

Materials Sustainability Framework Based on Corrosion Management System

©2024 Association for Materials Protection and Performance (AMPP). All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise) without the prior written permission of AMPP.

Materials Sustainability Framework Based on Corrosion Management System

This AMPP standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. Its acceptance does not in any respect preclude anyone, whether he or she has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this standard. Nothing contained in this AMPP standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. AMPP assumes no responsibility for the interpretation or use of this standard by other parties and accepts responsibility for only those official AMPP interpretations issued by AMPP in accordance with its governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

Users of this AMPP standard are responsible for reviewing appropriate health, safety, environmental, and regulatory documents and for determining their applicability in relation to this standard prior to its use. This AMPP standard may not necessarily address all potential health and safety problems, or environmental hazards associated with the use of materials, equipment, and/or operations detailed or referred to within this standard. Users of this AMPP standard are also responsible for establishing appropriate health, safety, and environmental protection practices, in consultation with appropriate regulatory authorities, if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this standard.

CAUTIONARY NOTICE: AMPP standards are subject to periodic review and may be revised or withdrawn at any time in accordance with AMPP technical committee procedures. AMPP requires that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of initial publication and subsequently from the date of each reaffirmation or revision. The user is cautioned to obtain the latest edition. Purchasers of AMPP standards may receive current information on all standards and other AMPP/NACE/SSPC publications by contacting AMPP Customer Support, 15835 Park Ten Place, Houston, Texas 77084-5145 (Tel: +1-281-228-6200, email: customersupport@ampp.org).

Document History:

2024-06-04: Approved by AMPP Standards Committee (SC) 13, Corrosion Monitoring and Measurement

AMPP values your input. To provide feedback on this standard, please contact: standards@ampp.org

AMPP SP21466-2024

©2024 Association for Materials Protection and Performance (AMPP). All rights reserved.

Materials Sustainability Framework Based on Corrosion Management System

Foreword, Rationale	4
Referenced Standards and Other Consensus Documents	5
Section 1 Scope	6
1.1 Sustainability	6
1.2 Corrosion Management System Framework.....	8
1.3 Material Stewardship.....	9
1.4 Common Tools and Common Practices	10
1.5 How to Use this General Standard.....	11
Section 2 Definitions	13
Section 3 Users and Value Drivers of this Standard	16
3.1 Overview	16
3.2 Value Drivers	17
Section 4 Materials Sustainability General Practice.....	18
4.1 Materials Sustainability Business Strategy	18
4.2 Materials Sustainability Performance Metrics	22
4.3 Materials Sustainability Life Cycle Evaluation with Respect to Corrosion.....	24
4.4 Materials Sustainability Evaluation Tools	30
4.5 Materials Sustainability Standard and Regulation.....	36
4.6 Emerging Digital Technology and Impact on Materials Sustainability	39
4.7 Emerging Methodologies	41
Other Referenced Documents.....	41
Appendix A Materials Sustainability Lessons Learned (LL) (Nonmandatory)	45
Appendix B Exemplary Industry and Materials Sustainability Issues (Nonmandatory)	48
Appendix C Corrosion Management Maturation Model (CMMM) (Nonmandatory).....	53
Appendix D Wind Turbine Sustainability Use Case (Nonmandatory)	55
Appendix E Oil Field Corrosion Inhibitor Sustainability Use Case (Nonmandatory).....	57
Appendix F Concrete Sustainability Use Case (Nonmandatory).....	59
Appendix G Recognized ESG/Sustainability Frameworks and Standards (Nonmandatory)	61

FIGURES

Figure 1 Sustainability Symbolizes the Optimization of Environmental Performance, Social Performance, and Economic Performance.....	7
Figure 2 World Production of Several Industrially Critical Materials as Estimated from United States Geological Survey Data	10
Figure 3 User's Journey in Finding this Standard's Value to Meet Their Needs vs. Standard Conventional Structure.....	12
Figure 4 Five Business-Level Strategies.....	20

Figure 5	Exemplary Enterprise Risk Assessment Matrix: How Materials Sustainability is Embedded in the Matrix	21
Figure 6	Materials Sustainability Life Cycle.....	25
Figure 7	Contextualizing Potential Impact of Material and Corrosion Management Professionals.....	26
Figure C1	Corrosion Management Maturity Model	53
Figure D1	Diagrammatic View of the Material Circularity Indicator Based on Ellen MacArthur Foundation (2015)	55

TABLES

Table 1	User Groups and Potential Value Drivers of AMPP SP21466 Materials Sustainability	16
Table 2	How an Organization Chooses the Right Materials Sustainability Maturity Model along with Corrosion Management Maturity Model* to Sustain Their Business (IMPACT Plus Program, SP21430).....	19
Table 3	Materials Sustainability Maturation Model and Metrics	23
Table 4	Common Tools in Sustainability Measurement and Monitoring	32
Table B1	Comparison of Key Industries and Their Sustainability Issues and Business Issues	50
Table G1	The Sustainability Standard Organization and Key Standard Landscape	61

Foreword

This general standard can be used by material performance and protection personnel and corrosion control personnel involved with operating plants and infrastructure, e.g., contractors involved in corrosion management, corporate sustainability report developers, and regulatory agencies. Specific practices are not covered for every situation because of the complexity and differences of all industries to which material sustainability can be exposed.

This standard may be utilized to integrate material sustainability management into an organization's existing corrosion management system or to establish stand-alone procedures for assessing the organization's material sustainability. Some processes covered in this standard may already be implemented by an organization in which case an organization can review and modify their existing processes to address the elements identified in this standard.

