OEM Tech Brief

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The U.S. Aluminum Casting Industry

The Aluminum Casting Industry at a Glance: Featured Die Casting Section

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Overview

Aluminum is the world's third most abundant element after oxygen and silicon. It is the most abundant metal making up about 8.3% by weight of the Earths solid surface. Aluminum metal is very reactive so native specimens are rare. It is found combined in over 270 different minerals. The major ore used in the production of primary aluminum is bauxite.

The process for extracting aluminum was very complex and expensive until in 1886 when Oberlin College student Charles Hall and French engineer Paul Heroult separately and simultaneously developed a relatively inexpensive electrolysis process by which aluminum is extracted from aluminum oxide. Prior to that aluminum was considered a precious metal. During the reign of Napoleon III (1852 to 1870) privileged guests at state dinners were served on aluminum plates while less privileged guests were served on plates made of gold and silver. When the Washington Monument was capped with a 100 ounce aluminum casting in 1884, the cost was today's equivalent of $300 per ounce or$4,800 per pound. The 6¼ pound casting was the largest ever produced to that time.

Primary Aluminum Production - 2013	
(000 metric tonnes)	
North America	379
South America	115
Western Europe	301
East & Central Europe	321
Asia (except China)	203
China	2,384
Mid-East	426
Africa	143
Oceana	165
ROW	90
Total	4,527

Source: International Aluminum Institute

In 1919 the Smithsonian Institute reported that 80 tons of aluminum was produced in 1889 and that grew to 80,000 tons in 1917. The major use of the increased production was in the manufacture of aircraft and dirigibles. The development of low cost electricity production, especially hydro-electric, drove the cost of producing primary aluminum down to more reasonable levels. Production of primary aluminum in 2013 was 4.527 million metric tons.

Primary versus Secondary Aluminum

Aluminum casting companies in the United States work almost exclusively from ingots ranging in size from a few pounds to sows weighing nearly 2,000 pounds. Ingot can be either primary aluminum or secondary aluminum.

Primary aluminum is nearly pure aluminum typically produced bauxite ore in a two-step process. Bauxite ore provides the basic material from which aluminum oxide (alumina) is produced using a chemical process. This process requires energy mostly in the form of fossil fuel at the rate of 13.5 MMBtu for one metric ton. High quality bauxite deposits containing 30- 50% aluminum oxide are concentrated in Australia, Brazil, Ghana, Guinea, India, Jamaica and parts of Russia and China. In North America, about 40% of the alumina required for primary production is produced in the region. About 5 tons of bauxite is required to produce 1.91 tons of alumina.

The next step in the aluminum refining process is an electrolytic process that reduces the aluminum oxide (alumina) leaving pure aluminum. Approximately 1.91 tons of alumina is required to produce one ton of aluminum. Using improved refining processes, the energy required to produce primary aluminum is down 25% since 1995 and the industry's carbon footprint is down nearly 40%.

Secondary aluminum is produced by melting recycled aluminum and purifying it. Recycled aluminum is classified as unused and used. Unused aluminum includes trimmings from sheet, machine borings and other aluminum that is relatively uncontaminated. Used aluminum comes from recycled cans, shredded automobiles and other post-consumer material. It takes about 10% of the energy required to produce primary aluminum to produce secondary aluminum.

Primary aluminum is nearly pure aluminum. Secondary aluminum contains residual amounts of contaminants that are reduced to levels within very low specified tolerances. Both primary and secondary aluminum are alloyed with other materials to produce the aluminum alloy desired.

Aluminum is infinitely recyclable with nearly 75% of all aluminum ever produced still in use today. Aluminum is one of the few materials in the consumer disposal stream that more than pays for the cost of its own collection.

Post-consumer scrap contains significant amounts of contaminants that must be removed in processing. This requires special equipment and processes. Manufacturing scrap can be relatively clean but may be contaminated by release agents or other lubricants used in the manufacturing process. Most aluminum casters purchase raw material in certified ingot form from scrap processors or primary aluminum. Processing of aluminum scrap requires special equipment and expensive environmental controls. A very few aluminum casters operate their own smelting facilities.

Casting of aluminum is environmentally clean and requires few environmental controls.

The secondary aluminum recycling supply chain is more complex than iron. The price differential between scrap purchase price and ingot selling price must be greater than iron to recover the added costs. Ferrous foundries use scrap directly from scrap recyclers but must invest in expensive to purchase and operate environmental controls.

