Corrosion: The Silent Challenge in Maritime and Shipbuilding Industry

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I. Opening Remarks

Good morning, and welcome to all distinguished guests, industry leaders, and innovation pioneers gathered here at ChemTECH World Expo 2026.

It is a profound privilege to address this esteemed forum that has served as the apex gathering for India's chemical process industries. As the Directorate General of Shipping, we stand at the intersection of maritime development, regulatory excellence, and technological innovation. Today, I wish to focus our collective attention on a challenge that touches every vessel that sails our seas, every structure that graces our shipyards, and every ambition we hold for India's maritime renaissance, the relentless menace of corrosion.

Corrosion is not merely an engineering problem. It is an economic imperative, an environmental responsibility, and a safety mandate that demands our unwavering commitment.

II. The Chemical Industry and the Chemtech Platform: Bridging Innovation and Application

The chemical industry serves as the backbone of modern civilization. From specialty chemicals that enable advanced manufacturing to industrial coatings that protect critical infrastructure, chemistry translates human ingenuity into tangible solutions. The ChemTECH platform represents the vitality of India's chemical sector, a platform that brings together innovators, manufacturers, and stakeholders to showcase cutting-edge technologies and best practices.

This convergence is particularly significant for maritime India. The formulations, coating systems, cathodic protection solutions, and materials engineering showcased here directly influence the longevity, safety, and economic viability of vessels that form the lifeblood of global trade.

Today, as India aspires to rank among the top five shipbuilding nations by 2047 and strengthen its position as a maritime power, the role of advanced chemical solutions in corrosion management has never been more critical.

III. The Magnitude of the Challenge

The numbers are sobering and demand our attention:

Corrosion is often viewed as a technical maintenance issue, but globally it has emerged as a major economic and climate challenge with direct implications for shipbuilding, maritime infrastructure, and oil & gas sectors.

Economic Impact

- Global cost of corrosion: ~USD 2.5 trillion annually, equivalent to 3.4% of global GDP.
- India (2019):
  - Total cost: USD 102 billion (~4.2% of GDP)
  - Avoidable cost: ~USD 25 billion (nearly 25% of direct corrosion losses).
- Maritime sector:
  - Global corrosion-related losses estimated at USD 50–80 billion per year (excluding indirect costs).
  - In India, limited studies indicate losses of ~USD 83 million in water transport and marine industries (2011–12), highlighting the need for updated assessments.

Environmental & Climate Impact

- Around 25% of global steel production is lost to corrosion, according to studies by Curtin University and Ohio State University.
- Replacement and renewal of corroded steel contribute 4–9% of total global CO_2 emissions.
- Steel production is highly carbon-intensive: a single 10m × 10m steel plate (20mm thick) emits ~3 tonnes of CO_2, excluding transport and coating emissions.
- Inadequate corrosion protection contributes more CO_2 emissions than the entire global aviation industry.

Maritime & Shipping Context

- Global steel demand (2024): 1.8 billion tonnes, projected to grow 2.9% by 2030.
- Shipbuilding alone consumes 32.2 million tonnes annually, with China, South Korea, and Japan accounting for 88.3%.
- Shipping emitted 858 million tonnes of CO_2 in 2022, exceeding aviation emissions.

Strategic Insight

- Corrosion mitigation is therefore not only an engineering necessity, but a critical enabler of decarbonisation, sustainability, and Viksit Bharat goals.

IV. The Maritime and Shipbuilding Imperative: India's Strategic Opportunity

India today stands at a defining moment in its maritime journey. Under **Maritime Vision 2047**, the nation has set clear and ambitious goals

- Current Status: India holds a marginal 0.06% share of global shipbuilding capacity, currently ranking 16th Globally in shipyard output.
- 2030 Target: Rank among the top 10 shipbuilding and ship-owning nations
- 2047 Vision: Achieve a position among the top 5 global shipbuilding nations, with projected capacity expansion to 4.5 million GT annually.

