AGA Galvanize the Future Essay Contest

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To: San Francisco Municipal Government
California Real estate Co., LtD.
–San Francisco Bay Tower Project investor and owner

Title: **Recommendation for application of hot-dip galvanized steel in San Francisco Bay Tower project**

Prompt: You are the lead architect/engineer on an upcoming project where you feel hot-dip galvanized (HDG) steel is the best solution. The owner is unsure, and it is your job to make a case to overcome his objection by for providing detail about the specific benefits of HDG (durability, longevity, sustainability, aesthetics, etc.) that address his concerns.

Summary

San Francisco Bay Tower is an 80-story, 1,100-foot skyscraper to be created in San Francisco Bay Area, it will be the tallest building in the city skyline. As the lead engineer of the SFB Tower project, I would like to recommend the usage of hot-dip galvanized (HDG) steel.

In this article, the history, manufacturing and engineering cases of HDG steel are introduced. Then, the advantages of HDG steel are elaborated in terms of mechanical behavior, durability, sustainability, duplex effects, aesthetics, and financial benefits. Furthermore, the article compares painted coating steel and polymer coating steel with HDG steel using life-cycle-cost analysis, Life-Cycle-Emission Analysis, and SWOT (Strength, Weakness, Opportunity & Threats) analysis.

The article arrives at the conclusion that HDG coating is the best choice of steel in SFB Tower, which stands in high salinity soil under dry atmosphere and facing conflagration tendency.

1. Construction Background

Singer Tony Bennett once said, ‘I left my heart in San Francisco, High on a hill, it calls to me’. And San Francisco coast (see Fig. 1.a) undoubtedly serves as the most popular place of interest. As Fig. 1b shows, there are several skyscrapers along the east coast of San Francisco, but none on west seashore. To enhance tourism and provide a better view of Golden Gate Bridge, San Francisco Government plans to build an 80-story, 1,100-foot San Francisco Bay Tower in the west coast.

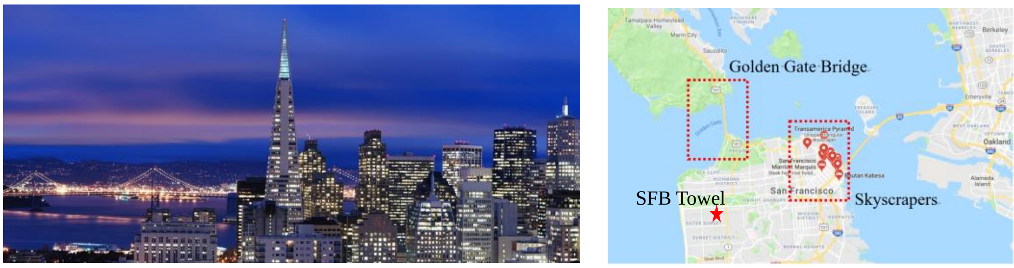


Fig. 1. a) San Francisco seashore night sight b) Construction plan

2. Introduction to HDG steel

In CORROSION 2016 conference, it was announced that the global loss in corrosion is estimated to be $2.5 trillion, and implementing better corrosion prevention could result in a global saving of 15% to 35% of the cost. [1]. Hot-dip galvanizing is an effective way to protect steel from corrosion and is gaining popularity.

As shown in Fig. 2a, hot-dip galvanizing (HDG) steel is steel coated with a zinc layer, and it is manufactured by immersion of the material in a bath of liquid zinc. As illustrated in Fig. 2b, the steel is manufactured by nine steps.

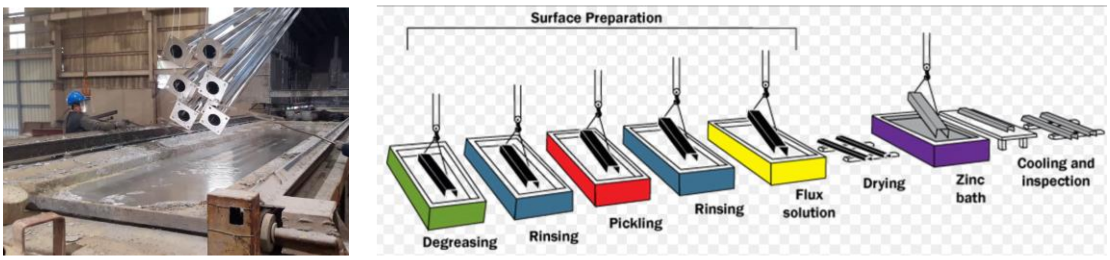


Fig. 2. a) Zinc coating b) HDG manufacture process

The history of galvanizing can be traced back to 300 years ago. In 1836, Sorel in France obtained the first patent for a process of coating steel by dipping it in molten zinc [2]. Nowadays, over 600,000 tons of zinc is consumed annually in North America alone for HDG steel. In California, there are over 100 applications of HDG steel, ranging from stadiums and museums to bridges and towels (see Fig. 3). [3]

