CHAPTER 1

Introduction to Zinc

It's a business. If I could make more money down in the zinc mines, I'd be mining zinc.

Source: Roger Maris

ELEMENT 30 ZN – *SPELTER*

Zinc, the metal that could change copper into gold, at least that was the wish of the early alchemists. They called the metal *counterfeht*[1]. It looked like silver, but it wasn't. Adding it to molten copper and the copper would turn to a beautiful golden color, but it was not gold. It was an "imitation" a *counterfeht*. This odd metal, if it was a metal at all, was a mystery.

Zinc went also by the name *spelter,* used mainly by those who worked with the metal. Spelter was possibly a corruption of the name for "pewter," the dull gray, lead-tin alloy. The Dutch, first to import the metal into Europe used the word, *spiauter* for a word to describe a mixture of lead and tin[2]. So, it very well may have been an early marketing ploy to give value to this dubious metal. Spelter was the name given to this metal up until relatively recent times. Today, the name zinc has firmly taken hold on the periodic table of elements.

Other names, in particular *calamine,* were frequently used for this metal before it was officially a metal. Calamine, the principal mineral of zinc, was the name used across Western civilizations since the time of the Romans. Calamine is zinc sulfide, and there are regions in Europe where the rich mineral deposits of zinc sulfide were mined.

Calamine, as well, lost out as a name for the principal mineral form of zinc and is now better known as the popular topical poison ivy cream, even though the lotion contains zinc oxide, not the

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[1] The German, Georgius Agricola, in his book, *De re metallica*, written in 1556.

[2] Dawkins J.M., *Zinc and Spelter,* 1950, Zinc Development Association, p. 24.

zinc sulfide of the mineral form. Instead of calamine, the term *sphalerite* is used as the name for the zinc sulfide mineral. For a long while the term *zinc blende,* from the German *zincblende*, was also used to describe the mineral. Confusion reigned on what this mineral or metal actually was.

As a metal, zinc in a wrought or cast form came late, sometime in the middle of the sixteenth century to the Western civilizations, definitely earlier in India. China also was an early zinc producer, using crucibles with charcoal to heat the ore. They made coins from zinc in the fourteenth century. The Romans would produce brass from copper by adding calamine and heating it in small crucibles. The zinc was obtained by reducing the ore, releasing carbon dioxide, and the fumes of zinc would rapidly be absorbed into the copper. Once melted, the slag-covered block would be hammered and the bright yellow color would appear.

The process of making brass was well known throughout antiquity. The method of creating brass from sphalerite (or calamine, as it was then known) was described in several texts. One such text, *Schedula Diversarium Artium*, written by Theophilus Presbyter in the eleventh century, describes the heating of crucibles in an open furnace, adding calamine, then strips of copper. Place back on the furnace for 9 hours and you arrive at a golden yellow color pleasing to look at. Figure 1.1 shows the mineral sphalerite with a large lump of copper on a plate of brass.

Zinc appeared as a known metal later than lead and tin. The mineral was known but as a distinct metal, zinc was not. Along with other colorful zinc minerals, sphalerite was easy to identify and so was mined in antiquity as a mineral to add to copper to produce the beautiful yellow brass. Granted, it was often mistaken for galena, a lead sulfide mineral, at one time a valuable mineral for making bullets.

Early brass artifacts dating back to the eighth century BCE were uncovered in the Gordion tomb excavated in Anatolia. The copper–zinc metal was called *oreichalkos* and later *orichalcum* by the Romans. The process of producing brass was well known and documented. Most brass production was established near the zinc mines because it was easier to cart copper to the area, than the large quantity of zinc mineral needed.

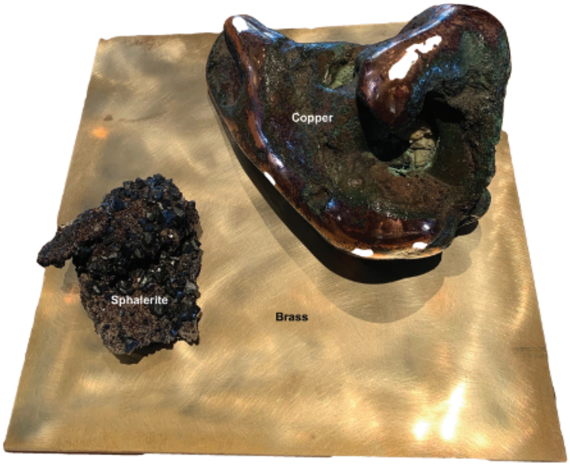
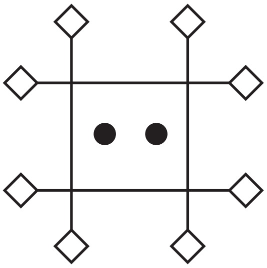


FIGURE 1.1 Sphalerite plus copper to make brass.

The reason zinc as a known metal was late to discovery is the difficulty of refinement. Up until the mid-1700s, metals were made by roasting the ores and burning off the oxides to free the metal. Trouble is, zinc has a low boiling point as metals go. As sufficient heat is applied to reduce the ore, zinc turns to gas and the fumes escape. Thus, the reduction of the ore the way other metals are produced just did not work for zinc.

The way the early alchemists found this *counterfeht*, it would condense on the walls of the flue and in cracks and crevices of the stone after roasting metal ores that contained zinc. Zinc is often found in ores of other metals, particularly lead, copper and silver. When the ores were heated the zinc would go up as vapors and condense on the stone. When it condensed, it formed long, whiskery tuffs the alchemists called *lana philosophica,* meaning "philosopher's wool."

Assistants to the alchemists would scrape and collect this wooly substance off the stone and out of the cracks of the flue walls. The alchemists placed a value on this special metal that was like tin but when added to copper would transform the copper into a golden yellow.



Alchemist symbol for zinc.

Zinc is a silver metal with a slight bluish hue. Zinc can be polished to a bright, silver but quickly tarnishes when handled. As zinc ages it turns to a rich gray color with whitish oxides in areas where moisture is allowed to accumulate.

Zinc is element 30 on the periodic table of elements, Figure 1.2. With the red metal, copper, on one side and gallium, a blue gray metal that melts in your hand, on the other, zinc falls in the twelfth row with cadmium and mercury.

Zinc has several isotopes, but the isotope zinc 67 is rather special. Zinc 67 occurs in approximately 4% of natural zinc. This isotope is highly sensitive to minute variations in transmitted energy. When it detects energy, it emits electromagnetic radiation making this isotope zinc 67 valuable for high accuracy measuring equipment. Zinc 67 is used to detect gamma ray vibrations with incredible sensitivity in the highly accurate atomic clock.

Zinc has a hexagonal crystal structure, which even though it is closely packed, it is less dense than the cubic structure of iron or copper. Figure 1.3. depicts a closely packed hexagonal crystal.

This metallurgical structure shows the crystal of zinc has six atoms in a near plane and another six slightly further away. This makes the bonds of the basal plane slightly stronger than the bonds of the parallel plane. This difference in distance and strength gives zinc an anisotropy that translates to forms made of zinc.[3]

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[3] Porter, Frank, *Zinc Handbook*, Marcel Decker Inc., NY, p. 45.

