Hot-Dip Galvanizing for Sustainable Design

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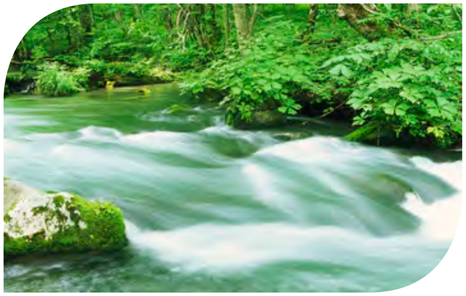



Hot-Dip Galvanizing for Sustainable Design

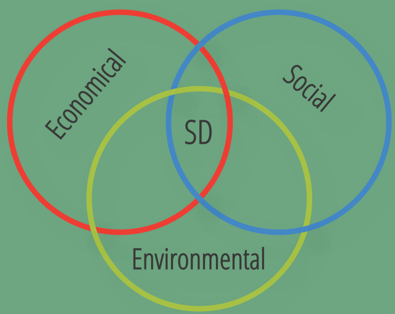
The Industrial Revolution dominated the 18th and 19th centuries, and many would argue the 20th century brought about the technology revolution. Considering all of the world's advancements in the last 300 years, one must wonder what progress the 21st century will hold. If the first decade is any indication,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

Sustainable development (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 own 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.

As the surge of environmental awareness increases, so do the number of false or misleading green marketing claims, known as greenwashing; therefore, it is necessary to educate specifiers and consumers about how to distinguish true sustainability from false claims. 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. Steel is a resilient building material,;however, when left unprotected and exposed to the atmosphere, it can succumb to corrosion; thus, steel used in these environments must be coated to improve its durability and longevity.

Sustainability is intrinsic to hot-dip galvanizing (HDG), the process of metallurgically bonding zinc to steel, and is a message the galvanizing industry promoted long before sustainable development was a trend. Not only does hot-dip galvanizing provide decades of maintenance-free longevity, but its primary components, zinc and steel, are natural, abundant and 100% recyclable – making hot-dip galvanized steel an infinitely renewable building material.

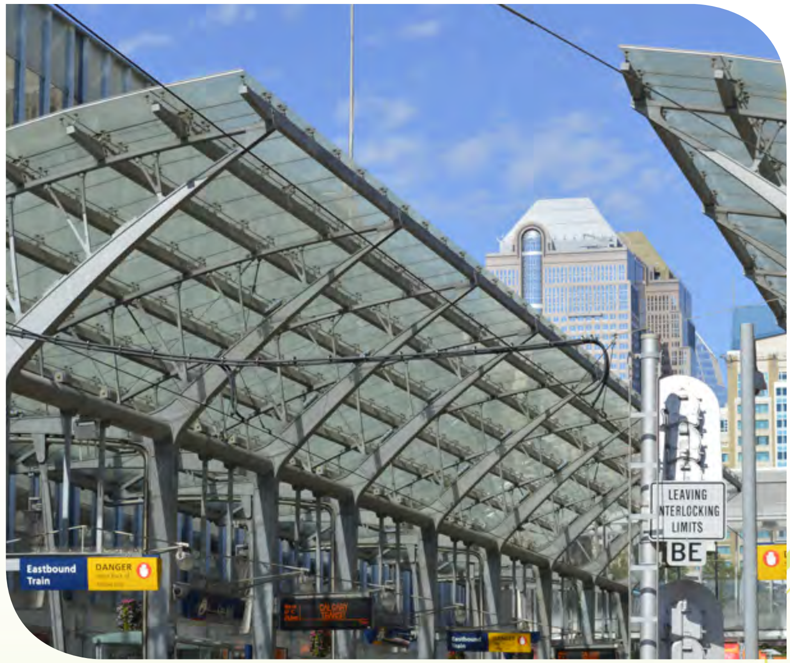
Hot-dip galvanizing is a proven steel corrosion protection system that transcends time with minimal economic or environmental impact. Utilizing hot-dip galvanized steel ensures less natural resources are consumed, less emissions are output, and less money is spent over the life of a project. This publication will quantifiably establish how hot-dip galvanized steel can positively contribute to the sustainable development revolution and protect the quality of life for future generations.



Steel + Zinc
The Healthy Metal

Before we examine the impact of hot-dip galvanized steel to the environment, it is import to understand the primary components of the corrosion protection system – zinc and iron– are naturally occurring, abundant elements. Iron ore (the main constituent in steel) is the 4th most abundant element in the Earth's crust, and zinc, which comprises 98% of the hot-dip galvanized coating, is the 24th.

Zinc naturally exists in the air, water, and soil – as most rocks and many minerals contain zinc in varying amounts. Annually, more than 5.8 million tons of zinc are naturally cycled through the environment by plant and animal life, rainfall, and other natural phenomena. The amount of zinc present in the environment varies from place to place and season to season. During the course of evolution, all living organisms have adapted to the zinc in their environment and use it for specific metabolic processes.



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

In fact, zinc, known as the healthy metal, is essential to life. All living things, from the smallest microorganisms to humans, require zinc to live. Zinc plays a critical role in cell division, growth, and wound healing, and also plays an important part in daily, bodily functions such as breathing, digestion, reproduction, and cognition. Of all micronutrients, zinc has the strongest effect on our immune system which can help prevent disease and fight infection.

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. Children are the most affected by inadequate zinc, and more than half of these annual deaths (450,000) are children under the age of five. To help combat this vulnerability, the International Zinc Association (IZA) partnered with UNICEF to develop the Zinc Saves Kids program (zincsaveskids.org).

Zinc is also common in day-to-day life; in fact, zinc oxides and other compounds are used in a number of household products. In addition to zinc-fortified foods, zinc is found in all sunscreens, as zinc oxide blocks more UV rays than any other single ingredient. Zinc is also found in cosmetics, tires, as well as in treatments for sunburn, diaper rash, acne, common colds, burns, and much more. However, one of the oldest and most common uses for zinc is in construction – as a corrosion resistant coating for steel.

Infinitely Renewable Resources

In addition to being natural and abundant, both zinc and steel are infinitely recyclable without the loss of any physical or chemical properties. This means rather than being down-cycled into other, lesser products, zinc and steel can be used as zinc and steel again and again without compromising their integrity. Therefore, hot-dip galvanized steel is a cradle-to-cradle product, as there is essentially no "grave" for the zinc or steel.