This vision is backed by decisive policy action. Schemes such as the **Shipbuilding Financial Assistance Scheme**, the **Shipbuilding Development Scheme**, and the **Maritime Development Fund** are designed to expand shipyard capacity, strengthen domestic ownership, and reduce India's dependence on foreign-built vessels and foreign shipping lines. The objective is not only to build more ships, but to build **globally competitive ships**.

In this context, corrosion management becomes a strategic enabler rather than a technical afterthought. For Indian shipyards, poor corrosion protection translates into higher lifecycle costs, premature steel renewal, loss of fuel efficiency, and reduced international acceptability. Conversely, vessels designed with robust corrosion prevention deliver **longer asset life, lower maintenance costs, and improved fuel efficiency** through smoother hull surfaces and reduced drag.

From a sustainability perspective, effective corrosion protection directly supports India's decarbonisation goals by reducing steel replacement, lowering energy consumption, and cutting emissions across the vessel lifecycle.

If India is to build ships that compete globally—not only at delivery, but throughout their service life—**durability, corrosion performance, and lifecycle efficiency must become core design and construction priorities**. Addressing corrosion well is not just good engineering; it is sound economics and smart national strategy.

V. Corrosion Challenges Specific to Maritime and Shipbuilding

The maritime environment presents unique and multifaceted corrosion challenges:

Corrosion in the maritime sector is fundamentally different from land-based infrastructure. Ships and offshore assets operate continuously in one of the most aggressive natural environments on earth, where multiple corrosion drivers act simultaneously and relentlessly.

The challenge is structural, operational, and strategic.

1. Why the Maritime Environment Accelerates Corrosion?

The marine environment creates near-ideal conditions for corrosion:

- **Seawater is a highly conductive electrolyte**, rich in dissolved salts and oxygen.
- Corrosion rates in marine environments can be **10–15 times higher** than in terrestrial conditions.

- Ships experience constant **wet–dry cycles**, temperature fluctuations, vibration, and mechanical stress.
- Exposure is continuous and unavoidable throughout the vessel's operational life.

As a result, corrosion is not localized—it is systemic across hulls, tanks, decks, pipelines, and offshore structures.

2. High-Risk Zones on Ships and Offshore Assets

Certain areas are particularly vulnerable and demand focused attention:

- **Ballast Tanks**
  - Continuously exposed to seawater and air.
  - Subject to fluctuating oxygen levels and microbial activity.
  - A leading cause of steel wastage and structural renewal, especially in bulk carriers and tankers.
- **Under-Insulation and Hidden Spaces**
  - Corrosion progresses invisibly beneath insulation or linings.
  - Often detected late, when structural damage is already significant.

These are not isolated technical issues—they directly affect safety margins, asset life, and operating costs.

The **IMO Performance Standard for Protective Coatings (PSPC)** has significantly raised the bar for corrosion protection in seawater ballast tanks. However, industry data indicates that coating systems frequently deteriorate well before their intended design life. Survey findings from classification societies reveal that peak corrosion issues often emerge during the third and fourth renewal surveys, highlighting the long-term consequences of early-stage quality lapses.

VI. Preventive Measures: From Reactive Repair to Strategic Corrosion Management

Addressing maritime corrosion requires a **lifecycle-based, prevention-first approach**. The industry must move decisively from repair-driven thinking to engineered durability.

1. Material Intelligence at the Design Stage

The first line of defense is informed material selection:

- Strategic use of **corrosion-resistant alloys, duplex steels, and advanced stainless steels** in high-risk zones.
- Moving away from blanket over-design toward **targeted durability engineering**.
- Designing structures to minimize corrosion traps and allow inspection access.

This approach embeds corrosion resistance into the asset's DNA rather than treating it as an afterthought.

