



HOT-DIP GALVANIZING FOR
**SUSTAINABLE
DESIGN**



TABLE OF CONTENTS

INTRODUCTION.....	1
WHAT IS SUSTAINABLE DEVELOPMENT?.....	2
Life-Cycle Inventory (LCI) & Life-Cycle Assessment (LCA).....	3
Leadership in Energy and Environmental Design (LEED®).....	4
Hot-Dip Galvanizing (HDG) & LEED®	5
WHAT IS ZINC?.....	6
WHAT IS HOT-DIP GALVANIZING?.....	7
ENVIRONMENTAL PERFORMANCE.....	8
LCI & LCA Overview.....	9
LCI Study.....	10
Steel.....	10
Zinc.....	11
HDG.....	12
LCA Production Phase.....	13
LCA Use Phase.....	13
LCA End-of-Life Phase.....	14
Complete LCA.....	14
Galvanizing vs. Paint in LCA.....	15
Balcony Case Study.....	16
Parking Garage Case Study.....	18
ECONOMIC PERFORMANCE.....	19
Initial Cost.....	20
Life-Cycle Cost (LCC).....	19
Galvanizing vs. Paint in LCC.....	19
Balcony Case Study.....	20
Parking Garage Case Study.....	22
SOCIAL PERFORMANCE.....	23
SUMMARY.....	24



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HOT-DIP GALVANIZING FOR

SUSTAINABLE DESIGN

 The Industrial Revolution dominated the 18th and 19th centuries, and many would argue, the 20th century brought about the technology revolution. Considering all of the world's advancements in the last 300 years, one must wonder what progress the 21st century will hold. If the first decade is any indication, the next revolution will be sustainable development.

Sustainable development, LEED®, and green are no longer just buzzwords to architects, engineers, developers, and specifiers. Whether an effect of stricter rules and regulations, a slow depletion of materials, or a conscious ethical decision, sustainable design and construction have become top priorities. Utilizing steel, which has been a vital component of modern construction since the industrial revolution, throughout the world's infrastructure can positively contribute to sustainable development. However, steel left unprotected can succumb to corrosion; thus, for true sustainability, the steel must be coated to improve its durability. Hot-dip galvanizing, the process of metallurgically bonding zinc to steel, has been used to protect steel for more than 150 years and provides maintenance-free corrosion protection for decades. Following the last 300

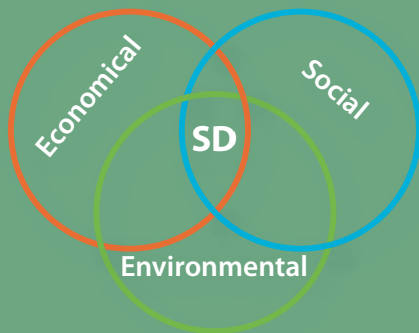
years of growth and development, a sustainable development revolution utilizing hot-dip galvanized steel will ensure the world can have many more centuries of safe, healthy growth and development.

As the surge of environmental awareness increases, so do the number of false or misleading green marketing claims, known as “greenwashing,” and the necessity to educate specifiers and consumers about how to distinguish true sustainable development from false claims. Greenwashing is the act of misleading consumers about the environmental practices of a company or the environmental benefits of a product or service¹. The purpose of this publication is to quantifiably establish how hot-dip galvanized steel can positively contribute to sustainable development.

WHAT IS SUSTAINABLE DEVELOPMENT?

Sustainable development (SD) is the social, economic, and environmental commitment to growth and development that meet the needs of the present without compromising the ability of future generations to meet their needs. Creating a more sustainable community, nation, and world is pertinent, and developers of the built environment (architects, engineers, material suppliers, etc.) shoulder a large part of the responsibility to protect the interests of present and future generations.

Specifiers may use a number of environmental impact assessment methods to measure how sustainable a product or process is; however, many methods are highly subjective. Factors considered in an evaluation can run from concrete tangibles, such as carbon emissions and energy use, to the more abstract, such as training courses and recycling initiatives. Two of the most accepted and well-known methods for measuring sustainability are the combination of life-cycle inventory (LCI)/ life-cycle assessment (LCA) and the US Green Building Council's Leadership in Energy and Environmental Design (LEED®).



“...developers of the built environment should shoulder a large part of the responsibility to protect the interests of present and future generations.”



Life-Cycle Inventory (LCI) & Life-Cycle Assessment (LCA)

One well-known environmental impact measurement method utilized in the marketplace is the combination of life-cycle inventory (LCI) and life-cycle assessment (LCA). LCI and LCA work in tandem to quantify the material flows, energy flows, and environmental impacts of a given product. A life-cycle inventory (LCI) study provides the measurement of the material flows, energy flows, and environmental releases for the production of a defined amount of a product. LCI is also known as a cradle-to-gate or gate-to-gate study, and is the

building block for performing an LCA. Life-cycle assessment (LCA) is a standardized scientific method for the systematic analysis of all material and energy flows, as well as environmental impacts attributed to a product from raw material acquisition to end-of-life management. LCA is considered a complete analysis (cradle-to-grave) of the true environmental impact of a product.

An LCA has four phases: goal and scope, life-cycle inventory, life-cycle impact assessment, and interpretation. This publication will review each of these in further detail as they pertain to hot-dip galvanized steel.

SUSTAINABLE DEVELOPMENT (SD) is the social, economic, and environmental commitment to growth and development that meet the needs of the present without compromising the ability of future generations to meet their needs.

LIFE-CYCLE INVENTORY (LCI) is the study and measurement of the material flows, energy flows, and environmental releases for the production of a defined amount of a product.

LIFE-CYCLE ASSESSMENT (LCA) is a standardized scientific method for the systematic analysis of ALL material and energy flows, as well as environmental impacts attributed to a product from raw material acquisition to end-of-life management.

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED®) is a third-party certification program, and the nationally accepted benchmark for the design, construction, and operation of high-performance green buildings.

Leadership in Energy and Environmental Design (LEED®)

LEED® is the nationally accepted benchmark for the design, construction, and operation of high-performance green buildings. LEED® promotes a whole building approach to sustainability by recognizing performance in five key areas of human health and environmental impacts: (1)sustainable site development; (2)water efficiency; (3)energy and atmosphere; (4)materials and resources; and (5)indoor environmental quality.

The selection of building materials is only a small aspect of LEED®, but LEED® is still the most well known system for measuring sustainability in this area. However, environmental critics often point out LEED® uses a relatively simplistic format to gauge the greenness of a product and has a loophole for non-green buildings to be highly rated. The argument about the simplistic format revolves around the fact

LEED® offers credit for recycled content of materials used and energy consumption and air quality impact over the useful life, but end-of-life implications, such as recyclability, are not considered. Though the energy consumption and environmental impact of a building during production/construction and use is important, what happens to a building at the end of its useful life can also have significant impacts.

Possibly even more frustrating is the loophole in the credit system. Industry professionals maintain a LEED® plaque is not necessarily analogous to sustainable development. Because each LEED® credit has the same weight (1 point), it is possible to garner enough credits for a high LEED® rating without obtaining a single point in energy efficiency. Critics argue this loophole allows some to undermine the rating system, and receive awards for being “green” when in fact the building’s environmental performance is poor. Regardless of these arguments, LEED® is still a useful rating system that provides a positive contribution to advancing sustainable development.