The 100% recyclability of hot-dip galvanized steel is a great benefit to minimizing environmental impact, but it is only half of the story. The ability of both zinc and steel to be recycled is important, but to capitalize on the positive contribution, they must actually be reclaimed for re-use. Therefore it is important to consider both the recycled content (amount of a product produced from recycled sources), and reclamation rate (how often a product is actually recycled at the end of its useful life). Steel is the most recycled material in the world, and zinc has a very high reclamation rate – and often the reclaimed zinc and steel are put right back into use (*Table 1*).

	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.

Table 1

Hot-Dip Galvanizing

Hot-dip galvanizing (HDG) is the process of immersing fabricated steel or iron into a kettle (bath) of molten zinc. There are three fundamental steps in the hot-dip galvanizing process: surface preparation, galvanizing, and inspection *(Figure 1)*.

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, chemical cleaning and fluxing. Degreasing removes dirt, oil, and organic residues, while the acidic chemical cleaning 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.

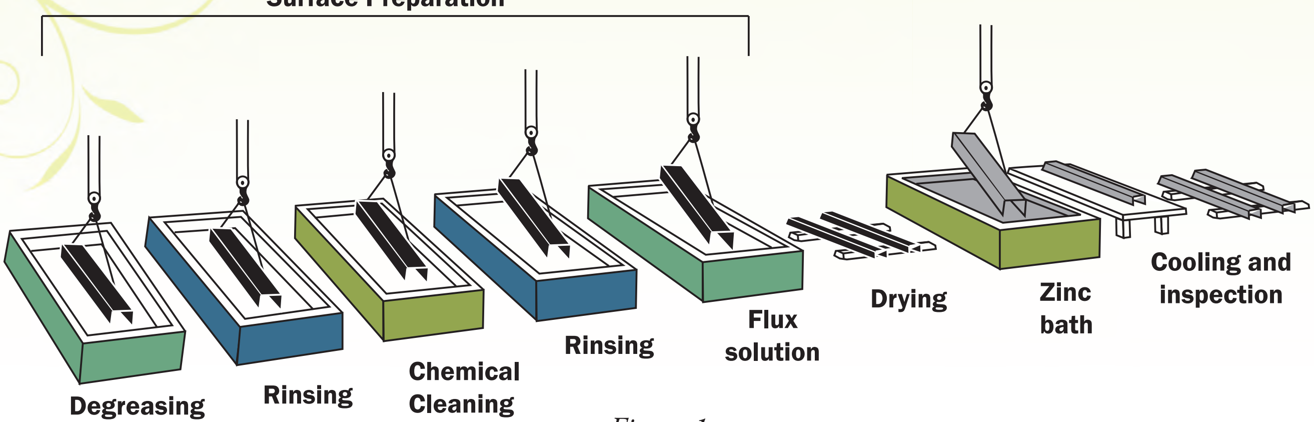


Figure 1

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.

HDG Benefits

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 2*). However, even if the coating were damaged, zinc's sacrificial action will protect exposed steel up to ¼ inch away.

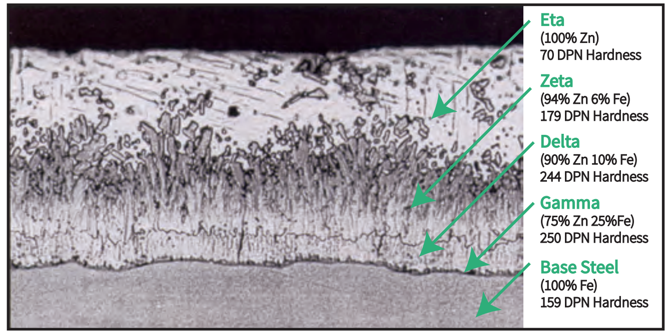


Figure 2

In addition to the cathodic protection offered by hot-dip galvanizing, there are a few other characteristics of the coating which provide longevity. First, the diffusion reaction that takes place in the galvanizing kettle 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, and complete coverage, 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 3*. For more information on the benefits of utilizing hot-dip galvanized steel, please see the AGA's publication *Hot-Dip Galvanizing for Corrosion Protection: a Specifier's Guide.*

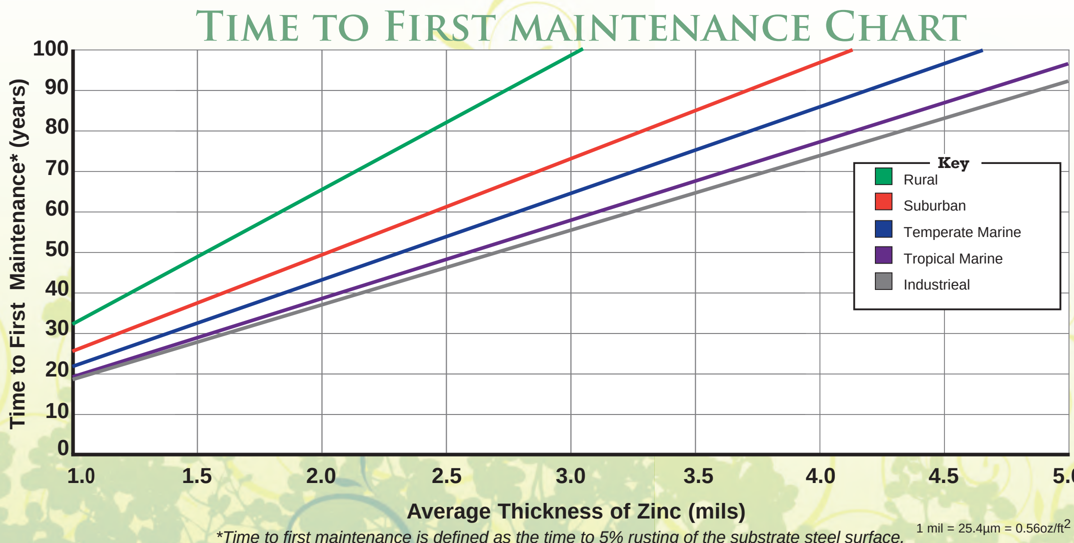


Figure 3

Environmental Performance of hot-dip galvanized steel

The production of any building material requires material and energy inputs and emission and waste outputs. The key to sustainable development is to ultimately lower the environmental impact of producing a product, through optimization of manufacturing. Specifiers who are committed to sustainable development have pushed for more transparency and objective measures of building materials' environmental impact in order to select those with less burden to current and future generations.

