DOE | MARKET RESEARCH STUDY
DOMESTIC CASTING INDUSTRY

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1.0 Metalcasting Industry Overview

Put simply, metalcasting is the process used to create simple or geometrically complex parts by pouring high temperature molten or liquid metal into a mold made of moist sand, metal, or ceramic.[1] Metalcasting businesses are called foundries or die castors, depending on the process. This report provides a historical perspective on the casting industry in the United States and explores the challenges the industry faces today.

1.1 Commonly Casted Metals and Casting Methods

All major metals can be cast, but the most common are iron, aluminum, magnesium, zinc, steel, and copper-based alloys.[2] The term "ferrous metals" refers to castings made of iron and steel. Iron castings can be made with grey iron, ductile iron, or malleable iron.[3]

There are at least 10 different methods for casting metal: Sand casting; Investment casting; Die casting; Low pressure casting; Centrifugal casting; Gravity die casting; Vacuum die casting; Squeezing die casting; Lost foam casting; Continual casting.[4] For a description of each, including applications, and the advantages and disadvantages of each method, see MachineMFG's blog 10 Different Types of Casting Process. Many facilities do additional work on castings, such as machining, assembling, and coating.[5]

In the North American Industrial Classification System (NAICS), iron and steel foundries, nonferrous foundries, and die casters are all classified as NAIC 3315 - Foundries. Within 3315, there are additional NAICS codes specific to metals and processes used.

Codes	Titles
3315	Foundries
331511	Iron Foundries
331512	Steel Investment Foundries
331513	Steel Foundries (except Investment)
331523	Nonferrous Metal Die-Casting Foundries
331524	Aluminum Foundries (except Die-Casting)
331529	Other Nonferrous Metal Foundries (except Die-Casting)

Figure 1: NAICS Codes That Fall Under 3315 – Foundries
Source: NAICS Association 2022[6]

However, not all metalcasting companies come under NAICS 3315, as clarified by the NAICS Association:

This industry group comprises establishments primarily engaged in pouring molten metal into molds or dies to form castings. Establishments making castings and further manufacturing, such as machining or assembling, a specific manufactured product are classified in the industry of the finished product. Foundries may perform operations, such as cleaning and deburring, on the castings they manufacture. More involved processes, such as tapping, threading, milling, or machining to tight tolerances, that transform castings into more finished products are classified elsewhere in the Manufacturing sector based on the product made.

Establishments in this industry group make castings from purchased metals or in integrated secondary smelting and casting facilities. When the production of primary metals is combined with making castings, the establishment is classified in Subsector 331, Primary Metal Manufacturing, with the primary metal made.[7]

1.2 Typical Casting Applications

Metalcastings are found in 90% of durable goods - in motor vehicles, aerospace, trains, mining and construction equipment, oil wells, appliances, pipes, hydrants, wind turbines, nuclear plants, medical devices, defense products, golf clubs, office chairs, cast iron pans, even toys.[8, 9]

Metal castings are found in 90% of all manufactured goods. Almost a third of metal castings are made for the car and truck market.

Industries that depend on metal castings include:

- Aerospace
- Agriculture
- Architectural /Ornamental
- Automotive /Trucking
- Construction
- Energy
- Food Processing
- Hydropower
- Infrastructure
- Marine
- Medical
- Mining & Mineral Processing
- Municipal/Water Sector
- National Defense
- Pulp & Paper
- Railroad
- Others[10]

Two of the largest applications are cars and trucks and pipes and fittings.