Hot-Dip Galvanizing and LEED®

As LEED® is the most common method for measuring sustainability, often specifiers question whether hot-dip galvanized steel can contribute credits. *The Materials & Resources Credit 4: Recycled Content* category specifically focuses on increasing the use of building products with high recycled content, thus reducing impacts caused by extraction and processing of raw metal and ores. The two primary components of hot-dip galvanized steel (steel and zinc) have high recycling and reclamation rates. The recycling rate, which is factored into the LEED® rating, considers how much of a particular product comes from recycled sources. The reclamation rate, which measures how often a product is actually recycled at the end of its useful life, is not currently used in the LEED® rating, but is also an important environmental indicator to consider (*Figure 1*).

Because of these high recycling rates, hot-dip galvanized steel contributes points under Credits 4.1 and 4.2 of the *Materials & Resources Credit 4: Recycled Content* category. LEED® requires the following to earn points in these categories²:

- Credit 4.1 (1 point) “Use materials with recycled content such that the sum of the post consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% of the total value of the materials in the project.”
- Credit 4.2 (1 point) “Use materials with recycled content such that the sum of the post consumer recycled content plus one-half of the pre-consumer content constitutes at least an additional 10% beyond Credit 4.1 (total of at least 20%) of the total value of the materials in the project.”

	Zinc ^a	Steel ^b
Recycling Rate	30%	70%
Post-Consumer Rate	14.6%	56.9%
Pre-Consumer Rate	15.6%	31.4%
Reclamation Rate	80%	100%
^a International Zinc Association (IZA), Zinc Recycling, 2004.		
^b Steel Recycling Institute, Steel Takes LEED® with Recycled Content, March 2009.		

Figure 1

The recycled content of a material assembly is determined by weight, and the recycled fraction is then multiplied by the cost of the assembly to determine the recycled content value. Hot-dip galvanized steel is both the material and the building product (the zinc metallurgically reacts with the iron in the steel, becoming one product); therefore, the value of the steel building product is directly multiplied by hot-dip galvanized steel’s recycled content.

With more than 70% combined recycled content, hot-dip galvanized steel easily meets the requirements of Credits 4.1 and 4.2 of the *Materials & Resources Credit 4: Recycled Content* category, contributing points for both.



WHAT IS ZINC?

Before we examine the impact of hot-dip galvanized steel to the environment, it is important to understand the primary component of the hot-dip galvanized coating – zinc. Zinc is a healthy metal, infinitely recyclable without the loss of any physical or chemical properties. Natural, essential, and abundant, approximately 30% of the world's zinc supply comes from recycled sources annually, and 80% of zinc that can be recycled is reclaimed.

Zinc, the 27th most abundant element in the Earth's crust, naturally exists in air, water, and soil. Most rocks and many minerals contain zinc in varying amounts. Approximately 5.8 million tons of zinc are naturally cycled through the environment annually by plant and animal life, rainfall, natural phenomena, and other activity. During the course of evolution, all living organisms have adapted to the zinc in their environment and use it for specific metabolic processes. The amount of zinc present in the environment varies from place to place and season to season.

Zinc is also essential to life for humans and even the smallest microorganisms. Zinc aids in digestion,

reproduction, kidney function, breathing, diabetes control, taste, smell, and much more. Although zinc in excess can be detrimental, zinc deficiency is a much greater concern. The World Health Organization (WHO) estimates 800,000 people in developing countries die each year due to lack of zinc in their diet.

Zinc is common in day-to-day life, in fact, zinc oxides and other compounds are used in a number of household products. Zinc oxide blocks more UV rays than any other single ingredient, thus it is common in sunscreens. Zinc is also used in cosmetics, tires, the treatment of sunburns, diaper rash, acne, cold sores, dandruff, the common cold, burns, other wounds, and much more. Additionally, one of the oldest and most common uses for zinc is in construction.

Zinc has been used in construction for more than 150 years to protect steel from corrosion. Zinc is most commonly used in construction as the protective coating of hot-dip galvanizing or other forms of zinc coatings. However, in Europe, and more recently, in the United States, pure zinc metal sheets have been used in roofing and paneling systems.



WHAT IS HOT-DIP GALVANIZING?

Hot-dip galvanizing (HDG) is the process of coating fabricated steel by immersing it in a bath of molten zinc. There are three fundamental steps in the hot-dip galvanizing process; surface preparation, galvanizing, and inspection (*Figure 2*).

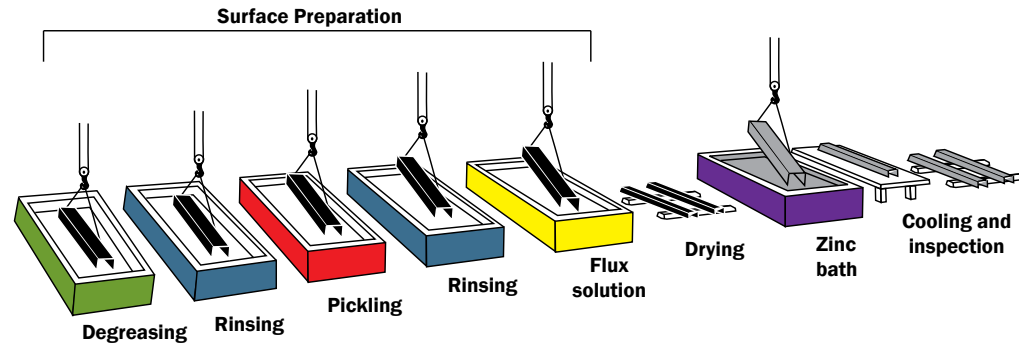


Figure 2

Surface Preparation

When the fabricated steel arrives at the galvanizing facility, it is hung by wire or placed in a racking system which can be lifted and moved through the process by overhead cranes. The steel then goes through a series of three cleaning steps; degreasing, pickling, and fluxing. Degreasing removes dirt, oil, and organic residues, while the acidic pickling bath will remove mill scale and iron oxide. The final surface preparation step, fluxing, will remove any remaining oxides and coat the steel with a protective layer to prevent any further oxide formation prior to galvanizing. Proper surface preparation is critical, as zinc will not react with unclean steel.

Galvanizing

After surface preparation, the steel is dipped in the molten (830 F) bath of at least 98% zinc. The steel is lowered into the kettle at an angle that allows air to escape from tubular shapes or other pockets, and the zinc to flow into, over, and through the entire piece. While immersed in the kettle, the iron in the steel metallurgically reacts with the zinc to form a series of zinc-iron intermetallic layers and an outer layer of pure zinc.

Inspection

The final step is an inspection of the coating. A very accurate determination of the quality of the coating can be achieved by a visual

inspection, as zinc does not react with unclean steel, which would leave an uncoated area on the part. Additionally, a magnetic thickness gauge can be used to verify the coating thickness complies with specification requirements.

Hot-dip galvanizing provides a number of benefits to the steel it protects. The metallurgically-bonded zinc-iron alloy layers not only create a barrier between the steel and the environment, but also cathodically protect the steel. The cathodic protection offered by zinc means the galvanized coating sacrifices itself to protect the underlying base steel from corrosion. The tightly adhered coating, which has bond strength of around 3,600 psi, is also extremely abrasion-resistant, as the intermetallic layers are harder than the base steel (*Figure 3*). However, even if the coating were damaged, zinc's sacrificial action will protect exposed steel up to ¼ inch away.