Fig. 3 a) Santa Fe Railway Museum   b) Cliff Harris Stadium

Fig. 3 c) MSU Bridge   d) Wilshire Grand Center (Tallest Tower in the West)

3. Advantages in using HDG steel

3.1 Mechanical behavior

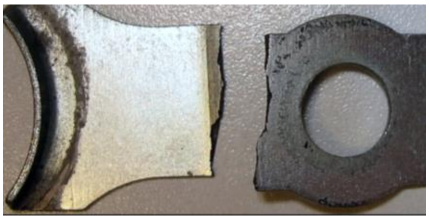
When making decision on material usage, the prime consideration is the mechanical behavior of a material since safety is decisive in engineering.

To elaborate, galvanized joints (see Fig. 4a) could automatically develop a **lock-up character**. Initially, galvanized surfaces will slip more than bare joints, but after the first few cycles of applied stress, any slippage will stop, and the surfaces will start to bond to one another, resulting in higher friction between the two galvanized surfaces and joint slip will be reduced.

Moreover, **hydrogen embrittlement** occurs when cracking is caused due to hydrogen bubble between the grains (see Fig. 4b). Usually steels having a tensile strength of 150 ksi or greater tend to suffer from this problem. The chemical reaction is explained in Fig. 4d [4]. However, the risk can be mitigated by a modified galvanizing process named flash pickling (less than 30 seconds in the pickling bath) the steel, which is necessary to remove any residues from the blasting operation and dwindles the amount of hydrogen trapped in steel.

Besides, **steel shear failure** (see Fig. 4c) commonly occurs in bolted joints, and **stress concentration** could make the shearing force as well as failure susceptibility at joints to be three times higher than at other parts (see Fig. 4e [5]). However, due to the fact that the material is immersed and the zinc flows into recesses and other areas difficult to access, **coating all areas** of complex shapes thoroughly can be guaranteed and fatigue at joints can be abated at maximum.

Fig. 4 a) Steel joint



b) Hydrogen embrittlement

c) Steel shear failure

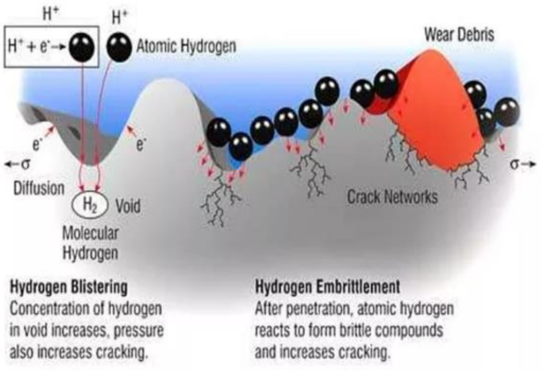
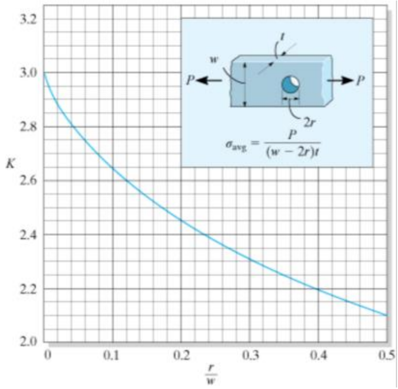


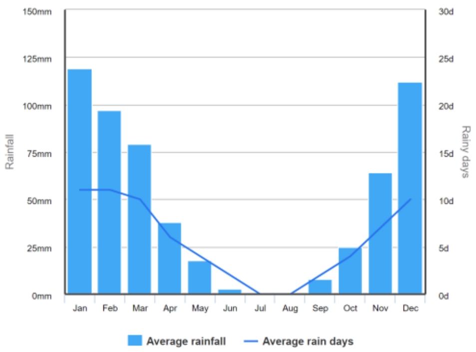
Fig. 4 d) Illustration for hydrogen embrittlement [4]



e) Stress Concentration [5]

3.2 Durability

Longevity is another significant factor to consider next to safety. California is well-known for its dry climate. As Fig 5a presents, there is almost zero precipitation in summer [6], and there could be more than ten fire incidents in San Francisco-in a single day [7], as illustrates in Fig 5b.