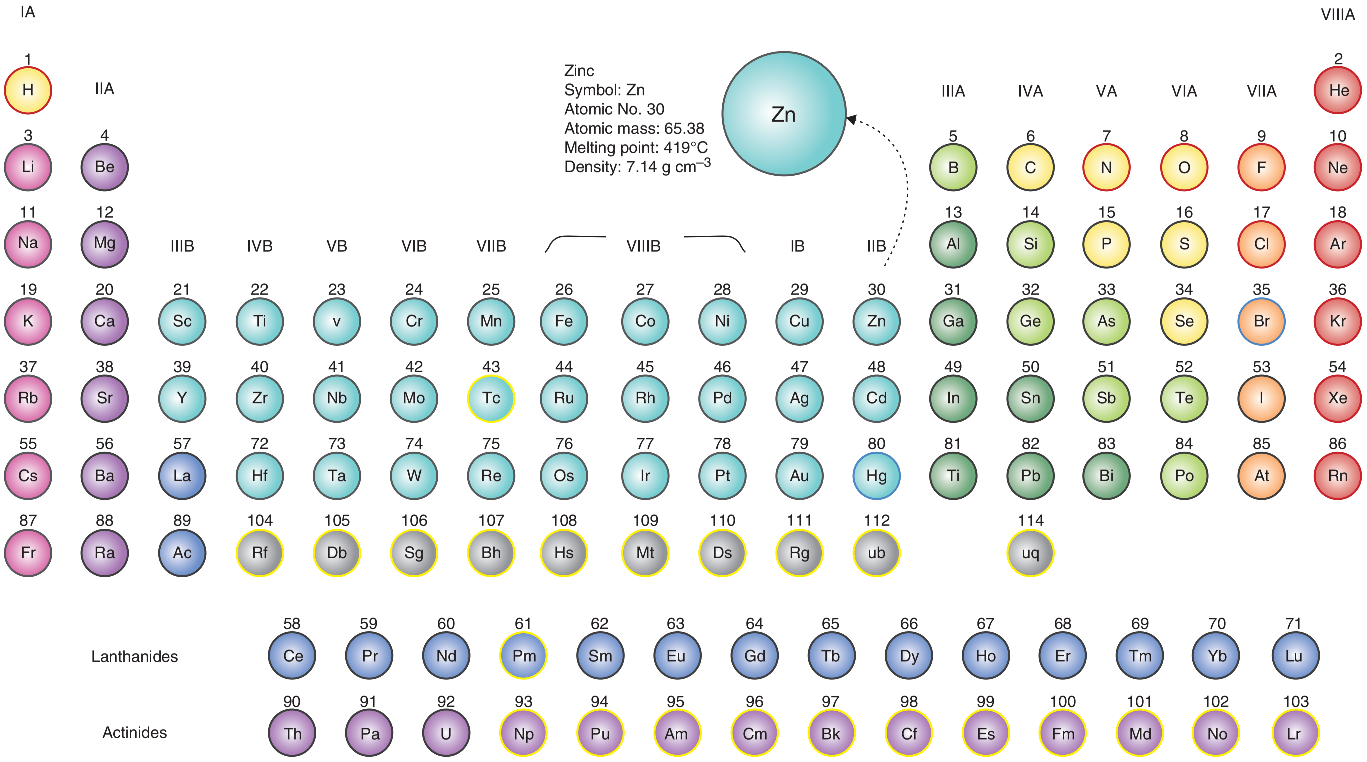


FIGURE 1.2 Periodic table.

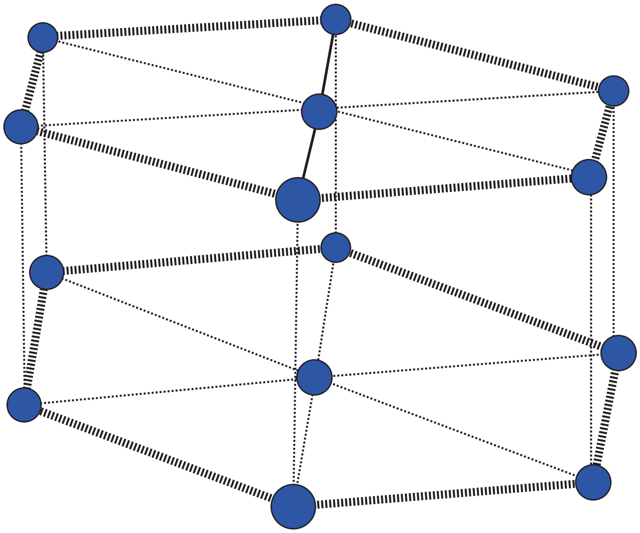


FIGURE 1.3 Zinc hexagonal crystal structure.

Another aspect of zinc is its ability to recrystallize rapidly after deformation. This prevents work hardening from occurring during forming operations and it also provides a level of "self-lubrication" as the crystals slip over one another during forming processes.

Note, the spangle that forms on galvanized steel is a large crystal of zinc that forms as it cools. It has the six triangular wedge-like symmetry reflecting the hexagonal crystal structure of the zinc crystal lattice. Figure 1.4 shows a close-up image of the spangle formed when zinc cools on a steel

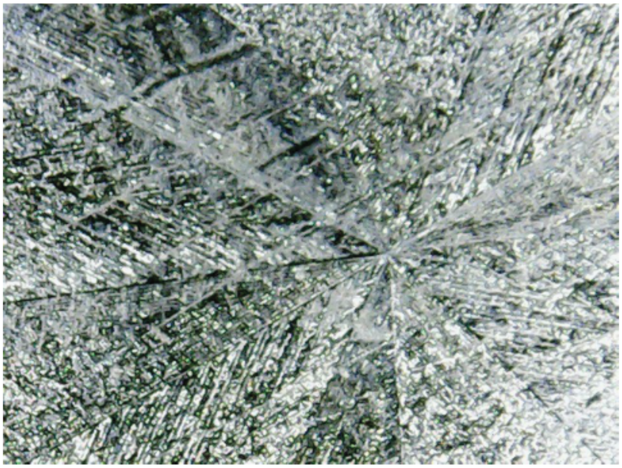


FIGURE 1.4 Spangle of galvanized.

FIGURE 1.5 Zinc coating on steel using a controlled refinement of the cooling process.

substrate. The wedges that expand out from a central point are called dendrites and the parallel lines are called subdendrites. When newly developed the galvanized surface has a crystalline reflective quality due to the way the subdendrites scatter the reflective light. The surface seems to come alive as you walk around a newly galvanized steel plate with the glittering reflection bouncing off the variations in the crystals.

This reflectiveness, achieved by hot-dipping steel into molten zinc, is a natural surface that forms due to slight imperfections in the zinc bath or slight roughness on the steel surface. These imperfections initiate the formation of the dendrite growth.

Artistic affects can be enhanced to take advantage of cooling rates of the molten zinc. These techniques are still in development in order to better understanding the parameters involved. However, cooling rates, “seeding” the molten bath with other elements can influence the effects.

The difficulty arises in the industrial controls in place by the galvanizing facilities. Artistic expression is not in their normal parlance.

Figure 1.5 shows a "wave-like" appearance that has developed on flat steel sheet. The reflectivity enhances the three-dimensional appearance of the zinc surface.

As the surface oxidizes, the zinc crystals still vary in appearance creating a dull, lower reflective patchwork appearance. The dendrites are still there, they have just developed a layer of zinc oxide that mutes the reflectivity. Figure 1.6 shows a galvanized plate that has been exposed to weather.

FIGURE 1.6 Galvanized that has weathered.

Zinc	**ELEMENT 30**
Atomic number 30	
Crystal structure:	Close-packed hexagonal
Main mineral source:	Sphalerite (Calamine)
Color:	Bluish white
Oxide:	White
Density:	7,068 kg/m^3
Specific gravity:	7.0
Melting point:	419°C
Thermal conductivity:	112 W/m °C
Coefficient of linear expansion:	19×10^{-6} m/m°C
Electrical conductivity:	26% IACS
Modulus of elasticity:	108 GPa

Most of the zinc found on the Earth's surface is from hydrothermal activity that brought the metal to or near the surface. Zinc is not found in the native state. Zinc is always found in combination with other elements and metals. Zinc is the 24th most abundant element within the upper crust of the Earth.