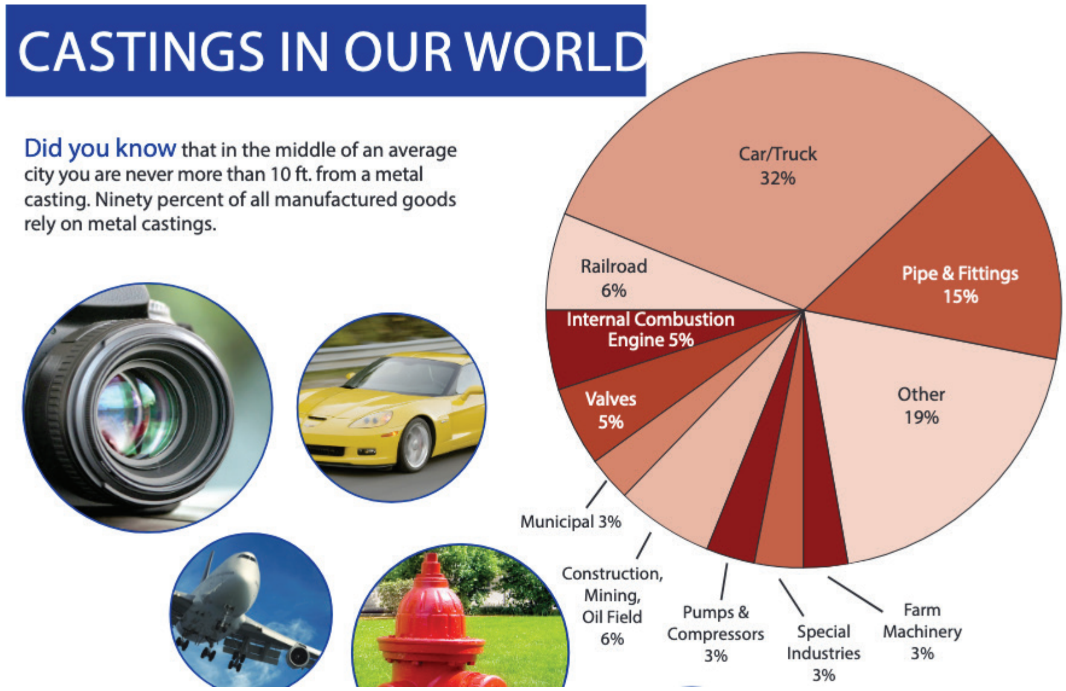

Figure 2: U.S. Castings, By Application Area
Source: American Foundry Society[11]

2.0 Casting Industry Past and Present

2.1 Historical Review of the Metalcasting Industry

2.1.1 U.S. Metalcasting Industry 2000-2001

To get a picture of how the U.S. metalcasting industry has changed over the last two decades, research looked at past industry reports, starting with a special report of the 1st International Forum on Casting Markets, published in December 2000: [Global Casting Report: Past, Present & Future](). At this forum, representatives from the United States, China, Europe, Japan, and Brazil provided reports on the state of their metalcasting industries. The contribution from David Kanicki of the American Foundry Society (AFS) provided a comprehensive summary of the state of the metalcasting industry in the year 2000.

Kanicki reported that at the turn of the century (1999-2000), the U.S. metalcasting industry was one of the 10 largest industries in America, despite a continuing decline in the number of foundries. Rapid and continuing consolidation of both foundries and the major markets they serve had changed the structure of the industry. The number of operating foundries had dropped from 6150 plants in 1955 to about 2900 by the year 2000. Of those 2900, 1900 were nonferrous operations. The remaining 1000 were iron and steel plants. The vast majority of foundries were small – 80% employed less than 100 workers; only 6% employed over 250.[12]

The largest user of U.S.-produced castings in 2000 was the car and light truck industry, which accounted for 33% of all castings, followed by the pipe and fittings market, which utilized 15% of all castings.[13]

In 1999, the U.S. industry, operating at about 82% capacity, shipped about 15 million tons of castings, which added up to about $29 billion in sales.[14]

Looking at the types of metals cast, in 1999, iron castings represented more than 70% of total shipments and 39% of total sales. Aluminum castings represented 13% of shipments and 26% of sales. Steel castings represented 11% of shipments and 13% of total sales.[15] Malleable iron production, which had peaked in 1965 in the U.S., had nearly disappeared by 2000, and steel casting shipments, which peaked in 1970s with the demand for railcars, had slowly declined.[16]

A significant trend noted in 2000 was the drop in gray iron production and the growth of ductile iron production. The decline of gray iron production was driven by the switch from iron to aluminum castings by U.S. automakers. Ford Motor Company had announced a goal to produce an all-aluminum engine by 2005. While a car produced in 1980 averaged 600 lbs. of cast iron, a 2000 vehicle averaged 325 lbs. of cast iron. Gray iron production dropped from 12 million tons in 1979 to 6 million tons in 1998.[17] During the same period, ductile iron production grew from 3 million tons to slightly more than 4 million tons.[18] Austempered ductile iron, first used in Chinese and European trucks, began being used in U.S.- built light cars and trucks in 1978, as it addressed the issues of weight, strength, stiffness, noise, cost, and recyclability.[19]