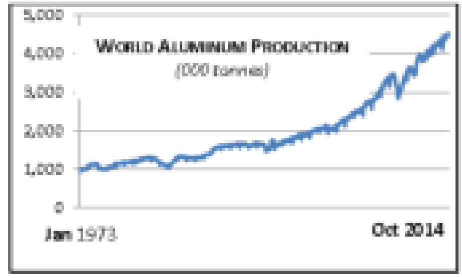
ALUMINUM SURGES

The production of aluminum has surged over the past 40 years. In 1973 world aluminum production was 12,017,000 tonnes and grew to 50,602,000 tonnes in 2013. The pace of production for 2014 is nearly 53,000,000 tonnes.

(000 tonnes)	Primary Aluminum Production	World Casting Proction	Percent of Primary AL Production
1999	23,721	7,188	30.3%
2000	24,657	8,046	32.6%
2001	24,510	8,178	33.4%
2002	26,156	8,635	33.0%
2003	27,986	9,340	33.4%
2004	29,857	10,208	34.2%
2005	31,905	11,718	36.7%
2006	33,938	12,279	36.2%
2007	38,132	12,727	33.4%
2008	39,971	10,932	27.4%
2009	37,706	10,237	27.2%
2010	42,353	10,880	25.7%
2011	45,789	13,197	28.8%
2012	47,787	14,052	29.4%
2013	50,602	15,357	30.3%

The world production of aluminum castings, as a percentage of primary aluminum production, has remained fairly consistent ranging from 25.7% of primary aluminum production to 36.7% of primary aluminum production. Data is not available for secondary aluminum production so the total aluminum available for manufacturing uses is not reported here.

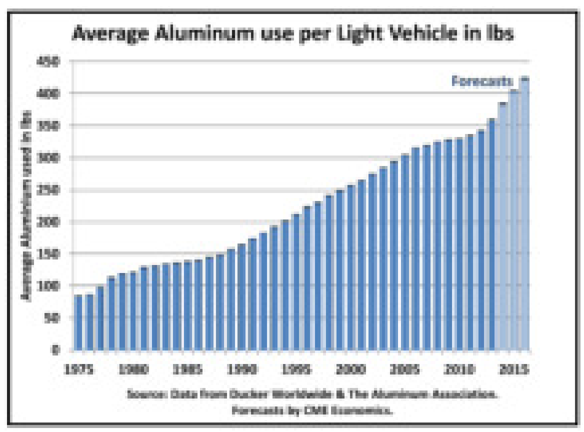
Bauxite deposits are geographically focused so it follows that the production of alumina is primarily in areas where bauxite is found. The production of aluminum from alumina is very electricity intensive so aluminum production tends to be located in areas with low electrical costs.



ALUMINUM VERSUS IRON

Aluminum castings started making significant inroads on iron castings almost as soon as the price of aluminum began to make it economically feasible, albeit a stretch. Momentum changed dramatically with the implementation of mandatory fuel economy standards for light vehicles.

CAFE legislation was passed in 1975, not to reduce what was already recognized as high levels of pollution created by automobiles, but to address the 1973 Arab oil embargo. The rules were challenged, plaintiffs were granted extensions and economic issues delayed comprehensive implementation until the mid-1980's. The standards continue to tighten with the EPA requiring vehicles



to meet a target of 63 grams of carbon dioxide equivalent per mile in model year 2025. It is most conveniently and understandable when expressed in miles per gallons but that is not the correct form.

Taking weight out of vehicles is one of the easiest ways to meet the EPA regulations. Aluminum is a very good way to take weight out. Initially, iron castings including engine blocks, heads, intake manifolds and transmission housings were converted to aluminum. In addition, steel wheels were largely replaced by cast aluminum wheels. In 1975, aluminum content in light vehicles was about 80 pounds. In 2012, aluminum content rose to an average of 343 pounds. About 85% of that weight is in engines (130 pounds), wheels (67 pounds), transmission and drive chain (70 pounds) and radiators (32 pounds). Eighty percent of engine blocks are aluminum, 99% of cylinder heads, 100% of radiators and transmissions and 70% of road wheels are aluminum. Smaller percentages of aluminum castings are used in suspension arms/links (14%), bumper beams (17%), steering knuckles (27%) and hoods (30%).

The 263 pounds of aluminum added to vehicles from 1975 to 2012 came at the expense of 765 pounds of iron castings.