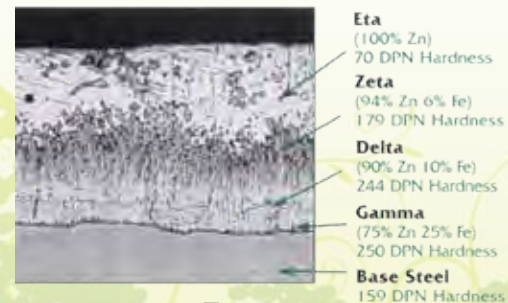


Figure 3

In addition to the cathodic protection offered by hot-dip galvanizing, there are a few other characteristics of the coating which provide longevity. First, reaction in the galvanizing kettle is a diffusion process, which means the coating grows perpendicular to the surface, ensuring all corners and edges have at least equal thickness to flat surfaces. Furthermore, the complete immersion in the zinc bath provides total coverage of the steel, including the interior of hollow structures. Finally, the zinc coating naturally develops an impervious layer of corrosion products on the surface, known as the zinc patina. The patina, cathodic protection, complete coverage and all of these other benefits, provide hot-dip galvanized steel with a long, maintenance-free service life. The time to first maintenance for hot-dip galvanized steel can be seen in *Figure 4*.

ENVIRONMENTAL PERFORMANCE OF HOT-DIP GALVANIZED STEEL

In 2008, the International Zinc Association (IZA) sponsored a study of the life-cycle inventory (LCI) and life-cycle assessment (LCA) of hot-dip

galvanized steel. IZA hired world-renowned environmental firms Five Winds International and PE International to conduct the study. Five Winds and PE International collected worldwide galvanizing data from the American Galvanizers Association (AGA), the European General Galvanizing Association (EGGA), Galvanizers Association of Australia (GAA), and Hot Dip Galvanizers Association of South Africa (HDGASA) to conduct the study.

The goal of the study was to provide a life-cycle inventory (LCI) for 1 kg of hot-dip galvanized steel product, and then using the LCI information, conduct a life-cycle assessment (LCA) to understand the full environmental impact of galvanized steel from production through use and end-of-life. The LCA is intended to not only provide an accurate picture of where galvanizing stands currently, but also to highlight opportunities for minimizing environmental impact in the future.

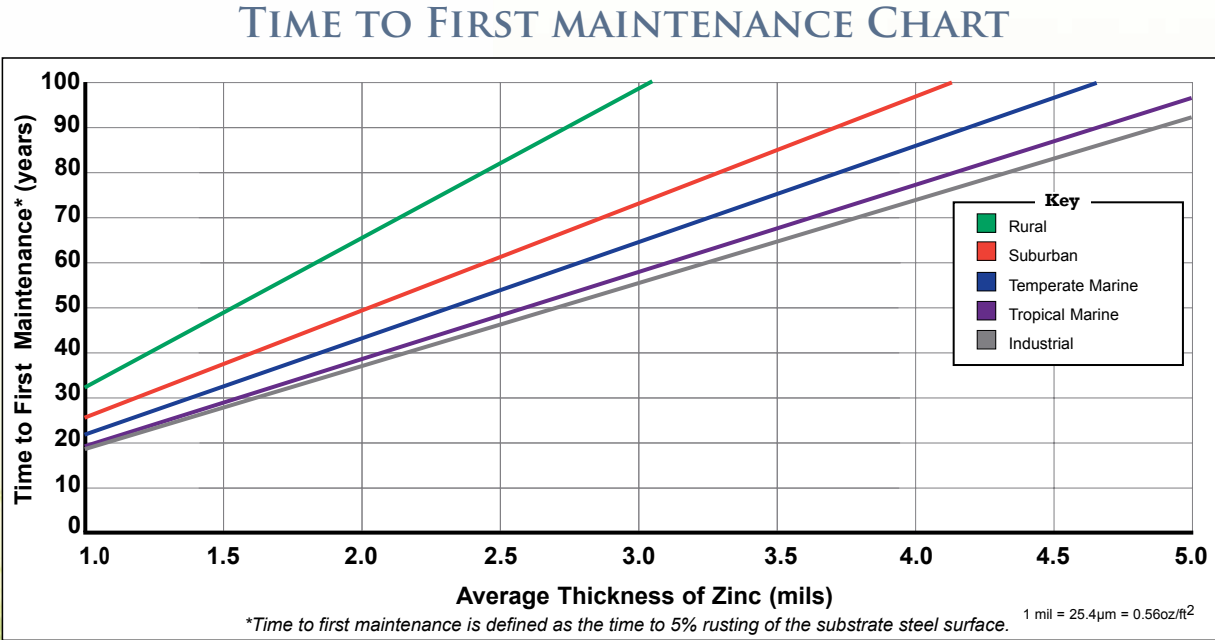


Figure 4

Throughout the LCI and LCA, a number of environmental criteria were measured. Before revealing the results of the study, it is important to define the criteria used.

PRIMARY ENERGY DEMAND (PED) measured in mega Joules (MJ), is the sum of the total primary energy consumed in the manufacture and supply of products.

JOULE (J) the SI unit of work or energy, equal to the work done by a force of one newton when its point of application moves through a distance of one meter in the direction of the force. A mega Joule (MJ) is one million Joules.

GLOBAL WARMING POTENTIAL (GWP) measured in kilograms CO₂ equivalent (100 years), is the potential to gradually increase over time the average temperature of Earth's atmosphere and oceans that induce changes to Earth's climate.

ACIDIFICATION POTENTIAL (AP) measured in kilograms SO₂ equivalent, is the amount of hydrogen ions created when a substance is converted into an acid, known as acid rain.

PHOTOCHEMICAL OZONE CREATION POTENTIAL (POCP) measured in kilograms ethene (C₂H₂) equivalent, is the creation of summer smog, or increased levels of ozone at ground level.

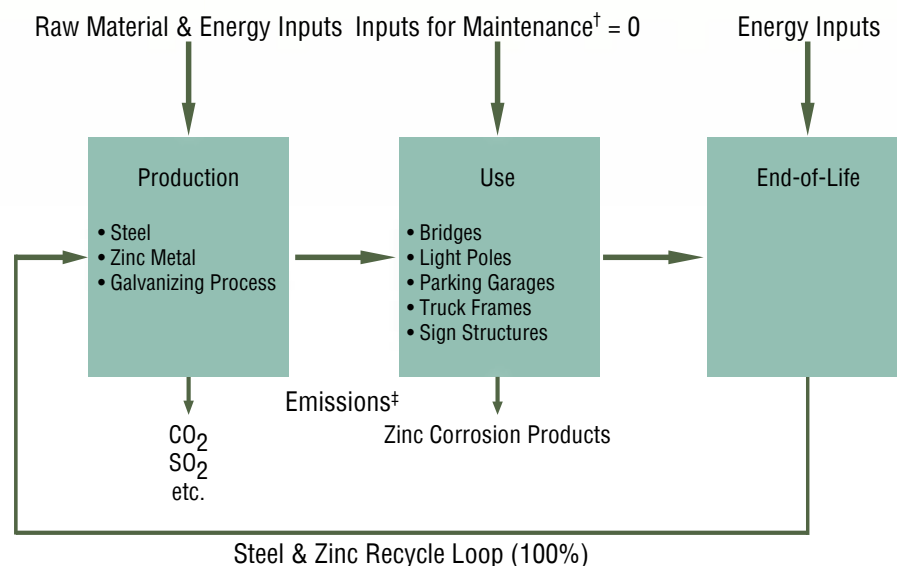
LCI & LCA Overview

The LCI study examines the environmental impact of producing 1 kg of hot-dip galvanized steel. The LCI of the hot-dip galvanizing process is a gate-to-gate study, which means it only examines the environmental impact generated from the time the product arrives at the galvanizer's facility up to the point when it is ready to be shipped to the job site. However, in order to really gauge the impact of producing 1 kg of hot-dip galvanized steel, the impact of producing steel and zinc must also be analyzed.

