Chapter 5

Creating aluminum markets

Writing about aluminum's value in 1862, Henri Sainte-Claire Deville said, "Aluminum is the intermediate metal between the noble and the base metals." The first article made of aluminum a baby rattle made for the infant Prince Imperial of France in 1856. "For this purpose it no doubt answered excellently, from its brightness, lightness, ring and cleanliness, but only a prince could afford to possess one in those days," metallurgy professor Joseph Richards wrote in 1896. Over the next few years, the primary uses of aluminum was jewelry and articles of ornament, but the metal did not stay in fashion for long "so that the rage for aluminium jewelry subsided almost as fast as it had arisen." Next came the French interest in producing artistic furniture, with carved moldings, cabinets, tabletops and other items. Fine aluminum wire produced by Vaugeois was used by Garopon in Paris to produce embroidery, lace and passementerie. Initial military interests in aluminum focused on decorative uses, such as spurs, sword handles, saber-sheaths, helmets and imperial eagles, whose weight fell from eight pounds to three. A helmet was fashioned for Emperor Napoleon III's cousin, the king of Denmark. By 1890, however, the Germans took the initiative in finding practical military uses for aluminum, including canteens, cooking utensils, pontoons and any other metallic component to a typical soldier's kit. "Every ounce of weight thus saved means as many more cartridges carried per man," Richards wrote. He noted that the Russian army had tried aluminum frames for its ammunition wagons, but the U.S. army had not yet adopted any aluminum articles. [1]

Because of its shine, aluminum was being used for locomotive headlights and shades for incandescent lights. Because it resisted rust better than iron, aluminum was being used in the mining industry for ore cars and lifting cages, where its lightweight saved lifting power. For industrial machinery in general, any moving part that could be constructed of lighter-weight aluminum could save energy. In medicine, aluminum was being used for tracheotomy tubes, suture wires, surgical instruments and dental plates. Aluminum continued to be used for scientific instruments – before 1860, Roseau of Paris made a seagoing sextant which weighed only one-third of a typical sextant. "For any scientific instrument where the inertia of a heavy moving part is to be avoided, aluminum is the material par excellence," Richards wrote. "For electrical instruments it has the additional advantage that it is absolutely without magnetism or polarity, if pure, and it thus makes the most suitable material for compass boxes, galvanometer cases, etc." The O.C. Striker company in Mainz, Germany patented an aluminum printing process in 1892 to replace the expensive Solenhofen lithographic stone. Very fine aluminum filings were being used for photographic flash powder. Aluminum powder was cheaper than magnesium and less likely to explode. [2]

By 1896, according to Richards, some of the methods used to fabricate aluminum metal dated back to the middle of the 19th century and were developed and described by Henri Sainte-Claire Deville in his 1859 book. Deville warned against using fluxes when melting aluminum, as they were "always useless and almost always harmful." He also noted that aluminum "is very slow to melt, not only because its specific heat is considerable, but its latent heat appears very large." Deville also noted that the fusion of aluminum alloys or impure aluminum could be very different. Lining crucibles with carbon protected them from adhesion by molten aluminum. He also noted that heating aluminum beyond its melting point until it was red hot could cause it to "attack" an iron crucible, forming a thin but tough skin. By 1896, large aluminum works were melting 500 to 1,000 pounds of aluminum at a time. "Aluminium can be cast very easily in metallic moulds, but better in sand for complicated objects," Deville said. "The mould ought to be very dry, made of a porous sand, and should allow free exit to the air expelled by the metal, which is viscous when melted." Richards noted that by 1896, Dr. C.C. Carroll of New York was considered an expert in casting aluminum dental plates, and the Passaic Art Casting Co. of New Jersey made fine aluminum castings using the Smith pressure-casting process. A large amount of cast-aluminum hollow-ware was being produced for culinary uses, including teakettles, he said. W.S. Cooper of Philadelphia produced large sand castings by adding a little copper to reduce the shrinkage of the aluminum, including cast bathtubs. [3]

Deville described a method from 1859 used to remove slag from molten aluminum. Three or four kilograms of aluminum was melted in a plumbago crucible without a lid and kept red hot and in contact with the air for a long time. Acidic fumes that left the molten aluminum indicated the decomposition of saline matter that impregnated the metal. The crucible could be withdrawn from the fire, and white, slaggy material could be skimmed from the surface. That slag, today called dross, could be remelted to recover aluminum. The process was repeated three or four times to produce purer aluminum, Deville said. He noted that he knew of no way to eliminate silicon from aluminum metal. “A particular characteristic of the metallurgy of aluminium is that it is necessary, in order to get pure metal, to obtain it so at the first attempt,” he wrote. Deville said lead, iron or copper could be removed to some extent by repeated melting and separating. Aluminum metal could be softened by heating it to a very low redness and then cooling quickly, such as by dropping into water. “Great care is necessary in annealing thin sheets which are being beaten into leaf, to avoid melting them,” Deville wrote. [4]

Hammering, rolling or drawing aluminum made the metal harder and stiffer, good enough to serve as hair-springs for watches. Before rolling aluminum bars, they should be softened and tapered down to form a head by hammering, Deville wrote. “The rolling is not difficult, except that a large amount of power is required (about as much for cold aluminium as for hot steel), and as the metal quickly gets hard it must be annealed often,” Deville wrote. Thin-rolled sheets could be further extended out by beating into leaf. Degousse of France was the first to produce aluminum leaf in 1859. By 1896, aluminum had been rolled as thin as tissue paper. Elwood Ivins of Philadelphia used a rolling process on a mandrill to produce aluminum tubes of various sizes, including 10 meters long by 1 millimeter in diameter. Aluminum was less ductile than gold, silver, platinum, iron or copper. In 1855, Vangeois of France produced a fine wire with less than pure aluminum. By 1896, aluminum wire as fine as a human hair was produced by drawing. Round or square aluminum tubes were also produced by drawing aluminum sheet that had been soldered together. [5]

The standard methods for grinding, polishing and burnishing metals did not work well with aluminum. According to Biederman, “The use of the old means of polishing and burnishing metals, such as soap, wine, vinegar, linseed oil, decoction of marshmallow, etc. is not effective with aluminium, but, on the contrary, is even harmful, because, using them, the blood stone and the burnishing iron tear the metal as fine stone does glass.” By 1896, the Pittsburgh Reduction Co. was using sheepskin, chamois skin or rag buff to polish aluminum, using the rouge the same as for brass. The company also sold a polishing powder for aluminum called Almeta Polish. Aluminum could be engraved if the metal was coated with a varnish made of turpentine and stearic acid, or some olive oil mixed with rum. Dirt and grease could be easily removed by dipping the metal in benzine or turpentine. According to Deville, a mat or frosted effect could be created by dipping the metal for an instant in a very dilute solution of caustic soda, washing with water, and then dipping in a strong nitric acid. Aluminum could not be welded except by electrical process. By 1896, the Thompson Electric Welding Co. had a special machine for making rapid welds with aluminum metal. [6]

Aluminum was difficult to solder for three reasons – the thin layer of aluminum oxide that quickly formed over exposed aluminum metal prevented solder from adhering to the metal; aluminum had a high conductivity of heat, making it difficult to produce a local temperature at the joint high enough to make solder flow; and aluminum was highly electro-negative, which caused a galvanic action to arise at the soldering joint and weakened the joint. “Aluminium may be soldered, but in a very imperfect manner, either by means of zinc, or cadmium, or alloys of aluminium with these metals,” Deville wrote. “But a very peculiar difficulty arises here – we know no flux to clean the aluminium which does not attack the solder, or which, protecting the solder, does not attack the aluminium.” Numerous scientists and experimenters came up various soldering formulas and techniques over the next 40 years. Attempts were also made to coat metals with aluminum to provide those metals with some of the protective properties of aluminum. One way was to submerge the metals in an aqueous solution and deposit the aluminum by electrolysis. According to Deville, Sevrard succeeded in veneering copper and brass with aluminum in 1854 “with considerable perfection.” In 1885, G. Gehring patented a method to aluminize metals that were difficult to melt as well as stoneware. H.C. Broadwell of Philadelphia claimed a way to coat iron sheet with aluminum. Deville noted that gilding metal with aluminum with electricity was difficult, but the Tissier brothers found a way to gild by using a solution of aqua regia and gold. [7]

By 1896, numerous uses for aluminum were being found. “At the time of this writing (1895), there are only four metals which are cheaper bulk for bulk than aluminium; viz. iron, zinc, lead and copper; and the amount of aluminium produced yearly is increasing much more rapidly than any of these,” Richards said. “Aluminium has therefore already won its place among the common metals of everyday life. It will, of course, be many years before it outstrips any of these, but I believe the ultimate goal of the aluminium industry will be reached only when it stands next in importance and value of annual production to iron.” [8]

In the early years of the aluminum industry, the new metal was “a solution looking for a problem.” Aluminum producers needed to develop and promote uses in order to sell aluminum. In the beginning, aluminum producers were not interested in fabrication as a business. Instead, they wanted to encourage other companies to find uses for aluminum. [9] Many U.S. manufacturing companies, however, were skeptical of aluminum’s value, and the Pittsburgh Reduction Co. was forced to develop fabrication methods on its own and even manufacture consumer products. The company was the first to cast aluminum. It had tried to sell ingot to another company to make teakettles, but when the other company backed away, the Pittsburgh Reduction Co. borrowed the mold and began casting teakettles itself. The company used high-purity aluminum for all its earlier products because alloy 1100 and other alloys did not exist at the time. The company also became the first to roll aluminum sheet. The company had been unable to convince a brass-rolling mill to make aluminum sheet, so the Pittsburgh Reduction Co. built a rolling mill in New Kensington, Pa. [10]