Incident Numl	Call Type	Call Da	Watch Da	Received DtTm
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18038532	Structure Fire	03/31/2018	03/31/2018	2018 Mar 31 08:42:11 PM
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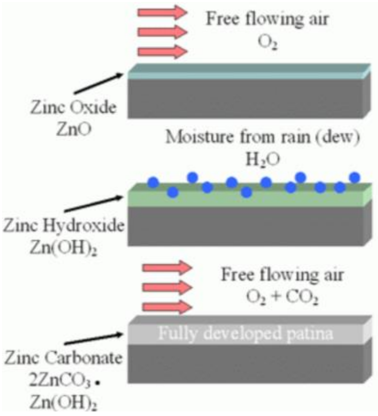
Fig. 5 a) Annual rainfall [6] b) Building fire incidents [7] on March 31, 2018

Fire resistance is vital in steel design because steel usually cannot survive in 1000 ℉. HDG proves to be a good protection against fire because the melting point of zinc is much higher than most organic paint coatings and polymer layers, and the evaporation of zinc absorbs a great sum of heat.

Due to high salinity in the Pacific Ocean, **abiding correlation protection** of zinc layer is another pros of HDG steel. The zinc of the galvanized coating is a barrier protection to the substrate steel, and as Fig. 6a [8] presents, solid and inert $Zn(OH)_2$ and ZnO can be produced and form a tightly-bonded (~3,600 psi) layer. It is estimated that HDG coating provides **at least 100 to 200 years of corrosion protection** in various environments, as depicted in Fig 6b [9].



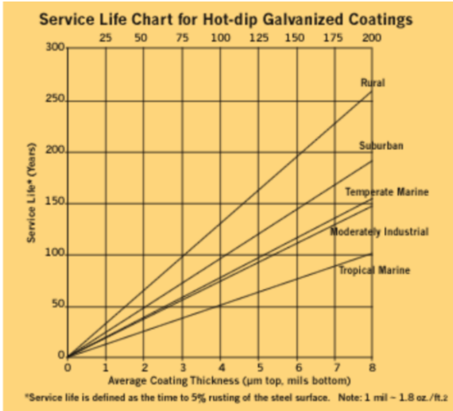


Fig. 6 a) zinc protection chemical reaction [8]   b) Zinc service time in various environments [9]

The convenient secondary maintenance is another strength in terms of durability. According to *ASTM A780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-dip Galvanized Coatings*, there are three accepted methodologies as Fig. 7 shows: (1) Applying zinc-rich paint (2) Coating with zinc solder (3) metalizing. Zinc-rich paint is easy to handle and usually applied, and its duplex positive effects will be explained in Section 3.4.


Fig. 7 a) Zinc-rich paint   b) Coating with zinc solder   c) Metalizing

3.3 Sustainability

Sustainability is intrinsic to HDG steel. As presented in Table 1 [10], Recycling content is the amount of a product produced from recycled sources. Reclamation rate measures how often a product is actually recycled at the end of its useful life. Because steel is the most recycled material in the world, and zinc also has a very high reclamation rate, HDG steel is **highly recyclable** and eco-friendly.

Table 1. Recycling and Reclamation Rates for both zinc and steel [10]

	Zinc[1]	Steel[2]
Reclamation Rate	80%	100%
Recycling Rate	30%	70%

[1] International Zinc Association (IZA) Zinc Recycling, 2004

[2] Steel Recycling Institute Steel Lakes LEED with Recycles Content, March 2009

3.4 duplex effects

Many scientists also investigate how HDG works with an additional painted layer, and the findings surprisingly shows that there is a **synergistic effect** between galvanized steel and paint. This duplex phenomena has mainly three benefits: (1) It can have **a color to match surrounding** structure (2) **Safety Marking** –tall structures are mandated to be painted safety orange and white for high visibility to air traffic (3) **Extending the Life of Galvanized Steel** – large in-place structures often cannot be re-galvanized and often an inorganic zinc-rich paint could provide barrier protection.

3.5 Aesthetics

The HDG steel could maintain its aesthetics because of its **long-lasting anti-corrosion** abilities and **smooth surface**.

Stanford Stadium is a persuasive example for its aesthetical value. Steel truss and thin-walled braces make space widened and scenery robust. The slogan ‘less is more’ is achieved.