It is generally accepted in the automotive industry that $2 in additional vehicle cost is reasonable to reduce weight by one pound. Ford Motor's 2015 F150 Pickup is the first "all aluminum" vehicle. There is about $1,000 in added cost due just to the use of aluminum. While the use of aluminum in light vehicles will continue to grow, only a small portion will be aluminum castings. Most of the growth in the use of aluminum will be extrusions and sheet.

Most reports compare iron and aluminum castings based either on tons (weight) or sales dollars. Neither makes any sense in the comparison. Iron weighs 491 pounds per cubic foot and aluminum weight 169 pounds per cubic foot. A comparison based on weight substantially understates the volume of aluminum cast relative to iron. IN 2012, the average aluminum casting sold for $2.358 per pound compared to $.641 for ductile iron, a multiple of 3.7 times the price of ductile iron. A comparison based on sales dollars overstates the importance of aluminum.

An "apples to apples" comparison is a comparison of the cubic feet cast.

United States	Cubic Feet of Metal Cast					
cubic feet	2007	2008	2009	2010	2011	2012
Gray Iron	17,425,255	15,694,110	10,796,054	11,796,400	13,271,690	19,250,762
Ductile Iron	17,429,735	16,120,910	11,442,352	12,336,601	17,210,183	20,071,886
Malleable Iron	300,204	268,839	158,525	-	457,026	382,110
Aluminum	24,043,787	22,650,627	15,505,886	16,060,924	19,826,036	22,815,953
Percent Al of Total	40.6%	41.4%	40.9%	40.0%	39.1%	36.5%

As the chart shows, aluminum is a larger share of the market than recognized when weight is used as a comparison. Several factors impact the volumes cast in any one year. For both iron and aluminum, automotive is the "900 pound gorilla." In 2012, 8.9% of gray iron castings were for automotive, 12.2% for ductile iron and 30.5% for aluminum. In die casting aluminum, fully 55% of production is for automotive applications. The significant drop in aluminum production that began in 2008 and started to reverse in 2010 was due to the drop in automotive production.

Each of the iron alloys and aluminum alloys have properties that can determine which is best in a particular application. There are times the materials are interchangeable with reasonable or no modification to the part design. As proof of this, consider the conversions of iron castings in automotive to aluminum. When the materials are substantially interchangeable, price becomes the determining factor. Aluminum is a preferable material from the standpoint of ease of processing.

A hypothetical casting weighing one pound in iron (.34 pounds in aluminum) that can be made identically in both iron and aluminum would cost $.641 in ductile and $.802 in aluminum. The price of aluminum is trending very slowly downward. When the cost of aluminum drops another 25%, the materials will be cost competitive. Aluminum is a much more prevalent element than iron in the earth's surface. A breakthrough in processing technology that lowers primary aluminum cost could bring a dramatic price drop. Also, aluminum is very easily recycled. As more primary aluminum is put into use and products reach the end of their life cycle and are reprocessed the supply of secondary aluminum will increase. An increased supply of secondary aluminum will put downward pressure on material costs.

There do not appear to be any imminent breakthroughs in primary aluminum processing. The price of secondary aluminum is moving very slowly. It will be some time before aluminum, as a material in itself, is price competitive with iron.

There are certain categories of castings where there is no comparison between iron and aluminum castings. Aluminum castings top out at about 3,500 pounds with a few somewhat larger. Iron castings top out at 200,000 pounds in the United States and even larger in Europe and China.

ALUMINUM CASTING PROCESSES: DIE CASTING

Major aluminum casting processes include die casting, permanent/semi-permanent casting and sand casting. Aluminum is cast in nearly all the standard casting processes.

Only a third of all aluminum casting is done with die casting, however about 61% of aluminum castings are done in die casting. Chicago White Metal is a company that works specifically with die casting processes for aluminum parts (also zinc and magnesium alloys). Let us delve into the processes of Die Casting as it relates to aluminum.

HIGH PRESSURE DIE CASTING (HPDC)

In terms of pounds, HPDC is the largest segment of aluminum casting with slightly over 60% of production produced by this method. Die casting is a near net shape process that produces castings with excellent surface finish. While it is not the fastest method, with cycle times ranging from one minute per cycle to four or five minutes per cycle, the labor content is minimal. It is frequently the lowest cost method of casting production.