As the ingots of aluminum began to pile up at the company’s new smelter, Charles Martin Hall continued to develop his process and look for useful alloys, and the price of primary aluminum fell from $4.86 per pound in 1888 to 78 cents by 1893. As business grew, new uses for aluminum appeared, including cooking utensils, foil, electric wire and cable, automobile bodies and engine parts. [11] In 1894, a typical display of aluminum items by the Pittsburgh Reduction Co. included cast and spun utensils, metal-backed brushes, collar buttons, tea balls, salt and pepper sets, bookmarks, trays, card counters, card cases, paper cutters, looking glass and picture frames, hairpins, combs, penholders, candlesticks, match boxes, spoons and house numbers. [12] The Pittsburgh Reduction Co. exhibited its products at the World’s Columbian Exposition in Chicago in 1893, an approach it continued for years to come – at the Pittsburgh Exposition Center starting in 1899, at the Century of Progress International Exposition in Chicago in 1933-1934, and at the New York World’s Fair in Flushing Meadows, New York City, in 1939. [13]

By 1900, aluminum production in the U.S. had reached 7 million pounds and the price, protected by tariffs, dropped to 33 cents per pound. Early in the industry's history, new uses for aluminum usually evolved out of aluminum's advantages over other metals, especially its light weight, and the industry's expansion in the market depended on aluminum substituting for other metals. Uses included light machinery, some architectural uses and even making horseshoes. Over time, uses included bicycle parts, cameras, shoe eyelets, locomotive headlight reflectors and lithographic stones. Since many of aluminum's physical characteristics in fabrication shapes were not well established, the Pittsburgh Reduction Co. found it necessary to prove to users the superior characteristics of the metal or establish its own fabrication facilities for casting, wire-drawing and tubing extrusion. [14] From 1888 to 1895, quality control for aluminum production was limited to a chemical laboratory. Mechanical testing was done by testing bureaus. If a salesman reported that a customer said the company's sheet metal was too soft or too hard, mill production had to be slowed up for more sampling. Because of this, the Pittsburgh Reduction Co. turned to using their own fabrication plants and sales force. [15]

Coins and cooking utensils

The idea of using aluminum for coinage dated back to 1856 when Henri Manteca of the French Academy proposed this use to Emperor Napoleon III. "It then combined high price with lightness, and if it had always kept that high value it might have been substituted for silver," Richards wrote in 1896. "But what a mistake it would have been! A single invention, which reduced the price of aluminum one-half, would have depreciated the value of this currency to the same extent." For coinage, Richards noted that aluminum could be cast, rolled, punched, stamped and take a fine impression, that it was light, smooth and non-corroding, that it was cheap to produce and in large supply, and it was difficult to counterfeit. [16] In April 1859, Scientific American reported that advances in the production of aluminum had reduced the price of the new metal enough to spur speculation about using aluminum for making coins. Exactly 50 years later, Scientific American reported that abrasion experiments in laboratories at the French mint had "proved" aluminum coins would last longer than gold, silver or even bronze coins. Aluminum was also four times lighter than silver, making it easier to carry large quantities of money. The mint was considering replacing about 56 million francs worth of bronze coins with aluminum coins. About 2,000 tons of aluminum, worth about 44 cents per pound in blanks, was ready for stamping. [17] China, Japan and Korea at one time utilized aluminum coins. [18]

In 1974, in response to rising copper prices, the U.S. Mint struck 1.5 million aluminum pennies, but none were released into circulation. The new pennies contained some trace metals. Alan Herbert first reported that the U.S. Mint had created the coin in the Feb. 20, 2001, edition of “Numismatic News.” Evidence came from a U.S. Capitol police officer who had found one of the coins on the floor of the Rayburn Office Building. According to the story, an unnamed congressman who dropped the coin told the officer to keep it. In January 2014, Randy Lawrence, the son of a former deputy superintendent at the Denver Mint, found one of the 1974 pennies. It was certified to be authentic and was valued as high as $2 million, but the U.S. Mint forced Lawrence to return the coin. [19]

A major use of aluminum by the end of the 19th century was culinary utensils. Six firms were manufacturing aluminum cooking utensils in the U.S. by 1895, according to Richards. The pioneering company was the Illinois Pure Aluminum Co. at Lamont, Ill., which opened a factory in 1893. The advantages for cooking utensils was that aluminum was not poisonous, easily cleaned, not corroded, did not scorch, cooked quickly, was light in weight and was durable. Richards, however, did not recommend aluminum for tableware such as knives, forks, spoons and plates as they quickly lost their polish. Aluminum was better for soup tureens and vegetable and meat covers and dishes. [20]

Household implements were a good mass consumer market. In the 1890s, the Griswold Manufacturing Co., of Erie, Pa., was casting cookware out of iron and aluminum. A Griswold advertisement promoted aluminum by saying, “Being solid, seamless, with no plating to wear off, it is just like solid silver in appearance.” Companies also claimed cooking in aluminum cookware was “waterless” because the tight lids prevented moisture from escaping. Many cookware companies also promoted cooking at low temperatures, but that may have been because high temperatures threatened to warp aluminum cookware. Aluminum cookware often resembled cast iron cookware in shape and design because manufacturers used the same molds. The high heat conductivity of aluminum led to the use of wooden handles on skillets and sauce pans, something not often seen on iron cookware. Griswold produced an extra heavy line of cast aluminum cookware called Battleship and then came out with the stylish Aristocrat Ware line in the 1940s and Symbol Ware line in the 1960s. [21]

The Wagner Ware Co. began producing cast iron cookware in 1891 and then began casting aluminum cookware in 1894. The company's most famous line was Magnalite, which referred to a proprietary alloy of magnesium and aluminum. Magnalite cookware production began in 1934, offering a more stylized design with domed lids and mission-style metal loop handles. The success of the Magnalite line led to Wagner's parent company buying out Griswold in 1957. The brand continued under the stewardship of the American Culinary Corp. A third line with a reputation for quality aluminum cookware was Guardian Service Ware, produced by the Century Metalcraft Corp. The cookware was distinguished by its hammered finish and uniquely shaped handles. [22]

As ingots of aluminum began to accumulate at the Pittsburgh Reduction Co.'s new smelter in New Kensington, Arthur Vining Davis took steps to making a few fabricated products, starting with an aluminum teakettle. [23] The company developed a prototype aluminum kettle in 1889 to interest cookware manufacturers, praising aluminum as lightweight, shiny, excellent at conducting heat and easy to clean. The teakettle helped to attract the interest of cooking utensil manufacturers. [24] In 1890, Davis borrowed molds from the Griswold Co. and cast some aluminum teakettles. Griswold was impressed and ordered 2,000 of the teakettles, and the Pittsburgh Reduction Co. went into the fabricating business for the first time. [25] The Pittsburgh Reduction Co. had tried to sell ingot to Griswold to make teakettles, but when Griswold backed away, the Pittsburgh Reduction Co. borrowed the mold and began casting teakettles itself. [26] By 1900, Sears and Roebuck began to advertise aluminum pots and pans in its catalog. [27]

With more aluminum available, smaller aluminum cookware manufacturers merged to create larger companies. The New Jersey Aluminum Co., founded in Newark, N.J., in 1890, the Aluminum Manufacturing Co., founded in Two Rivers, Wis., in 1895, and the Manitowoc Aluminum Novelty Co., founded in Manitowoc, Wis., in 1898, merged in 1909 to form the Aluminum Goods Manufacturing Co., headquartered in Manitowoc. By 1910, all company offices and manufacturing equipment had been moved to Manitowoc. The company received its first government contract in 1911, an $80,000 contract to manufacture aluminum canteens developed by Joseph Koenig for the Army. Koenig filed a patent for his canteen design in April 1911, which was granted in May 1913. The company had 400 employees and a 90,000-square-foot manufacturing facility by 1914. The next year, the company acquired the facilities of the Standard Aluminum Co., in Two Rivers. The company focused on producing cooking utensils for the next two years and established the Mirro brand in 1917. The company continued to grow and increased its capital to $12 million by 1920. [28]

During World War II, the Aluminum Goods Manufacturing Co. retooled its factories to make aluminum products for the military. After the war, the company began to produce aluminum toys, including the popular Sno-Coaster saucer sled, and the company changed its name to the Mirro Aluminum Co. The company started making 16-foot aluminum boats under the Mirro-Craft name in 1958, and in 1971 it acquired Cruisers Inc. of Oconto, Wis., which made fiberglass boats. At its peak, Mirro was the largest manufacturer of cooking utensils in the world, with eight plants in three states and products ranging from pots and pans to small boats and aluminum siding. The company sold off its boat business in 1982. Mirro was acquired by several companies after that, and the plant was acquired by Skana Aluminum in 2009 to be used as a contract custom aluminum rolling mill. [29]

From the mid-1890s through 1910, the fastest growing use for aluminum was cooking utensils. In 1901, the Pittsburgh Reduction Co. took over Hill, Whitney & Wood, a failed manufacture of kitchen utensils located in Massachusetts, and moved much of the equipment to the Pittsburgh Reduction Co.’s plant in New Kensington. [30] Alcoa president Roy Arthur Hunt recalled the transaction in a 1951 address. When a representative of Hill, Whitney & Wood asked Davis in 1901 if it was the Pittsburgh Reduction Co.’s intent to get into the cooking utensil business, Davis said no. The man then said, “You’re in the cooking utensil business now, because we can’t pay you what we owe you for aluminum, and you will have to take over our company.” [31]