2. Advanced Surface Engineering and Protective Systems

Modern coating technologies have significantly improved:

- High-performance epoxy and polyurethane systems.
- Zinc-rich primers for galvanic protection.
- Emerging nanocomposite coatings offering enhanced barrier properties.

However, performance depends as much on **execution as on chemistry**:

- Proper surface preparation.
- Controlled application conditions.
- Skilled workmanship and inspection discipline.

A superior coating poorly applied is no protection at all.

3. Cathodic Protection as a Strategic Enabler

Cathodic protection remains a cornerstone of maritime corrosion control:

- Sacrificial anodes and impressed current systems protect submerged structures.
- When integrated with coatings, they significantly extend service life.
- Design, installation, and monitoring are critical to effectiveness.

Cathodic protection should be viewed as **complementary reinforcement**, not redundancy.

4. From Reactive to Predictive: The Digital Shift

The most transformative change is the shift toward **predictive corrosion management**:

- Real-time sensors monitoring humidity, electrochemical activity, and material loss.
- **Digital twins** creating virtual replicas of ships and offshore assets.
- AI-driven models predicting corrosion risk before visible damage occurs.

This allows operators to intervene early—reducing unplanned repairs, downtime, and steel renewal.

VII. Marine Antifouling & Anti-Corrosion Coatings – Technology, Regulation, and Way Forward

1. Context and Importance

Marine biofouling and corrosion remain two of the most persistent challenges affecting ship efficiency, safety, and environmental performance. **Biofouling increases hydrodynamic drag, fuel consumption, emissions, and maintenance costs, while also acting as a vector for invasive species.** Corrosion compromises structural integrity, leads to high lifecycle costs, and in extreme cases contributes to catastrophic failures. Together, these issues have direct implications for operational efficiency, safety, and sustainability of the maritime sector.

2. Fouling and Corrosion Mechanisms

Biofouling begins with **rapid formation of a conditioning film, followed by microbial attachment, biofilm maturation, and eventual macrofouling by algae, barnacles, mussels, and other organisms.** Corrosion occurs simultaneously through electrochemical reactions and microbially induced processes. These mechanisms vary significantly with geography, temperature, nutrient levels, and operational profiles, making a single universal technical solution impractical.

3. Antifouling Technologies

a) Historical context and regulatory shift

- **Early antifouling systems relied heavily on toxic biocides**, culminating in organotin-based self-polishing coatings that provided high performance but caused severe ecological harm.
- **Global regulatory action under the IMO AFS Convention** necessitated a transition toward environmentally acceptable and compliance-driven antifouling solutions.

b) Low-surface-energy and fouling-release coatings

- **Silicone- and fluoropolymer-based systems reduce surface energy**, weakening the adhesion strength of fouling organisms rather than relying on toxic action.
- Effective fouling removal is achieved through vessel movement and hydrodynamic forces, making these coatings suitable for ships with regular operational speeds.
- Research indicates potential reductions in fuel consumption and emissions when applied under appropriate operating conditions.

c) Biomimetic and surface-structured coatings

- Inspired by **natural antifouling surfaces such as shark skin and Nepenthes plants**, these coatings use micro- and nano-scale surface patterning to disrupt organism settlement.
- These systems offer a **non-toxic, long-term antifouling approach** by targeting physical attachment mechanisms.
- Key challenges include coating durability, manufacturing complexity, and large-scale commercial deployment.

d) Conductive and photocatalytic coatings

- These technologies **employ electrochemical effects or light-induced radical generation to inhibit early-stage microbial colonisation**.
- Laboratory and pilot-scale studies demonstrate promising antifouling performance.
- Practical limitations remain related to power requirements, material stability, and integration with existing hull systems.

e) Advanced polymer-based and environmentally compatible systems

- **Zwitterionic, biodegradable, silicate-based, and polymer–nanocomposite coatings** are under active development to balance antifouling efficacy with environmental safety.
- Research focuses on improving coating longevity, controlled performance, and reduced ecological impact.

f) **Current limitations and research gaps**

- Many **advanced antifouling systems face constraints related to cost, mechanical durability, operational sensitivity, and scalability.**
- Widespread adoption depends on demonstrating clear lifecycle performance benefits across diverse vessel types and operating environments.