HDG & LEED®

In 2013, the USGBC approved the LEED® v4 rating system, which was fully integrated in October 2016. The new system included a revamped Materials & Resources credit area that targets more transparency in materials to facilitate the selection of more sustainable building products. In the past, LEED® was more subjective and prescriptive, but v4 focuses on more objective measures to assess the sustainability of a building.

In LEED® v4, the Materials are Resources credit category has moved away from single criterion such as recycled content, VOC levels, etc., to a comprehensive approach to evaluate the environmental impact of building materials. The new Building Product Disclosure and Optimization (BPDO) credits are directly related to material transparency and supply chain responsibility.

There are three main BPDO credits within the Materials and Resources area[1]: Environmental Product Declarations (EPDs), Sourcing of Raw Materials, and Material Ingredients (Health Product Declarations (HPDs)). Each BPDO credit has one to three points available and require the project team to collect and submit information on at least 20 materials from five different manufacturers to achieve a point under Option 1.

The American Galvanizers Association (AGA) has published an industry-wide (generic) EPD for hot-dip galvanized steel including hot-rolled sections ,plate, and hollow structural sections (HSS). According to the BPDO Credit for EPD, this industry-wide EPD can be submitted for one-half of a product. The EPD is available from UL Environment, Inc., or can be downloaded from galvanizeit.org/epd.

Additionally the AGA has developed Health Product Declarations (HPDs) based on the type of zinc a galvanizer uses in his process – high grade/special high grade or prime western. These HPDs link to Safety Data Sheets (SDS) on the zinc products which include the chemical inventory data necessary to count as one product toward the requirement. The HPDs can be found through HPD Collaborative, or can be downloaded from galvanizeit.org/hpd.

Measuring Sustainable Development

Specifiers may use a number of environmental impact assessment methods to measure how sustainable a product or process is; however, all methods have strengths and weaknesses. One of the most well-known green rating systems is the US Green Building Council's Leadership in Energy and Environmental Design (LEED), but other standards such as the International Green Construction Code (IgCC) are also becoming more commonplace. Most rating systems and standards/codes evaluate environmental impact through measuring resource/energy inputs and emission/waste outputs. The following is a list of terms that will be useful when considering sustainability.

Environmental Product Declaration (EPD) is a standardized way of quantifying environmental impact of a product from an LCA, according to designated Product Category Rules (PCRs) and verified by a third-party in accordance with ISO 14025.

Greenwashing is the act of misleading consumers about the environmental practices of a company or the benefits of a product or service[2].

Health Product Declaration (HPD) is a material ingredients list or chemical inventory of a product to 0.1% (1000 ppm), similar to a Safety Data Sheet (SDS).

Leadership in Energy and Environmental Design (LEED) is a third-party certification rating system developed by the US Green Building Council (USGBC) for the design, construction, and operation of high-performance green buildings.

Life-Cycle Assessment (LCA) is a method to calculate the lifetime environmental impact of a product from raw material acquisition to end-of life, or a cradle-to-grave study.

Life-Cycle Cost (LCC) is the total monetary cost (initial and maintenance) of a product throughout its lifetime.

Life-Cycle Inventory (LCI) is the data collection portion of an LCA that consists of detailed tracking of all the flows in and out of a product system, including raw materials, energy, and emissions, or an inventory of the cradle-to-gate.

Product Category Rules (PCR) define the rules and requirements for EPDs of a certain product category. They are a key part of ISO 14025 as they enable transparency and comparability between EPDs.

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 own needs.

Throughout the EPD 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 total renewable and non-renewable energy consumed in the manufacture of a product.

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 MegaJoule (MJ) is one million Joules.

Global Warming Potential (GWP) measured in Kilograms CO_2 equivalent (100 years), is greenhouse gass that gets trapped in the troposphere and have the potential to gradually increase over time the average temperature of Earth's atmosphere.

Acidification Potential (AP) measured in Kilograms SO_2 equivalent, is the amount of hydrogen ions created when a substance is converted into an acid, Known as acid rain.

Eutrophication Potentional (EP) measured in Kilograms N equivalent, is the enrichment of nutrients in water/soil that destroys the ecosystem.

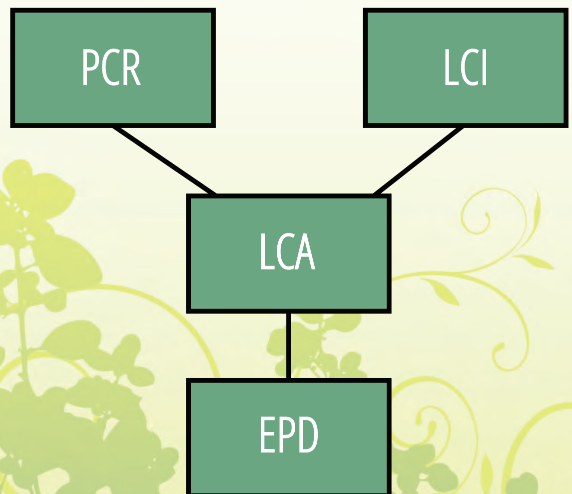
Photochemical Ozone Creation Potential (POCP) measured in Kilograms O_3 equivalent, is the creation of summer smog, or increased levels of ozone at ground level.

Environmental Product Declaration (EPD)

In 2016, the AGA released an industry-wide Environmental Product Declaration (EPD) developed by world-renown environmental firm thinkstep, Inc. and verified by UL Environment, Inc. The background life-cycle assessment utilized galvanizing data collected from the AGA, zinc information collected from the International Zinc Association (IZA), and steel/fabrication information from the American Institute of Steel Construction (AISC), Steel Tube Institute (STI), and the GaBi database.

The EPD covers galvanized hot-rolled structural steel, plate, and hollow structural sections (HSS). In addition to the full EPD, the AGA released three transparency briefs – one on each product type. The EPD and briefs were developed in accordance with ISO 14025 including background LCA in accordance with ISO 14040/14044 standards according to the product category rule (PCR) for *North America Designated Steel Construction Products.*

The EPD is a cradle-to-gate study representing the raw materials supply (A1), transport (A2), and manufacturing stages of hot-dip galvanized steel (A3), as well as the benefits associated with the recovery of zinc scrap during the galvanizing process (D). The raw material stage (A1) accounts for raw material acquisition of both the steel and the zinc, as well as steel-making and fabrication (*Figure 4*) and zinc concentration and refining (*Figure 5*). The manufacturing stage (A3) accounts for the application of the zinc metal to the steel through the hot-dip galvanizing process (*Figure 6*). The credit (D) only accounts for recycling during the production of the hot-dip galvanized coating (zinc dross and skimmings), and not for the full recyclability of the hot-dip galvanized steel product at the end of life.