The Pittsburgh Reduction Co. followed up by acquiring one of Hill, Whitney & Wood’s former customers, a company that sold kitchen utensils door-to-door. Together they formed the basis of the Pittsburgh Reduction Co.’s new wholly-owned subsidiary, the Aluminum Cooking Utensil Co. This was a competitive market, and the Pittsburgh Reduction Co. was only the third largest manufacturer of kitchen utensils in 1909. That year, the Pittsburgh Reduction Co. expanded further into the market by investing in the Aluminum Goods Manufacturing Co., a partially-owned subsidiary. By 1912, the

Pittsburgh Reduction Co. controlled more than 75% of the expanding U.S. kitchen utensil market. [32] Alcoa built a 46,000-square-foot warehouse at its East St. Louis Works site in 1911 for the Aluminum Cooking Utensil Co. Cookware products were stored at the warehouse, but the only manufacturing conducted there was buffing. The warehouse operation shut down in 1932. [33] The Aluminum Cooking Utensil Co. went on to produce the Wear-Ever line of aluminum utensils. [34] In 1934, Alcoa established the New Kensington Inc. subsidiary to produce a gift line of aluminum cooking utensils. [35]

The story of one aluminum cookware company that competed with Alcoa through the 20th century is a tale of deft footwork, as it fended off one economic challenge after another. On Sept. 27, 1911, a small group of businessmen in West Bend, Wis., incorporated the West Bend Aluminum Co., after a local pocketbook manufacturing plant burned down. The seven men each put up $1,000 to create an aluminum cookware manufacturing company. Two of the men were skilled tool-and-die makers who had previously worked for an aluminum cookware manufacturer. The founders rented a former button factory on the west bank of the Milwaukee River and ordered 3,000 pounds of aluminum from Alcoa. The first products with the West Bend name included saucepans in four sizes, a frying pan, a pie pan and a water dipper. The West Bend Aluminum Co. first exhibited its products in 1913 at a hardware association meeting in Milwaukee. In 1914, the company moved across the Milwaukee River to establish a 14,000-square-foot manufacturing plant. Net sales reached $73,244 in 1913 and climbed to $124,304 in 1914 and $241,160 in 1915. [36]

With West Bend’s continuing growth, a three-story addition to the plant was completed in 1918, and sales reached $1.5 million in 1920. The West Bend Aluminum Co.’s anchor customer was Sears, Roebuck & Co., which sold West Bend’s products entirely by mail order through 1926. Sears purchased about 40% to 50% of West Bend’s production through 1919. During World War I, the West Bend Aluminum Co. won a U.S. contract to manufacture mess kits for the Army, but the war ended just as production began. West Bend tried to introduce its products in department stores after World War I, but the market was dominated by two larger companies. In 1921, the company introduced a new product called the Waterless Cooker, designed for use on wood or coal stoves and sold by door-to-door salesmen. In 1922, the West Bend Aluminum Co. introduced the Flavo-Drip line, a new drip coffeemaker which did not require a paper filter. The coffeemaker eventually led to the development of the Flavo-Perk range-top coffee percolator. By 1929, the West Bend Aluminum Co. ranked third in the U.S. for sales of aluminum cookware. In 1932, it introduced the Flavo-Seal line of heavy-gauge cookware, which was successful and led to another three-story addition to the factory in 1937. [37]

The West Bend Aluminum Co. also got into copper products, starting with a beer stein in 1932. During the Great Depression, copper prices dropped to about a quarter that of aluminum, impacting West Bend's sales, which dropped from more than $3 million in 1928 to less than $1 million in 1932. Sales did not pass the $3 million mark again until 1940, but the company managed to make a profit every year. In 1941, on the eve of World War II, aluminum was earmarked for military uses only, and the West Bend Aluminum Co. won a contract with the U.S. Navy to produce 20 mm brass anti-aircraft cartridge cases. Through the war, West Bend produced 300 different items under defense contracts. The company was recognized at the end of the war with six Navy "E" awards for outstanding achievement. [38]

During the war, the West Bend Aluminum Co. purchased the Kissel automobile plant in Hartford, Wis., which was converted into military production. After the war, West Bend used the former automobile plant to produce the first air-cooled outboard motor for small boats. The motor was sold by Sears, Roebuck & Co. under the Elgin name in 1947 and by the West Bend Aluminum Co. under the West Bend and Shark names. Chrysler Corp. bought West Bend's outboard-motor and industrial engine division in 1965. When the Korean War started in 1950, aluminum, copper and steel were earmarked for military purposes only, and the West Bend Aluminum Co.'s civilian production was limited. The company once again began to produce for the military and continued to do so after the Korean War ended in 1953. The company changed its name from West Bend Aluminum Co. to West Bend in 1961. It was privately held until it was acquired by Rexall Drug & Chemical Co. in 1968, by which time West Bend's sales had reached $69 million. The company was acquired by Premark International Inc., a corporation split off from Kraft Inc., in 1986. [39]

New alloys and processes

One of the most significant developments in the aluminum industry came in 1908 when the German chemist Alfred Wilm discovered a new metallic alloy called Duralumin that was to aluminum what steel was to iron. By using a special heat treatment, the alloy took on the strength of mild steel. [40] The alloy was first produced in the town of Dueren, Germany, for which the alloy was named. After seven years of research, Wilm found that the alloy became increasingly solid several days after the metals were melted together. [41] He patented his discovery in 1910. Duralumin was made by combining 95% aluminum with magnesium, copper and manganese. The alloy hardened over time, and its tensile strength increased rapidly in a matter of days. It was widely used for lighter-than-air airships and later airplanes. [42] The first aircraft made of duralumin was made in 1919. [43]

At first, the only U.S. company licensed to use Duralumin was the Electric Boat Co. of Connecticut, which showed little interest in using it. Prior to World War I, Alcoa tried to develop an alternative to Duralumin without success. During the war, the federal government pressed Alcoa to mass produce Duralumin, but the company's metallurgists had difficulty understanding the alloy's properties. Finally Paul Merica and other government scientists at the National Bureau of Standards proposed a theory that explained the mechanism behind the heat treatment used to make Duralumin. Alcoa chemist Earl Blough was able to use this information to develop a new alloy called 17S that could be produced on a large scale. The development of the 17S alloy affected how Alcoa viewed its research and development facilities. From that point on, the focus would not be just on improving production methods but also to creating new materials for new markets. [44]

In 1920, Alcoa acquired the Cleveland laboratory of the Aluminum Casting Co. as payment for debt owed on aluminum purchases made during World War I. Two metallurgists with aluminum experience came with the laboratory – Zay Jeffries and Robert Archer. Jeffries had worked on casting problems for the manufacture of aircraft engines during World War I. Under Alcoa during the 1920s and 1930s, the laboratory came up with 20 new alloys. The first new sheet alloy, called 17S, was based on Duralumin and debuted in the 1920s with the first commercial all-metal passenger airplane, the Ford Trimotor. About 200 Ford Trimotors were made in the 1920s and 1930s, but production ceased during the Great Depression. The 17S alloy was susceptible to corrosion in salt spray, which led to the development of Alclad, which was 17S alloy sheet coated with pure aluminum bonded on both sides. [45] Edgar H. Dix, Alcoa's chief metallurgist, had developed a way to clad sheet alloys with a thin aluminum surface in 1926, making the popular Alclad product possible. [46]

During the 1920s and 1930s, new hard aluminum alloys were developed by Alcoa, including non-heat-treatable 5005 and 5052 for sheet, and heat-treatable 2024 and 6061 for a variety of uses. By World War II, the U.S. aluminum fabrication industry included 13 sheet mills, eight foil mills, four rolled rod and bar plants, 10 bare wire mills, 12 insulated or covered wire and cable plants, 17 extruded product plants, 16 drawn-tube plants, 12 powder plants and 59 forgings and impact extrusion plants. New aluminum alloys were developed during the war, including 7075, commonly used for aircraft, 6063 for extrusions and 380 for casting. Up until World War II, most research in alloys was done by Alcoa, but alloy research progress really took off after 1950. [47]

In the 1930s, Alcoa scientists developed a higher strength alloy than 17S called 24S. By increasing the magnesium level from 0.5% to 1.5%, the design strength of 24S was boosted from 40,000 pounds per square inch to 50,000. Cold-working by stretching and rolling and then quenching the alloy with water and allowing it to age could increase the strength of 24S to 57,000 psi. The new alloy was used in the manufacture of the very successful Douglas DC-3 aircraft. Another precipitation-hardening alloy system developed by Alcoa in the 1930s led to the creation of the 61S alloy, now called 6061, which added 1% magnesium, 0.6% silicon and 0.3% copper to aluminum. A number of alloys of 60S were later developed that were known for ease of fabrication, corrosion resistance and low cost, with strengths of 35,000 to 50,000 psi. The new alloy was used in trucks, buses, rail cars, trailer tanks, storage tanks, building construction and light aircraft. [48]

Nearly all of the 300,000 airplanes built in the U.S. during World War II used 24S aluminum alloys. Another new alloy called 76S, which combined zinc, magnesium and copper to aluminum, was first used commercially for aircraft propellers in 1940. Cracking in the alloy was addressed by adding small amounts of chromium. This led to a new alloy called 75S, which contained 5.5% zinc and had a design strength of 73,000 psi when artificially aged. The 75S alloy was used in the manufacture of the B-29 Superfortress bombers near the end of the war. In more recent years, Alcoa developed the 7075 alloy with 8% zinc, 2.3% copper and 2% magnesium that had strength levels up to 90,000 psi when extruded and was used in the manufacture of the