The LCI study examined the impact of producing steel, zinc, and the galvanizing process. Combining the LCI's of all three, a cradle-to-gate study, provides the true impact of producing 1 kg of hot-dip galvanized steel, which is the same as the production phase of the LCA.

The LCA study examines the full environmental impact of hot-dip galvanized steel from production to end-of-life. LCA is considered a cradle-to-grave study, as it considers initial impact of production, impact during use due to maintenance and/or emissions generated, and the end-of-life impact or credit. For hot-dip galvanized steel, a more accurate term would be cradle-to-cradle, as the zinc and steel are both 100% recyclable at the end-of-life. The LCA study conducted by Five Winds and PE International examined a hot-dip galvanized structural beam (16 m, 940 kg) and a utility pole (10.7 m, 184 kg). Each hot-dip galvanized product will yield slightly different results, but the figures provided here can be used as a guideline. *Figure 5* is a visual representation of hot-dip galvanized steel's LCA.

LCA OF GALVANIZED STEEL



[†] For all but the most aggressive, corrosive environmental conditions, there are no energy or raw material inputs during use (75+ years).

[‡] For hot-dip galvanized steel, naturally occurring zinc oxide, zinc hydroxide, and zinc carbonate.

Figure 5

LCI Study

Steel

To fully understand and appreciate the environmental impact of producing hot-dip galvanized steel, it is necessary to start with the production of steel. The LCI of steel includes the mining of virgin material as well as the reuse of recycled scrap. Steel is the most recycled material in the world, with 70% of steel produced made from recycled material. In addition to the raw material, the LCI also examines the energy consumed and emissions created by melting the material, casting the pieces into plates, beams, etc., and the impact of fabricating the steel for its end use. After fabrication, the steel is sent to the galvanizer's facility to be coated. As *Figure 6* shows, very little solid waste is created throughout the process.

STEEL PRODUCTION

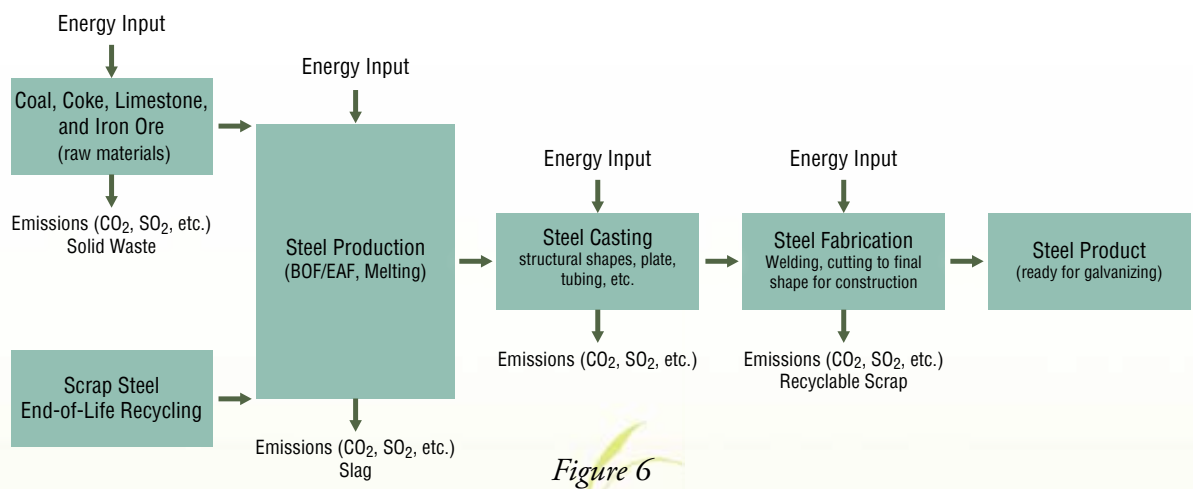


Figure 6

Utilizing industry information from the GaBi database (a collection of environmental product declarations (EPDs)), an LCI was conducted to determine the amount of energy and emissions required to produce 1 kg of steel. The steel's mass will also comprise the majority of the weight of 1 kg of hot-dip galvanized steel, but the resulting numbers take into consideration the weight of the zinc as well. Therefore, the values presented here represent the primary energy demand (PED), global warming potential (GWP), acidification potential (AP), and photochemical ozone creation potential (POCP) for the amount of steel contained in 1 kg of hot-dip galvanized product (*Figure 7*).

Steel LCI (Cradle-to-Gate)	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO ₂ equiv.)	Acidification Potential (AP) (SO ₂ equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C ₂ H ₂ equiv.)
1 kg of HDG Steel	21.64 MJ	1.55 kg	0.00459 kg	0.000763 kg

Figure 7

Zinc

Other than the steel, zinc is the primary component of hot-dip galvanizing. Similar to steel, the production of zinc comes from both mined zinc ore and recycled sources. In fact, 30% of zinc produced annually comes from recycled material. The LCI for zinc analyzes the energy consumed and emissions created from mining, concentration, and refining. The refined zinc is sent to the galvanizer’s facility in large blocks or ingots to be melted in the kettle. *Figure 8* shows a simplified look at zinc production. The zinc refining process also creates little waste; in fact, during the process byproducts such as copper, cadmium, and lead are separated from the zinc to be used for their own purposes.