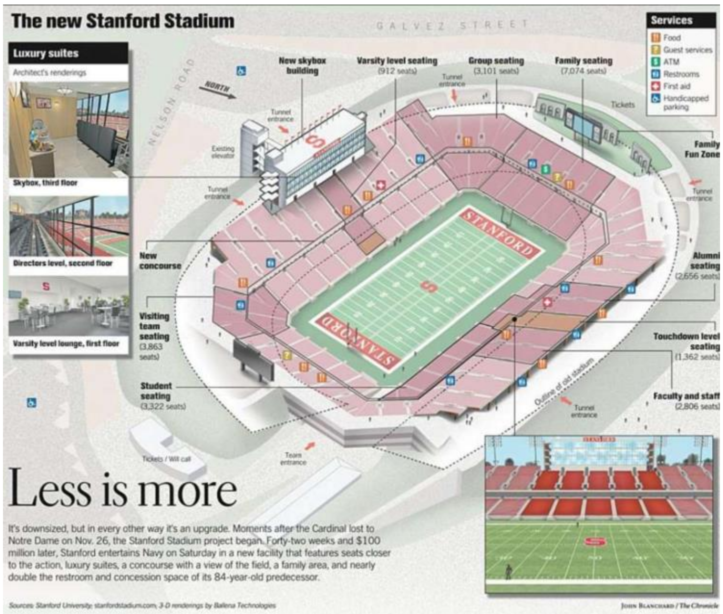


Fig. 8 Design conception of Stanford Stadium

3.6 Financial Benefits

Due to the **slowly descending price of zinc**, as shown in Fig. 9, hot-dip galvanizing is becoming more competitive. In comparison, paint and powder coatings have their cost increased by 100% or more in the past five years [11]. Another point to consider is maintenance fee. Direct maintenance costs for any project are typically 2-5 times the initial cost. Thus, the over-100-year longevity makes HDG steel **sufficiently economic in maintenance**. According to relevant study, **HDG steel is 2-6 times more economical compared with other commonly used coating steel** [12].

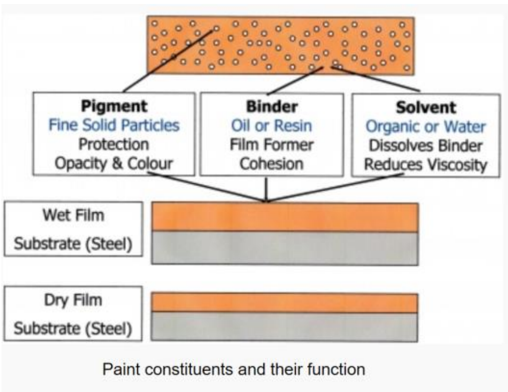
Fig. 9 Descending price of zinc (in blue color) [11]

4 Comparison with other two coated steel

4.1 Introduction of two coatings

As depicted in Fig. 10a, **Painted Coating** steel has three components: (1) pigments (2) binder (3) The solvent. It protects steel from corrosion by **blocking air contact**.

Materials in **Polymer coating** include polyaniline, polypyrrole, and polythiophen. It is first investigated by Shirakawa et al. [13]. In 1985, DeBerry firstly reported that the stainless steel covered by PAni could be kept for a relatively long period [14]. Fig 10b illustrates how polymer prevent corrosion: **Ion Exchange**.



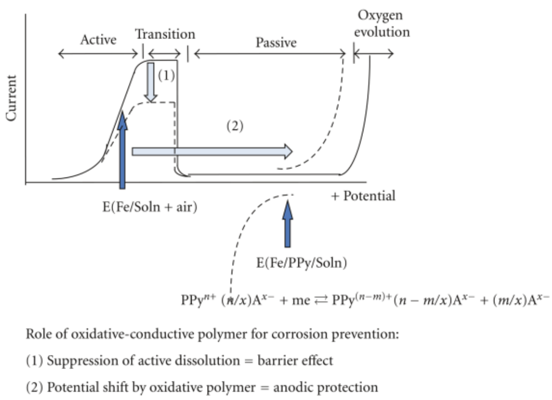


Fig. 10 a) categories of painted coating steel b) corrosion prevention of polymer

4.2 Life-Cycle-Cost Analysis

The SFB towel is designed to be approximately 2,500,000 ft^2 area, 60,000 tons steel usage and 100 year design span. It has complex structures as well as large structural makeup, and it locates in an area with very high atmospheric corrosion (C5M). All materials are precast (in shop), calculated with US average with 5% interest rate and inflation rate.

