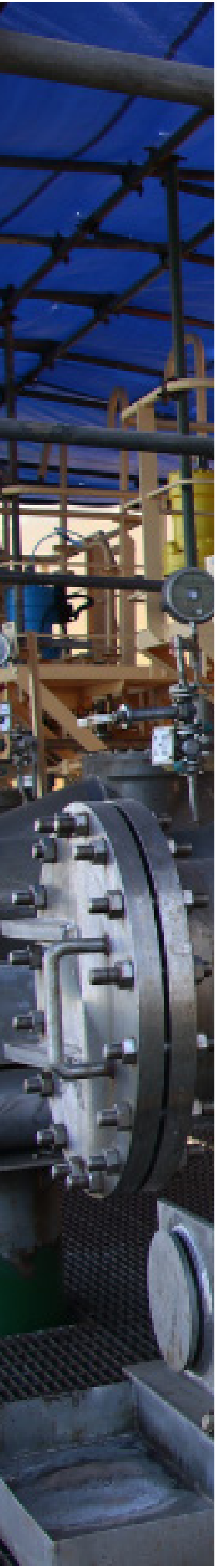
10.1 Handling, Preparation, and Installation

Seals should be inspected prior to installation, even if no visible damage is expected. PTFE-based seals intended for LNG service should be handled carefully to avoid:

- Nicks or cuts at seal lips
- Distortion during handling or assembly
- Contamination that could interfere with sealing

Successful LNG seal installation depends on careful attention to several critical details. The seal must be oriented correctly relative to the pressure direction, and springs must be properly seated and free from damage to ensure consistent energization.

Appropriate lead-in chamfers are also essential to prevent lip damage during installation. When lubrication is used, it must be compatible with LNG service and selected so that it does not interfere with sealing performance at cryogenic temperatures.



10.2 Commissioning and Cooldown Observations

The initial cooldown phase is often the most revealing period in LNG operation. During commissioning, it is important to closely monitor for leakage as temperatures transition, inspect accessible seals after cooldown, and document any changes observed during early operation.

Leaks that appear during this initial cooldown are frequently the result of preload or installation issues rather than material incompatibility. The key takeaway is that many LNG seal failures attributed to “material issues” actually originate from installation or commissioning practices.

SECTION 11

When to Engage a Seal Engineer

While many LNG sealing applications can be addressed using established design practices, certain conditions warrant early involvement of a seal specialist.

Applications That Benefit from Engineering Support

Engaging a seal engineer is recommended when:

- Operating temperatures approach the lower limits of material capability
- Leakage requirements are extremely stringent
- Equipment experiences frequent thermal cycling
- Hardware tolerances are uncertain or non-standard
- Retrofitting seals into existing LNG equipment

Early collaboration can prevent costly redesigns, rework, or field failures.

Seal performance is highly sensitive to factors such as spring load selection, gland geometry, and the behavior of hardware materials at cryogenic temperatures.

Addressing these considerations early in the design process allows potential sealing issues to be identified and corrected before hardware is finalized or equipment is commissioned.

SECTION 12

Cryogenic LNG Seal Design Checklist

Use this checklist during design reviews, seal selection, or troubleshooting for LNG applications operating down to −320°F.

A. Operating Conditions

Media:
☐ Liquified Natural Gas
☐ LNG vapor / boil-off gas
☐ Purge gas

Temperature Range:
1. Ambient startup temp: ______________
2. Minimum operating temp: ___________
3. Expected thermal cycles: ___________

Pressure Conditions:
1. Minimum differential pressure: ___________
2. Maximum operating pressure: ___________
3. Vacuum or near-zero pressure conditions present? (Yes / No)

Motion Type:
☐ Static
☐ Slow dynamic
☐ Intermittent or cycling motion
☐ Continuous rotation

B. Seal Design

Spring type:
☐ Helical
☐ Cantilever
☐ Canted coil

Materials:
1. Spring material: ______________
2. Jacket material: ___________

Seal orientation verified? (Yes / No)

C. Gland Design

Gland type:
☐ Split
☐ Step Cut
☐ Solid
☐ Other: __________

Cryogenic Dimensions verified? (Yes / No)

Lead-In Chamfers Provided? (Yes / No)