Zinc has a poor strength to weight ratio as compared to other metals used in industry.

Zinc alloys are ductile at room temperature. Zinc castings are not ductile.

Zinc is subject to fracture when formed at low temperatures.

High elasticity – resiliency under shock loading

Soft edge

Zinc and zinc oxides are nontoxic unless consumed in large amounts. Zinc oxide fumes are hazardous when inhaled and will cause flu-like symptoms that can last 1–2 days.

It has superior corrosion resistance in many natural environments. Zinc is subject to corrosion in low pH and high pH environments.

FINISHES:

Mill finish – as rolled.

Semi-bright

Preweathered – darkened

Zinc can be painted.

Coil-coated zinc sheet in various colors are available on the market.

Oil-based paints are not recommended. Saponification can develop.

Plating with other metals such as copper, silver, nickel, and gold are possible.

Artificial patina:	Zinc can receive artificial patinas of white, black, browns, mottled browns with green and reddish oxides as well as iredescent hues of transparent greens, purples and reds.
Bright appearance:	Zinc can be polished but the luster quickly diminishes as oxides form. The color is typically a matte gray to grayish blue.
Reflectance of ultraviolet:	The oxide of zinc absorbs ultraviolet light. Its use in sun protection is well known. Protection is afforded by absorption of the ultraviolet radiation and not allowing it to pass to the skin.
of infrared:	Zinc oxide in powder form is used extensively in paint. It is a white powder and will reflect infrared radiation.
Relative cost:	*Medium*
Strengthening:	Zinc does not gain strength from cold working as other metals do. Instead, alloying with small amounts of copper and titanium are used to improve strength and add creep resistance.
Recycle ability:	Zinc is easily recycled because of the low melting point. Zinc is captured in from galvanize coated steels as vapor during the recycling process of coated steels.
Welding and joining:	Zinc can be welded and soldered.
Casting:	Zinc is a common casting metal. Used for many small cast parts where strength is less a requirement
Plating:	Zinc can be electroplated with other metals.
Etching and milling:	Zinc can be etched chemically and readily machined.

THE ZINC ATOM

All metals have at most three electrons in their outer shell. Zinc, element 30 on the periodic chart, has two electrons in the outer shell. This gives it an oxidation state of +2, making the zinc atom divalent in all compounds. Figure 1.7 depicts a typical zinc atom with the two electrons in the outer orbit shell. For zinc, there is always two covalent bonds formed when the zinc atom combines with other elements.

Oxygen readily joins with zinc to form ZnO and Zn(OH)2, with oxygen alone making a double bond and the two hydroxide combinations each with a single bond.

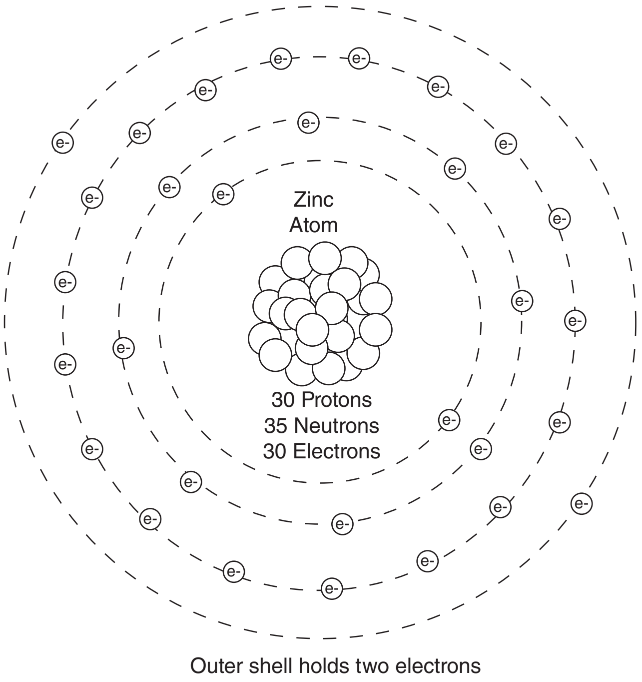
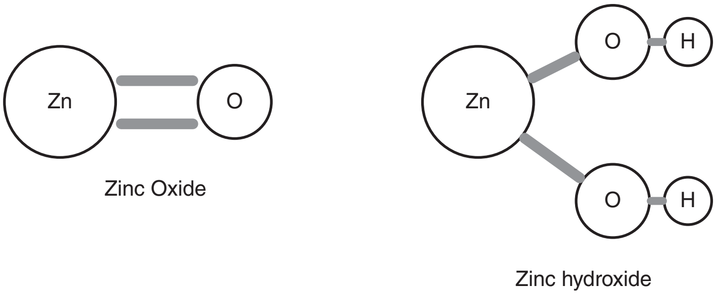


FIGURE 1.7 Zinc atom with two electrons in the other shell.



High-purity zinc is a strong oxidizer and when exposed to the atmosphere quickly tarnishes and forms the oxide and hydroxide. The standard potential of zinc can be expressed thermodynamically[4] as:

$$Zn \leftrightarrow Zn^{2+} + 2e^{-} \quad E0 = -0.763\ v$$

This represents a strong drive to combine with other elements.

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[4] Zhang, Z.G. Corrosion and Electrochemistry of Zinc. Plenum Press, NY, 1996.

HISTORY

The discovery of zinc as a metal is credited in the West to the Swiss alchemist, Paracelsus. Dr. Paracelsus, as he was known because he was a physician and a philosopher as well, in 1526, described a metal he called *zinek,* as one of the seven known metals. Paracelsus lived around Basel and wrote extensively on various subjects. He is credited, among other things, as the father of toxicology.

Zinc ore was mined in Germany for the making of brass in the region around the Harz Mountains. The nearby town of Goslar, Germany, was a center of mining and zinc mining existed from around 1550. By 1650, a large-scale zinc ore production and refinement was underway. The mines around this region produced iron, silver, copper, lead, and zinc.

The process of refining the metal still was a mystery to the west. China and India would supply the metal in a refined state to European companies for producing brass by alloying with copper. Eventually, by the middle part of the eighteenth century, zinc-mining operations in Sweden and the region around Silesia would become important sources for the ore.

In the early 1700s, Bristol, England, the Bristol Brass Company would import zinc from India. William Champion, the son of the founder of the company, created a method of smelting his own zinc using a process notably similar to one developed centuries earlier in India. The company previously would import the zinc to make its brass plates, now it could produce and refine its own zinc from ore. William Champion has been credited with the early manufacture of industrial quantities of zinc.

Champion saw how the metal workers in India were extracting zinc from the ore pyrometallurgically by adding a distillation process to capture the fumes and condense the zinc oxide. The zinc was heated to turn it into vapor, the vapor would condense on the cooler walls of a chamber similar to the way it would condense on the cooler stone walls of the alchemists flue. This condensed zinc was zinc oxide. The key was to remove the oxygen by adding charcoal to the heated chamber and this would remove the oxygen from the zinc oxide creating carbon dioxide and leaving the zinc as a lump of metal.

In those days, brass was the main product that set the demand for zinc. Brass was used to clad the hulls of English sailing ships. Muntz metal, an alloy of copper and zinc, contains 40% zinc. Developed specifically as a cladding for ship hulls in 1832, Muntz, named after its inventor, George Fredrick Muntz of Birmingham, England, replaced copper as an anti-fouling cladding on the hulls of oceangoing ships. Because it had zinc, it was significantly cheaper than pure copper and still would protect the wood hulls from teredo shipworms. Muntz metal was also much stronger than copper, and the zinc lowered the melting point to 904°C from 1085°C for copper.