Boeing 777 commercial aircraft. [49] One new alloy available in the final years of the war, 75S, was used on the wings of Boeing B-29 bombers and had a tensile strength of 82,000 pounds per square inch. [50]

In addition to new alloys, new methods and processes for joining or shaping aluminum pieces were developed. During the 1940s, the Trane Co. developed a brazing process to join aluminum components for the aircraft and air conditioning industries. Alcoa and United Aircraft Products jointly developed a dip brazing process that increased production rates, cut costs and created a more efficient product design. [51] In 1940, the Northrop Aviation Corporation developed the heli-arc welding process for joining aluminum. By 1962, it was the most popular way to weld aluminum. [52] During World War II, a German engineer named Johannes Croning developed a method to fabricate aluminum for aircraft parts called shell molding, which used a plastic shell instead of a more expensive metal die. After the war ended, Croning joined the Polygram Casting Co. Ltd., an English foundry that later applied for a U.S. patent. Interested U.S. companies included Union Carbide and Monsanto. By 1953, more than 100 foundries had adopted the process, but one metallurgist said it “is no panacea.” [53]

The Italian engineer Ilario Properzi developed a continuous-casting process for aluminum for use by the wartime aircraft manufacturing industry. Properzi made more improvements after World War II, and the Nichols Wire and Aluminum Co., an independent aluminum fabricator, introduced the process to the U.S. Continuous-casting enabled a single machine to convert aluminum ingot directly into redrawn rod, eliminating several intermediate steps in the conventional process. The success of the Properzi process was discouraged by the initial cost, at $175,000 per machine, and by the radical changes required in operating techniques. There were seven Properzi installations in the U.S. by 1962. [54]

Another World War II discovery came when a Royal Air Force officer, Anthony Bagnold Sowter, noticed that when two sheets of copper were cut with dull shears, a weld sometimes appeared on the sheared edge. It was a well known phenomenon, but Sowter recognized its industrial application. On Oct. 25, 1949, while living in Wembley, England, Sowter filed a patent with the U.S. patent office for a cold-pressure welding process for aluminum based on his discovery. Patent No. 2522408 was assigned to General Electric Ltd. of London, England. Sowter went to work at General Electric Ltd., a British welding equipment manufacturer, to conduct research on the phenomenon, which was given the trade name Koldweld. By 1962, the Koldweld process was gaining in use among aluminum fabricators. [55]

Fabricating – sheet, foil and wire

The Pittsburgh Reduction Co. pioneered the production of sheet aluminum in 1895. The company had been unable to convince a brass rolling mill to make aluminum sheet, so the Pittsburgh Reduction Co. built a rolling mill in New Kensington, Pa. [56] After 1907, as Alcoa, the company continued producing sheet even as numerous competitors entered the field beginning in 1914. The U.S. government fixed the maximum price for sheet aluminum during World War I. In 1923, Alcoa produced nearly 96% of all the 2S and 3S alloy aluminum sheet sold to the public. Two ways of producing cold-rolled sheet aluminum existed – coil and flat methods. Coiled sheet could be produced at higher speed and at lower cost. From 1922 through 1931, Alcoa produced coiled sheet with common alloys up to 36 inches wide, Duralumin coiled sheet up to 20 inches wide, Duralumin flat sheet up to 60 inches wide and flat sheet of common alloys up to 100 inches wide. But Alcoa soon faced competition from a major producer – the Reynolds Metals Co. began producing sheet at its plants in Louisville, Ky., Richmond, Va., and Farmingdale, N.Y. in 1931. [57]

Alcoa also expanded its aluminum casting business. In May 1909, Alcoa opened a sand foundry in Cleveland, Ohio. In 1917, it opened a mold plant on a piece of farmland outside the city limits. During World War II, the company invested $15 million to expand its Cleveland facility and became a principal supplier of forged aluminum for aircraft parts, including propeller blades. In 1943-1944, the Cleveland Works facility employed 10,300 people. By 1945, the facility had become the world’s largest aluminum and magnesium forging plant. In May 1955, Alcoa opened a $40 million plant in Cleveland that it built for and leased to the U.S. Air Force to make light alloy forgings for military aircraft. Alcoa bought the plant from the government in 1982. A total of 3,000 people worked at Alcoa’s Cleveland facilities by 1965, and the company expanded the facilities to handle titanium. Alcoa invested $21.5 million between 1970-1977 to modernize and upgrade the facility, including the construction of a wheel line facility in 1972. Alcoa consolidated forging operations at the Cleveland facility with the company’s Vernon, Calif., operations to create the Alcoa Forging Division. [58]

The Pittsburgh Reduction Co. was the first company to make aluminum extrusions, starting in 1904. The process created tubing, channel, angle and complex cross-sectional shapes for all types of manufacturing, including buildings. [59] The extrusion process was first patented for manufacturing lead pipe in 1797. Manual power was used until the introduction of the hydraulic press in 1820. By the end of the 19th century, extrusion methods existed for copper and brass alloys. Alexander Dick invented the modern hot extrusion process in 1894, which was applicable to most non-ferrous alloys including aluminum. Demand by the military for extruded aluminum products rapidly increased during the two world wars, but demand by the transportation and construction sectors made up most of the demand after World War II. [60] By 2017, the aluminum extrusion process had been perfected for many uses. Aluminum billets were preheated to 800 to 925 degrees Fahrenheit, coated with a thin film of lubricant, and pushed through a special die by a hydraulic ram. Liquid nitrogen flowed around the die to keep it cool and to prevent oxidizing by the extruded metal. Harder alloys would pass through the extrusion die more slowly. Specific target temperatures for the metal emerging from the die needed to be met for certain alloys. After the extruded metal cooled, it went to a stretcher for straightening and work hardening. [61]

In 1901, a new powerful explosive was discovered that combined ammonium nitrate and powdered aluminum. [62] Alcoa began to produce aluminum powder in 1910, a product the U.S. had been forced to buy from Germany. Over time, Reynolds and Alcan got into aluminum powder production. [63] By 1920, Alcoa had discovered that aluminum powder could be used as a pigment in paint. [64] A process of spraying molten aluminum to create a powder of droplets was developed in the 1920s. The resulting powder could be flattened into flakes in a ball mill for use as a coating or pigment. Aluminum powder appeared in paints during the 1920s. [65]

The earliest production of aluminum foil was by Gautschi, in France, in 1903, using the classical pack-rolling method of reducing metal to foil thickness. Gautschi stacked a number of thin sheets of aluminum into a pack and rolled it between heavy iron cylinders that were internally heated by hot water. This was repeated with a progressively smaller gap between the iron cylinders until the desired foil gauge was obtained. [66] Robert Victor Neher invented a method for continuous aluminum-rolling foil production in Switzerland in 1907 and launched the first foil-rolling mill in 1910. [67] The Neher sons and Edwin Lauber discovered the “endless rolling process” at a plant which had been producing aluminum in Schaffhausen, Switzerland, since 1886. Lauber, Neher & Cie. Emmishofen began to produce aluminum foil in 1910 at Kreuzlingen, Switzerland. Foil had been around for centuries, but tin started being replaced by aluminum. [68]

The Pittsburgh Reduction Co. began rolling aluminum foil as an experiment in 1905 and introduced foil in the U.S. market in 1913. [69] As part of its vertically-integrated expansion into foil and other products, Alcoa built the Alcoa Edgewater Works rolling mill and fabrication plant on nine acres on the Hudson River in Edgewater, N.J., in 1916. [70] The site, about three miles south of the George Washington Bridge, was a former centuries-old cemetery for Civil War veterans, Dutch settlers and a Mohawk princess. “When Alcoa bought the property, they moved the cemetery and whatever bodies they needed to move,” former Edgewater City Councilor Mary Hogan explained in January 2015. The facility produced a wide variety of products, from rolled foil to aircraft parts, with a busy waterfront. The floors of the 10-story building were supported by special “mushroom columns” designed to carry the weight of the materials and rolling equipment. The plant went dormant in the 1960s and real estate developers began to eye the site. [71] The site was added to the National Register of Historic Places on Aug. 10, 1978, and the building was later demolished. [72]

Alcoa’s U.S. competition in foil manufacturing eventually came from the Reynolds Metals Co. The story began around 1900 when R.J. Reynolds asked his son Richard S. Reynolds to leave law school and go to work at the family’s tobacco company. While there, R.S. Reynolds helped advance the company by moving it from chewing tobacco to smoking tobacco and formulating a milder blend that became Camel brand cigarettes. He also invented an all-metal moisture-preserving container called the Prince Albert Tin, a technological breakthrough for the tobacco industry. In 1912, R.S. Reynolds left the family tobacco company and started the Reynolds Corporation with his two brothers. They developed household cleaners until the start of World War I, when soap was deemed unessential by the government. [73] R.S. Reynolds put his knowledge of foil packaging to work during the war by developing a watertight gunpowder drum for the U.S. Army. After the war ended, he learned that R.J. Reynolds Tobacco Co. was having a difficult time locating an adequate supply of foil. At the time, the metals of choice for foil were tin and lead, but R.S. Reynolds turned his attention to aluminum. Aluminum could be rolled thinner than existing metal packaging and was less expensive because of its greater yield per pound. Aluminum foil was more brilliant, held greater eye appeal, was lighter in weight and had better protective properties as a packaging material. [74]