According to life-cycle-cost analysis, as shown in table 2 and Fig. 11, even though the preliminary investment for HDG steel is higher than other two choices, HDG steel has supreme advantage in economics later on, and provides 91.9% savings compared to Paint Coating, and 83.7% savings in contrast with Polymer Coating. The obvious **long-term financial strength** makes HDG steel the optimal choice.

Table 2. Life-Cycle-Cost Analysis

Coating	100-year Life-cycle cost	Savings /maximal cost
Hot Dip Galvanizing	$ 48,840,000	91.9%
Acrylic Paint Coating	$ 603,780,000	0
Moisture Curing Polyurethane	$ 299,820,000	50.3%

Acrylic Paint Coating: Hand/Power Surface Prep / 6mil DFT Minimum, SP3 grade.

Moisture Curing Polyurethane: MCU Pent Sealer/MCU/MCU, SP3 grade.

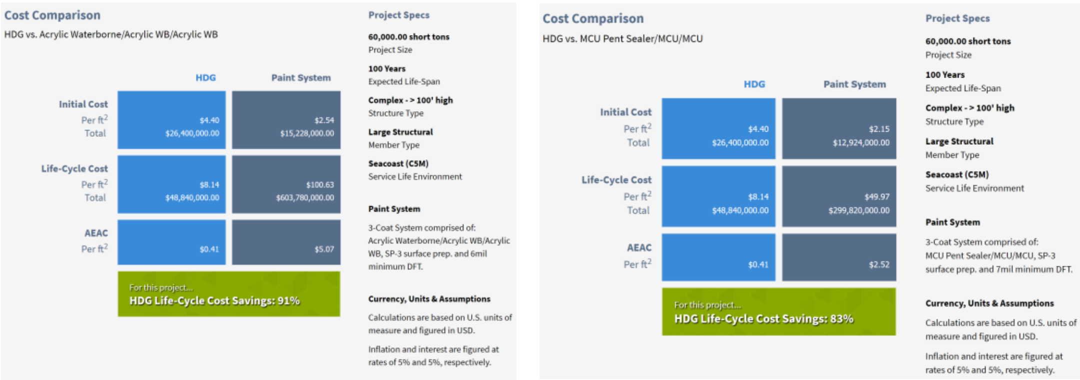
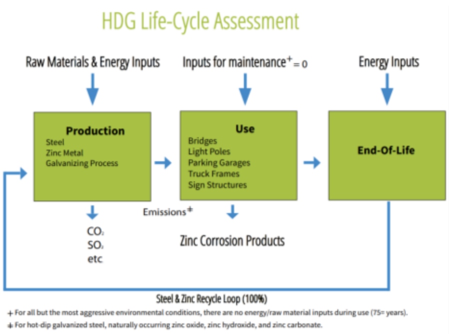


Fig. 11 a) HDG & APC comparison b) HDG & MCP comparison

4.3 Life-Cycle- Emission Assessment

Another consideration is whether the material is eco-friendly. A Life-cycle assessment (LCA) was conducted by scholars [15], and the result highlights the pros of HDG steel in its **low CO_2 emission in manufacturing**. As illustrated in Table 3, according to LCA, HDG steel has zero CO_2 emission in production phase compared with painted steel. Moreover, steel and zinc in the galvanized coating can be highly recyclable, which is shown in Section 3.3. Paint, in contrast, becomes a permanent part of the waste stream or emissions. To sum up, HDG steel is highly **eco-friendly**.



Production Phase	Primary Energy Use	Global Warming Potential (GWP) (CO_2 equiv.)	Acidification Potential (AP) (SO_2 equiv.)	Photo Chemical Ozone Creation Potential (POCP) (ethene equiv.)
1 Kg HDG Steel	0 MJ	0 kg	0kg	0kg
Painted Steel	P_1 MJ	P_2 kg	P_3 kg	P_4 kg

Table 3. Complete Life-Cycle Cost of HDG and painted steel

4.3 SWOT Analysis

SWOT analysis is a strategic planning technique is I use it to compare painted coating steel, polymer coating steel and HDG steel.

In Table 3a – 3c, it can be concluded that HDG steel is much better than other two choices because it has comprehensive strengths in many aspects, and has strong development potential due to its low long-term investments. Moreover, it is strongly supported by American Galvanizers Association.