A1: Steel Production

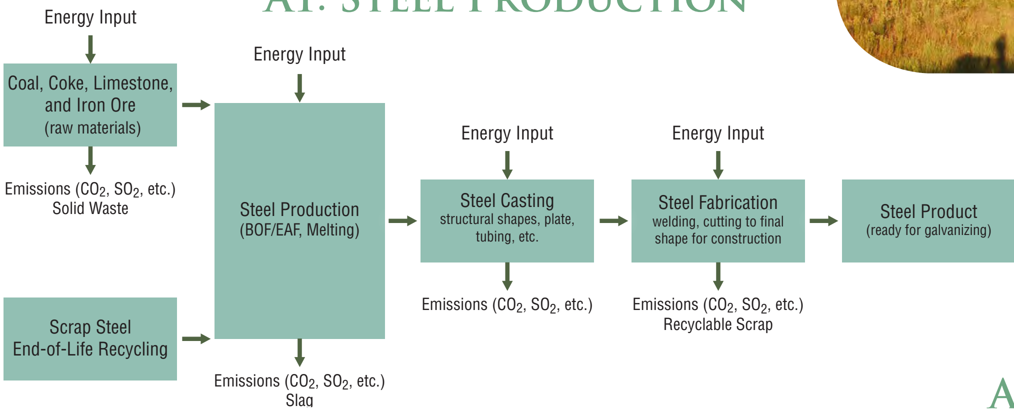


Figure 4

A1: Zinc Production

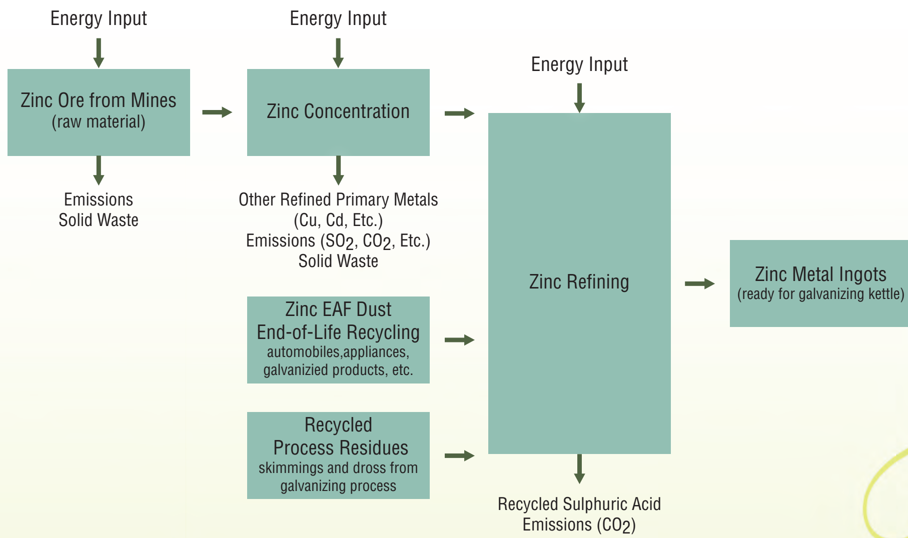


Figure 5

A3: Hot-Dip galvanizing

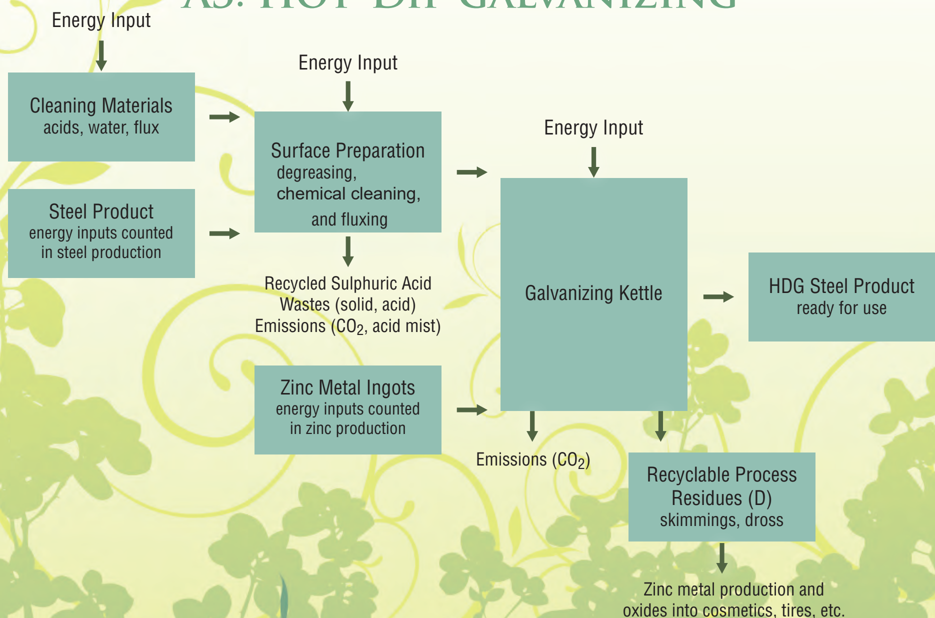


Figure 6

Each of the three products studied (hot-rolled sections, plate, and hollow structural sections (HSS)), used the same data for A2, A3, and D, as the raw material and energy input and emission outputs are virtually identical. However, the A1 data does change for each product, based on the steel-making and fabrication requirements (*Table 2*). Looking at all three products input and output flows using the US EPA's TRACI 2.1 methodology, the EPD shows the overall impact of the galvanizing process is minimal in comparison to the raw materials supply. In each of the three products, the hot-dip galvanized coating application accounts for no more than 15% of the total energy or impact, and in the case of HSS, the HDG is no more than 10% (*Figure 7*). To view the full EPD, please visit galvanizeit.org/epd.