In HPDC, liquid aluminum is injected under pressure into steel molds in special machines. The process used in aluminum casting is called cold chamber die casting. Hot chamber die casting is a process used for zinc and sometimes, magnesium.

In cold chamber die casting, precise amounts of metal are injected in the mold. After a pre-determined time, the mold is opened and the solidified casting is removed. Molds are frequently water-cooled to reduce the amount of time required for solidification. The aluminum is injected very quickly and can create a turbulent flow trapping air in the casting. If this is a problem, vacuum can be applied to the die reducing the risk of entrapped air.

State-of-the-art die casting cells operate fully automated. Automated machine controls determine the fill volume and speed of fill. Robots spray release agent on the molds and remove castings. Castings are placed by the robot in trim dies and trimmed pieces are placed in part carriers. Real time shot monitoring tracks key parameters of every shot. Any variation outside established control limits stops the process and notifies appropriate personnel. Scrap can be reduced to virtually zero.

Advantages of HPDC include:

- Near net shape casting
- High precision tolerances. Common is +/- .002 inches per inch.
- Extremely high repeatability
- Ability to cast very thin sections
- Lowest cost method of casting
- High yield due to pressure filling requiring smaller amounts of metal melted
- Excellent casting surface finish
- Gates and runners are usually removed with trim dies.

As a historical note, the first die cast engine block was offered as an option in the 1961 AMC Rambler. The block was cast by Doehler-Jarvis in their Toledo, Ohio, die casting plant.

The North American Die Casting Association (NADCA) in their 2014 State of the Industry report forecasts growth of 6.8% in 2014 compared to 2013. Most of the growth is expected from the recovering light vehicle market.

THE MARKET FOR ALUMINUM CASTINGS

The largest single market for aluminum castings is NAICS 3361 Motor Vehicle Manufacturing. Permanent mold are the single most prevalent casting method followed by high pressure die castings. The following information is from a Ducker Worldwide 2011 report titles "Aluminum in 2012 North American Light Vehicles." The aluminum content is expected to be an average of 343 pounds per vehicle. Of that, 81% or 278 pounds are aluminum castings. The balance is composed of flat rolled, extruded and forged aluminum components. In 2025, the percent of total aluminum castings is expected to drop to 62% but grow in weight to 336 pounds. This is consistent with the industry perception that the easy conversions to aluminum castings have been done. Of the 4.8 billion pounds of aluminum castings in light vehicles, 69.4% will be used in wheels (16.5%), transmissions (16.4%), cylinder blocks (13.3%), cylinder heads (12.3%) and heat transfer (10.8%). Some of the growth will come from conversions of iron castings to aluminum in brake calipers and suspension components. Other growth will come from the conversion of steel stampings to die castings produced on very large, state-of-the-art die casting machines.

All Aluminum Metal Casting - 2012

NAICS	Description	U.S. $ (000,000)	Percent
3361	Motor Vehicle Mfg	2,777.41	30.6%
3364	Aerospce Product & Parts Mfg.	1,647.10	18.1%
336	Transportation Equipment	764.13	8.4%
3345	Navigational, Measuring, Medical & Control Instr.	610.55	6.7%
33361	Engine, Turbine & Power Transmission	690.38	7.6%
3352	Household Appliances	274.14	3.0%
33341	HVAC and Commercial Refrigeration	234.95	2.6%
333911	Pump & Pumping Equipment	219.10	2.4%
3334	Ventilation, Heating, AC & Commercial Refrig.	222.40	2.4%
33531	Electrical Equipment	196.44	2.2%
335312	Motor and Generator	179.49	2.0%
336991	Motorcycle, Bicycle and Parts	133.46	1.5%
333112	Lawn and Garden Equipment	148.71	1.6%
334210	Telephone Apparatus	157.85	1.7%
336999	All Other Transportation Equipment	76.79	0.8%
335122	Nonresidential Electric Lighting Fixtures	88.81	1.0%
339920	Sporting and Athletic Goods	86.17	0.9%
	All Others - 11 Categories	582.97	6.4%
	Total	9,090.85	100.0%

Source: "AFS Metalcasting Forecast & Trends 2014"

The second largest casting segment in dollars is NAICS 3364 Aerospace Product and Parts Manufacturing. While it is 18.1% of sales dollars compared to light vehicles 30.6% it is much further apart in pounds. Aerospace parts tend to be larger, more complex and produced in much smaller quantities adding to the cost. In addition, mandated aerospace manufacturing quality procedures can add significant cost. It is not unusual for required inspection processes to include 100% x-ray.