Zinc is a metal that has been in and out of art and architecture over the years. Since its discovery, or more so, since the time when casting and rolling into sheets, zinc has found use in architecture. The skyline of Paris is a testimony to the beauty and durability of the metal. Napoleon, around 1805 instructed the chemist Jean-Jacques Dony to develop the rich mines of zinc ore in the Vielle-Montagne. Dony developed a method of refining the ore using a horizontal distilling process that involved a series of retorts set into a furnace. The ore would be roasted, and the zinc fumes would be released and condensate, forming molten zinc. Figure 1.8 is a diagrammatic representation of the retort process.

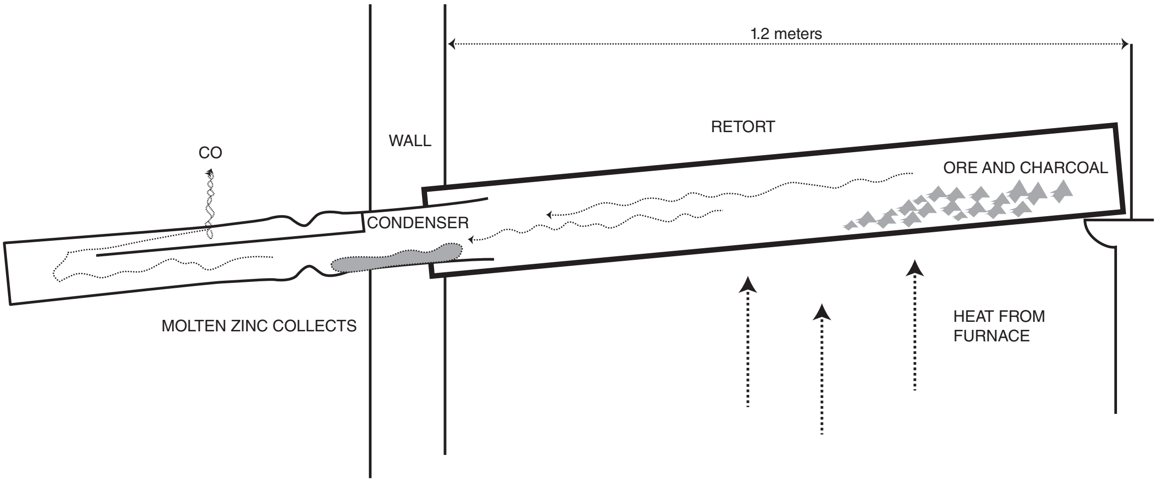

FIGURE 1.8 Diagram of a Horizontal Retort.
Source: Developed by Dony.

Dony set these retorts in series within a furnace and required a vast amount of heat energy. The process remained in use until the first half of the twentieth century. First, the reaction required the temperature within the retort to reach 1100°C or greater for the chemical reaction to occur between ZnO and carbon. The carbon was introduced from the charcoal, which would burn, creating carbon dioxide gas. Further heat would be applied to vaporize the zinc. Zinc oxide would form as a vapor, and when it combined with the heated carbon, the oxygen would be stripped away and vent out as carbon dioxide. The zinc would be condensing on the cooler portion of the retort and collect along the bottom as liquid metal.

These retorts would be set into arrays and charged with ore and charcoal.

With this new source of the metal, rolling into sheets and plates was possible using rolling techniques perfected with copper and iron plates. The first zinc-rolling mill for sheets of zinc was developed by Dony in 1812, making this metal available as an architectural cladding material to compete with copper and tin-plated steel.

Zinc has a long history in art and architecture. Its use as an alloy metal with copper to make brass was well understood by the Romans and Egyptians, who were attracted by the allure of the golden color the addition of the mineral calamine made with copper. At least they understood that something in the ore would interact with copper and produce brass. Zinc as a metal was unknown to early civilizations because it could not be separated from its ore as other metals. When copper, lead, tin, or iron ore were heated the metal would fall to the bottom of the furnace but zinc would boil and turn to vapor.

In China and in India, early metalworkers found ways of isolating zinc by roasting the ores in crucibles with charcoal and then allowing them to cool. Zinc would separate in small lumps where it could be collected and remelted.

FIGURE 1.9 An example of modern Bidriware made from zinc.

In the fourteenth century, there was an artform called Bidri that used hammered copper and zinc forms with incredible inlay artwork. Figure 1.9 is a modern example of the artwork. Bidri is a product that originated in south central India and is attributed to the Bahamani sultans in the fort city of Bidar. They used the process of engraving and repossé to produce elaborate designs in metal bowls and plates as well as the bases of hookahs.

They would often inlay other metals such as silver or gold and then darken the background metal with sulfide compounds and polish off the top sections.

This area of India is still a major center for manufacturing unique metal work. Today, brass, copper, and zinc are still handcrafted here in the old tradition. It is important to note, these incredible art pieces were created from zinc–copper alloys, where the zinc was 4 times the amount of copper in the base metal to as much as 16 times. Zinc was being produced in large quantities in India as early as the fourteenth century.

There was no known process of producing zinc in Europe until several centuries later. In 1982, an archeological study of the mines in the region around Zawar in Rajasthan was undertaken by a British-Indian research group. They found intact furnaces and clay retorts that indicated smelting of zinc on a significant scale had been underway centuries ago[5]. The clay retorts were positioned at an angle. The neck-down area was lower than the enlarged section and positioned through a wall of clay and stone into a cooler chamber – much the same way as William Champion and Jean-Jacques Dony arranged their retorts to capture zinc vapor and condense it to create a pure form of zinc. William Champion traveled often to India, and apparently he studied the Indian process and brought it back to England.

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[5] Jagdish Mittal, *Bidri Ware and Damascene Work in Jagdish and Kamla Mittal Museum of Indian Art*, Hyderabad, 2011, p. 39.

Other examples of zinc used in the far Eastern cultures predate the arrival of the metal to Europe. Zinc was rarer than copper and iron in these early times, and the utility of the metal was not yet understood until larger quantities could be produced.

In Europe, once more intense refinement of the metal took form and quantities of the metal became available, artists and artisan began to understand certain beneficial characteristics. One was the low melting temperature, much lower than copper or iron. Once melted, it had good fluidity and could be poured into simpler molds and achieve good detail.

Zinc-cast statues date back to the mid- to late-1700s in Europe, where it was extensively promoted for use in northern Europe. In Prussia, it was used on buildings and ornament for the new capital city of Berlin. Karl Friedrich Schinkel, the architect, artist, and city planner pushed for its use in statuary and building ornamentation in the early 1800s, where the silvery blue metal was used to adorn the new Prussian capital.

In Paris, one has to marvel at the silvery roofs and ornamentation that distinguishes that city. The Baron Hausmann, Prefect of the Seine Department of France under Napoleon III, undertook a vast redevelopment of the famous city in the mid-1800s. This started the cladding of the famous mansards of Paris. Supposedly, the Baron Hausmann had a relative in the zinc-mining business. It could also have been that Hausmann wanted to have a crème colored stone used for the walls of his building design and the use of copper may have led to staining. One of the great benefits of zinc is that its oxides do not stain adjacent materials.