Rationale

AMPP's vision statement approved in 2021 is to provide "A world built and protected with safe, reliable, sustainable materials." Furthermore, one of AMPP's objectives for achieving the goal of sustainability is to "Enhance industry's ability to adopt sustainable business practices." An industry standard for material sustainability based on the corrosion management system framework, therefore, becomes timely to provide a common basis for organizations to assess their performance in following material sustainability and materials stewardship best practices. Due to its wide industry application of material sustainability concept and practices, this first AMPP standard on material sustainability is created as a general standard to pave the way for future AMPP standards that can cover specific material sustainability topics, products, and industries in the future while also putting materials stewardship, including asset integrity and corrosion management system frameworks, into an even broader strategic context.

Referenced Standards and Other Consensus Documents

Unless specifically dated, the latest edition, revision, or amendment of the documents listed in the table below shall apply.

AMPP/NACE/SSPC, www.ampp.org:

NACE SP0113	Pipeline Integrity Management Methods Selection and Implementation Standard Framework for
NACE SP21430	Establishing Corrosion Management Systems
NACE/ ASTM G193	Standard Terminology and Acronyms Relating to Corrosion
NACE SP21412/ SSPC-CPC 1	Corrosion Prevention and Control Planning

American Petroleum Institute (API), www.api.org:

API RP 580	Risk-Based Inspection Program
API RP 581	Risk-Based Methodology

ASTM International, www.astm.org:

ASTM E2432	Standard Guide for General Principles of Sustainability Relative to Buildings
ASTM E2986	Standard Guide for Evaluation of Environmental Aspects of Sustainability of Manufacturing Processes
ASTM E2114	Standard Terminology for Sustainability Relative to the Performance of Buildings
ASTM E2129	Standard Practice for Data Collection for Sustainability Assessment of Building Products
ASTM E3200	Standard Guide for Investment Analysis in Environmentally Sustainable Manufacturing

British Standards Institution (BSI), www.bsigroup.com:

PAS 2050	Specification for the assessment of the life cycle greenhouse gas emissions of goods and services
PAS 2060	Specification for the demonstration of carbon neutrality
PAS 2080	Carbon management in buildings and infrastructure

European Standards, www.en-standard.eu:

EN 15804	Sustainability of construction works Environmental product declarations Core rules for the product category of construction products
EN 15978	Sustainability of construction works Assessment of environmental performance of buildings Calculation method

International Organization for Standardization (ISO), www.iso.org:

ISO 14020	Environmental statements and programmes for products – Principles and general requirements
ISO 14025	Environmental labels and declarations — Type III environmental declarations — Principles and procedures
ISO 14040	Environmental management — Life cycle assessment — Principles and framework
ISO 14044	Environmental management — Life cycle assessment — Requirements and guidelines
ISO 14067	Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification
ISO/TS 14072	Environmental management — Life cycle assessment — Requirements and guidelines for organizational life cycle assessment
ISO 14097	Greenhouse gas management and related activities — Framework including principles and requirements for assessing and reporting investments and financing activities related to climate change
ISO 15392	Sustainability in buildings and civil engineering works — General principles
ISO 15684-5	Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing
ISO 17889-1	Ceramic tiling systems — Sustainability for ceramic tiles and installation materials — Part 1: Specification for ceramic tiles

AMPP SP21466-2024

©2024 Association for Materials Protection and Performance (AMPP). All rights reserved.

ISO 21930	Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services
ISO 21931-1	Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment — Part 1: Buildings
ISO 55000	Asset management — Overview, principles and terminology
ISO 55001	Asset management Management systems – requirements
ISO 55002	Asset management – Management systems – Guidelines for the application of ISO 55001

International Sustainability Standards Board (ISSB), sasb.org/standards:

N/A	Metal and Mining Sustainability Accounting Standard
N/A	Iron and steel producers Sustainability Accounting Standard
N/A	Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning
N/A	Oil and gas – exploration and production Sustainability Accounting Standard
N/A	Oil and gas – refining and marketing Sustainability Accounting Standard

In AMPP standards, the terms *shall* and *must* are used to state requirements and are considered mandatory. The term *should* is used to state something that is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

Section 1: Scope

This standard aims to provide a framework for users and their respective organizations in assessing both the material sustainability and material stewardship of their operations using recognized industrial methods, resources, and practices built on the corrosion management framework. Some of these methods, resources, and practices are already covered in the corrosion management system framework; however, some are expanded upon within this standard using a material sustainability maturity model beyond the corrosion management framework. Therefore, this standard aims to empower material and corrosion professionals to better deliver value from a life cycle and circular economy standpoint while leveraging existing and emerging tools to support assets, operations, enterprises, stakeholders, and communities through the value chain.

1.1 Material Sustainability

This standard is built upon the most widely accepted definition of sustainable development by the Brundtland Commission to the United Nations in 1987: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”¹ Sustainability is generally considered to be the intersection of economic performance, social performance, and environmental performance, as shown in [Figure 1](#).

Material sustainability is focused on optimization of a material's value from its economic performance, social performance, and environmental performance when it is designed, sourced, processed, manufactured into products, maintained throughout the product lifecycle, and redirected at its end-of-life. Material sustainability is also connected to material stewardship where materials are introduced into and managed by society towards long-term objectives at optimal environmental, economic, and social impacts, often in a holistic corrosion and asset integrity management context.

Current global production and consumption models project an unsustainable path for humanity's existence. It is reported that extraction of material resources from the earth was expected to reach 88.6 billion tons in 2017 (3 times that in 1970), and more than twice that by 2050.² Meanwhile, the safe boundaries for four of the nine key ecological processes and systems that regulate the stability and resilience of the Earth's ecosystem have already been exceeded.³ The corresponding economic impacts of these current trends are predicted to be severe, with global price volatilities and supply chain interruptions leading to as much as U.S. \$4.5 trillion in lost global economic growth by 2030, or U.S. \$25 trillion by 2050.⁴

Material exploration, refining from the ore to produce the end product is energy intensive with adverse effects on the environment similar to that of safe disposal at the end of its life cycle. Material and corrosion professionals shall consider these effects in order to optimize and/or increase the lifespan of the material usage either by an appropriate maintenance strategy or reusing/recycling, ensuring a minimal or negligible amount of the material is safely disposed of/discarded. With the development in material technology and innovation, equipment/ components that are currently produced with a preset lifespan should be reconsidered to produce products with higher lifespans (repurposing, remanufacturing, etc.) or better and more stringent recycling processes.