Environmental Product Declaration

	Hot-Rolled Structural Sections	HDG Steel Plate	HDG Hollow Structural Sections	Credit for Zinc Recycling (All 3)
	A1-A3 Total	A1-A3 Total	A1-A3 Total	D
Renewable Primary Energy	1,010 MJ	991 MJ	1,230 MJ	-60.3 MJ
Non-Renewable Energy	18,700 MJ	22,200 MJ	31,200 MJ	-162 MJ
Total Energy	19,700 MJ	23,200 MJ	32,400 MJ	-222 MJ
Use of Secondary Material	1.02 mt	0.81 mt	0.07 mt	0 mt
Radioactive Waste	0.00876 mt	0.000804 mt	0.000579 mt	-0.0000147 mt
Materials for Recycling	0.0205 mt	0.0205 mt	0.0205 mt	0 mt
GWP (CO_2)	1.48 kg	1.79 kg	2.68 kg	-0.0156 kg
AP (SO_2)	0.00728 kg	0.00728 kg	0.0100 kg	-0.000117 kg
EP (N)	0.000216 kg	0.00029 kg	0.000509 kg	-0.00000702 kg
POCP (O_3)	0.0586 kg	0.0892 kg	0.143 kg	-0.00266 kg
ADPf (MJ)	16,500 MJ	20,000 MJ	29,600 MJ	-125 MJ

Table 2

Energy & Impact Assessment

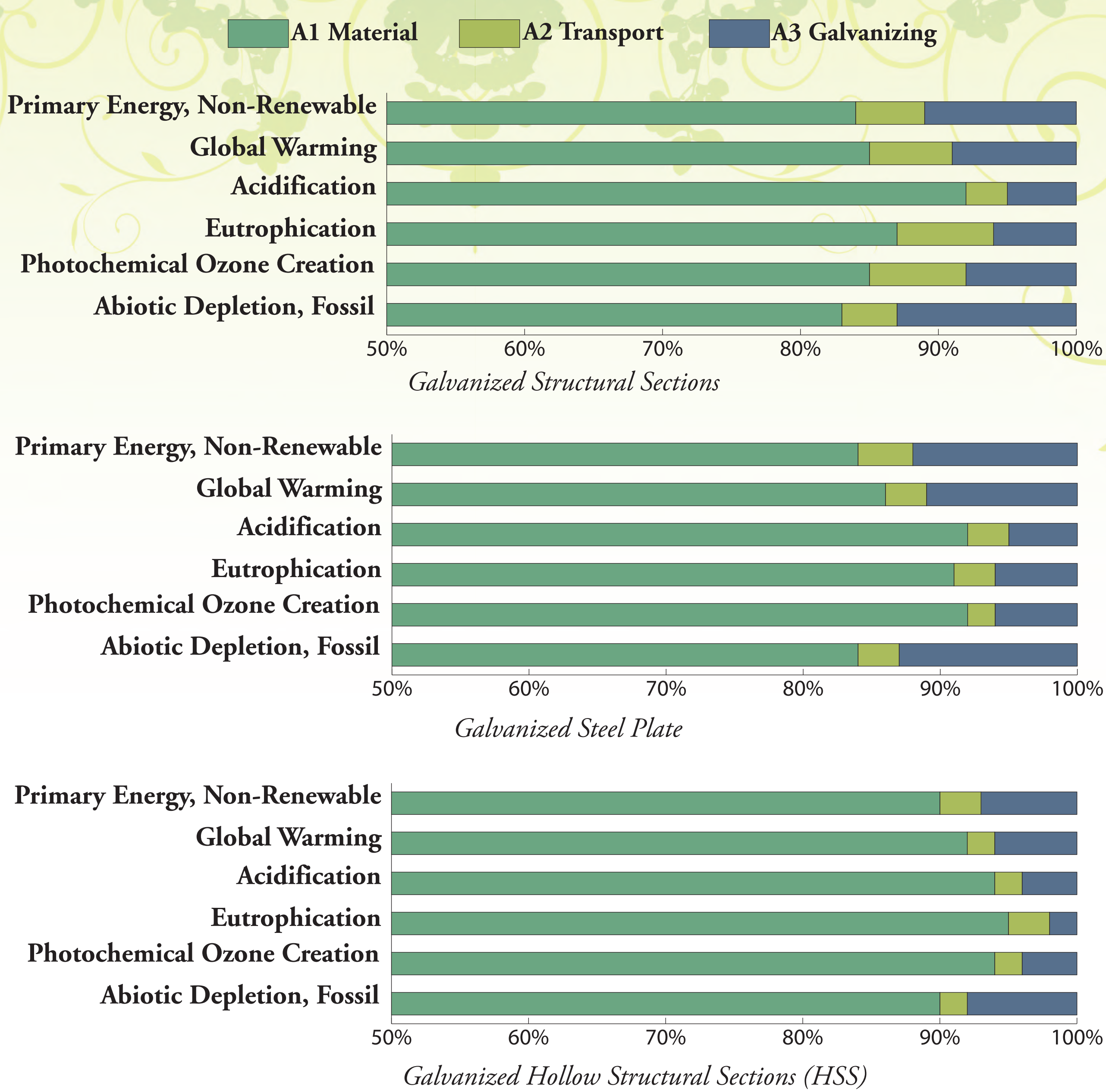


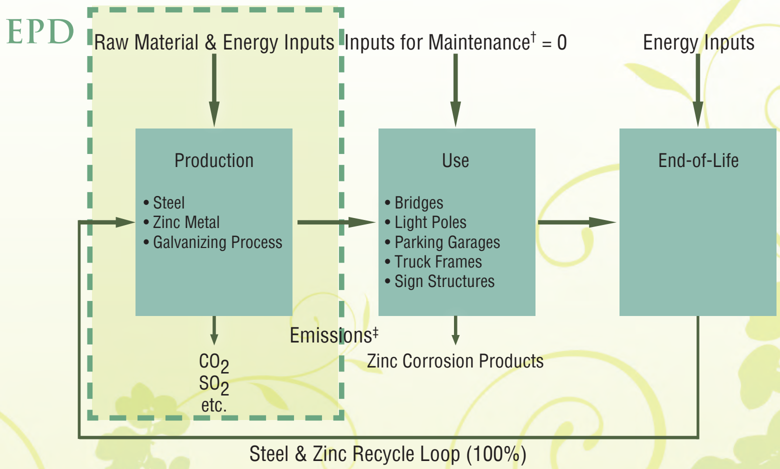
Figure 7

Life-Cycle Assessment (LCA)

The cradle-to-gate study represented in the EPD is only part of hot-dip galvanized steel's sustainability story. When evaluating hot-dip galvanizing on a full life-cycle (cradle-to-grave) basis, there are additional environmental benefits. The longevity of hot-dip galvanized steel means the raw material and energy inputs, as well as the emissions and waste outputs are isolated to the production phase, as there is no maintenance required for 70 years or more in most environments, and HDG is 100% recyclable at the end-of-life (*Figure 8*).