One of the main sources of zinc was the mine, La Vielle Montagne in Kelmis, called *La Calamine* in French. This area, on the border of Germany was the source for much of the zinc used France at the time of this adornment and reconstruction of Paris. La Vielle Montagne started in the 1400s as a source for zinc used in manufacturing brass. The La Vielle Montagne Zin Mining Company was formed to supply Paris with the zinc needed to redevelop the city under Hausmann. The company became VM Zinc and is one of the largest suppliers of zinc in the world.

The zinc mines around Vielle-Montagne, had been in use since Roman times and this readily available ore was ideal for making a statement for France. As early as 1815, some of the first roofs of Paris were being clad in this silvery metal, zinc, and today close to 90% of the roofs of the great city are still covered in zinc. UNESCO, the United Nations Education, Scientific and Cultural Organization is considering making the zinc roofs of Paris a World Heritage.

The Prussian source of zinc was the area known as Silesia. Silesia, a region in present-day Poland, produced zinc that was known for its low sulfur. Very extensive manufacturing of zinc products took place in this region. The central part of Europe mined and produced much of the zinc used in the world during the 1800s.

It was soon discovered that coating iron in molten zinc would provide galvanic protection to the iron and later steel. By 1830, coating iron with zinc was in wide use throughout Europe. Later that century, steel was invented and overtook iron as a building material. As the less corrosion resistant steel came into major use the later part of the century, coating steel with molten zinc as a sacrificial layer became a major enterprise that continues today. The vast majority of zinc used today is to protect steel by hot dipping in baths of molten zinc.

The largest industrial companies producing zinc for architectural and industrial use were centered on this central region of Europe. Europe is the major producer of rolled zinc even today and some consider zinc the “European metal.” In the late 1700s major zinc works in Bristol, Sweden, the upper Silesia region of Prussia and near Delach in Austria were in full operation, for the most part involved with alloying with copper to form brass.

After Dony’s work in developing smelting and sheet production processes in Liege, Belgium, the Vieille Montagne Zinc Company was established in 1851 and became one of the largest producers of zinc sheet and ingot. Around the same time in Germany, along the Rhine in Westphalia zinc production also increased and formed one of the largest zinc production companies still in force today, Rhinezink.

The first use of rolled-zinc sheet occurred in Liege, Belgium, where in 1811 the roof of the Church of St. Barthelemy was covered with thin rolled plates. Also, in 1812, the tower steeple of the restored Cathedral of St Paul in Liege, was roofed with these first rolled-zinc sheets.

In 1837, the famous St Charles Hotel in New Orleans had a dome and roof clad in zinc sheets made from imported zinc sheeting from Vielle-Montagne to complement the white marble of this Grecian-style palace. This was the first use of architectural zinc in North America.

In North America, there was a period of time when the metal fell out of favor as a surfacing material in architecture and as a metal for sculpture. Knowledge of the metal waned. From around 1930 to 1990, the expertise in the use of zinc was deficient in North America, while in Europe it was taking a stronger position as a metal of architecture due to production practices that developed in France and Germany after the Second World War.

Early in North America, zinc was considered a waste byproduct in the production of lead. Lead and zinc were often mined together. It wasn’t until the mid- to latter part of the 1800s that the metal zinc became valuable as a coating for steel and as an alloying element to add to copper to make brass bullet cartridges. Lead, of course, was the material for bullets. Around 1872, zinc became a commodity of interest as steel production took off in the United States after the civil war.

The need for galvanizing became critical with the arrival of steel. Steel was now being produced inexpensively as the Bessemer process advanced in development. Engineers were designing structures with steel and galvanizing, or coating with zinc. It was long known that zinc is as an excellent corrosion inhibitor for steels. The patent for galvanizing steel was filed in 1837 by the French Chemist Stanislas Sorel but the notion of zinc as a sacrificial material was described by Luigi Galvani and Alessandro Volta in the late eighteenth century.

In any event, once the economy of steel production was established, the need for zinc as the protective coating expanded and mining of zinc in the Americas began in earnest. Zinc mining and smelting expanded in various areas around the United States. Zinc deposits in Wisconsin, Illinois, and Missouri were exploited as the smelting process improved. In the late 1800s and early 1900s, American zinc-mining dominated supply of ore for the world. The large European companies had exhausted much of their supply of high-quality ore and turned their attention to importing zinc from American mining interests. The area around Joplin, Missouri, into Kansas and down to North Eastern Oklahoma became the center for zinc mining due to high-quality *jack,* as it was called. The Joplin, Missouri, area became the main supplier to the world as several million tons of high-quality ore was mined in this region. Every major rail line in North America passed through this region to transport zinc and lead ore eastward. Poor miners became wealthy with the rich finds of this metal ore they called jack.

A process of using vertical retort condensing was invented by the New Jersey Zinc Company. This process, was a modification of the horizontal retort developed by Dony in Belgium and was in wide use until the 1960s. In 1858, two immigrants, Fredrick W. Mattheiessen and Edward C. Hegeler, opened a zinc smelting plant in LaSalle, Illinois. Energy needed for the smelting operation was readily available and transportation on canals and rivers opened this region to the world. Before long the La Salle Zinc Works was producing 4,000 tons of zinc a year, making this one of the largest producers of refined zinc in the world. The La Salle Zinc Works continued to expand and supply zinc to galvanizing facilities for the burgeoning steel operations in the United States. They opened a rolling mill to produce slabs of zinc and eventually sheet and strip zinc. From an architectural context, they produced a sheet and strip zinc for roofing and flashing along the lines of what was being produced in Europe in the hopes of expanding the market for zinc in the United States in a similar fashion to its popularity in Europe. The product they produced was called *Titanaloy* because it was an alloy of zinc with small amounts of titanium added along with copper. It was introduced to the architectural market in the 1960s. The alloy gave zinc sheet improved creep resistance and improved strength. The alloy had been developed and patented by the New Jersey Zinc Company in 1949 and was licensed out for use by others 10 years later.

The Ball Metal and Chemical, a division of the Ball Corporation famous for their Ball Mason Jars, was another producer of zinc sheet in the United States. The Ball Corporation wanted corrosion resistant lids for their glass jars, and zinc, with its malleability and decent corrosion resistance, would suffice.

Their product for the architectural industry was called, Microzinc. Introduced in the early 1970s, this preweathered zinc sheet was alloyed with copper and titanium, similar to LaSalle's Titanaloy. The Ball Corporation spun off several of its business entities in the early 1990s and one was the zinc

TABLE 1.1 Common Minerals of Zinc

Mineral Name	Chemistry
Sphalerite (also called Calamine)	ZnS
Marmatite (variety of sphalerite)	$(Zn,Fe)\ S$
Hemimorphite	$Zn_4Si_2O_2(OH)_2 \cdot H_2O$
Hydrozincite	$Zn_5(CO_3)_2(OH)_6$
Smithsonite	$ZnCO_3$
Willemite	Zn_2SiO_4
Zincite	ZnO

production and rolling line in Tennessee. This became the Alltrista Zinc Products Company then later the Jarden Corporation in 2001. Today it operates as ARTAZN and is one of the largest producers of zinc strip and zinc-based products in the world. Still operating out of Tennessee, ARTAZN produces sheet and coil for the architectural market as well as manufactures the blanks for coinage used by countries around the world, including the US penny. The penny is zinc with a thin jacket of copper plate.

ZINC MINERAL FORMS

Zinc ores, like that of other heavy metals, are mostly below ground. The common zinc ore is sphalerite, sometimes called zinc blende in the United States and calamine in Europe. Sphalerite is composed of approximately 5% to 15% zinc. Table 1.1 shows the common mined minerals of zinc and Figure 1.10 shows several of the common minerals. The reddish center mineral is zincite, the top left and right minerals are smithsonite, while the black crystalline mineral at the bottom is smithsonite, "jack," from Joplin, Missouri.