As World War I came to an end, the Reynolds brothers sold their cleaners business, and R.S. Reynolds turned to creating a new foil packaging company. He established the U.S. Foil Co. in Louisville, Ky., in 1919, which later became the Reynolds Metals Co., to manufacture tin foil for cigarette packaging. Later the company turned to aluminum, a cheaper and more durable metal, replacing tin. [75] The U.S. Foil Co. began rolling aluminum foil and promoting aluminum foil for food and cigarette packaging in 1926. The Reynolds Metals Co. was formed in 1928 and continued to grow through the Great Depression. [76] In 1924, the U.S. Foil Co. acquired The Eskimo Pie Corporation, a large user of foil, and began using aluminum foil as a packaging material for the first time in 1926. Reynolds' sales reached nearly $13 million by 1930, and as the company continued to expand and grow it moved its headquarters from Louisville to New York City. [77] In 1935, the company prospered with the development of rotogravure printing on aluminum foil. [78] In 1936, the company made its first international venture by organizing a company to make aluminum foil in Havana, Cuba. In 1938, the company moved its headquarters to Richmond, Va. [79] Uses for aluminum foil soon expanded beyond packaging. In the 1920s, aluminum appeared in foil form in electrical capacitors. [80] In 1934, when Admiral Richard E. Byrd made his second exploratory expedition to Antarctica, his Advance Meteorological Base used aluminum insulation from Alcoa. [81]

In 1930, Alcoa spent $3 million building a rolling mill in Massena, N.Y. The mill was the only facility in the U.S. capable of handling large rolled shapes of aluminum used for building bridges, railroad cars, street cars, trucks and buses. By 1938, Alcoa faced competition for the production of smaller rolled shapes from the Bohn Aluminum & Brass Corporation, Reynolds Metals, the Revere Brass & Copper Co., and Extruded Metals Inc. Reynolds planned to add 2 million pounds of capacity to its rolling mills and was the leader in the production of aluminum foil. Alcoa and Johnston Tin Foil & Metal Co. also produced foil, and the imports of foil from Switzerland were large and increasing since the signing of a reciprocal trade agreement made between the U.S. and Switzerland in January 1936. [82] Consumer use of aluminum foil fell during World War II as military applications took over. Principal uses of aluminum foil during the war included packaging to prevent damage by moisture, vermin or heat; electrical capacitors; insulation; and anti-radar chaff. By the end of the war, eight plants in the U.S. were rolling foil, and aluminum became available for commercial uses again, including building insulation and consumer food items. The first all-foil food containers appeared on the market by 1948. About 90% of all foil produced by 2011 was aluminum. [83]

The Pittsburgh Reduction Co. first began to produce wire and cable in the early 1890s when other companies refused to try. [84] Overall, the aluminum market had matured by 1909 and aluminum had become an acceptable metal. Exaggerated claims and incorrect applications had hurt the metal's reputation and the kitchen utensil market helped establish aluminum as a common metal, but future expansion depended on high-volume markets in transportation, electrical transmission and more architectural and engineering applications. The electrification of the nation and the growing use of automobiles offered an opportunity for new markets. In 1898, as the price of copper wire climbed to 14 cents per pound and the price of an experimental aluminum wire dropped to 29 cents per pound, Arthur Vining Davis traveled to San Francisco and tried to sell aluminum wire to a utility company – before the Pittsburgh Reduction Co. even had wire or rod facilities built. It wasn't until 1908 that the aluminum wire market was well established. [85]

In 1895, electrical resistance testing at the Westinghouse Electric & Manufacturing Co. and Lehigh University led to a new and important product over the next decade and a half – long-distance electrical power transmission cables. [86] Aluminum was not as good a conductor of electricity as copper, but it was much lighter. This fact helped promote aluminum for transmission cable, once a solution was found to counter aluminum's lack of tensile strength. In 1908, the Pittsburgh Reduction Co.'s head electrical engineer, William Hoopes, discovered a way to wrap six aluminum wires around a galvanized steel strand to create a composite cable with 20% less weight and 57% more strength than copper cable. The new cable was called ACSR for "aluminum cable, steel reinforced." New equipment and products needed to be developed for splicing, terminating and handling to make full use of ACSR. Alcoa initially relied on sharply reducing prices when ACSR's engineering merits were not generally accepted, but by 1912, Hoope's ACSR had established a position in the marketplace. Alcoa also had to provide technical expertise to consumers because aluminum conductors needed to be utilized differently from copper. Alcoa set up a research and development facility at Massena, where aluminum wire and cable had been manufactured since 1904. Over time, aluminum completely replaced copper in the electrical transmission cable market. [87] Through the 1930s, Alcoa produced and sold virtually 100% of all the aluminum electrical transmission cable in the U.S. [88]

A light-weight metal for transportation

Aluminum found maritime uses as early as 1891 when Swedish industrialist Alfred Nobel ordered the creation in Switzerland of Le Migron, the first passenger boat to use an aluminum hull. [89] Escher, Wyss & Co. of Zurich built the gasoline-powered yacht Mignon entirely out of aluminum. At 43 feet long, 6 feet at the beam and with a 2-foot 2-inch draft, the hull was made of sheet 3/32 of an inch thick, held together with aluminum rivets. All of the Mignon’s machinery was aluminum, including the propeller, with the exception of the cranks and shafts. On its trial run, the Mignon attained a speed of eight miles per hour. The Vendenesse was a sea yacht built at Saint-Denis in 1892 for Count Chabonne. With 12 tons displacement and about one ton of aluminum, the yacht withstood a long stay at the harbor at Havre without any impacts from seawater. Impressed by the results of the Vendenesse, the French Minister of the Marine ordered a torpedo boat constructed to be carried by the warship La Foudre. [90]

In 1894, the Scottish shipbuilding company Yarrow & Co. built Sokol, a 58-meter torpedo boat made of aluminum, for the Russian navy. The Sokol could reach a record speed of 32 knots. [91] It had its first trial run in September 1894 and was the largest vessel constructed of aluminum. Rossiter & Co. of Baltimore, Md. built aluminum boats for the American arctic explorer Walter Wellman. Galanaugh of Philadelphia constructed aluminum rowing shells. The American racing yacht Defender which defeated the English yacht Valkyrie III in 1895 in the American Cup race had an aluminum-bronze hull to the waterline and aluminum-nickel alloy hull above the waterline. [92] On Aug. 5, 1937, the Ranger defended the America’s Cup sailing race against a British challenge. The J-Class racing yacht was the first sailboat of its size to have a mast, boom and spinnaker pole made entirely of Alcoa aluminum. [93] After World War II, as the aluminum industry found itself with abundant capacity for consumer products, aluminum hulls became more common on small fishing and recreational boats, but large ideas also emerged. In the mid-1970s, Kaiser Aluminum began to build large welded prismatic aluminum tanks for specially built ships to transport liquid natural gas from Africa to the U.S. The ships were built, the tanks were installed and sea trials were conducted, but the commercial operation was never completed. [94]

In the world of land transportation, two records were broken in 1894 with horses wearing aluminum horseshoes and pulling all aluminum racing sulkies. An aluminum horse-drawn cab operated in Paris in 1895, and an aluminum railway carriage was expected soon. [95] The mass transportation sector quickly discovered the advantages of aluminum's light weight. In 1894, J.P. Morgan's Hartford Railway in New Haven, Conn., began to produce lightweight passenger cars using aluminum seats. [96] And in 1925, Alcoa partnered with the General Aluminum Products Co. to build the first aluminum bus body. [97] But the automobile industry presented a greater demand. In 1899, German automobile manufacturer Karl Benz presented the first sports car with an aluminum body at the Berlin International Motor Show. [98] Two years later, Benz presented a race car with aluminum parts for a prestigious race in Nice, France. [99] Cast aluminum transmission cases and pistons became common by 1900, and the Pittsburgh Reduction Co. began to fabricate lightweight aluminum bodies and parts for automobiles in 1901. [100] The first U.S.-built car to have an aluminum body was the 1902 Marmon. The aluminum body was attached to a wooden frame. [101] The Marmon Co. of Indianapolis, Ind., produced six of the cars in 1904. The company made all of the car's components, including cast-aluminum bodies and a 90-degree V-4 air-cooled overhead valve engine. The company traced its roots back to 1851 when it manufactured flour milling machinery. Over 30 years as an automobile manufacturer, the company produced more than 250,000 U.S. automobiles. [102]

By 1904, demand was growing for sheet and castings for automobile bodies. In 1908, when aluminum prices plummeted during a recession, an opportunity briefly existed for use of aluminum sheet for automobile bodies, but steel manufacturers found a way to alloy a small amount of aluminum in steel to create low-cost sheet for pleasure vehicles. By 1908, aluminum castings were found in engine beds, gear cases, rear axle housings and other parts of automobiles. [103] Aluminum and aluminum alloys appeared in the 1908 Bugatti, including sand castings and formed body panels that were butt-welded by oxy-fuel torch and then polished. Pierce Arrow used cast aluminum bodies from 1912 to

1917. The eighth-inch to quarter-inch thick body panels were cast and then welded together in the assembly process. The cast six-cylinder engines were secured to aluminum crankcases. European car manufacturers used aluminum for artistic auto body designs in the 1920s and 1930s. [104]