Figure 1: Sustainability Symbolizes the Optimization of Environmental Performance, Social Performance, and Economic Performance

1.1.1 Economic Performance

“Economic performance” refers to the deliverance of an economically acceptable and safe level of performance throughout the life cycle. This shall be measured in multiple ways related to reliability, availability, capital and operational efficiency, and the ability to function at an acceptable level throughout the full life cycle from concept selection to abandonment, including avoiding obsolescence. With respect to material sustainability, economic performance shall be optimized through proper asset management and efficient manufacturing procedures.

Material and corrosion professionals along with other decision-makers have a unique opportunity to rethink the corrosion management framework to not only keep their business profitable but to also make it more sustainable. Good inspection planning based on Risk Based Inspection (RBI) retains asset integrity for safe and continuous operations, thereby reducing the Probability of Failure (PoF) and the resultant risks such that material replacement or renewal shall be minimal or negligible. Budgeting future maintenance, inspection, repair, decommissioning, and increasingly important carbon expenses into the base investment assessment of an enterprise ensures asset integrity, environmental, financial, public confidence, stakeholder value, and other goals are achieved as integral parts of the business, not an afterthought or a future liability. The cost of corrosion is a key milestone in how AMPP charted its course toward a better understanding of economic performance and the impact of corrosion.⁵

1.1.2 Social Performance

Social performance considers the extraction, manufacture, application, and abandonment of a product with the lowest impact on society. This is often seen as producing the lowest carbon footprint but may also be viewed in terms of cost to society and the impact of maintaining accessible costs to not further engender energy poverty or restrict economic growth. An example of enhancing social performance is utilizing ethical sourcing in supply chain management. This is also in line with the Environmental, Social, and Governance (ESG) movement that has grown from a corporate social responsibility initiative launched by the United Nations into a global phenomenon in the last two decades. Maintaining strong community connections is a further assurance of social performance in that involving local stakeholders provides a knowledgeable, engaged, and invested talent pool to feed operations, maintenance, inspection, sourcing, and other functions within and around an enterprise that benefit from stronger employment and education futures than might otherwise be available, all while supporting their communities.

1.1.3 Environmental Performance

Material sustainability shall examine the environmental effects that may occur during extraction, manufacture, application, and abandonment. The environmental performance of a process can be defined according to the impacts made to the nine planetary boundaries: novel entities, stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, biogeochemical flows, freshwater use, land system change, biosphere integrity, and climate change.³ The World Federation of Engineering Organizations defines environmental stewardship as: “the wisest use of the finite resources in nature to produce the greatest benefit while maintaining a healthy environment for the foreseeable future.” Material sustainability practices shall therefore consider environmental performance metrics.

Material sustainability as a subset of the broader topic of sustainability is increasingly important as climate change is seen to alter the global environment. Decarbonization, i.e., reducing CO₂ in the atmosphere, e.g., Carbon Capture, Utilization, and Storage (CCUS) is one way to measure the effectiveness of the approaches used in material extraction, manufacture, and use during and after operation. Consideration for decarbonization may lead to a non-traditional corrosion management framework that differs from that currently employed by material and corrosion professionals. While many efforts have focused on the decarbonization of materials and climate change, the other eight planetary boundaries shall also be considered when incorporating material sustainability into a corrosion management framework to capture scenarios wherein a material or process with a lower carbon footprint has a greater environmental impact in any of the other planetary boundaries.

All these considerations are in addition to but do not displace or transcend traditional environmental performance goals of permitted, non-permitted, operational, and transient (i.e., asset failures) effluent concentrations, thermal pollution, habitat destruction/disruption, and other mainstays of industrial design, operation, and asset integrity management performance. This is further understood to apply throughout the asset’s lifecycle.

1.2 Corrosion Management System Framework

The Corrosion Management System Framework is a set of policies, processes, and procedures for planning, executing, and continually improving the ability of an organization to manage the threat of corrosion for existing and future assets. The term “corrosion” is not limited to metal oxidation and generally refers to material degradation caused by chemical or electrochemical reactions between the material and its environment. In most cases, managing corrosion includes 1) optimizing corrosion control actions and minimizing life cycle corrosion costs, and 2) meeting safety and environmental goals. The IMPACT Plus program administered by AMPP describes the framework in more detail.⁷

While traditional Corrosion Management System Frameworks do not directly consider material sustainability, corrosion management, and material sustainability management do complement each other through materials stewardship. Energy and raw materials are used to refine ore, clay, and other raw materials and create other

materials such as metals. These refined materials can be subject to degradation and loss by corrosion. The use of composite materials blended with other ingredients (e.g., reinforcement) improves desired mechanical properties and can improve corrosion resistance. Reducing corrosion of materials not only reduces operating and maintenance costs but also reduces the amount of raw materials and energy that would be required to create replacement material. As an example, one must frequently replace corroded steel with new steel, and steel production uses energy and creates greenhouse gases. Reducing the amount of steel to be replaced due to corrosion therefore has quantifiable effects on greenhouse gas creation. The steel industry is among the three biggest global producers of carbon dioxide. Every ton of steel produced in 2018 emitted on average 1.85 tons of carbon dioxide, equating to about 8 percent of global CO₂ emissions. The CO₂ emissions associated with the steelmaking required to replace corroded steel will be 4.1-9.1% of the total by 2030 considering the European Union and recent U.S. greenhouse gas reduction targets.⁶ Implementing corrosion management best practices can drastically reduce the greenhouse gas emissions associated with the replacement of corroded steel.