Zinc is not as abundant as other elements. It comes in around 24th, just ahead of copper as elements that make up the Earth. Zinc is always found with other elements such as lead, copper, and sulfur. As the Earth formed, zinc combined with sulfur. This mineral was heavy compared to other substances and sank below the surface. Large deposits are mined in the Americas, Australia, and Asia where the ore has risen from tectonic activity over the millennial. Approximately 13 million metric tons of zinc ore are mined each year. Table 1.2 shows the comparison with other metals mined around the world.

Because zinc ores are relatively low in zinc, they have to be concentrated by crushing the rock and then floatation to remove other materials. Concentrating the ore increases the yield to around 60% zinc. Other metals, such as lead and copper, are removed as well. The concentrated ore is sent to the smelter where one of two methods are used to refine the zinc. The pyrometallurgic process, which uses the system of roasting and condensing or electrolytic refinement, which also begins with roasting but uses electrolytic processes to remove the zinc. Nearly all the zinc produced today involves the electrolytic method.

The electrolytic method also known as the Roast-Leach-Electrowin (RLE) process extracts the zinc by electrolysis. Essentially zinc oxide is produced from the concentrated zinc sulfide by roasting the ore at high temperature. This creates zinc oxide and sulfur dioxide. The sulfur dioxide is converted to sulfuric acid, which is then used in the leaching and electrolysis step. The zinc oxide is dissolved in the sulfuric acid in several concentrated steps. Other impurities are removed by a process of cementation. The concentration must be as pure as practical in order to efficiently pull the zinc out of solution. The impurities, often other metals, are also collected.

Once the concentrate is sufficiently pure, electrolysis begins. Here the zinc is removed from solution by electrolysis in the sulfuric acid electrolyte and deposits on the cathode. Oxygen forms at the anode. The zinc is stripped from the cathode, melted, and cast into ingots.

FIGURE 1.10 Various ores of zinc.

ZINC IN ART

Zinc as an artistic material or architecturally aesthetic surface was slow to be established in the United States. In the late 1800s there was a movement where statues and monuments were manufactured from zinc. The movement began in Europe, mainly France, where it was called *la statuomanie,* or *statue mania*. Statues proliferated throughout Europe and this eventually came to the United States as the Victorian era of architecture set in. The arrival of the movement coincided with the end of the American Civil War, and across the country, monuments to the solders of the war became commonplace. In addition to commemorating the civil war solder, state capitals, cemeteries and wealthy landowners adorned their buildings and gardens with sculpture. This, coupled with the

TABLE 1.2 Metal Mining around the World

Metal	Metric Tons Mined
Nickel	2.7 million
Zinc	13 million
Copper	20 million
Magnesium	29 million
Chromium	44 million
Aluminum	64 million
Iron	2.5 Billion

Source: Based on 2020 USGS Mineral Commodity Summary

Gothic and Italianate revival styles, ushered in with the Victorian era, opened zinc to the fashion of the time, with elaborate zinc castings or stamped zinc sheeting for both statue manufacture and fenestration on Victorian homes.

Figure 1.11 shows a typical Victorian era architecture that swept across the United States in the late 1800s. These homes were adorned with metal features made from tin and zinc, much of the work imported from Europe.

Copper alloys, such as gunmetal (85-5-5-5), with 85% copper, 5% zinc, 5% lead, and 5% tin, were used by sculptures during this time as well, but zinc played an important role. Zinc required less energy to melt, had a pleasing color that did not need to be patinated and protected with wax, and was affordable. As it weathered, it did not stain light colored stone or brick.

Zinc sculpture flourished during the late 1800s and early 1900s as patterns from European sculptures were taken and molds were generated from bronze castings to allow multiple zinc sculpture replicas to be made. Often, the zinc was treated to replicate the appearance of other materials such as bronze or stone. Plating copper to zinc was common and advertised as an alternative to bronze sculpture. Figure 1.12 shows a copper-plated zinc statue produced as a memorial to the union soldiers of the Civil War. There are many similar replicas of this same casting owing to the reuse of the molds.

A method of electroplating the zinc with copper came into widespread use as a way to obtain “bronze” for a more economical price. A true bronze sculpture might cost a hundred times that of a zinc sculpture. Sculptures made from zinc were quick and simpler to cast and the detail was similar.

On close inspection, these slush cast sculptures lack detail a similar bronze might have. Figure 1.13 is the face of a “Dough Boy” from World War I. This particular sculpture was slush cast numerous times from the same mold. The detail was good enough for the many replicas produced and shipped across the United States. As you can see, it too was plated in copper to mimic bronze.

There were numerous replicas of the Dough Boy manufactured by two competed firms at the time in the United States. You can find these copper-plated zinc sculptures in cemeteries and memorials all across the country.

Three methods of creating zinc sculptures were in use during the late nineteenth and early twentieth century. Sand casting, similar to cast methods used on copper alloys, was one method. A second process is known as slush casting. This method, similar to permanent mold type casting, involved pouring the molten zinc into the mold, allowing it to cool briefly so only the zinc at the interface of the mold wall cooled, then pouring the excess, still molten, metal out. This method was quick, and the outer surface would capture detail of the mold. Stiffness was achieved by thickening the walls. On occasion, several molds would be produced for a large assembly and then joined by

FIGURE 1.11 Vaile Mansion. Example of early Victorian Era homes in the US.
Source: Library of Congress

solder or by "welding" them together by pouring a band of zinc in segments along the joint between larger elements. Figure 1.14 shows the "Goddess of Liberty" statue erected on the top of the State Capital dome in Austin, Texas. This large sculpture was designed by the architect Elijah E. Meyers and cast in 1888. The sculpture is over 5 m tall and assembled from 80 unique cast panels. The panels were cast in zinc and assembled to an internal iron armature. It remained on the dome for nearly 100 years before damage from storms and fractures from thermal movement required it to be removed and replaced.

The third method involved stamping zinc sheet. The zinc sheet was heated and pressed into wood molds. Matching male and female dies were used to create the thin zinc panel. These would

FIGURE 1.12 Copper-plated zinc sculpture.

then be assembled by soldering the plates. Large sculpture could be created this way by incorporating an internal structure.

Initially, many of the sculptures were imported, but this quickly changed. Several enterprising companies set up foundries to create their own sculpture, often copying the designs of European artists.

The Monumental Bronze Company from Bridgeport, Connecticut, sold zinc statues in the late 1800s and early 1900s. They called the metal “white bronze,” perhaps to give the statues a level of mystery and to ask a higher price.

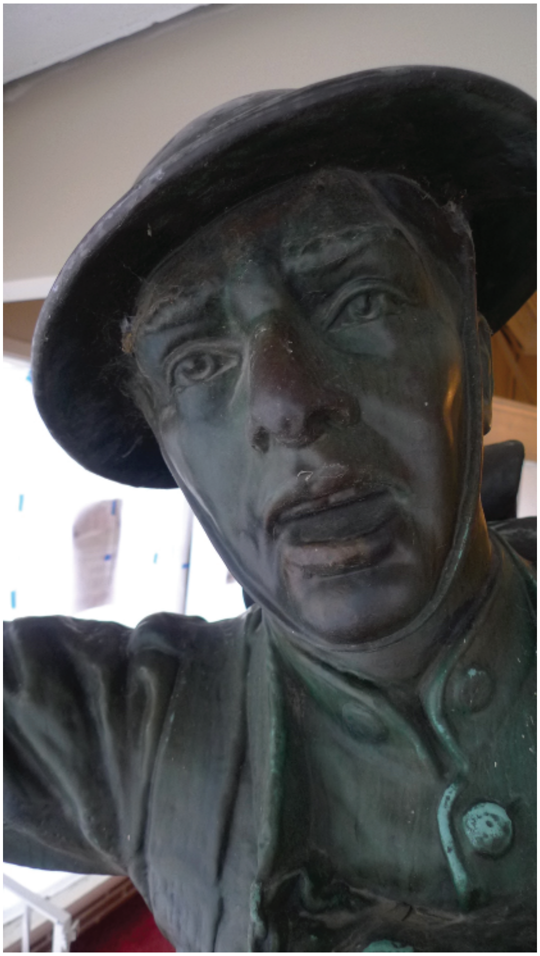

FIGURE 1.13 World War I Dough Boy slush cast zinc. Copper plated.