Automobile manufacturers perfected new ways to form aluminum between 1900 and 1910, including drop-hammering and power-hammering. Hydraulic stretching appeared around 1920, and drawing and stamping appeared around 1935. The result of these new processes was new and novel shapes. In the early years, aluminum sheet was more expensive than steel, which created the first “car caste system” – cars with steel body panels were made for the masses, while cars made with aluminum body panels were made for the wealthy. [105] By World War I, as much as 25% of the Pittsburgh Reduction Co.’s aluminum production was sold as a harder alloy for automobile manufacturers, and 80% of U.S. automobiles had aluminum crankcases and gear boxes. [106]

In an effort to consolidate control in this growing industry, Alcoa organized several major aluminum foundries in Ohio, Michigan and New York into the Aluminum Castings Co. in 1912. The new company soon dominated the castings industry and was later investigated by the federal government. [107] In 1922, Alcoa and several manufacturers of engine pistons joined together to form the Piston Patent Estate. Two types of patents applied to the manufacturing of aluminum pistons – process patents and structural patents. Alcoa held 45 out of 53 design patents, including most of the essential process patents, but other companies owned key structural patents. The Piston Patent Estate was formed to end disputes between these patent holders. It operated by transferring all the patent rights to a single trust company in Cleveland, Ohio, and Alcoa obtained an exclusive license from the trust company to issue sub-licenses to piston-manufacturing companies. [108] In 1948, Alcoa developed the first forged aluminum wheels, which were first used on Mack trucks. Alcoa produced the first aluminum wheel for a modern passenger car for the 1955 Cadillac Eldorado. The high-strength wheel was produced from hot aluminum in a giant press. [109]

As the price of aluminum came down after World War II, aluminum was used more and more in mass-produced automobiles. In 1961, British Land Rover produced V-8 engine blocks with aluminum cylinders. [110] In 1972, a concept car was developed for General Motors called the XP-

895 Chevrolet Reynolds Aluminum Corvette Concept Car. The goal of Reynolds Metals was to convince General Motors to make a production Corvette with an aluminum body. The idea was not new – special European models and the Ford Cobra existed – but an aluminum production car did not. Reynolds Metals used their new 2036-T4 alloy. Chevrolet provided stress analysis and Reynolds Metals handled everything else. A main production issue was the need to spot-weld the body. Some parts needed to be thicker, and a two-part epoxy was used to eliminate crevices that could trap salt and dirt. The concept car weighed about 400 pounds less than a steel-bodied prototype. The project was shelved in 1974 because the traditional fiberglass-bodied Corvette was selling well. [111]

The 'killer app' – aircraft

It wasn't until after World War I that aluminum found a transformative use: "The killer app is the airplane, which didn't even exist when they were going all gung ho and gaga over this stuff," University of Maryland technology historian Robert Friedel said in 2014. [112] Aluminum was present from the very beginning of the aircraft age when Wilbur and Orville Wright made the first powered-flight carrying a human being over a beach near Kitty Hawk, N.C. on Dec. 17, 1903. Their craft, the Flyer-1, was powered by a part-aluminum engine. [113] The two initially tried to use a gas engine from an automobile but found it to be too heavy and came up with a new engine with aluminum components. [114] The lightweight engine had a block and crankcase cast with aluminum from the Pittsburgh Reduction Co. The engine weighed as much as Orville Wright, the pilot, but produced 13 horsepower. The brothers had only hoped for 8 horsepower. [115]

The next step was to use aluminum for the framework and skin of aircraft. John Bevins Moisant is often credited with building the first metal airplane, using steel and aluminum. Moisant, who lived from 1868 to 1910, was known as the "King of Aviators." He was an American aviator, aeronautical engineer, flight instructor, businessman and revolutionary. His first aircraft design was the Moisant Biplane, alternatively known as "L'Ecrevisse," which he built in Issy-les-Moulineaux, Paris, France. The experimental aircraft was the first all-metal aircraft in the world, being constructed entirely from aluminum and steel, and was completed in February 1910. In the biplane's inaugural flight, and Moisant's first flight, the plane crashed after ascending only 90 feet with limited air time. Moisant funded his aviation career with proceeds from business ventures in El Salvador, where he led two failed revolutions and coup attempts against President Figueroa in 1907 and 1909. Just months after becoming a trained pilot, Moisant died after being ejected from his airplane over a field west of New Orleans, La., where he was competing for the 1910 Michelin Cup. [116]

During World War I, the Germans pioneered the use of wrought aluminum alloys of the Duralumin type in the framework of Zeppelin airships and to replace wood in the frames of airplanes. Aluminum castings were also used for engine blocks in airplanes at this time. [117] In 1916, Alcoa produced its first aircraft alloy, called 2017-T4. Primarily formed as sheet and plate, the alloy was integral to the making of the USS Shenandoah rigid airship. [118] These new alloys made it possible for aircraft designs to make the leap from wood and canvas biplanes to modern designs.

Aircraft design historically was different from ships, locomotives, automobiles and other forms of transportation – it was the first major technology where weight was an overriding concern. By the mid-1930s, several innovations in aircraft design that began with wood and fabric aircraft had evolved into this new standard. The new aircraft were sturdy, sleek, all-metal monoplanes with improved power plants and lightweight structural materials. The new aircraft featured tightly cowled multiple engines, retractable landing gear, variable-pitch propellers and stressed-skin aluminum construction. But according to a 1999 article by Peter L. Jakab in the Journal of Aircraft, some key design innovations had evolved earlier with wood and fabric planes, including the fully-cantilevered wing and the monocoque fuselage, particularly during World War I. Cantilevered wings were made as self-supporting beams to avoid the need for external wire and bracing, and a prominent design was the box spar, which provided necessary rigidity. The monocoque fuselage, based on the French word for single shell, was a thin wooden shell supported internally by bulkheads and longitudinal stringers. [119]

The first aircraft of modern design was made of steel, not aluminum. On Dec. 12, 1915, the Junkers J1 made its first flight. Nicknamed the Tin Donkey or the Sheet Metal Donkey, the J1 was the world's first practical all-metal aircraft. Hugo Junkers, whose credentials included construction of an internal combustion engine and other equipment, incorporated a number of revolutionary design elements in the J1 only

12 years after the Wright brothers' first flight at Kitty Hawk. Junkers eliminated most exterior struts and guy wires by using internal bracing for the single-wing plane. But because Duralumin had only been invented six years earlier and did not exist in large quantities, Junkers opted to use steel to build the J1. That included welded strip-steel angle stock, I-beams and steel tubing for the fuselage and 17-inch wide electrical steel – similar to the type used to manufacture laminated-core AC transformers – to plate the exterior and the wings. [120] The welding, however, created maintenance problems, and the weight made the craft sluggish and hard to maneuver in flight. [121]

Two years later in 1917, the Zeppelin-Staaken E-4/20 made its first flight. The E-4/20 was the first four-engine, all-aluminum stressed-skin, heavier-than-air airliner ever built. Most aircraft at the time were small, single-engine biplanes made of wood and canvas. Count Ferdinand von Zeppelin had been focused on the uses of aluminum alloys to handle power-to-weight issues and had heard of Igor Sikorsky's revolutionary four-engine Le Grand and Ilya Muromets aircraft. The latter were used as heavy bombers in World War I, and the German government expressed interest in the potential for large strategic bombers, which came to be called Riesenflugzeuge – "Giant Aircraft" or R-Planes. The E-4/20 had a 102-foot wingspan, a semi-monocoque fuselage, a cantilevered monoplane wing and an enclosed hull that could carry 18 passengers and a crew of five. The commercial version of the aircraft's accommodations included radio-telegraph communication, a toilet, a galley and separate mail and baggage storage. The aircraft had a top speed of 143 mph, a cruising speed of 131 mph, a range of 750 miles and a fully-loaded weight of 18,739 pounds. The aircraft was constructed of thin Duralumin sheets, and the wing was self-supporting. After test flights in 1920 and 1922, the Inter-Allied Commission enforcing the Versailles Treaty ordered the only E-4/20 that had been built broken up. [122]

On Nov. 6, 1922, the Dornier Do J "Wal" made its first flight. The German twin-engine flying boat featured a high-mounted strut-braced monoplane wing with two piston engines and an aluminum hull. It was nicknamed the "whale." Production took place in Italy because of restrictions in place after the Versailles Treaty. A military version was built and sold to various European and South American nations, and a civilian version featured a cabin for up to 12 passengers. Norwegian explorer Roald Amundsen and five others used two Do J aircraft in an unsuccessful attempt to reach the North Pole in 1925. [123]

The U.S. entered the aviation field in a big way on June 11, 1926, when the Ford Trimotor made its first flight. Nicknamed “The Tin Goose,” the aircraft was intended for civilian use but eventually saw military service. Henry Ford and his son Edsel Ford, along with 19 others, had invested in the Stout Metal Airplane Co. in the 1920s. Ford bought out Stout and its single-engine design in 1925 and added two more engines. The Trimotor made use of advanced techniques, including corrugated-metal control surfaces. Ford claimed it was “the safest airliner around.” But while the corrugated aluminum skin added stiffness, it also added air drag and reduced the aircraft’s overall performance. The design was so similar to an aircraft produced by Junkers that the German company sued Ford and won when Ford tried to market the Trimotor in Europe. Ford countersued in Prague in 1930 and was decisively defeated a second time. During the 1920s, the Ford Aircraft Division was reputedly the largest manufacturer of commercial aircraft in the world. The company also made a single-seat commuter aircraft called the Ford Flivver, or “Sky Flivver.” [124]