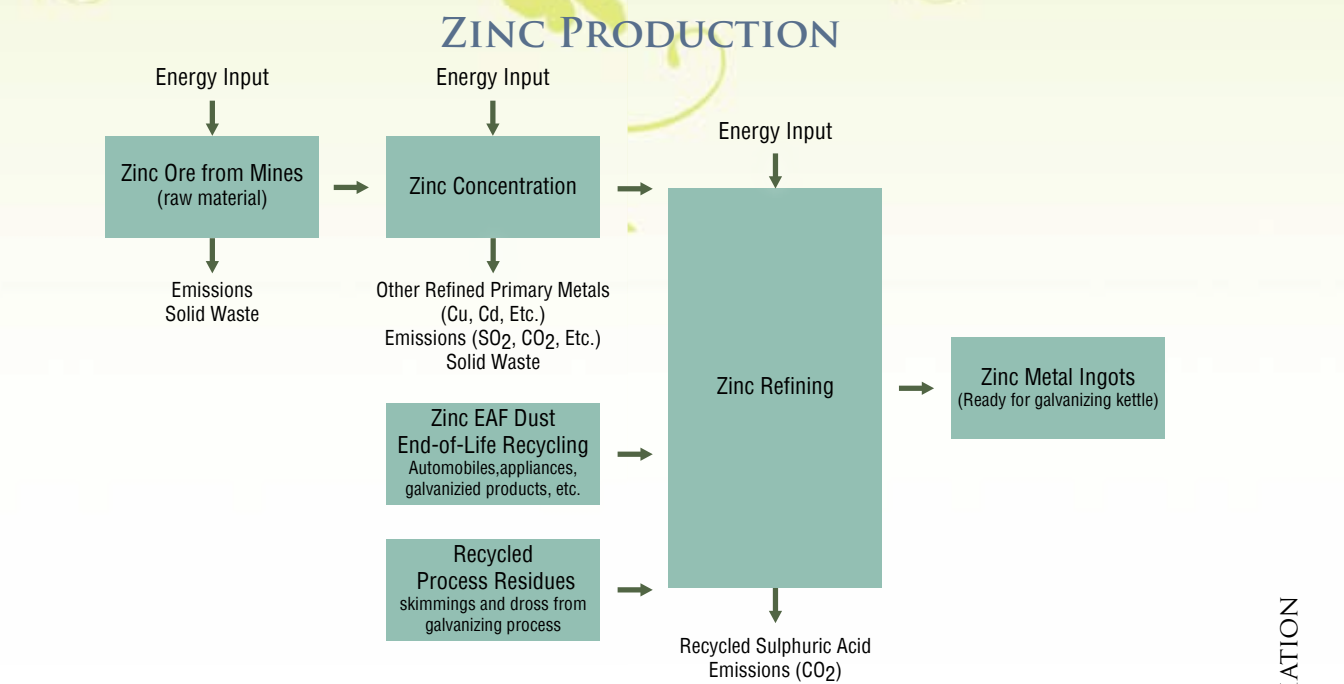


Figure 8

Utilizing worldwide data collected from the zinc industry, an LCI was conducted to determine the environmental impact of producing 1 kg of special high-grade zinc. As was explained before, the majority of the hot-dip galvanized steel product’s mass is comprised of the steel. Therefore, the values represented here for zinc are based only on the amount of zinc present in 1 kg of hot-dip galvanized product (*Figure 9*).

Zinc LCI (Cradle-to-Gate)	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO ₂ equiv.)	Acidification Potential (AP) (SO ₂ equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C ₂ H ₂ equiv.)
1 kg of HDG Steel	2.46 MJ	0.160 kg	0.00115 kg	0.000614 kg

Figure 9

Hot-Dip Galvanizing

The final step to determining the LCA production phase for hot-dip galvanizing is to evaluate the energy demands and emissions generated by the hot-dip galvanizing process itself. The gate-to-gate study considers the additional energy and emissions of the process beyond the inputs of the steel and zinc. *Figure 10* below depicts the additional products and energy required to coat the steel with zinc.

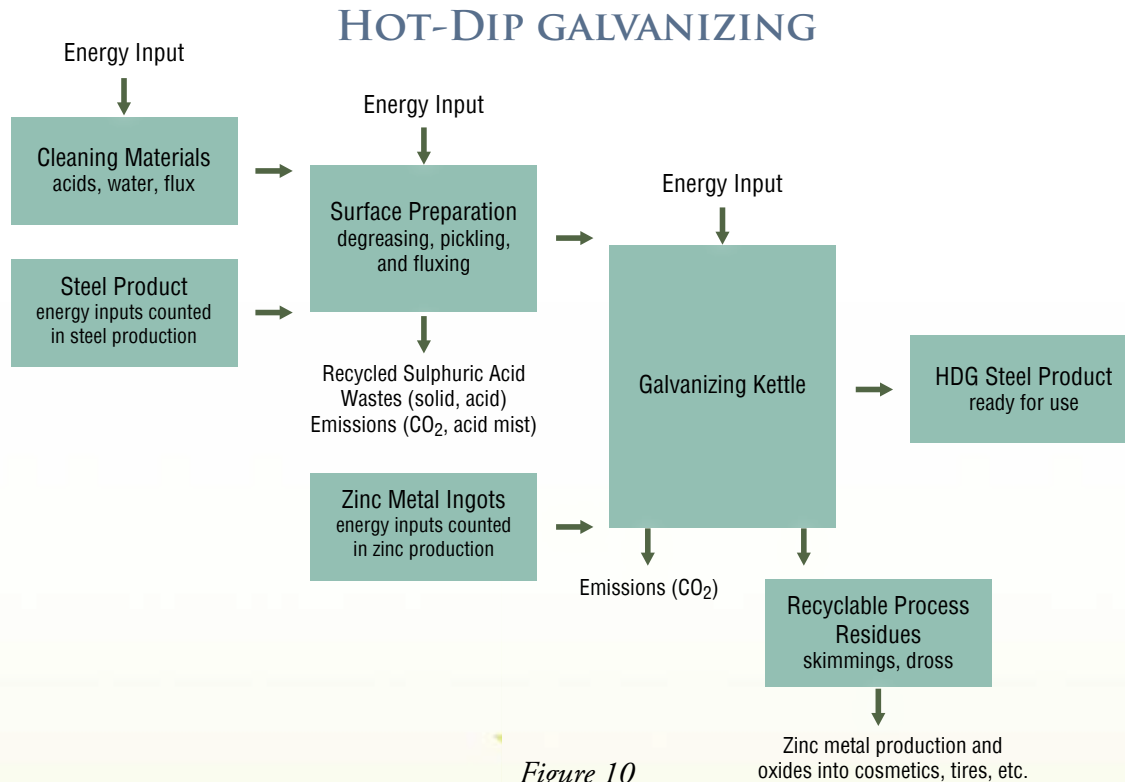


Figure 10

Utilizing world wide data collected from the galvanizing industry, an LCI was conducted to determine the environmental impact of coating steel with zinc during the hot-dip galvanizing process. The energy demand and emissions data for galvanizing had slight variations mainly due to the differences in the energy mix (electricity vs. natural gas), efficiencies within the process, and the differences in power grid mixes at various locations. Again, these average values represent only the gate-to-gate impact of the galvanizing process, excluding the impacts of the production of steel and zinc (*Figure 11*).

HDG Process Only Gate-to-Gate	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO ₂ equiv.)	Acidification Potential (AP) (SO ₂ equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C ₂ H ₂ equiv.)
1 kg of HDG	1.80 MJ	0.0991 kg	0.000407 kg	0.0000265 kg

Figure 11

LCA Production Phase

The LCA production phase for hot-dip galvanizing (cradle-to-gate) combines the PED, GWP, AP, and POCP from all three LCI's: steel, zinc, and galvanizing. Therefore, at the point when the product leaves the galvanizer's facility, the environmental impact of 1 kg of hot-dip galvanizing is shown in *Figure 12*.

Production Phase (Cradle-to-Gate)	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO ₂ equiv.)	Acidification Potential (AP) (SO ₂ equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C ₂ H ₂ equiv.)
1 kg of HDG Steel	25.9 MJ	1.80 kg	0.00615 kg	0.000824 kg

Figure 12

LCA Use Phase

The second phase of an LCA examines the additional material and energy inputs and emission outputs generated while a product is in use. As mentioned before, hot-dip galvanized steel requires no maintenance for 75 years or more. Consequently, hot-dip galvanizing accrues no additional environmental impact throughout its service-life. While hot-dip galvanizing's environmental impact is isolated to the production phase, the environmental impact of other coating systems, such as paint, increases during use (*Figure 13*). Paint, which must be maintained repeatedly throughout use, generates additional environmental impact during each maintenance cycle.

Paint coatings require regular maintenance on a predetermined cycle of 12-20 years. P₁, P₂, P₃, and P₄ (*Figure 14*) represent the additional environmental costs associated with the maintenance of painted steel. Therefore, a project with a targeted 60-year life will require at least two to four maintenance paintings. Each maintenance-cycle (whether touch-up, maintenance, or full repaint), will require additional energy and material inputs and generate emissions and waste outputs. Furthermore, there are indirect environmental costs associated with conducting maintenance, such as additional exhaust due to traffic delays/detours when maintaining a painted steel bridge.