4. IMO AFS Convention and Regulatory Framework

The **IMO's International Convention on the Control of Harmful Anti-Fouling Systems, in force since 2008**, marked a global shift from performance-only solutions to environmentally responsible coatings. It **banned organotin compounds and introduced a dynamic mechanism** to control future harmful substances. Recent amendments include controls on **cybutryne**, effective from 2023. The Convention mandates certification, inspection, and compliance for ships engaged in international trade, supported by updated MEPC guidelines and best-practice documents.

India, as a Party to the International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS Convention), has operationalized the Convention through incorporation into domestic legislation under **Part XII-B of the Merchant Shipping Act, 1958**, supported by the **Merchant Shipping (Control of Anti-Fouling System) Rules, 2016**. The Directorate General of Shipping acts as the competent authority for enforcement, survey, certification, and compliance monitoring for Indian-flagged ships and foreign ships operating in Indian waters.

Amendments adopted by the IMO, including the prohibition of **cybutryne effective from 1 January 2023**, are implemented nationally through statutory circulars, revised certification formats, and updated survey regimes. India's approach ensures regulatory alignment with IMO instruments while providing clarity to shipowners, managers, Recognized Organizations, and port State control authorities on compliance timelines, certification requirements, and enforcement mechanisms. This framework balances environmental protection, operational feasibility, and international trade obligations, while reinforcing India's commitment to preventing marine pollution and the introduction of invasive species through ship hull biofouling.

5. Strategic Takeaway

The future of antifouling and anti-corrosion technology lies in **balanced solutions—** technically effective, environmentally compliant, and economically viable at scale. While innovation is accelerating, ship operators will continue to prefer proven, cost-effective systems unless new technologies demonstrate clear lifecycle benefits aligned with IMO regulations and global sustainability goals.

VIII. Global Anti-Corrosion Coatings: Trade, Technology Trends, and Sectoral Perspective

1. Global Production Trends

Global production of anti-corrosion additives has expanded steadily, driven by rapid industrialization, large infrastructure investments, and a growing emphasis on asset life-cycle extension **across oil & gas, marine, automotive, and construction sectors.** Production has grown at a **CAGR of approximately 4–5%**, **reflecting strong demand in emerging economies** alongside stable replacement and maintenance demand in mature markets. A structural transition toward **environmentally friendly, water-based, and smart corrosion protection solutions** is underway, aligning with tightening global regulations on emissions and hazardous chemicals.

2. Major Producing Countries

China dominates global production with a **35–40% market share**, supported by large-scale chemical manufacturing, export-oriented policies, and cost advantages. The **United States** contributes **20–25%** of global output, focusing on high-performance and specialty formulations for industrial and energy applications. **Germany** accounts for **10–12%**, driven by advanced R&D and sustainable, eco-friendly additives**. India has emerged as a fast-growing producer with an 8–10% share**, backed by government support and rising infrastructure demand. **Japan and South Korea** together contribute **5–7%**, specializing in high-performance and technology-intensive formulations. Across regions, investment is increasingly directed toward **nanotechnology-based and biodegradable inhibitors**.

3. Global Trade and Pricing Dynamics

Global exports of anti-corrosion additives are estimated at **~1.2 million metric tons**, growing at a **CAGR of ~3.8%**, with export values exceeding **USD 4.5 billion**. Imports total approximately **950,000 metric tons**, valued near **USD 4 billion**, driven by demand for specialized and regulation-compliant products. Average export prices stand at **~USD 3,750 per metric ton**, while imports average **~USD 4,210 per metric ton**, reflecting premiums for high-performance and eco-friendly formulations.