Another company, M.J. Seelig and Company, established a foundry for casting zinc in Brooklyn in 1851. He is credited with casting the first zinc artwork in America for a Fair in New York in 1852.[6] The Seelig firm was prolific in casting zinc statues. Some were modeled after works from Europe, others were created by Moritz J. Seelig himself. The Seelig Company sold its sculptures through the J.W. Fiske Company and the J.L. Mott Iron Works Company. Each had catalogs of various sculptures for sale and marketed these across the United States. Some of these early statues had been copper plated and sold as "finished in bronze" in an attempt to add some panache. Others were

FIGURE 1.14 "Goddess of Liberty." Texas State Capital Building. Erected in 1888.
Source: Philip Arno Photography/Shutterstock

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[6] Grissom, Carol A., Zinc Sculpture in America 1850–1950.

painted, like the "Goddess of Liberty," shown in Figure 1.14. This zinc sculpture was painted white to look like marble. Others were left in the traditional blue-gray color.

The supply of zinc for statues in the United States proliferated for nearly a century, perhaps peaking after the First World War. There were a number of foundries involved with producing sculpture from zinc in the United State as well as companies involved with the importation of sculptures from Europe. Many of these sculptures are still performing well even though they have been exposed for years.

Cracks from the condition known as creep are apparent in a few sculptures. Often, the fissures are mistaken for open seams due to freeze–thaw cycles. Creep is one of the major issues faced with unalloyed zinc. Creep is a condition where under sustained loading, even light loading such as the weight of the metal, deformation, and elongation occurs. Creep was an issue that had to be overcome if zinc was to be used as an architectural cladding. This was overcome in the 1960s as alloys were developed to give zinc better strength and the ability to resist creep.

ZINC AS AN ARCHITECTURAL METAL

Across Europe, zinc was considered a metal of architecture and ornamentation for buildings. Major cities, Paris, Berlin, Brussels, and others incorporated zinc in the architecture that defined the city. The Prussian architect Karl Friedrich Schinkel introduced zinc as an architectural metal in his designs for the city of Berlin. He was a city planner, artist, and architect who applied zinc in various ornamental forms on his designs in the early part of the nineteenth century.

France of course continues to adorn its buildings in Paris with zinc. From its elaborate mansard roofs to bay window dormers, cresting and other relief that grace the buildings of the city. Figure 1.15 shows a few of the beautiful zinc roofs that give France its character.

Still today, zinc is considered a major architectural metal for some of the most stunning architecture in Europe. Daniel Libskind chose zinc to clad the intricate shapes of the Jewish Museum in Berlin and the Filix Nussbaum Haus in Osnabrück, Germany.

The Winery Cantina de Il Bruciato, in Carducci, Italy, is an excellent example of the stunning use of zinc on modern architecture. See Figure 1.16. The design firm, Fiorenzo Valbonesi Cesena created an amazing addition to the Winery, using Rhinezink's preweathered zinc called Graphite Gray.

In the United States, the use of zinc was slow to develop. Initially, in the beginning of the twentieth century, zinc had a few inroads beyond statuary. Stamped panels, building ornamentation and other features, often painted were made from zinc.

Figure 1.17 shows the Folly Theater in Kansas City, constructed in 1900 and then renovated in 1980. When the metal work was taken down to be repaired, the workers were initially confused. The metal was different than the copper or terne-coated metal used on many of the buildings constructed in that era. Zinc had disappeared in the United States as a building material, and those who had worked with sheet metal for decades had no idea what this metal was. It wasn't magnetic, it could be soldered, it was dull bluish-gray, but it wasn't stainless steel. Zinc had fallen out of the vocabulary of sheet-metal workers for at least a generation in the United States. Replaced with lead-coated copper, terne-coated stainless steel, the blue-gray metal was for the most part completely unknown.

The upper cornice, capitals, railings, and ornamentation around the windows of the theater shown in Figure 1.17 were made from zinc and painted. The balusters were spun zinc and soldered together. Other elements were stamped and joined with soldered seams. For the most part, the metal was in good condition, a few open seams and missing elements, but the zinc had performed quite well even though the building had suffered decades of neglect.

There are various reasons, many psychographic in nature but mostly due to a lack of knowledge and understanding. Zinc as a building material was not especially promoted prior to the development of the zinc–copper–titanium alloy that entered the architectural picture in the early 1970s. Galvanizing was the main use of zinc and still is today, with almost 80% of the zinc produced going to protect steel either in automobiles, structures, or appliances.

FIGURE 1.15 Zinc roofs in Paris.

FIGURE 1.16 Winery Cantina de Il Bruciato designed by Fiorenzo Valbonesi Cesena. Image courtesy of the architect.

There were companies, like the Mesker Brothers of St. Louis, who touted the use of galvanized steel and galvanized iron castings for building facades. Figure 1.18 shows a bank façade created as a kit by the Mesker Brothers. Similar facades can be found in small towns across the United States where various parts could be assembled around the entryways and streetscapes.

Galvanized steel, both painted and unpainted, were the extent of zinc usage by architects for decades. The *Architectural Sheet Metal Manual* developed by the sheet metal industry in North America was silent on zinc. In 1929, the National Association of Sheet Metal Contractors published

FIGURE 1.17 Folly Theater in Kansas City, Missouri.

a beautifully detailed book titled, *Standard Practice in Sheet Metalwork*, no mention of zinc other than galvanized iron. The Sheet Metal Publication Company of New York, published, *The Universal Sheet Metal Pattern Cutter*, Volume II, discusses zinc in the same light as copper for assembling roofs, but makes no distinctions. On page 337 of the volume, zinc sheet roofing is listed as weighing 8 pounds per square foot (39 kg/m^2), as compared to 1 pound per square foot (4.8 kg/m^2) for copper. This would put zinc at a thickness of over 0.25 inches (7.5 mm). Granted, often early unalloyed zinc sheet was thick, much thicker than the copper–titanium alloys we use today. This was either a response for concerns of mechanical creep or a lack of knowledge of the metal. Most likely, the latter.

There is very little said in publications on architectural conservation that discuss the use of zinc on American historic buildings. The US Department of the Interior, 1992 publication, *Metals in America's Historic Buildings*, Part I, by Margot Gayle and David Look, AIA, mentions zinc and says, "Although the popularity and use of zinc roofing in America varied greatly, its use was never as widespread as tinplate."

The 1976 publication, *Architectural Sheet Metal*, by SMACNA[7], lists the metals copper, lead coated copper, stainless steel, aluminum, terne, terne-coated stainless steel, galvanized steel, and lead. No mention is made of zinc. The lack of knowledge of zinc as an architectural metal from those that worked with sheet metal architecture and the design community is a clear indication of why the metal was not used or considered for use.