LCA USE PHASE: HDG VS. PAINT

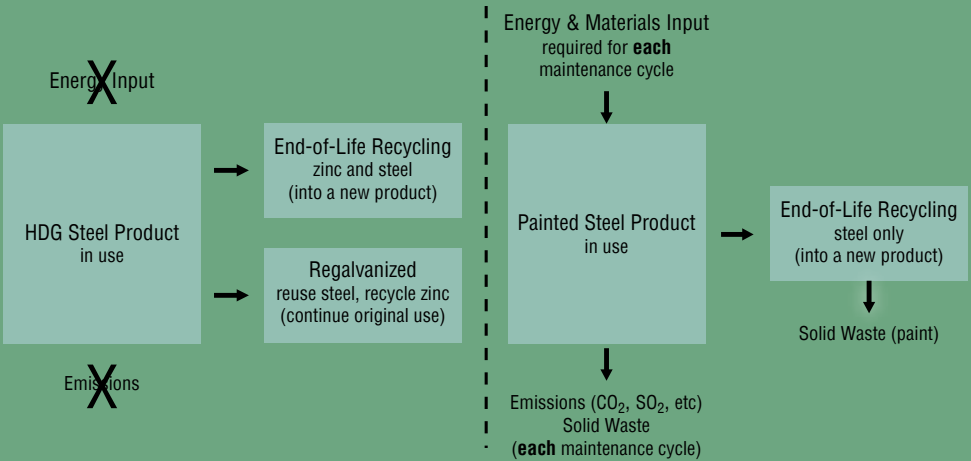


Figure 13

Use Phase	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO ₂ equiv.)	Acidification Potential (AP) (SO ₂ equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C ₂ H ₂ equiv.)
1 kg of HDG Steel	0 MJ	0 kg	0 kg	0 kg
Painted Steel	P ₁ MJ	P ₂ kg	P ₃ kg	P ₄ kg

Figure 14

LCA End-of-Life Phase

The final phase of the LCA is the end-of-life. As highlighted before, both steel and zinc are 100% recyclable without the loss of any properties. Products/materials recycled at the end-of-life receive an energy credit in LCA, as recycling cuts down or eliminates waste, and conserves energy and natural resources (virgin material) by being reused. When a structure constructed with hot-dip galvanized steel is demolished, the galvanized material is captured and sent to a steel mill for recycling. While in the electric arc furnace (EAF), the zinc is captured as zinc-rich EAF dust and can be reused in the zinc production process. The molten scrap steel is then ready to be cast into new steel shapes (*Figure 15*).

The primary component of the hot-dip galvanized product, the steel, contributes the majority of the end-of-life credit (*Figure 16*). The same credit for the steel is provided whether it is painted or galvanized. However, the zinc of the HDG coating is also 100% recyclable, while the paint coating becomes a permanent part of the waste stream, or is burned off as emissions.

Complete LCA

The complete life-cycle assessment (LCA) for hot-dip galvanizing combines the PED, GWP, AP, and POCP from the production, use, and end-of-life phases. As hot-dip galvanizing requires no additional maintenance during use, the complete LCA values mirror the production values, with the exception of the energy demand, which has decreased due to the end-of-life recycling credit (*Figure 17*).

LCA END-OF-LIFE PHASE



Figure 15

End-of-Life	Primary Energy Demand (PED)
1 kg of HDG Steel	-8.61 MJ

Figure 16

Complete LCA (Cradle-to-Grave)	Primary Energy Demand (PED)	Global Warming Potential (GWP) (CO ₂ equiv.)	Acidification Potential (AP) (SO ₂ equiv.)	Photo Chemical Ozone Creation Potential (POCP) (C ₂ H ₂ equiv.)
1 kg of HDG Steel	17.3 MJ	1.80 kg	0.00615 kg	0.000824 kg

Figure 17



Galvanizing vs. Paint in Life-Cycle Assessment (LCA): Case Studies

Although the LCI and LCA studies conducted by IZA, Five Winds, and PE International focused on hot-dip galvanizing, applying common knowledge about paint systems, the following can be inferred:

- Steel, with its high recyclability and low environmental impact, is the primary component in the LCA of both galvanized and painted steel.
- Hot-dip galvanizing has less environmental impact than paint during the use phase, as HDG requires no maintenance.
- At end-of-life, the zinc of the galvanized coating is recycled, making HDG 100% recyclable, while paint coatings enter the permanent waste stream or create emissions.

Although the mass of the coating, whether galvanizing or paint, may seem minimal compared to that of the steel, when you consider entire structures utilizing thousands or even millions of kilograms of steel, the importance of the additional environmental impact produced by the coating is more evident. To highlight the difference the coating has on the overall environmental impact, consider the following case studies utilizing published environmental information.



Case Study 1: Balcony Structure

VTT Technical Research, renowned for establishing environmental product declarations (EPDs) for building products, conducted life-cycle assessments (LCAs) comparing a hot-dip galvanized balcony to a painted balcony of identical design³. The goal of the study was not only to measure the sustainability of hot-dip galvanized steel, but also to establish a baseline for future improvements. The study demonstrates although the steel comprises the majority of both balconies, the coating is a significant part of the LCA profile.

The environmental assessments of the balconies were based on the following parameters:

- 60-year service life
- 1,715 lbs (778 kg) galvanized steel; 420 ft² (39 m²) painted steel
- Galvanized coating corrosion rate of 0.5 – 1.0 microns per year (ISO 14713)
- Paint system: zinc-rich epoxy primer (40 microns), epoxy intermediate (160 microns), polyurethane topcoat (40 microns)
- Paint Maintenance: year 15, 30, and 45 (ISO 12944)

The environmental impact criteria examined were the same as the LCI/LCA study: primary energy demand (PED), global warming potential (GWP), acidification potential (AP), and photochemical ozone creation potential (POCP). The results show the durability of the coating plays a huge role in the overall environmental impact. The three maintenance-cycles required for the painted balcony account for almost half of the energy requirement for the painted structure, while the galvanized balcony required no additional material or energy inputs. The following graphs illustrate the total PED of each phase of the LCA, the percentage of the PED consumed by the coating, and the GWP, AP, and POCP values.