In contrast, many other corrosion protection systems require regular maintenance and upkeep. Each of these maintenance-cycles would require additional raw material and energy inputs, and emission and waste outputs. When looking at the simple cradle-to-gate study reported in the EPD, these additional impacts are not assessed – which prevents the specifier from understanding the full impact of the building product. When utilizing hot-dip galvanized steel, the initial environmental impact is the only impact, unless the product is in service more than 70 years.

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 8

In 2008, the AGA developed a life-cycle assessment (LCA) with thinkstep, Inc. (formerly PE International) which shows the environmental impact of hot-dip galvanized steel from the production phase to the end-of-life. The cradle-to-grave study is actually more of a cradle-to-cradle study, as both the zinc and steel of hot-dip galvanizing are 100% recyclable, essentially eliminating a "grave" for the product. The LCA took into account life-cycle inventories for structural steel, zinc, and the galvanizing process to fully understand the environmental impact of producing hot-dip galvanized steel, then added the use and end-of-life management.

In order to compare the LCA data from 2008 to the EPD study from 2015, the data from both studies were input into the EPA's TRACI 2.0 standards (*Table 3*). Looking at the average of the three products from 2015 in comparison to the 2008 average, the impacts are very similar; therefore, it is logical to assume that if the 2015 study was extended to cover use and end-of-life, the impacts would be in line with the 2008 data. Although some impact

2008 LCA Data

	PED (MJ)	GWP (kg)	AP (kg)	EP (kg)	POCP (kg)
Steel	21,640	1.55	0.00459	0.000536	0.000763
Zinc	2,460	0.160	0.00115	0.0000614	0.0000614
HDG Process	1,800	0.0991	0.000407	0.0000320	0.0000265
Total LCA Production	**25,900**	**1.80**	**0.00615**	**0.000568**	**0.000824**

Comparison of 2008 LCA to 2015 EPD*

	PED (MJ)	GWP (kg)	AP (kg)	EP (kg)	POCP (kg)
Structural (2015)	19.5	1.46	0.369	0.000201	0.0550
Plate (2015)	23.0	1.77	0.374	0.000237	0.0856
HSS (2015)	32.2	2.66	0.519	0.000362	0.1390
EPD (2015) Average	**24.9**	**1.96**	**0.420**	**0.000267**	**0.0932**
LCA (2008) Average	**25.9**	**1.81**	**0.328**	**0.000222**	**0.1050**
*Impact Assessment Method: TRACI 2.0					

Table 3

areas appear to have increased since 2008, it is important to understand there were differences in the data. Most importantly, the 2008 study relied on steel data from the GaBi database and did not fully account for fabrication of the steel, whereas the 2015 study used data from the American Institute of Steel Construction (AISC) and the Steel Tube Institute (STI), which did account for total fabrication. Additionally, the 2008 study was an international study and the 2015 study only includes North American data.

To fully understand the environmental impact of hot-dip galvanized steel, it is important to look beyond the production phase of the product to the use and end-of-life. Hot-dip galvanizing is unique because virtually all of the environmental impact is realized during production. In all but the most aggressive, corrosive environments, hot-dip galvanized steel provides 70 years or more of maintenance-free longevity, meaning during use, there is little or no environmental impact (*Figure 9*). On the other hand, paint and other corrosion protection systems often require a number of maintenance-cycles which each require energy and material inputs and create emission and waste outputs.

Furthermore, at the end-of-life, both the zinc and the steel of a hot-dip galvanized article are 100% recyclable and able to go back into the production phase to create more zinc and steel (*Figure 10*). For other coating systems, the coating would be blasted off creating waste, or burned off, creating emissions, while only the steel would be salvaged. The recyclability of both the zinc and the steel result in a primary energy demand (PED) credit when considering the full cradle-to-grave (cradle-to-cradle) study.

LCA Use Phase: HDG vs. Paint

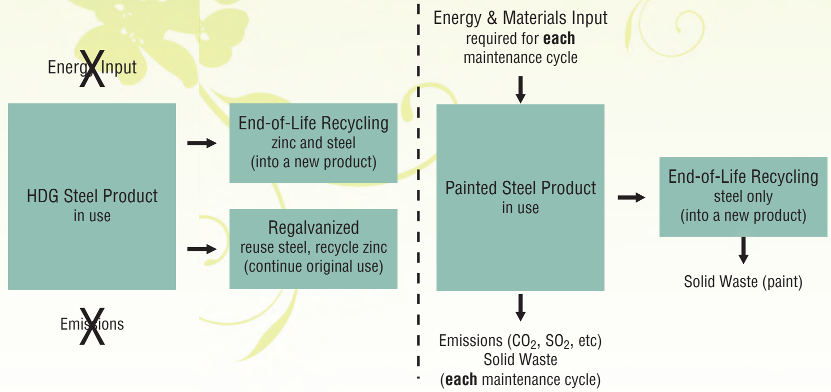


Figure 9

LCA End-of-Life Phase

Figure 10

Galvanizing vs. Paint LCA Case Studies

Although steel is the primary component of hot-dip galvanized steel, there is a significant difference in the environmental performance of hot-dip galvanizing in comparison to other corrosion protection systems. Two major differences between hot-dip galvanizing and other coatings, such as paint, are that HDG's maintenance-free longevity eliminates additional environmental impact during use, and the zinc coating is recycled at the end-of-life. These differences can lead to significant disparity in the environmental impact of steel projects, as can be seen in the following case studies.

Case Study 1: Balcony Structure

VTT Technical Research, renown 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 design[3]. 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 balcony
  - HDG Corrosion Rate: 0.5–1.0 microns per year (ISO 14713)
  - No HDG Maintenance Required
- 420ft^2 (39m^2) Painted Balcony
  - 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: 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.