As in the example above, much of this standard's discussion focuses on steel and steel corrosion caused by oxidation of the ferrous material. This is a reflection of the fact that construction has traditionally relied on steel, for which oxidation is typically the primary corrosion mechanism of concern. Many existing assets and current standards will continue to rely on steel, and controlling oxidation will continue to be the primary concern for the foreseeable future. However, some industries are turning to alternative materials that are more resistant to oxidation or have different governing degradation mechanisms. Alternative materials can be attractive when they are anticipated to have longer service lives and/or require less maintenance intervention. In such instances, they can be a valuable strategy for optimizing corrosion control actions and minimizing life cycle corrosion costs, and subsequently in achieving materials sustainability, depending on the environmental impacts associated with their life cycle or the life cycle of the asset relying on such materials. While this standard frequently gives examples related to steel and its oxidation, the use of alternative or non-metal materials does not preclude this standard from being applicable nor its information from being useful. The concept that implementing corrosion (i.e., materials degradation) management best practices can reduce greenhouse gas emissions and improve sustainability is anticipated to be widely applicable regardless of the type of material or system being considered.

ISO 55000, 55001, and 55002 shall be referred to for Asset Management Implementation. A well-designed and implemented Corrosion Management System (CMS) is and shall be a key part of an organization's sustainable business practices. NACE SP21430, Standard Framework for Establishing Corrosion Management Systems, was published by NACE in 2019. One of three key areas that illustrate the benefits of a CMS is sustainability.

1.3 Material Stewardship

Material stewardship is the process of managing the flow of materials through society to improve their sustainability by mitigating economic, societal, and environmental impacts and maximizing their efficiency and durability, typically in a corrosion and asset integrity management context. Four key strategies have been defined to pursue material stewardship. These are known as the four Ds: Dematerialization, Durability, Design for multiple lifecycles, and Diversion of waste streams through industrial symbiosis.¹²

Predictions of materials' supply constraints using reserve-to-demand ratios suggest that, within decades, we will be running up against planetary boundaries for several materials of industrial importance, such as nickel, copper, and precious metals (see [Figure 2](#)). Material stewardship strategies in the 21st century shall focus on decreasing this pace of consumption.¹³

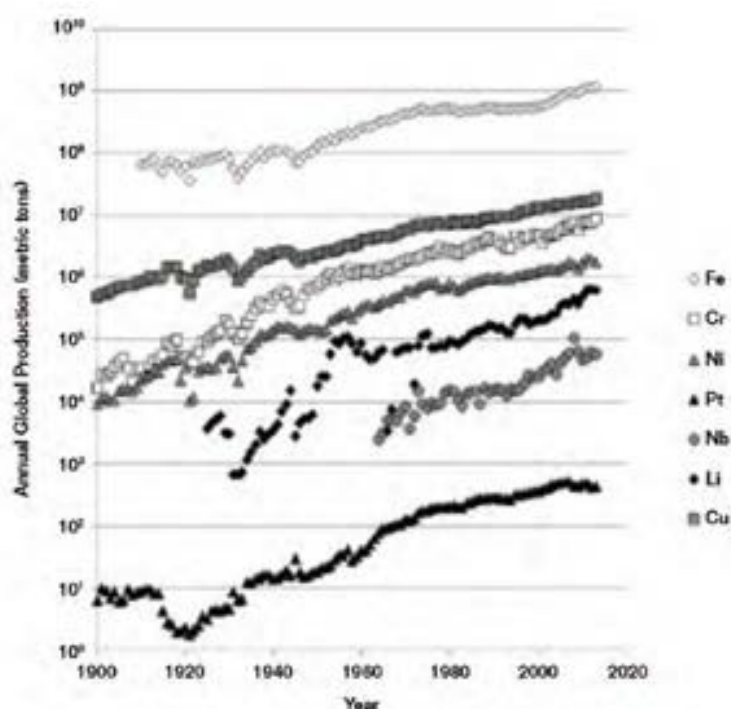


Figure 2: World Production of Several Industrially Critical Materials as Estimated from United States Geological Survey Data¹⁴

The material stewardship approach is associated with the concepts of cradle-to-cradle and the circular economy. Cradle-to-cradle is a biomimetic method for product (and system) design that intentionally seeks to harvest materials (and/or energy) at the end of life for future products and the circular economy is a broader view that patterns economic, agricultural, and industrial systems around circular lifecycles, in which activities such as product reuse, maintenance, repair, refurbishment, etc. enhance value and reduce waste. These approaches contrast with more conventional material usage models or a linear economy, which tend to be linear and near-term; focused on near-term financial profit, functionality, and reliability, without consideration of decommissioning costs, impacts, or approaches.

1.4 Common Tools and Common Practices

Users of this standard shall use the tools and practices outlined in this standard to measure the degree to which their handling of materials (raw material sourcing, manufacturing, use during operation, maintenance, reuse or recycle, disposal) is considered sustainable at different maturity levels. Furthermore, this standard aims to provide a reasonable starting point for organizations to find a common ground for material sustainability management and materials stewardship, particularly building on the corrosion and asset integrity management framework. As industry's understanding of material sustainability and material stewardship practices evolve, this standard will be updated.

This general material sustainability standard is the initial attempt by AMPP to empower end users and organizations to become advocates for material sustainability and material stewardship in a practical manner through corrosion management. However, it has limitations regarding the depth, scope, and use cases where more specific material sustainability standards may be developed to meet these needs. In the meantime, continued use of this standard, its tools, and knowledge sharing will help the users, stakeholders, and knowledge communities to build bridges toward more targeted guidance following this standard's expectations in a more specific context.

AMPP SP21466-2024

©2024 Association for Materials Protection and Performance (AMPP). All rights reserved.

At the same time, this standard's metrics have and will continue to inform a broader approach and application for AMPP IMPACT PLUS Corrosion Management Maturity Audits to provide operators insights into materials stewardship and materials sustainability outcomes based upon their existing performance and forecast achievable improvements targeting and maintaining stronger future results.