There were producers of zinc sheet in the United States. Mattheiessen and Hegeler's LaSalle Zinc Works produced the product, Titanaloy, and Ball Metal and Chemical had their sheet product,

FIGURE 1.18 Mesker Brothers Kit Façade made of galvanized steel.

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[7] SMACNA stands for the Sheet Metal Air Conditioning National Association. This is the association of those contractors that work on sheet metal applications across North America.

Microzinc 70. Both developed in the 1970s as roofing and flashing sheet metal but neither made a huge impact at the time with the design community or the metal fabricators. There was a lot of mis-information and no promoting group like what existed for aluminum, steel, and copper in the United States.

It wasn't until the late 1980s when the large European zinc manufacturing companies set their sights on the vast North American market and began a marketing and education campaign in earnest.

More than 90% of the architectural use of zinc that exists today was built after this period. Zinc use as a viable architectural metal in the United States has flourished and grown exponentially in the last three decades as education, knowledge and experience of this enigmatic blue-gray metal has expanded within the design community and the metal fabrication industry.

HEALTH AND HYGIENE

Zinc is a necessary element for human and animal life. Approximately 15 milligrams of zinc, is needed each day. Next to iron, zinc is one of the most important metals needed for proper development and, like iron, we are often deficient and need supplements of zinc.

Zinc is used by the body to create the enzymes needed for cell growth and aids in liver and kidney functioning as well as healing, fending off fatigue and even the common cold. We take zinc lozenges that contain zinc compounds to ward off or at least reduce the effect of common viruses and nasal congestion.

Both zinc and its oxide are not considered harmful to humans or animal life in light and moderate exposure. Humans use zinc oxide as a skin ointment to protect from the sun or as topical anti-inflammation cream to combat insect bites and poison ivy. It is found useful to combat and heal diaper rash on infants, burns and as a colorant in some cosmetics. The low toxicity of zinc enables it to be used as sunscreen to protect against harmful ultraviolet radiation. The maximum amount of zinc oxide in these various ointments, per accordance with the Food and Drug Administration of the United States, is approximately 25%.

Zinc in drinking water will change the taste when levels begin to exceed around 40 mg/liter. If the water is carbonated, the zinc ions go into solution much faster. Zinc is amphoteric, so it is attacked by both acids and bases. Milk, soda, and lemonade, for example, will attack the zinc more rapidly than distilled or tap water. Leaving these liquids in a zinc container can lead to dissolution of the zinc at levels that will alter the taste and increase toxicity.

Taking too much zinc into the body by drinking water, juice, food, or dietary supplements can cause adverse health effects such as vomiting, stomach cramps, and nausea. Extended intake of zinc will affect the kidneys and pancreas. Excessive zinc intake can block iron and copper absorption, leading to deficiencies in these important elements.

Not getting enough zinc in the diet can be just as bad, however. Young children require zinc to grow and develop properly. Too little zinc will also affect the immune system.

The zinc ion in solution can be harmful to animal and plant life. However, the zinc ion is a rapid oxider and combines quickly with oxygen and other substances. The occurrence of the zinc ion would be rare. When zinc is in the soil it will usually combine with other substances. That is one of the reasons we do not see zinc in pure form naturally. Too much zinc will interfere with plant growth as the free zinc ion is toxic to plants. This is what happens around smelting sites. Zinc is usually the least of the concerns as these sites have other more harmful substances such as lead and cadmium. Plants require zinc in very small amounts, or they will not grow. Zinc is considered a micronutrient for the health of plants.

When working with zinc, the most significant issue develops when inhalation of the zinc oxide fumes occurs. This can happen when welding or soldering zinc or welding galvanized steel. It can occur when cutting galvanized steel with plasma or other high temperature methods or working with casting zinc. Any high-temperature process that puts zinc oxide in the air can create the problem. Inhaling the fumes, even small concentrations can induce flu – like symptoms that lasts several days. Aches, chills, and fever set in. The first sign is a metallic taste in the mouth or throat irritation. This condition is as old as the metal itself and has several names, “brass foundry ague,” “zinc fever,” “brass shakes,” and “metal fume fever.” Whatever the name, it is not something to experience.

Similar to other metals, the early mining practices were ill-conceived. There are a number of zinc mining sites across the United States that were used for over a century. Often, smelting operations were located near these sites. Dust, air, water and slag waste accumulated in these sites. Zinc by itself, is not particularly toxic. Zinc ore though, is often accompanied by lead, cadmium and arsenic. Early mining was centered around lead and the zinc was considered a nuisance and quickly discarded. In the mining area of southwestern Missouri, the zinc minerals were called “jack,” “black jack,” or “rosin jack,” depending on its color. Lead smelting was easier and the market for lead was significant. It was easier to work with at the time and bullets, made from lead, were in high demand.

The lead contamination along with other metals such as cadmium and arsenic are the major issues, still in existence today long after the mining and smelting operations ceased. These large mining sites, often located near towns and rivers, operated for decades. The accumulation of waste and contamination are considered toxic and are all in some form of remediation by the government. Deep pits, collapsing mine shafts, and the effect on water quality are conditions being faced by communities in and around these old mining operations. Most of these antiquated operations are no longer in business but the scar left by the operations is still there.

Today, the zinc industry in North America and Europe take the environment and environmental impact of their efforts seriously. Recycling of existing zinc currently stand at about 30% and is expected to increase as new systems of recovery bring the cost of recycling down. Recycling zinc from sheet, scrap zinc, and stamped zinc is relatively straightforward.

Figure 1.19 shows the recycled blanks from making the penny. These blocks will be remelted and turned into more coins or possibly, an architectural surface.

Recycling zinc that has been coating via the galvanizing process requires additional processes where the zinc is captured out of the vapor and dust from recycling steel. There are several processes that involve taking zinc out of the fumes generated from the melting and recycling of steel. As the steel is heated, the zinc melts and vaporizes. From the vapors the zinc is removed and repurposed.

FIGURE 1.19 “Un-money.” Recycled blanks of zinc off-fall from penny manufacture.

Another method is to remove the zinc by leaching the metal with acid and electrowinning to recover the metal out of the acid bath.

Using zinc as a coating of steel in the process known as galvanizing is considered an environmental and sustainable coating process. There is energy consumed in the mining and smelting operation as well as the heating of the molten zinc bath. However, there are no VOCs (volatile organic compounds) released and the life cycle impact of hot-dipped galvanized is very low. The steel and the zinc can be recovered and recycled. The steel structure will last longer and have far less maintenance when properly done as compared to paint coatings. The initial cost of galvanizing is very low as well.

THE ENIGMATIC METAL

Zinc is possibly the least understood and enigmatic as metals go in an art and architectural context. Not unlike the hidden metal in the mineral form to our ancestors. More clarity of what zinc is about is coming into focus. As Figure 1.20 shows all the various names for the metal as we tried to figure out what its real value was.

FIGURE 1.20 The names give to element 30 over the ages.

We often want to interpret the various metals through the same looking glass as far as how they are used. “If the metal can be cast, then it should have similar behavior,” one might assume. “If the metal is produced in sheet, then it must form and work similar to other sheet metal forms,” sheet metal is sheet metal to many.

Zinc, however, is different. It is both very corrosion resistant, yet it sacrifices itself rapidly to other metals if conditions are right. Zinc is easy to form, until the temperatures drop, then it can get brittle and crack when forming cold. Where most metals work harden from cold working, zinc relaxes. Zinc casts as easy as plastics, uses less energy than other metals, can even be injected into molds. Zinc can be elongated to extremes in superplastic forming. It sometimes acts more like a polymer than a metal.

The next chapters will explore this interesting metal and describe what distinguishes zinc from the other metals we use in art and architecture.