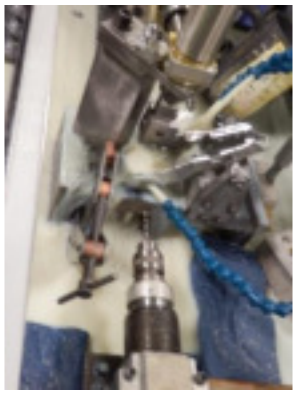
The category NAICS 336 Transportation Equipment refers to medium/heavy duty truck components, trailer components, railroad rolling stock and other transportation equipment. This is about 8.4% of aluminum casting demand. Sand casting is a common method for castings used in this category.

At 6.7%, NAICS 3345 Navigational, Measuring, Medical & Control

Instruments is the next largest segment by sales dollars. This is essentially the instrument market and castings sizes can vary substantially. The next category in descending order of sales dollars at 7.6% is NAICS 33361 Engine, Turbine & Power Transmission. This refers primarily to stationary power plants.

VALUE ADDED OPERATIONS

Most aluminum castings require machining at some level before they are put in final applications. More than other metals cast, aluminum casters have opted for captive machining operations.



Aluminum is one of the easiest metals to machine and bringing machining in-house eliminates one step in the supply chain. Each time a step is reduced in the supply chain, a cost reduction of 10-15% in cost of the outside service is achieved. Thus, aluminum casters with captive machining operations have a cost advantage over casters who use independent machining operations or supplying just the castings and requiring customers to obtain outside machining. Those customers who have captive machining capabilities will not see as much of an advantage.

Approximately 50-60% of aluminum casters have in-house machining capabilities beyond simple drilling, tapping, etc. As the size of the caster grows, the more likely they are to have in-house machining capacity. This is a growing trend and a few larger machine shops have indicated interest in acquiring aluminum casting operations.

Heat treating is another relatively common value added operation. Aluminum casters that produce significant volumes of castings requiring heat treating typically have in-house heat treat capabilities. Others use outside heat treat companies.

Pressure testing is not an un-common requirement for aluminum casting and is usually done in-house.

NEW TECHNOLOGIES

Several new technologies are having an impact on the aluminum casting industry.

Additive manufacturing, or 3D printing, is one of the most notable. Additive manufacturing builds a product through the three dimensional printing with a variety of material options. The mediums include wax, coated, sand and even powdered metals among others. Printers can now build models up to four feet in diameter and ten feet high. The process is slow and expensive but can provide significant savings in cost and time for single part manufacturing, prototypes and mold making.

Very large high pressure die casting – machines with tonnage over 2,000 tons – are taking die casting to new levels. Improvements in process controls and better technology are allowing for the mass production of larger and more complex castings. Flow and solidification technology improvements are paving the way to thinner and higher quality components. The result is the conversion of aluminum castings made using higher cost methods and the conversion of large, rangy aluminum stampings to castings.

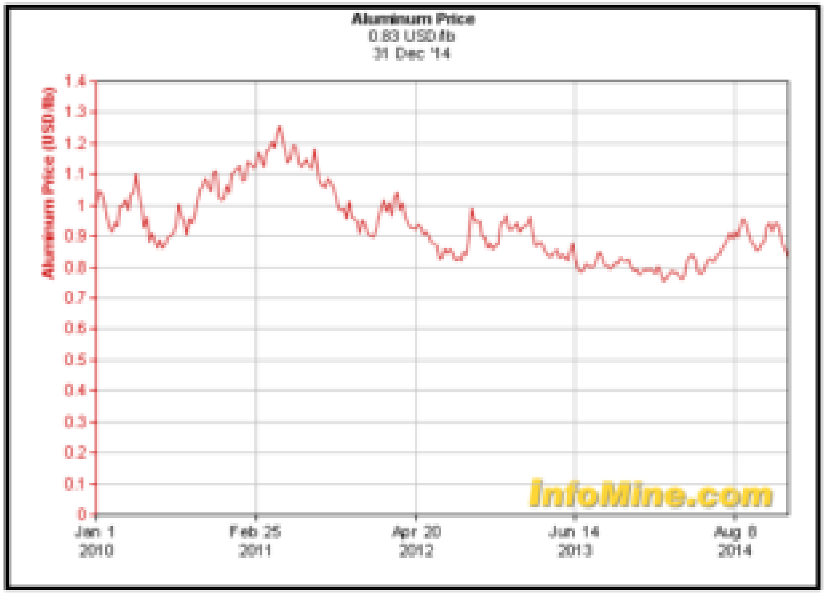
Semi-solid castings are produced by forcing aluminum the consistency of tooth paste into dies under very high pressure. The resulting casting has strengths higher than standard castings and nearing the strength of forged aluminum parts. It has the ability to produce parts more complex than can be made using traditional forging. SS casting uses about 35% less energy than traditional die casting. The added strength either is used to reduce weight or make further in-roads on iron castings. Safety-related suspension components in light vehicles are very slowly being converted to semi-solid aluminum castings from iron castings. The progress is relatively slow since the size of SS castings are comparatively small so the weight savings is nominal. In converting safety components, the industry is rightly cautious.