[Appendix A](#) (nonmandatory) has compiled some Lessons Learned in the industry that can be complementary to this standard. These lessons capture some critical knowledge in the practice that the standard may not cover.

1.5 How to Use this General Standard

[Figure 3](#) outlines how a user shall navigate through this standard in assessing their organization or business and decide how they can improve their organization by utilizing materials sustainability and materials stewardship processes based on the corrosion management system framework to produce a broad sustainability management program. The following steps should be followed for the first-time user:

- a) Start with [Section 3](#) and [Table 2](#) in order to understand which user group your organization is in. Use [Paragraph 3.2](#) to determine potential value drivers for your group and decide if you can benefit from this standard.
- b) Use [Figures 4](#) and [5](#) to determine the material sustainability maturity model type from [Table 2](#) that best suits your organization's business strategy.
- c) Determine your organization's material sustainability maturity from [Table 3](#).
- d) Use [Paragraphs 4.2](#) and [4.3](#) to determine next steps for improvement.
- e) Use [Paragraph 4.4](#) to assess economic performance, environmental performance, and social performance.
- f) Use [Paragraphs 4.5](#), [4.6](#), and [4.7](#) to expand the horizon and depth including regulatory environment, emerging digital technology, and emerging methodologies to further enable materials sustainability and materials stewardship, thus sharpening your business strategy and business performance.

Users should be aware that this standard provides a framework for how the materials sustainability of a process, asset, fleet, or organization should be evaluated; it does not provide a prescribed list of "sustainable" solutions and technologies for the user to select from. The solutions and technologies that are sustainable will depend on local conditions and vary on a case-by-case basis. As a result, this standard empowers the user to identify which solution(s) is sustainable in the context of their own scenario based on the data and analytical tools currently available.

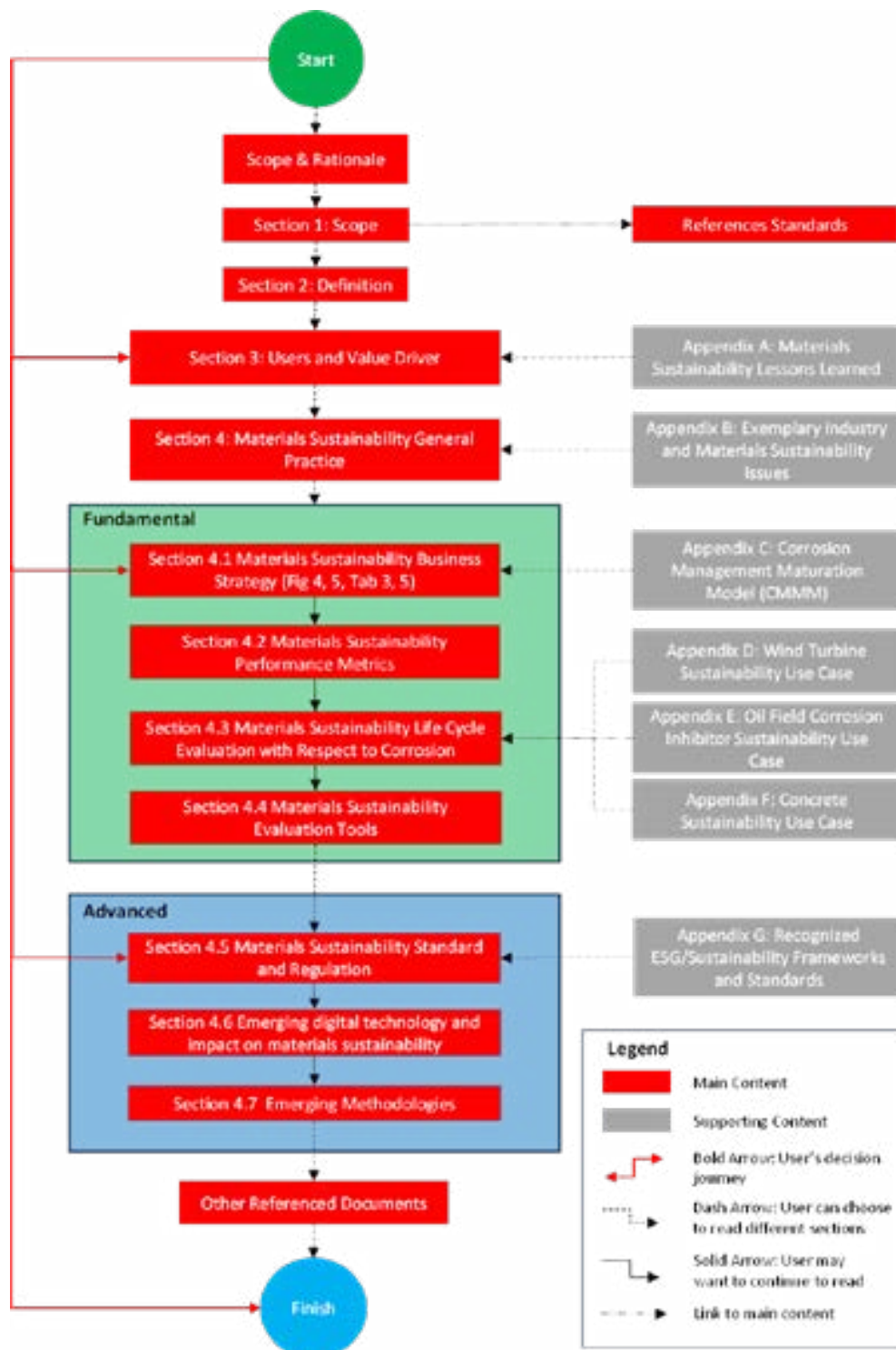


Figure 3: User's Journey in Finding this Standard's Value to Meet Their Needs vs. Standard Conventional Structure

Section 2: Definitions

The definitions of many of the corrosion-related terms used in this standard may be found in NACE/ASTM G193 or ISO:¹¹

Additive Manufacturing (AM): The process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies.