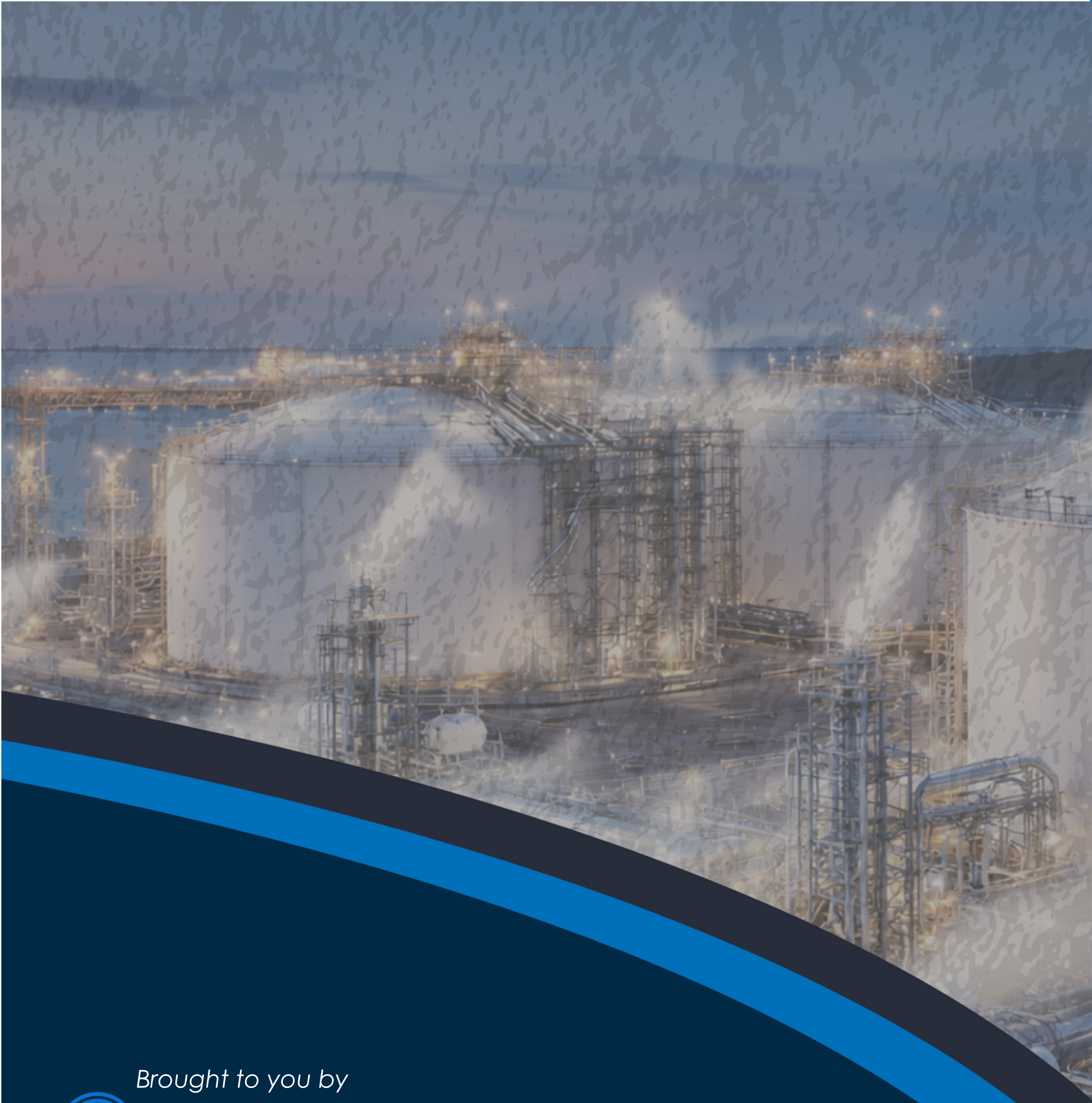
D. Hardware & Surface Finish

Materials:
1. Surface Finish: _________________
2. Hardware Material(s): ___________

Shaft roundness / face flatness verified? (Yes / No)

E. Installation & Commissioning

Seal inspected prior to installation? (Yes / No)
Proper installation tools used? (Yes / No)
Cooldown leakage observed? (Yes / No)



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