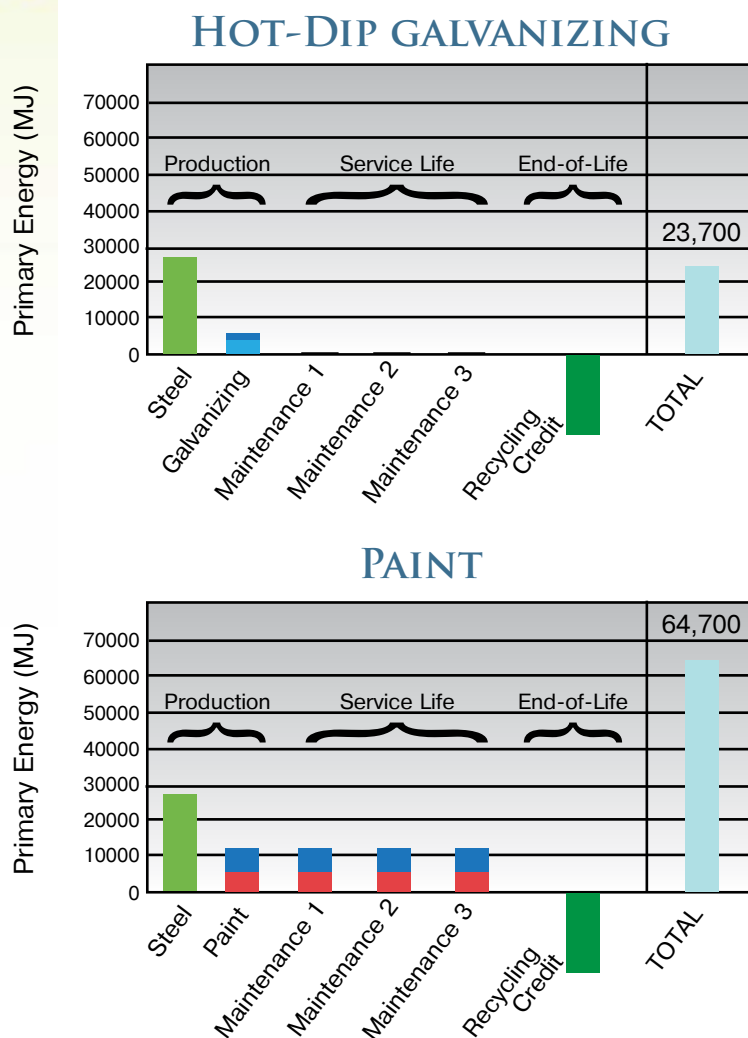


Figure 18: Life-Cycle Energy: HDG vs. Paint

Figure 18 shows the total primary energy demand (PED) for the hot-dip galvanized balcony is 23,700 MJ (30.5 MJ/kg), or just 37% of the 64,700 MJ (83.2 MJ/kg) required for the painted balcony. Keep in mind, if the painted balcony is left in service for even one more year, an additional maintenance-cycle would be required and more energy demand and emissions would be added to the values shown, while the galvanized balcony will remain untouched.

The difference in the energy demand for each balcony structure is even more striking when you consider the percentage of the total energy attributed to the coating. Galvanizing only contributes 16% of the total energy demand, where paint contributes 69% by the end of the 60-year life (Figure 19). According to the study, each paint maintenance cycle consumes an amount of energy equal to that used in the original production, while galvanizing protects the steel throughout the entire 60-year life without maintenance.

In addition to the energy savings, there are significant differences in GWP, AP, and POCP. For each indicator, galvanizing has a fraction of the environmental impact of the paint coating (Figure 20).

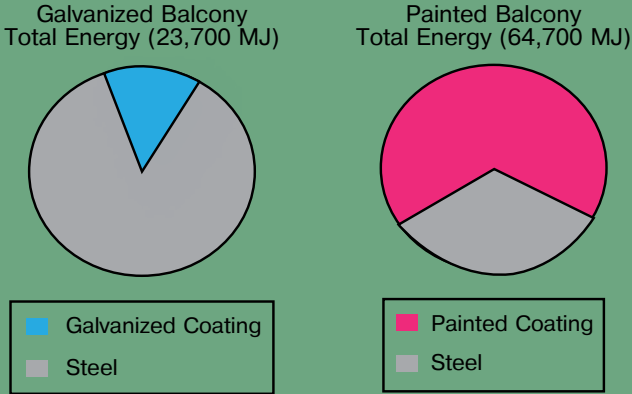


Figure 19: Coating Energy Consumption: HDG vs. Paint

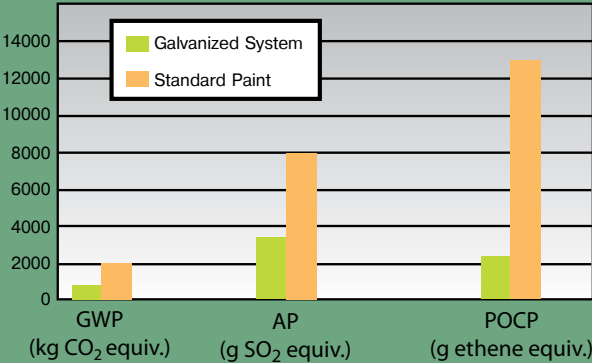


Figure 20: Emissions: HDG vs. Paint



Case Study 2: Parking Garage

The Institute for Environmental Protection Technology at the Technical University of Berlin conducted life-cycle assessments (LCAs) comparing a hot-dip galvanized parking structure to a painted one⁴. Similar to the VTT Technical Research study, the Technical University of Berlin strived to determine the environmental impact of hot-dip galvanizing as well as establish a benchmark for future improvements. The results of the study demonstrate once again the significant impact the coating plays in the overall environmental impact of the parking garage.

The following parameters were used in the parking structure study:

- 60-year service life
- 1 m² steel part (20m²/metric ton)
- Galvanized coating corrosion rate of 1 micron per year (ISO 1461, C3 environment)
- Paint system: 3-coat system, 240 microns thick
- Paint Maintenance: year 20 and 40 (ISO 12944)

This study also examines the PED, GWP, AP, and POCP values for each system. The results for each impact area are much less for the hot-dip galvanized garage than for the painted one. Similar to the painted balcony, the two maintenance cycles required for the painted garage significantly increase the resource and energy consumption of the painted garage. As galvanizing requires no maintenance during the 60-year life, the total energy and resource consumption for the galvanized structure is only 32% of that required for the painted garage, and the GWP is 38% of paint. Furthermore, the AP is 15% less than paint, and the POCP 33% less (*Figure 21*).

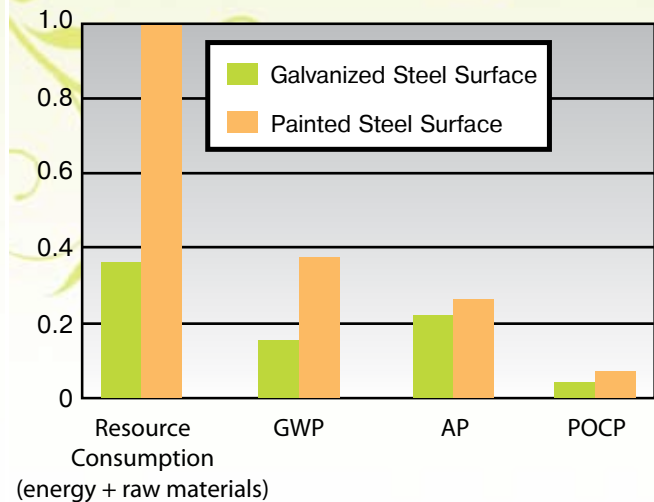


Figure 21



ECONOMIC PERFORMANCE OF HOT-DIP GALVANIZED STEEL

In addition to environmental impact, true sustainable development must also consider economic impacts. Similar to environmental analyses, to understand the complete cost of a corrosion protection system, one must look beyond initial cost to the life-cycle cost (LCC). Life-cycle cost (LCC) is the analysis of the true cost of a coating system over its entire service life. LCC considers initial costs, touch-up costs, maintenance costs, coating costs, inflation, and opportunity costs. Too often, specifiers base their decisions on initial cost alone; a potentially crippling mistake for future generations.

When selecting a corrosion protection system based solely on initial cost, specifiers fail to consider the cost of future maintenance, which also often means a failure to earmark money in future budgets for that maintenance. This all too common oversight contributes to the increasing corrosion problem throughout North America.

The most recent estimates, as reported in a 2001 study conducted by NACE, FHWA, and CC Technologies, show metallic corrosion costs the US economy \$297 billion per year, or 3% of the GDP. However, the \$297 billion only reflects the direct cost of corrosion. There are also indirect costs (traffic delays, lost commerce, safety, etc.) to consider, which can be 5-11 times greater than direct costs. Although corrosion is a natural phenomenon – and thus can never be completely eliminated – it is a misconception nothing can be done. One of the quickest and most effective ways to cut the cost of corrosion is to specify and budget for corrosion protection systems based on life-cycle cost.