Note: Historical terms include: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication, and freeform fabrication.

As Low As Reasonably Practicable (ALARP): Industry terminology usable to help quantify the threat risk to "As Low As Reasonably Practicable" Adaptable to Sustainability concepts, via third party verification and stop work authority criteria. Often best explored via FMECA and Lessons Learned type workshops.

Artificial Intelligence (AI): The capability to acquire, process, create, and apply knowledge, held in the form of a model, to conduct one or more given tasks.

Asset Integrity Management (AIM): The term for an organization's capacity to run effectively and accurately, whilst also protecting the wellbeing of all personnel and equipment with which it interacts – as well as the measures in place to assure the asset's life cycle. Asset integrity applies to the entirety of an asset operation, from its design phase to its decommissioning and replacement.

Asset Management (AM): The coordinated activity of an organization to realize value from assets.

Carbon Dioxide Equivalent (CO₂ Equivalent or CO₂e): The unit for comparing the radiative force of a GHG to that of carbon dioxide.

Carbon Footprint: The sum of GHG emissions and GHG removals in a product system, individual, event, organization, or service, expressed as CO₂ equivalents (CO₂e) and based on a life cycle assessment using the single impact category of climate change.

Carbon Price or Carbon Tax: A charge on the emission of greenhouse gases equivalent to the corresponding potential cost caused by future climate change, forcing emitters to take on or internalize the cost of pollution. It is also called the "social cost of carbon" by many mainstream economists as the best method for pricing carbon.

Circular Economy (CE): An economy that is restorative and regenerative by design, and which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.

Coatings: (1) A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film. (2) (in a more general sense) a thin layer of solid material on a surface that provides improved protective, decorative, or functional properties.

Corrosion: A naturally occurring phenomenon commonly defined as the deterioration of a material (usually a metal) that results from a chemical or electrochemical reaction with its environment.

Corrosion Control: A systematic method for applying the technology of corrosion prevention to any process.

Corrosion Management System Framework: A framework utilized to develop a stand-alone Corrosion Management System or to integrate corrosion management into an organization's existing management system.

Corrosion Management System (CMS): The documented set of processes and procedures required for planning, executing, and continually improving the ability of an organization to manage the threat of corrosion for existing and future assets and asset systems.

Decarbonization: The process of reducing "carbon intensity" or lowering the amount of greenhouse gas emissions produced by the burning of fossil fuels. Generally, this involves decreasing CO₂ output per unit of electricity generated. Reducing the amount of CO₂ occurring as a result of transport and power generation is essential to meet global temperature standards set by the Paris Agreement and some governments.

Dematerialization: A reduction of the amount of material and energy used in a design solution. Miniaturization of a product to use just the amount of material needed to achieve a design is a new trend in the marketplace.

Design for Multiple Life Cycles (DfML): One of the approaches to facilitate the implementation of multiple life cycles in order to maximize the utility of the resources used in developing a product by integrating the features that can help prolong the lifetime of the product.

Digital Twin (DT): The fit-for-purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation.

Digital Representation: The data element represents a set of properties of an observable manufacturing element.

Diversion of Waste: The process of diverting waste from landfills.

Durability: The ability of a physical product to remain functional, without requiring excessive maintenance or repair, when faced with the challenges of normal operation over its design lifetime.

Economic Sustainability: A state in which the economic performance is maintained for the present and future generations.

Embodied Carbon: A measure of the CO₂ emissions associated with the manufacturing, transportation, and installation of building materials.

Embodied Energy: The energy consumed by all of the processes associated with a product or service including material extraction (quarrying/mining), manufacturing, transportation, fabrication processes, and product delivery.

Environmental, Social, and Governance (ESG): A framework that an organization can integrate into its overall business strategy to generate value for all interested parties of the organization, such as owners, investors, customers, employees, suppliers, and the community.

Environmental Sustainability: A state in which the ecosystem and its functions are maintained for the present and future generations.

Failure Mode and Effects Analysis (FMEA): A step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service.

Failure Mode, Effects, and Criticality Analysis (FMECA): Extends FMEA by including a criticality analysis, which is used to chart the probability of failure modes against the severity of their consequences.

Greenhouse Gas (GHG): The release of a gas to the atmosphere. A GHG such as CO₂ can absorb energy from the sun and trap heat in the earth's atmosphere. Without GHGs, the earth's average temperature would be around -18 °C, rather than the current average of 15 °C. The earth's natural greenhouse gas effect is one key parameter that makes the planet livable for humans.

Life Cycle Assessment (LCA): The systematic evaluation of the environmental impact of a product(s) that includes all stages of its life cycle.

Life Cycle Costing (LCC): The direct monetary costs involved with a product or service and not environmental impact.

Life Cycle Inventories (LCI): The data collection portion of LCA.

Life Extension (LE): The additional period of time beyond the original design or service life (but within the assessed remnant life) for which permission to continue operating a plant system is granted by the regulatory bodies.

Linear Economy: A system where resources are extracted to make products that eventually end up as waste and are thrown away.

Machine Learning (ML): A process by which a functional unit improves its performance by acquiring new knowledge or skills, or by reorganizing existing knowledge or skills.

Management: The act or skill of controlling and making decisions. It is a broader term that can be applied to many different contexts, including business, government, and personal life.

Material: The matter from which a thing is or can be made.

Material Stewardship: The process of managing the flow of materials through society to improve their sustainability by mitigating economic, societal, and environmental impacts and maximizing their efficiency and durability.

Material Sustainability: The way materials are sourced, processed, manufactured into products, maintained through the product lifecycle, and redirected at their end of life.

Metallic: Of, relating to, or consisting of metal.

Non-metallic: Of or relating to a non-metal.