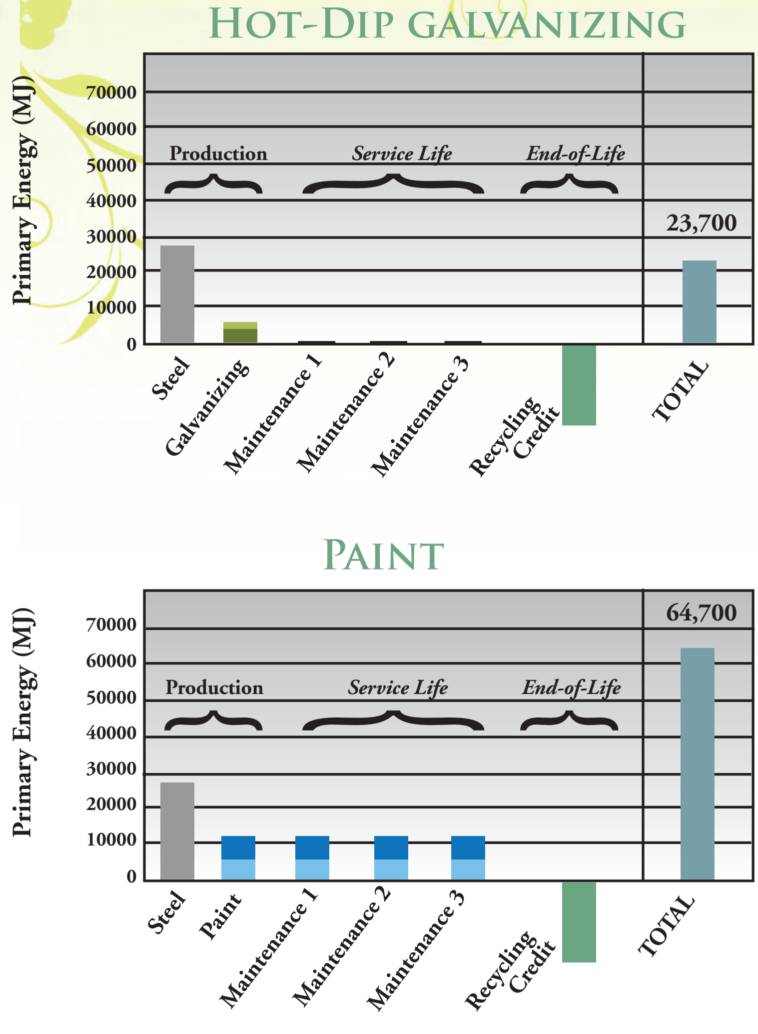


Figure 11: Life-Cycle Energy: HDG vs. Paint

Figure 11 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 12*). 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 13*).

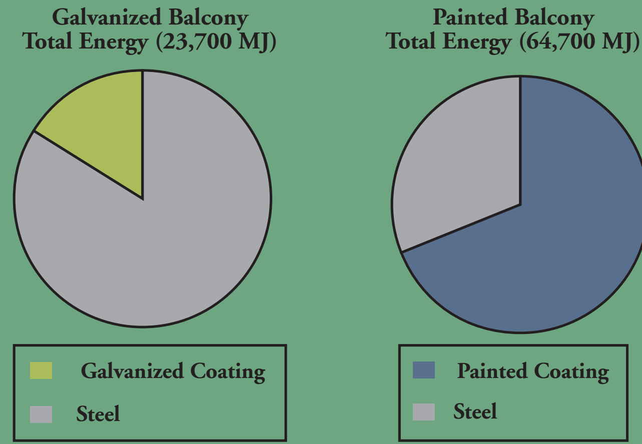


Figure 12: Coating Energy Consumption: HDG vs. Paint

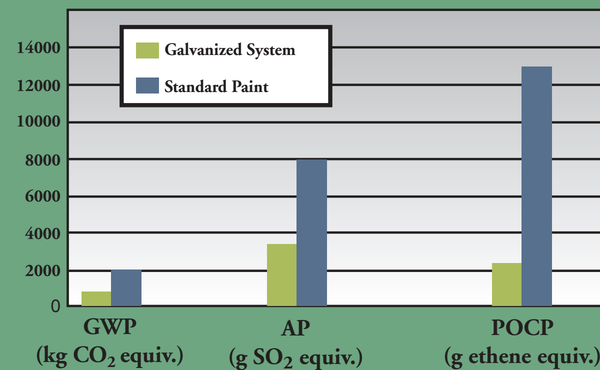


Figure 13: Emissions: HDG vs. Paint

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 one[4]. 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 m^2 steel part (20m^2/metric ton)
- Galvanized coating corrosion rate of 1 micron per year (ISO 1461, C3 environment)
  - No HDG Maintenance Required
- Paint system: 3-coat system, 240 microns thick
  - Paint Maintenance: years 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 14*).

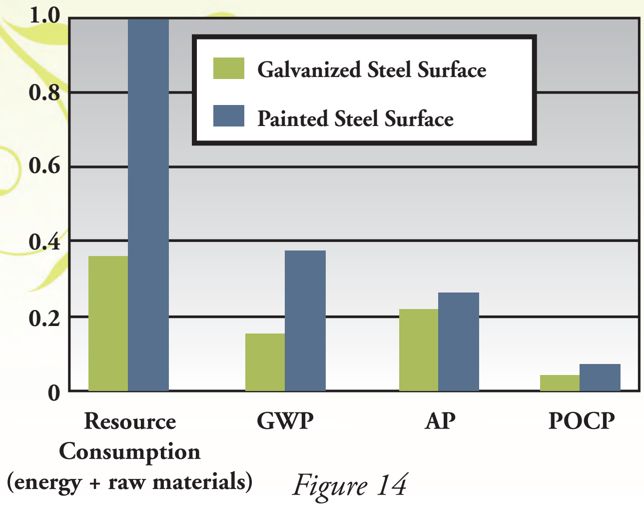


Figure 14

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. 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 direct cost of corrosion in the US is estimated to be 3% of the GDP, or $557 billion in 2016. However, the $557 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[5]. 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.

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 two- and three-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 70 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.

"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."

Galvanizing vs. Paint LCC Case Studies

Calculating life-cycle cost can be cumbersome, so in order to facilitate the calculation, the American Galvanizers Association (AGA) developed an online calculator at lccc.galvanizeit.org. The calculator uses the equation found in ASTM A1068 *Practice for Life-Cycle Cost Analysis of Corrosion Protection Systems on Iron and Steel Products*, and cost data from a national survey of paint manufacturers. The paint data is collected by KTA Tator, Inc. and was last published in a 2014v National Association of Corrosion Engineers (NACE) paper[6]. The hot-dip galvanizing cost data is a national average derived from a 2016 AGA Industry Survey.