4. Strategic Trade Patterns

China leads exports (**480,000 MT; ~40%**), followed by Germany (**150,000 MT; ~12.5%**) and the United States (**120,000 MT; ~10%**). Major importers include China (**250,000 MT; ~26.3%**), the United States (**180,000 MT; ~18.9%**), **and India (70,000 MT; ~7.4%), highlighting increasing product specialization and technological differentiation.**

5. Technology and Formulation Trends

- **Epoxy and polyurethane systems** remain dominant, accounting for **over 60% of marine and heavy-duty protective applications**, due to superior adhesion, chemical resistance, and durability.
- Regulatory pressure on Volatile Organic Compounds (VOC) emissions is accelerating adoption of:

    - **Water-borne, high-solids, and powder coatings**, now forming **~30% of new industrial formulations**
- Advanced performance-enhancing systems include:
    - Zinc-rich primers for cathodic protection
    - Glass-flake and ceramic-reinforced epoxies extending coating life by **5–10 years**
    - Nano-additives and graphene-based barriers improving impermeability
- Lifecycle optimisation and condition-based maintenance are increasingly influencing coating selection.

6. Sectoral Demand Perspective

- **Oil & gas sector** accounts for **25–30% of global demand**, driven by pipelines, offshore platforms, refineries, and terminals.
- **Marine and shipping sector** remains a key consumer:
    - Over **55% of marine coatings demand** comes from repair, maintenance, and dry-docking activities
    - Exposure to saline and aggressive environments necessitates high-performance systems
- Infrastructure, power, and transportation collectively contribute **~40% of total demand**, particularly in emerging economies.

7. Indian Perspective and Strategic Relevance

- India is among the **fastest-growing anti-corrosion coatings markets**, driven by:
    - Port modernisation and coastal infrastructure
    - Shipbuilding and repair initiatives
    - Oil & gas pipelines, refineries, and power assets
- Indian demand is increasingly shifting toward:
    - Environment-compliant and low-VOC systems
    - Long-life coatings to reduce maintenance costs
    - Indigenous manufacturing aligned with *Make in India*
- Tropical climate, high salinity, and humidity make corrosion protection a **strategic asset-management priority** rather than a consumable expense.

IX. DG Shipping's Commitment to Quality-Led Maritime Growth

The Directorate General of Shipping remains committed to:

1. **Promoting IMO Performance Standard for Protective Coatings (PSPC) Compliance:** Through technical guidance, industry workshops, and active engagement with shipyards and suppliers
2. **Fostering Innovation:** By facilitating partnerships between the chemical industry and maritime stakeholders to develop India-centric corrosion solutions
3. **Capacity Development:** Through the upcoming **India Ship Technology Centre**, which will provide design, research, and innovation support aligned with global standards
4. **Sustainable Maritime Growth:** Ensuring that the expansion of India's shipbuilding capacity translates not merely into increased tonnage, but into vessels of superior quality, longevity, and environmental performance

X. Closing Remarks

The ChemTECH platform has historically bridged the gap between chemical innovation and industrial application. I urge this esteemed gathering to deepen that engagement with maritime stakeholders. Establish joint working groups with shipbuilders. Conduct pilot projects within Indian shipyards. Align your R&D roadmaps with India's vision of becoming a top five shipbuilding nation.

On behalf of the Directorate General of Shipping, I extend our heartfelt wishes for the continued success of the ChemTECH initiative and the maritime focus within this platform. May this Expo serve as a catalyst for innovations that protect our vessels, sustain our shipyards, and propel India's maritime renaissance forward.

The silent battle against corrosion continues, unrelenting and invisible. But with the ingenuity of India's chemical sector, the determination of our shipbuilders, and the steadfast commitment of our regulatory framework, we shall not merely manage this challenge—we shall transform it into a competitive advantage.

India's maritime future is written not in wood or steel alone, but in the chemistry that protects them. Together, let us ensure that this future is built to last.

Thank you.