One of the most famous planes in history took off for the first time on April 28, 1927 – the Ryan NYP, named the Spirit of St. Louis. The aluminum-sheathed aircraft was custom built by Ryan Airlines of San Diego, Calif., on a rush order in under 60 days for Charles Lindbergh’s solo trans-Atlantic flight. Lindbergh, a former U.S. Air Mail pilot, accomplished the feat on May 20-21, 1927, and won the $25,000 Orteig Prize. The aircraft was loosely based on the 1926 Ryan M-2 single-wing mail plane. Lindbergh, who was concerned about race competition, was on hand to oversee its construction and opposed a twin-engine design because he believed it would increase the risk of mechanical failure. To increase fuel efficiency, the Spirit of St. Louis was also one of the most advanced and aerodynamically streamlined designs of the era. [125]

Many of the great aircraft innovations began in one-of-a-kind experimental airplanes. On May 6, 1930, the Boeing Model 200 Monomail aircraft made its first flight. Only two of the experimental aircraft were made for U.S. Army evaluation, and its design was a noted departure from the traditional biplane configuration. The Monomail featured a single, low-set, all-metal cantilevered wing, retractable landing gear and a streamlined aluminum fuselage – all adding to the plane’s aerodynamic efficiency. The advanced design, however, lacked a suitable engine and propeller technology. By the time variable-pitch propellers and more powerful engines became available, Boeing had come out with another design, the Boeing 247. [126] Two aircraft often cited as embodying the structural revolution of the 1930s were the Boeing 247D, introduced in 1933, and the Douglas DC-3, introduced in 1935. Both planes had cowled multiple engines, a single low-wing configuration, retractable landing gear and all-metal construction. The fuselages of both planes were constructed of light-metal frameworks with sheet metal panels riveted in place. The Boeing 247 had a heavy main spar running through the cabin from wing to wing, and passengers had to step over the support beam when moving about. The DC-3 had a multicellular wing that avoided the need for a heavy main spar. [127]

The Boeing 247 made its maiden flight on Feb. 8, 1933. It was the first airliner to incorporate advanced designs such as an all-metal (anodized aluminum) semi-monocoque construction, a fully cantilevered wing and retractable landing gear. Seventy-five of the aircraft were built and put into use by Boeing Air Transport later in 1933. Aircraft that followed the 247 used larger engines, larger airframes and four engines instead of two, but the basic formula continued until pressurized cabins became available with the Boeing 307 Stratoliner. The Boeing 247 was faster than the Boeing P-12, an open-cockpit biplane that was the premier aircraft of the day in the U.S. The 247 was also the first twin-engine passenger transport capable of flying with one engine out of service. A concern of pilots in the early days of commercial aircraft, however, was that few airfields existed capable of handling the weight of the eight-ton aircraft. [128]

The experimental Douglas DC-1 aircraft flew for the first time on July 1, 1933. Only one example of this model was built, but its design led to the DC-2 and DC-3. Development of the DC-1 can be traced to the 1931 crash of TWA Flight 599, a Fokker F.10 tri-motor aircraft that suffered a structural failure to its wing. Investigators believed water had seeped between the layers of the laminated wood and dissolved the glue holding the layers together. Following the accident, the U.S. Department of Commerce’s Aeronautics Branch placed stringent restrictions on the use of wooden wings for passenger airlines. Boeing’s answer was the 247. Douglas followed with an aircraft for TWA that could carry 12 passengers and a crew of three with two engines and variable-pitch propellers. Both planes relied on aluminum for structural and surface components. [129]

Another world famous aircraft made its maiden flight on Feb. 23, 1934 – the Lockheed Model 10 Electra. The twin-engine, aluminum-sheathed monoplane airliner was developed by the Lockheed Aircraft Corp. to compete with the Boeing 247 and the Douglas DC-3. Amelia Earhart used an Electra on her unsuccessful flight around the world in 1937. When the U.S. government banned single-engine aircraft for carrying passengers or for night flying, Lockheed had an aircraft ready to meet the need with the Electra. [130] Lockheed followed that up with the XC-35, which made its first flight on May 9, 1937. Only one of the experimental twin-engine aircraft was ever built. It was the second plane to have a pressurized cabin. The XC-35 was built for the U.S. Air Corps to perform high-altitude research and to test the feasibility of pressurized cabins. Lockheed engineers modified a Model 10 Electra with a new fuselage featuring a circular cross-section that could handle the pressure differential. The XC-35 could maintain a cabin pressure of 12,000 feet altitude while flying at 30,000 feet. The aircraft played a key role in development of the Boeing 307 and B-29 Superfortress aircrafts, which were the first mass-produced pressurized aircraft. [131]

The Boeing 307 Stratoliner made its first flight on Dec. 31, 1938. The aircraft was the first commercial transport aircraft to enter service with a pressurized cabin, allowing it to cruise at 20,000 feet. Design of the Boeing 307 began in 1935 as a four-engine airliner based on Boeing's B-17 heavy bomber design. Pan American Airways ordered the first two Boeing 307s in 1937. Howard Hughes bought a Boeing 307 for a round-the-world flight, hoping to break his own record of 91 hours 14 minutes set in July 1938 in a Lockheed 14. Hughes had his Boeing 307 fitted with extra fuel tanks and was set to go when Germany invaded Poland and World War II dashed his plans. During the war, military and government officials needing to cross the Atlantic Ocean turned to Pan American Airways' 14 flying boats and TWA's five Boeing 307s. [132]

Buildings and furniture

By 1945 and the end of World War II, a number of new aluminum alloys and processes had been developed by researchers. Alcoa's 75S and Reynolds' R303 alloys were widely used and considered the strongest aluminum alloys ever used. Alcoa's 75S contained zinc, copper, manganese, magnesium and chromium was believed to reduce the weight of airplanes by 400 pounds because of its strength. Alcoa was considering using 75S for construction of a skyscraper building. Alcoa's 63S debuted during World War II was noted for its ability to hold a bright, clean anodic coating. New aluminum processes developed during the war included welding, brazing and resin bonding, electrolytic finishes, and commercial electroplating with nickel, copper, silver, chromium and gold using a zinc immersion procedure. New uses for aluminum in construction included ship superstructures, roofing sheet, spandrels, coping, window frames and sills, hardware and venetian blinds. A railroad bridge in Massena, N.Y. was constructed using 100-foot long 10-foot wide girders made of aluminum plate. [133]

In 1998, about 36% of aluminum consumption in the U.S. went to transportation, 25% went to packaging, 14% to building, 8% to electrical, 7% to durables, and 10% to other uses. [134] By 1895, aluminum was being used to construct candelabra, chandeliers, picture frames, mural decorations and other architectural elements as the metal resisted corrosion by the sulfurous air produced by combustion for heat and lighting. Aluminum was being used for fancy grillwork decorating desks, shelves, staircases, and elevator shafts and cars. [135] One of the first major examples of aluminum used in building came in 1906 when architect and designer Otto Wagner incorporated aluminum into his advanced and bold design for the Austrian Postal Savings Bank in Vienna – including for the furniture. [136] Beginning around 1925, architects became increasingly interested in using aluminum for windows, doors, roofing and hardware as the metal resisted corrosion by weather. [137] Alcoa began to manufacture and sell aluminum windows in 1928, its first application in the building and construction market. The residential windows were promoted as lightweight and energy efficient. [138] The Empire State Building, built in New York City in 1931, was the first major building where aluminum was widely employed in construction, both in the basic structure and the interior. [139]

In 1949, Alcoa used aluminum forms filled with fiberglass when building its new rolling mill in Davenport, Iowa. Plans were in the works for a new 30-story office building in Pittsburgh constructed with aluminum walls. Use of aluminum alloys in all sectors of the economy was growing as more satisfactory methods of joining these products were developed. Uses in the building sector were continuing to grow, accounting for about 17% of the usage of aluminum, with another 17% going to transportation. [140] In 1952, Alcoa built the first aluminum-sheathed skyscraper – the Alcoa Building in downtown Pittsburgh. It served as the company’s headquarters for 40 years. By 1958, more than 600 major buildings used Alcoa aluminum for curtain walls, windows and cladding. [141] By that time, the company was producing a wide variety of consumer goods, including roofing, windows and siding, and using a wide variety of marketing means, including weekly TV shows. [142] In 1972 and 1973, the World Trade Center was built in New York City. The twin 1,350-foot towers used about 4,500 tons of aluminum in their exterior curtain walls. [143]

Aluminum furniture became commonplace after World War II, but in the first decades of the 20th century, aluminum furniture bordered on works of art. The first all-aluminum furniture was exhibited in France in 1921. [144] Alcoa began to produce and sell aluminum furniture in 1922. The first set of furniture went to the directors' room at the Mellon National Bank in 1924. [145] The idea caught on, and aluminum furniture appeared in the newly decorated Free Library of Philadelphia, the Waldorf-Astoria hotel in New York and the New York Insurance Co. building in New York. In the late 1920s, Alcoa's Alcraft factory in Buffalo, N.Y., began to produce aluminum chairs for sale in Europe and the U.S. Each chair weighed less than eight pounds. The aluminum was sand-blasted, primed, spray-varnished and then coated twice with colored enamel. Standard colors included walnut, mahogany, oak, two shades of green and a satin finish. The idea was make the chair resemble traditional wood furniture. [146]