Table 3a. SWOT analysis for HDG steel

Strengths	Weaknesses
(1)Good mechanical behavior (2)Strong Durability (3)Outstanding sustainability (4)Duplex effects with paint coating (5)Aesthetical value (6)Long-term financial benefits	(1) High first-time investments (2) Manufacture process is a bit complex
Opportunities	Threats
(1) It is strongly supported by American Galvanizers Association. (2) Attractive in long-term investment	(1) The engineering applications are fewer than paint coating, and constructors may be unfamiliar with HDG steel.

Table 3b. SWOT analysis for paint coating steel

Strengths	Weaknesses
(1)Universally used (2)Easy to apply, no sophisticated tools required (3) Aesthetical value	(1) High long-term investments (2) It cannot cover every corner of steel and stress concentration happens on joints (3) Not eco-friendly (4) Weak corrosion resistance
Opportunities	Threats
(1) Constructors may be familiar with it due to its widely application and prefer to use paint coating	(1)Much higher life-cycle maintenance compared with HDG steel (2)High risk potential for fire disasters

Table 3c. SWOT analysis for polymer coating steel

Strengths	Weaknesses
(1)There are many different types of polymer (2)Layer is thick and light	(1) Weak fire resistance (2) Manufacture process is very complex (3) Not eco-friendly, cannot be recycled (4) Weak corrosion resistance
Opportunities	Threats
(1) It has research value in engineering application of polymer for chemists.	(1)The engineering applications are fewer than paint coating, and constructors may be unfamiliar with polymer coating steel. (2)Much higher life-cycle maintenance compared with HDG steel (2)High risk potential for fire disasters

5. Conclusion

This article concludes that HDG coating is the best choice of steel in SFB Tower, and its benefits can be summarized as (1)Good mechanical behavior (2)Fire resistance, abiding correlation protection and convenient secondary maintenance (3)Maintenance-free longevity, highly recyclable and low CO2 emission (4)Duplex effects with paint coating (5)Aesthetical value (6)Long-term financial benefits, and it could have 91.9% savings compared to Paint Coating, and 83.7% savings in contrast with Polymer Coating.

To sum up, I strongly support the application of HDG steel in SFG towel.

Thank you for your evaluation!

Content words: 1989

[1] NACE International, NACE study estimates global cost of corrosion at $2.5 trillion annually, March 8, 2016. https://inspectioneering.com/
[2] American Galvanizers Association, HDG process, https://www.galvanizeit.org/hot-dip-galvanizing/what-is-hot-dip-galvanizing-hdg/hdg-process
[3] American Galvanizers Association, Case Studies, https://www.galvanizeit.org/project-gallery/gallery
[4] Sidheshwar Kumar, Hydrogen embrittlement causes & effects, https://www.slideshare.net/
[5] UWMC Engineering, Mechanics of Materials Example: Stress Concentrations, Sep 23, 2015. https://www.youtube.com/watch?v=c-fXX-BMGvs
[6] Fire Incidents. https://data.sfgov.org/Public-Safety/Fire-Incidents/wr8u-xric/data
[7] Trip advisor. Francisco: https://www.tripadvisor.com/Travel-g60713-s208/San-Francisco:California:Weather.And.When.To.Go.html
[8] American Galvanizers Association, Corrosion Protection, https://www.galvanizeit.org/hot-dip-galvanizing/why-specify-galvanizing/corrosion-protection
[9] T. J. Langill, the Fabrication.com. https://www.thefabricator.com/article/metalsmaterials/predicting-the-service-life-of-galvanized-steel
[10] American Galvanizers Association, Zinc Recycling, https://www.galvanizeit.org/hot-dip-galvanizing/what-is-zinc/zinc-recycling
[11] W. Adams. Zinc price analysis and forecast. November 3, 2015. https://www.fastmarkets.com/base-metals-news/quarterly-reports/zinc-price-analysis-forecast-q4-2015/
[12] American Galvanizers Association, HDG Economic Advantages. , https://www.galvanizeit.org/hot-dip-galvanizing/is-galvanizing-sustainable/hdg-economic-advantages
[13] C. K. Chiang, C. R. Fincher, Y. W. Park et al., Electrical conductivity in doped polyacetylene, Physical Review Letters, vol. 39, no. 17, pp. 1098–1101, 1977.
[14] D. W. DeBerry, Modification of the electrochemical and corrosion behavior of stainless steels with an electroactive coating, Journal of the Electrochemical Society, vol. 132, no. 5, pp. 1022–1026, 1985.
[15] American Galvanizers Association, Life-Cycle Assessment. https://www.galvanizeit.org/parking-seminar/environmental-advantages/life-cycle-assessment