To demonstrate the economic advantages of utilizing hot-dip galvanized steel, the following case studies were run on the automated calculator (www.lccc.galvanizeit.org). 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.

"...the hot-dip galvanized balcony reduces the total cost over the life of the structure by 96%."

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 ft^2)
- *Surface Prep*: SP-10 automated
- *Primer*: Inorganic Zinc, shop spray application
- *Intermediate*: Epoxy, shop spray application
- *Topcoat:* Polyurethane, shop spray application
- 3% inflation, 2% interest

The initial and life-cycle costs for the paint and galvanizing are shown below.

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	$4.83	$2,028	$29.31	$12,310	$0.84
[a]Average Equivalent Annual Cost					

Table 4

Even for the relatively small amount of steel utilized, the hot-dip galvanized balcony reduces the total cost over the life of the structure by 96%. 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 ft^2)
- *Surface Prep*: SP-10 automated
- *Primer*: Inorganic Zinc, shop spray application
- *Intermediate*: Epoxy, shop spray application
- *Topcoat*: Polyurethane, shop spray application
- 3% inflation, 2% interest

The initial and life-cycle costs for the paint and galvanizing are shown below (*Table 5*).

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	$0.05
IOZ/Epoxy/Polyurethane	$4.23	$3,172,500	$25.65	$19,237,500	$0.74

[a]Average Equivalent Annual Cost

Table 5

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 54% savings over paint. However, when the life-cycle costs are considered, hot-dip galvanizing provides a 92% savings over the painted garage.

"The hot-dip galvanized parking structure provides a 54% savings over paint....when life-cycle costs are considered, HDG provides a 92% 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 failure 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 while galvanized transmission and distribution poles maintain service during natural disasters such as hurricanes.

> "The purpose of utilizing hot-dip galvanizing is to minimize corrosion. Less corrosion of infrastructure, building, electricity grids, etc. translates to a healthier, safer world."

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 steel with zinc through the hot-dip galvanizing process protects against 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 of future generations to do the same.

FOOTNOTES

[1] LEED®-NC Versions 2.2 and 2009.

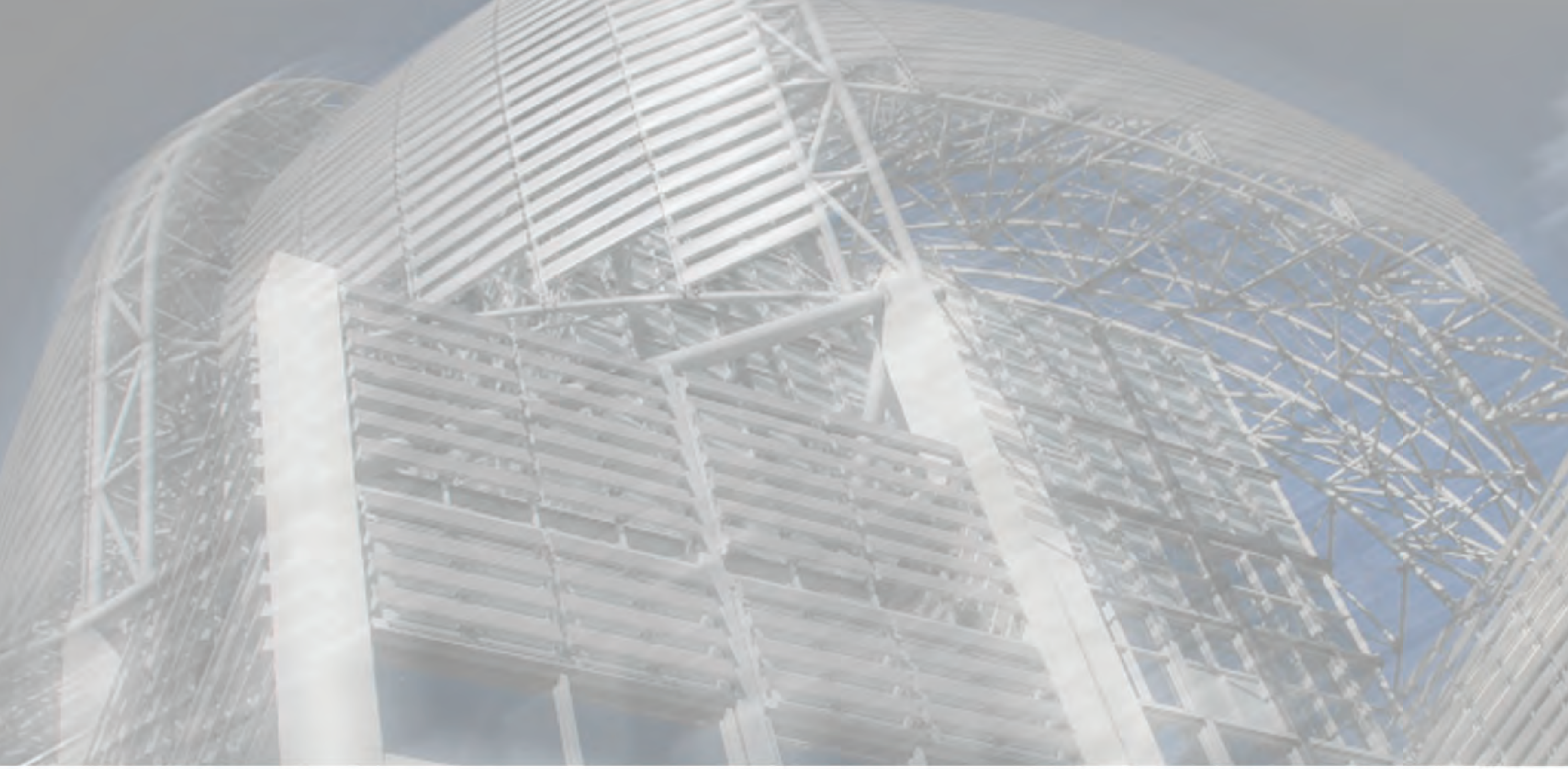
[2] *Six Signs of Greenwashing*, TerraChoice Environmental Marketing Inc., 2007.

[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, FHWA, CC Technologies. FHWA-Rd-01-156. 2002. *Corrosion Costs and Preventative Strategies in the United States.* (Brongers, Konch, Pager, Thompson, Virmani).

[6] NACE Paper #2016-7422 *Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work* (Helsel, Lanterman).



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