Energy is a major expense in metal casting. New furnace designs and improved metal handling are producing savings in melt costs. Major melting practices in aluminum casting include crucible (usually gas fired), reverberatory (usually gas fired but can be electric) and induction melting (electric). About 55% of the energy used in the production of castings is used for melting. Of that energy, the 60% is for gas. Gas fired crucibles can have thermal efficiency as low as 7% and top out at 19%. Improved furnaces and operating practices provide significant cost reductions, even at historic low gas prices.

The Future of Aluminum Castings

Looking ahead, the future of aluminum casting in the United States looks good. It looks even better for North America. The casting market is a derivative market.

That is, castings are used in other products with only a small portion sold to consumers as castings. Demand is dependent on the demand in major aluminum casting markets, the general economy, raw material cost and competition from imports.



The U.S. economy is stable and growing slowly. This is good news and bad news. There are no bubbles such as technology or housing driving a boom. The good news is there are no booms to go bust. The housing bust in 2007 started the rationalization of the light vehicle market and ended with a major recession. The economy has recovered to near pre-recession levels and in some segments surpassed pre-recession highs. There is nothing in the economy to suggest this will turn downward. The population growth in the United States is 0.7% per year according to the World Bank. For the economy to grow faster requires personal consumption to increase from current levels. This is, in fact happening,

Imports are less and less a threat every day. After the massive outflow of casting in the 1980's and 1990's the tide has turned. U.S. metal casters report that on basic casting, they can compete with anyone. Raw material costs are competitive world wide. The U.S. enjoys competitive energy rates. Very high productivity in U.S. metal casters helps offset lower offshore labor costs. Logistic costs and other supply chain costs level the playing field with most countries. It becomes more difficult to compete when high labor content is added in machining and other value added processes. Casters report that work is slowly coming back.

The tsunami in Japan in 2011 caused major disruptions in Japanese light vehicle manufacturer supply chains. As a result, more Japanese components are regionally based, a boon for the United States.

Major offshore sources sending aluminum castings to the United States include Mexico, Canada, Japan, Korea, Germany and Italy. Mexico presents the major threat to U.S. aluminum casters, if your view is the United States. If your view is North America, the view is much better.

The price of aluminum ingot has dropped in the past five years. This is in part due to decreased demand, primarily in China. Also, there were issues with price manipulation by hedge funds and banks in 2011. These appear to have been either resolved or reduced. The increased aluminization of light vehicles with aluminum sheet and extrusions will increase demand for aluminum and keep prices high until the recycling market catches up. Prices will then begin to drift down as aluminum recycling volumes increase.

The North American light vehicle market has substantially recovered so demand from that mature market has stabilized. Added castings to light vehicles will be nominal. The metric to watch is the age of the North American fleet. According to R. L. Polk, the average age of vehicles was 9.8 years in 2002 and rose to 11.4 years in 2012. The mature level of light vehicle sales in North America is about 17 million vehicles a year. If the age of the fleet increases, the sales rate will drop until the fleet reaches a new age then return to 17 million. Conversely, if the age drops, sales will increase for a short time until the new age is reached.

Aerospace, the second largest market for aluminum castings will continue to grow. In addition to the demand for new aircraft, increasing new applications for aluminum in aircraft construction are being found. While this is a significant portion of the aluminum casting market in dollars the total pounds is significantly less than that value implies. Aircraft castings sell for a premium price per pound.

In summary, the market for aluminum castings in the short term is stable and growing at 4-5% a year.

Excerpt written by The Folk Group, a leading merger and acquisition specialist serving the metal casting industry. www.folkgroup.com