Preservation: The act of keeping something as it is, especially in order to prevent it from decaying or to protect it from being damaged or destroyed.

Social Sustainability: The ability to provide sustainable, successful places in a social context. Social sustainability combines the design of the physical realm with the design of the world, infrastructure to support social and cultural life, provides social amenities, systems for citizen engagement, and spaces for people and places to evolve.

Stewardship: The careful and responsible management of something entrusted to one's care. Often used in the context of environmental conservation, where it refers to the responsible use and protection of natural resources.

Standard Development Organizations (SDOs): Member-supported organizations, some accredited by the American National Standards Institute (ANSI) in the U.S., that develop and maintain standards to meet industry needs.

Stop Work Authority: The ability to cease work (design, ops, inspection, etc.) on the grounds of a safety or sustainability argument. Should be related to the ALARP criteria.

Sustainability: The maintenance of ecosystem components and functions for future generations, to address economic efficiency, social issues, and environmental preservation.

Third-Party Review or Verification: A methodology whereupon the design/operations are independently corroborated by a separate entity usually applied to safety-critical items only, but might be extended to sustainability criteria also. Can be related to the ALARP criteria.

Triple Bottom Line (TBL): A business concept that states companies should commit to measuring their social and environmental impact—in addition to their financial performance—rather than solely focusing on generating profit, or the standard “bottom line.”

Value Chain: A series of relationships between owners, designers, constructors, operators, suppliers, consultants, regulators, and communities that enable everyone to collaboratively contribute to the success of a project, operation, or industry.

Waste Management: The administrative and operational activities involved in the handling, pretreatment, treatment, conditioning, transport, storage, and disposal of waste.

Section 3: Users and Value Drivers of this Standard

3.1 Overview

This standard is applicable to a range of users. Each functional user group is composed of individuals with differing roles and needs regarding sustainability and material stewardship. Table 1 documents the different user groups and potential value drivers of this standard for each group. The user groups discussed below are composed of individuals who may have different titles across various industries but share the same functional role in business operations. Some Lessons Learned in [Appendix A](#) have shown how different users can collaborate to improve materials sustainability.

Table 1
User Groups and Potential Value Drivers of AMPP SP21466 Materials Sustainability

User Group	Specific Role in the Organization	Responsibility	Specific Value Drivers of this Standard to the User Group
End User	Materials and Corrosion Engineering Staff, Maintenance staff, Operating staff	Responsible for measuring the degree to which their handling of materials (manufacturing, use during operation, maintenance, reuse, or recycling) is deemed sustainable.	This standard provides a recognized and primary assessment process/criteria for industry to evaluate what materials selection, handling, and maintenance choices are sustainable, including creating cross-functional awareness and collaboration toward long-term asset integrity and environmental and business performance goals.
Heavy Influence	Engineering Leaders Design Project Leaders Chief Technology Officers (CTOs) Materials Manager	Responsible for setting the technical direction of engineering projects or businesses/operations.	This standard enables companies to recognize a CMS as a sustainability contribution (economic, social, and environmental benefits of CMS). It also provides a basis for development of future quantitative tools and best practices for analyzing sustainability of CMS practices from a holistic perspective.
Light Influence	Contract and procurement managers Research Scientists Academic staff and students AMPP IMPACT Navigators Industry maintenance organizations	Responsible for exerting opinions locally (procurement manager who insists on delivery of sustainability data with purchased goods), or may broadly influence an industry in an informal way (i.e., publishing a widely circulated research paper that leads to the change of minds or some business practices).	This standard provides cross-functional support to the organization and industry in maintaining accountability to material sustainability, stewardship, and holistic asset integrity management objectives; including informal benchmarking, feedback on functional and economic performance, and innovation.
Champion	Materials and Corrosion Experts / Consultants/ Scientists AMPP IMPACT Navigators Chief Sustainability Officers (CSOs) HSE Manager/Quality Manager Risk, Reliability, and Anomaly Manager	Responsible for supporting and sharing informally and/or formally for the function of sustainability practices.	This Standard encourages sharing lessons learned (LL) in all aspects including technical and human factors without contravening company intellectual property or confidentiality. It also assists in developing high-value, targeted improvement strategies to enhance company, industry, and regional performance towards material sustainability/stewardship goals; including asset integrity management initiatives. When evaluating and benchmarking performance, Champions would help to navigate the best courses of action toward lasting improvements.

Economic Buyer	Project Managers/ Engineers Finance Manager	Responsible for directly assessing costs related to purchasing decisions and/or operational costs.	A method to ensure inclusion of all factors influencing sustainability that are affected by corrosion including maintenance, serviceable life, fate at end of life, worker safety, environmental protection, etc. It also serves as a way of identifying and indexing suppliers and project partners that will be most effective in achieving material sustainability and stewardship objectives throughout the value chain.
Veto Power	Executives Regulators Environmental Advisor Auditor	Responsible for go/no go of business and engineering projects/decisions.	Define a baseline of understanding/definitions for sustainability in asset integrity management for high-consequence infrastructure. Provide guidance, metrics, and tools AMPP and other SDOs can reference so future standards can target sustainable results. A lack of standardization can result in greenwashing or disbelief in the environmental benefits of things carefully designed to minimize their impact. Provides a context within which to identify and develop the right projects, initiatives, and business relationships necessary to achieve defined material sustainability and stewardship objectives, as well as how to measure and drive progress toward those objectives under holistic asset integrity management and business performance strategies.
Product Developer	Architect, Materials Manufacturers, Original Equipment Manufacture Traditional (Subtractive) or Additive	Organizations (or individuals) responsible for both concept and execution of a new project.	The standard facilitates the recognition of organizations and individuals as sustainable business partners because of their ability to consistently deliver solutions with material sustainability and asset integrity management by incorporation of material stewardship.

3.2 Value Drivers

This list of value drivers indicates some of the particular usages of this standard as they are envisioned from a diverse audience.