“ Life-cycle cost (LCC) is the analysis of the true cost of a coating system over its entire service life. LCC considers initial costs, touch-up costs, maintenance costs, repainting costs, inflation, and opportunity costs. ”

Initial Cost

When selecting a corrosion protection system, initial cost will always be considered. Initial cost takes into account all of the labor and material costs for producing the coated product. Many specifiers erroneously believe hot-dip galvanizing is not economical on an initial cost basis. However, when considering common 2- and 3-coat paint systems used for corrosion protection, hot-dip galvanizing is very cost competitive.

Life-Cycle Cost

In order to meet the economic component of sustainable development, life-cycle cost (LCC), which can be quite cumbersome to calculate, must also be considered. As hot-dip galvanizing provides maintenance-free performance for 75 years or more in most environments, its life-cycle cost is almost always the same as its initial cost. Conversely, painted systems require routine maintenance on a predictable schedule, which increases the cost of the system over the life of the project. Consequently, when analyzing LCC, hot-dip galvanizing has an unquestionable advantage over paint systems.

Galvanizing vs. Paint in Life-Cycle Cost (LCC): Case Studies

To facilitate the calculation of LCC, the American Galvanizers Association (AGA) developed an automated, online calculator at www.galvanizingcost.com. The LCC calculator uses paint data collected from a worldwide survey conducted by KTA Tator, Inc. and published in a paper presented at the National Association of Corrosion Engineers (NACE) conference in 2006⁵. The galvanizing information was collected from a 2006 nationwide survey conducted by AGA, and excludes any fabricator markup.

To demonstrate the economic advantages of utilizing hot-dip galvanized steel, the following case studies were run on the automated calculator (www.galvanizingcost.com). To correlate economic impact with environmental impact, LCC analyses were run on balcony and parking structures similar to the environmental case studies. Some logical assumptions about the mix of the steel products, paint system and application used, etc. were made when the information was unavailable. Similar to the environmental impacts, the coating system also has huge implications in LCC.



Case Study 1: Balcony Structure

The following parameters were used in the LCC comparison for the balcony structures:

- 60-year service life
- C3 Medium Corrosion environment
- Light structural pieces: 1.05 tons (420 ft²)
- Inorganic Zinc primer: SP 10 automated surface prep, spray application in the shop
- Epoxy intermediate: two-pack product, spray application in the shop
- Polyurethane topcoat: two-pack product, spray application in the shop
- 2% inflation, 4% interest

The initial and life-cycle costs for the paint and galvanizing are shown in *Figure 23*:

Coating System	Initial Cost		Life-Cycle Cost		AEAC ^a
	Per ft ²	Total	Per ft ²	Total	Per ft ²
Hot-Dip Galvanizing	\$1.10	\$ 462	\$1.10	\$ 462	\$0.05
IOZ/Epoxy/Polyurethane	\$3.10	\$1,289	\$9.69	\$4,070	\$0.43

^aAverage Equivalent Annual Cost per ft²

Figure 23

Even for the relatively small amount of steel utilized in the balcony, the hot-dip galvanized balcony reduces the total cost over the life of the structure by 88%. The costs represented here may not seem like much, but the difference between the costs of the coatings is clear. Consider if you were developing a multi-family residential building, and were planning to install 100 identical balconies. Which coating would you choose?





Case Study 2: Parking Garage

The parking garage LCC comparison was based on the following parameters:

- 60-year service life
- C3 Medium corrosion environment
- Typical mix size/shapes: 3,000 tons steel (750,000 ft²)
- Inorganic zinc primer: SP-10 automated surface prep, spray application in the shop
- Epoxy intermediate: two-pack product, spray application in the shop
- Polyurethane topcoat: two-pack product, spray application in the shop
- 2% inflation, 4% interest



The initial and life-cycle costs for the paint and galvanizing are shown in *Figure 24*:

Coating System	Initial Cost		Life-Cycle Cost		AEAC ^a
	Per ft ²	Total	Per ft ²	Total	Per ft ²
Hot-Dip Galvanizing	\$1.76	\$1,320,000	\$1.76	\$1,320,000	\$0.08
IOZ/Epoxy/Polyurethane	\$2.30	\$1,725,000	\$7.27	\$5,451,272	\$0.32
^a Average Equivalent Annual Cost per ft ²					

Figure 24

Although the same paint system applied to the parking garage costs slightly less than for the balcony, it is still initially more expensive than the hot-dip galvanized structure. Initially, the hot-dip galvanized parking structure provides a 23% savings over paint. However, when the life-cycle costs are considered, hot-dip galvanizing provides a 76% savings over the painted garage.

SOCIAL PERFORMANCE OF HOT-DIP GALVANIZED STEEL

The third aspect of sustainable development, social ramifications, is a bit harder to measure. However, there are some inherent positive social impacts for utilizing hot-dip galvanizing. The social aspect of sustainable development is woven within both the environmental and economic impact, and is most easily measured by improvements to quality of life and social progress. In addition to characteristics already discussed, such as its maintenance-free durability and longevity, hot-dip galvanizing provides positive social impact in the area of safety. The purpose of utilizing hot-dip galvanizing is to minimize corrosion. Less corrosion of infrastructure, buildings, electricity grids, etc. translates to a healthier, safer world. As North America's infrastructure continues to age and deteriorate faster than it can be maintained, the likelihood of a potential life-threatening disaster also rises.

Additionally, hot-dip galvanizing can help minimize the damage of natural disasters. Hot-dip galvanizing meets the new, stricter seismic standards, written to make structures more durable in earthquakes. History also shows hot-dip galvanized earth anchors minimize the damage to mobile homes during tornadoes and galvanized transmission and distribution poles maintain service during natural disasters such as hurricanes.

In addition to the many social benefits hot-dip galvanizing attributes to the built environment, the hot-dip galvanizing industry strives to improve our current social, economic, and environmental position. The industry adopted a Sustainable Development Charter in 2005 providing a commitment to responsibly manage all environmental and human health risks keeping employees, citizens, and the community safer. Furthermore, rather than rest confidently in our current position, the industry actively participates in research aimed at improving the sustainability and efficiency of the galvanizing process and hot-dip galvanized products.



SUMMARY

Sustainable development is a vital aspect of the present and future built environment. And although there are a number of different methods for measuring sustainability, they all ultimately have the same goal – to build as necessary for the present without compromising the future. Hot-dip galvanized steel is uniquely positioned to largely contribute to building a sustainable future. Steel alone is a vital and necessary part of modern construction,

but its susceptibility to corrosion when left exposed is a detriment to sustainable development. Coating the steel with zinc through the hot-dip galvanizing process protects steel from corrosion with minimal environmental, economic, or social impacts. Therefore, utilizing hot-dip galvanized steel can anchor the sustainable revolution by fulfilling the goal of sustainable development without compromising the ability for future generations to do the same.



FOOTNOTES

¹ *Six Signs of Greenwashing*, TerraChoice Environmental Marketing Inc., 2007

² LEED®-NC Versions 2.2 and 2009

³ Vares, S., Tattari, K., Hakkinen, T. 2004. *Life-Cycle Assessment study for hot-dip galvanized balcony system compared with painted balcony system*. Results. Research report No. RTE1324/4 (confidential), VTT, 57 pages

⁴ Woolley, Tom B. Arch. PhD, *Galvanizing and Sustainable Construction: A Specifiers' Guide*, 2008

⁵ NACE Paper #6318 Expected Service Life and Cost Considerations for Maintenance and New Construction *Protective Coating Work* (Helsel, Melampy, Wissmar)



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