In 1932, American designer Russell Wright's all-aluminum breakfast room was put on display at the Philadelphia Museum in the "Design for the Machine" exhibit. Designers at the time looked to aluminum as a symbol of progress, streamlining and modernity. In 1934, the Warren McArthur Corp. of Rome, N.Y., produced a side table using aluminum, plastic laminate and plywood. The next year, the company produced an all-aluminum upholstered easy chair. Frank Lloyd Wright used aluminum for prototype chairs and desks for his renowned Johnson Wax building in Racine, Wis. By 1935, aluminum furniture had become more commonplace, often found in many hotel lobbies where it stood as an outstanding piece of decoration. Similar developments occurred in Europe, especially France. In 1930, French designer Rene Herbst exhibited a tubular aluminum chair with a perforated seat. In 1933, Louis Sognot and Charlotte Alix produced a bed of polished Duralumin for the Maharajah of Indore. Critics of the designs for aluminum furniture in 1931 noted that aluminum furniture often was made to look like wood, and the designs imitated wooden furniture. It was even called a "mongrel form." [147]

Following World War II, aluminum producers turned to producing furniture as a way to address two economic problems – a shortage of timber and an over-capacity of aluminum production. In London, a department store exhibit was titled “Aluminium – From War to Peace.” Items on exhibit included saucepans, operating tables, desks, chairs, trolleys and lamps, all in aluminum. An English trade association, the Aluminium Development Association, established a research branch to explore the potential market for aluminum furniture. Kitchen units and equipment were one category, and bedroom furniture made up a second. However, no new designs emerged. Instead, aluminum furniture design was based on copies of wood or metal furniture from before the war. An October 1946 article in the journal Light Metals spoke of the “lack of any really courageous scheme of design which suits the peculiar characteristics of aluminium and which, at the same time, fits in with the somewhat conservative tastes of the general public.” At about the same time in England, there were serious attempts to encourage the use of surplus World War II aluminum from the aircraft industry to boost the aluminum furniture industry. One major factor that inhibited that goal was price – aluminum bedroom furniture could cost five times as much as wooden furniture. On the other hand, one of the most famous British chairs of the post-war period, the BA chair, manufactured by Ernest Race, was very successful – about 250,000 BA chairs were produced from 1945 to 1969. [148]

One of the most well known aluminum inventions involved inexpensive folding lawn chairs. In 1947, Fredric Arnold of New York created the first aluminum folding chair with fabric strapping for the seat and back. [149] On May 22, 1956, Fredric Arnold submitted an application to the US Patent Office for a collapsible folding chair made of aluminum tubing and fabric straps for the seat and back. The patent was accepted and registered on Feb. 3, 1959. Arnold noted that lightweight folding chairs made of tubular metal, including aluminum, were being manufactured and marketed, but their design posed difficulties for manufacturing processes and for space used in shipping and storage while at the same time providing a stable and rigid body support. His patent application included two designs – a chair that folded from back to front, and another which folded from side to side. [150] By 1957, the Fredric Arnold Company of Brooklyn, N.Y. was manufacturing more than 14,000 chairs per day. [151]

By the end of World War II, aluminum production in the U.S. had grown by 600% and producers needed to find a new market for all that aluminum metal. That's when the Cessna aircraft company began to manufacture aluminum furniture. By 1950, the all-aluminum contract furniture market was so successful that Cessna began sales-testing a new line at the Marshall Field's store in Chicago. The magazine Modern Metals reported that Cessna furniture was being produced by assembly line techniques on a 3.5 mile long conveyor at the company's Hutchinson, Kan., plant. In the 1950s, in an attempt to promote aluminum for commercial and residential end uses, Alcoa, Reynolds and Kaiser established design departments to find ways to turn fabricated aluminum stock into appealing products. Reynolds established a Styling and Design Department in 1950, Alcoa set up a Market Development Department in 1955, and Kaiser hired Franklin Hershey, the chief stylist for the Ford Motor Co., to manage Kaiser's Industrial Design Department. In 1957, Alcoa budgeted $3 million to support design promotion in the U.S. The turn to design went global. In 1953, Cabinet Maker magazine described the international interest in aluminum furniture, with the latest designs incorporating pre-cast aluminum in furniture coming from Rosselino of Italy, Salterino and Porset in America, and Ernest Race in England. In 1961, the British Aluminium Co. sponsored a furniture design competition, with mixed results. [152]

Between the wars

Alcoa was in a good position to profit from World War I. By 1907, the company's Niagara Falls plant had grown to three large potlines. Capital investment in Alcoa had grown from $2.3 million to more than $90 million from 1900 to World War I. During this time, the company was protected from domestic competition by the Hall and Bradley patents and from foreign competition by tariffs, and the company successfully endured cyclic economic vagaries. From 1905 to 1909, the company saw average profits of 29.5%. That fell to about 17.6% after the patents expired – until the outbreak of World War I spurred sales and profits back to 22.01%. World War I also ended the threat of cheap imports from Europe and opened up international markets. From 1915 through 1918, Alcoa's annual production increased from more than 54,000 tons to 76,000 tons, as the British, French and Italian allies bought nearly 45,000 tons of aluminum from the company. [153]

By the time the U.S. entered the war, nearly 90% of Alcoa's production went into military equipment and supplies. The manufacture of cooking utensils at New Kensington was shifted to mess kits, canteens, helmets, gas masks, identification tags and other lightweight equipment for combat personnel. New products were developed for trucks and aircraft. [154] Shortages of aluminum metal began to appear when the war broke out in 1914, and prices rose dramatically, especially with increased aluminum demand for airplanes and munitions. In March 1918, President Woodrow Wilson imposed price controls on aluminum, and the use of aluminum for military equipment and essential civilian needs was placed under government regulation. [155] According to George David Smith's 1988 history of Alcoa, the company's profits could have gone higher if prices had been allowed to rise to free-market levels. Arthur Vining Davis served as an advisor to the War Industries Board, but the company's monopoly status attracted suspicion. The Secretary of the Navy accused Alcoa of selling canteens at inflated prices, and Alcoa's prices were put under stricter government control. [156]

By the end of the war, Alcoa's New Kensington plant had 3,292 workers producing aluminum goods in the 1 million-square-foot plant. [157] Alcoa found itself with excess capacity as the huge demand fell and aluminum imports returned competition. Price controls were lifted, and aluminum production spilled over into civilian uses. Alcoa also learned that it needed to put more effort into improving products. Germany had developed Duralumin, and the U.S. government put pressure on the company to find a similar alloy. Alcoa eventually came up with its own 17S alloy, a Duralumin substitute. [158] Facing a sharp decline in demand and the return of competition by European producers, Alcoa returned to the normal consumer market and found that many military applications from the war had civilian uses. Aluminum's use in aircraft was particularly important, where new and stronger alloys were developed. [159] Demand for aluminum also grew for automobiles – until the Great Depression when demand fell dramatically in all sectors of the economy, especially in automobile and aircraft manufacturing. [160]

For many U.S. companies, industrial growth between the two world wars came with rapid expansion during the 1920s followed by dramatic economizing during the Great Depression. By 1920, the U.S. Census reported that America had become predominantly an urban nation, and a new class of industrial workers earned enough for consumer goods beyond the basic necessities of life – telephones and automobiles moved from luxuries to necessities. According to Smith, Alcoa responded to this economic climate by vertical expansion and promoting the use of aluminum in more and different ways. While the aluminum industry lost ground to steel and iron in automobiles, it gained in the new field of air transportation. Aluminum use in the construction of the Empire State Building and Rockefeller Center foreshadowed a potentially large market in building. In the mass consumer market, aluminum increasingly appeared in window screens, furniture, packaging, foil and high-fashion gift ware. [161]

During the boom times before the stock market crash in 1929, several major U.S. firms considered entering the aluminum smelting business, including General Electric, DuPont and Ford, but they all decided it was too risky. In 1932, the Bohn Aluminum and Brass Corporation looked at alternatives to bauxite for alumina production but backed out because of the collapsed economy. Throughout the ups and downs of the inter-war period, Alcoa benefited from economies of scale and vertical integration and enjoyed significant profits through most of the 1920s. Alcoa even began an aggressive program to double primary capacity in 1925. That all changed when the stock market crashed in 1929. Within five years, the number of workers at Alcoa fell from 24,857 to 13,652, and gross revenues fell from $34.4 million to $11.1 million. Then in 1936, pent-up demand for aluminum created a booming market, and Alcoa made a good recovery until 1939. [162] By the late 1930s, the price of aluminum had dropped to 30 cents per pound, and the metal was being used in more than 2,000 different products. [163]

Through vertical integration, Alcoa held its nearly perfect monopoly for raw materials between the wars. From 1928 through 1937, Alcoa produced about 2.15 million tons of alumina, or about 98% of the total U.S. output, through its wholly-owned subsidiary the Aluminum Ore Co. The remaining 2% was produced by the Pennsylvania Salt Co. Alcoa used only 78% of its alumina and sold the remainder for uses other than the production of primary aluminum. The bauxite used to make this alumina came from high-grade deposits in Arkansas, mined by the wholly-owned subsidiary Republic Mining and Manufacturing Co., and from substantial bauxite deposits in Dutch Guiana, mined by the wholly-owned subsidiary Surinaamsche Bauxite Maatschappij. During this time period, Alcoa also had a nearly perfect monopoly in the production of ingot primary aluminum. [164]

Alcoa was the sole producer of primary aluminum ingot in the U.S. from 1909 through 1940. The company’s highest production year was 1939, when Alcoa produced 163,500 tons of primary aluminum. Most of Alcoa’s primary aluminum was used in its own fabrication plants, but some was sold to independent fabricators. Between 1935 and 1938, about 51,000 tons of secondary aluminum was produced from scrap. Alcoa was in control of the market for fabrication of aluminum cable and large rolled structural shapes up to 1940, but the company faced serious competition in all other fabrication markets. [165] But just as the World War I and the stock market crash dramatically changed the aluminum industry, so would World War II.

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