3.2.1 Assessment Process and Ranking Criteria

This standard serves to facilitate a recognized assessment process and ranking criteria for material sustainability, i.e., the Materials Sustainability Maturation Model, with an applicability focus especially on the industries engaged with materials and corrosion experts, and incorporating all phases of the product life cycle.

3.2.2 Corrosion Management

This standard serves to interface the existing standards and methodology of corrosion management with sustainability practices. It recognizes that corrosion management is an important tool for achieving sustainability with economic, social, and environmental benefits.

3.2.3 Incorporation of Lessons Learned

This standard builds upon the collective knowledge of materials and corrosion experts regarding the lessons learned through the full product life cycle and beyond the life cycle to minimize repeat learning.

3.2.4 Purchasing Framework

This standard can help serve as a purchasing framework that ensures the inclusion of all factors influencing sustainability that are affected by corrosion, including maintenance, serviceable life, fate at end of life, life extension beyond the initial design life, worker safety, environmental protection, etc.

3.2.5 Materials Selection

This standard recognizes that materials selection is critical for material sustainability, as the suitability and compatibility of materials with their process medium plays a major role in preventing material deterioration and degradation. A good selection of materials of construction in the design phase will keep the maintenance/repair cost to a minimum until the end of the design life.

3.2.6 Asset Integrity

This standard defines a baseline of understanding/definitions for sustainability in asset integrity management for high-consequence infrastructure. It also provides guidance, metrics, and tools that AMPP and other standard development organizations (SDOs) can reference so that future standards can target sustainable results.

3.2.7 Product/Brand Recognition

This standard provides tools that product developers can track and be recognized for their level of sustainability as a business partner.

3.2.8 Corporate Sustainability Report

This standard provides specific tools and measures that Corporate Sustainability Officers and organizations can enhance their sustainability improvement by ensuring that material sustainability and corrosion management framework is also applicable and should be foundational to their sustainable business.

Section 4: Materials Sustainability General Practice

4.1 Materials Sustainability Business Strategy

The users of this material sustainability standard shall examine how selected material sustainability practices support their overall business-level strategy first. A company's relative position within its industry determines whether a company's profitability is above or below the industry average. The fundamental basis of above-average profitability in the long run is a sustained competitive advantage.¹⁶ There are two basic types of competitive advantage a company can possess: low cost or differentiation. The two basic types of competitive advantage combined with the scope of activities for which a company seeks to achieve them, i.e., whether the activities target the broad market or a focused segment of the broad market, lead to three generic strategies for achieving above-average performance in an industry: cost leadership, differentiation, and focus. The focus strategy has two variants, cost focus and differentiation focus. The method was further expanded to give commonly recognized business-level strategies as shown in [Figure 4](#). This figure presents five overall business strategy types that different business organizations may have to choose to compete for their advantage: Cost Leadership Strategy, Differentiation Strategy, Focused Cost Leadership Strategy, Focused Differentiation Strategy, and Integrated Cost Leadership/Differentiation Strategy.

As a simplified example, practicing material sustainability through decarbonization may initially increase the cost of products or services, in which case it would not align with a broad Cost Leadership Strategy. However, this practice may support a business-level strategy that relies on differentiation through the distinctiveness of the products and services. Differentiation by meeting the demand for products and services with reduced en-

environmental impacts and/or increased benefits to communities would convey high perceived and true value to the customer, in which case material sustainability practices would successfully align with the business-level strategy. Gradually, various activities in the company fit and mutually reinforce each other such that competitors can't easily imitate them.¹⁷

Table 2 presents a Material Sustainability Maturity Model that shall be used to select the model that is best aligned with their business-level strategy. The ultimate goal of the material sustainability model selected or developed will help the company gain a sustainable competitive advantage and serve its customers and shareholders. This model applies to various industries while some exemplary industry and materials sustainability issues are captured in [Appendix B](#) (nonmandatory).

At the business tactic level, the business decision is often made with a risk assessment matrix (RAM) as shown in [Figure 5](#). The matrix fully considers safety, schedule, legal, finance, and operations in order to arrive at a balanced decision. Companies may consider different or additional factors, e.g., environment, material sustainability, material stewardship, reputation, etc. It is likely that some companies that have advanced their maturity in material sustainability and their business-level strategy may develop their RAM with material sustainability as a new factor, which may allow them to develop an advantage in the industry. Once a company has decided that material sustainability aligns with its business-level strategy, the immediate question is whether material sustainability can be easily measured from the RAM perspective. Different answers may be appropriate for different companies. This will be discussed in the next section.

Table 2
How an Organization Chooses the Right Materials Sustainability Maturity Model along with Corrosion Management Maturity Model* to Sustain Their Business (IMPACT Plus Program, SP21430)

Maturity Level	Maturity Type	New Metrics	Benefits/Return**	Required Investment	Examples	CMMM Basis
5	Leading	Leading material sustainability in the industry and market, achieving a balance of material sustainability, and, more important, business advantage and profit.	\$\$\$\$\$	\$\$\$\$	Corporation has already built material sustainability into investment evaluation and decision process	CMMM - Innovating and Leading
4	Advancing	Strong sustainability having a use for all waste products, such as CO ₂ sequestration or recycled plastic and glass. Has systems thinking, always taking the full product lifecycle into account for decisions consistently. The longer to safely run the plant, the lower the carbon impact by eliminating the potential rebuilding the plant	\$\$\$\$\$	\$\$\$	Companies that have built decarbonization as part of their business-level strategy "Focused Differentiation Strategy" for example, Outokumpu Steel used recycled steel to create steel products with low carbon emissions.	CMMM - Optimized and Proactive
3	Established	Improved sustainability, able to use long-term thinking, systems thinking taking full product life-cycle into account for decisions	\$\$	\$\$	Successful companies often safeguard their best practice to sustain their competitive advantage.	CMMM Managed and Integrated