Kanicki noted that the industry was excited about the increase in aluminum casting, which had grown from 1 million tons shipped in 1987 to 1.8 million tons by 1999 and were expected to reach shipments of nearly 3 million tons by 2008 – attributed to the switch from cast iron to cast aluminum for lighter weight cars. In 2000, 25% of U.S.- produced engine blocks were aluminum, and it was anticipated that by 2007, 55% would be aluminum. However, the use of aluminum for manifolds *was* expected to decline as OEMs switched to plastic.[20] Cast magnesium production was also expected to see rapid growth during the next decade, driven almost entirely by the U.S. automotive industry seeking ways to reduce vehicle weight.[21]

Copper-alloy casting production had remained fairly stable since 1990 and was expected to continue to be so, with an expected annual growth rate of 1% from 2000 to 2010. However, brass, and bronze casting producers had been impacted significantly by the switch to plastics.[22]

In 2000, metalcasting executives believed the 3 most significant threats to the U.S. metalcasting industry were: government regulations, imported castings, and a lack of skilled workers.

In 2000, U.S. metalcasting executives believed the three most significant threats confronting the U.S. metalcasting industry were: increasingly stringent government regulations, imported castings, and the lack of skilled workers.[23]

Another report from the Cast Metals Coalition (CMC), A Vision for the U.S. Metal Casting Industry 2002 and Beyond (based on a workshop held in October 2001) provided some additional facts and observations on the U.S. metalcasting industry in 2001, which have been summarized in the list below, including some of the CMC recommendations to help small foundries compete.

As of 2001:

- The U.S. is the world's leading casting producer with 21% of world casting markets.
- There are approximately 2,950 metalcasting companies in the U.S.
- The industry employs about 225,000 people.
- U.S. casting shipments totaled 14.3 million tons in 2000.
- Leading metalcasting states include Alabama, Indiana, Illinois, Michigan, Ohio, Pennsylvania, and Wisconsin
- The metalcasting industry consumes 328 trillion Btu annually. Annual energy costs in metalcasting are over $1 billion. About 55% of energy costs are consumed in melting. Mold making, core making, heat treatment and post-cast operations also use significant energy. *CMC noted that research to improve these operations and reduce melting requirements will help the industry save energy and improve competitiveness*.
- Most metalcasters are small businesses, of which 94% employ less than 250. *These small foundries are not positioned to perform the research necessary to remain competitive. CMC noted that collaborative research partnerships such as the Cast Metal Coalition, which bring together industry, academia, and government, are proving vital to conducting the research needed to raise the technology of U.S. metalcasting products and processes.*[24]

2.1.2 U.S Metalcasting Industry 2005

Tonnage: After 2000, U.S. metalcasting shipments dropped, but by 2005 the U.S. industry was rebounding, as the industry had increased its shipping totals for the past three consecutive years, showing a 4.7% gain in 2005. The U.S. shipped a total of 12,896,533 tons in 2005.[25] Here's the 2005 U.S. production breakdown, by metals casted:

U.S.: 12.90 million tons total
Gray iron: 4.46 million tons
Ductile iron: 4.46 million tons
Steel: 1.29 million tons
Aluminum: 2.10 million tons[26]

Productivity Per Plant: U.S. metalcasting productivity per plant was 5,419 tons in 2005.[27]

Number of Facilities and Metals Cast: In 2000, the U.S. had 2900 metalcasting facilities. By 2005, the U.S. had dropped to 2,380 facilities. Of those, 1,499 were casting nonferrous metals; 619 were casting iron; and 262 were casting steel.[28]

For global statistics, see Modern Casting's complete December 2006 report: 40th Census of World Casting Production—2005.

2.1.3 U.S Metalcasting Industry 2010

Tonnage: Following the 2008-2009 recession, Modern Castings, in its December 2011 report, 45th Census of World Casting Production - 2010, reported that, after four straight years of reducing its casting production, the U.S. reported an 11.2% increase in 2010. In 2010, the U.S. produced 8.24 million tons, positioning it as the third top producer worldwide, behind China and India.[29] Here's the 2010 U.S. production breakdown, by metals casted:

U.S.: 8.24 million tons total
Gray iron: 2.63 million tons
Ductile iron: 2.75 million tons
Steel: 980,000 tons
Nonferrous: 1.87 million tons[30]

Productivity Per Plant: After the hit of the global recession, plant production was still not back to pre-2008 levels in 2010, but in 2010 all of the top ten producing nations had increased their metalcasting productivity per plant since 2009. The U.S. was third in plant productivity in 2010, at 4,038 tons per plant. Germany was the leader in productivity, with 7,808 tons per plant. [31] Modern Casting, in its December 2011 report described the global metalcasting industry in 2010:

> With few exceptions, casting production dipped in 2009 across the board. The current casting data from 2010 shows countries making slight production increases, but production is still not back to pre-2008 levels. The top two producers, China and India, are the exception. Germany, regaining its position at number five after its drop to six last year, showed 23% growth, although the country is still not above 2008 levels. In a year that included a devastating earthquake, Japan saw 8.5% growth. Prior to 2012, Japan's production had been decreasing since its peak in 2006.[32]

Germany's major casting markets are automotive, machinery and equipment manufacturing, and rail vehicle construction.[33]

2.1.4 U.S. Metalcasting Industry 2015

In 2015 global metalcasting production was described as "stagnant" worldwide, as growth was only .5%. For three years in a row – 2013, 2014, and 2015 – worldwide casting production grew annually by less than 4%.[34]

While China and India have many more metalcasting plants, they are not as productive as German and U.S. plants.

Tonnage: In the U.S., metalcasting production shipments dropped 0.8% from 2014 to 2015. In 2015

U.S. Metalcasters shipped 10.39 million metric tons, down from 10.47 million metric tons in 2014. With this drop in tonnage, revenues dropped 6.2% from 2014 to 2015. However, compared to 2010, U.S. tonnage was up over 26% in 2015, up from 8.24 metric tons shipped in 2010.[35]

Production Shipment Trends (metric tons)					
Country	2015 Total	2014 Total	+/-% 2015 vs 2014	2010 Total	+/-% 2015 vs 2010
US Metric	10,388,272	10,470,939	-0.8	8,238,233	26

Figure 3: U.S. Metalcasting Shipment Trends 2010 - 2015 (Metric Tons)
Source: Modern Casting 2016[36]

At 10.39 million metric tons, the U.S. continued to hold its position as the third top producer worldwide. *China produced 45.6 million metric tons and India produced 10.77 million metric tons in 2015.*[37] Here's the U.S., China, and India 2015 tonnage, by metals cast:

Individual Countries (metric tons)										
Country	Gray Iron	Ductile Iron	Malleable Iron	Steel	Copper Base	Aluminum	Magnesium	Zinc	Other Nonferrous	Total
U.S. Metric	3,328,124	3,115,418	51,374	1,493,743	255,354	1,622,999	146,456	324,174	50,630	10,388,272
China	20,200,000	12,600,000	600,000	5,100,000	750,000	6,100,000	-	-	250,000	45,600,000
India	7,410,000	1,180,000	50,000	880,000	-	1,250,000	-	-	-	10,770,000

Figure 4: Top 3 Producers Metalcasting Production 2015 (Metric Tons)
Source: Modern Casting 2016[38]

Revenues, Per Metal: Here's the **U.S. 2015 shipment revenues, by metal cast:**

Casting Shipments (value in U.S. dollars)								
Country	Gray Iron	Ductile Iron	Malleable Iron	Steel	All Nonferrous	2015 Total	2014 Total	% Change
United States	4,215,990,000	4,987,260,000	102,320,000	7,225,320,000	12,488,140,000	29,022,030,000	30,946,280,000	-6.2

Figure 5: U.S. Metalcasting Shipment Values 2015 (U.S. Dollars)
Source: Modern Casting 2016[39]

Number of Facilities and Metals Cast: The number of U.S. metalcasting plants dropped to 1,978 by 2015, down from 2,060 in 2010 and 2,380 in 2005. China has had 26,000 plants since 2010. India added 100 plants from 2010 to 2015 to total 4,600 plants. Germany went from 630 plants in 2005 down to 588 in 2015.[40]

Here's the 2015 U.S. and China metalcasting plant breakdown, by metals casted:

Total U.S. Metalcasting Plants 1,978
Iron Casting Plants 634
Steel Casting Plants 355
Nonferrous Casting Plants 989

Total China Metalcasting Plants 26,000
Iron Casting Plants 14,000
Steel Casting Plants 4000
Nonferrous Casting Plants 8000[41]

China's key domestic buying industries for castings include Bearing Manufacturers, Mining and Construction Equipment Manufacturers, and Auto Parts Manufacturers in China.[42]

Productivity Per Plant: U.S. production, per plant has been increasing. While China and India have a lot more metalcasting plants, data seems to indicate that their plants are not as productive as U.S. plants. U.S. production per plant reached 5,256 tons in 2015, up from 4,038 tons per plant in 2010.[43] Only Germany exceeded the U.S. in plant productivity in 2015 (Modern Casting's report does not go into any detail regarding why German or U.S. plants are more productive).

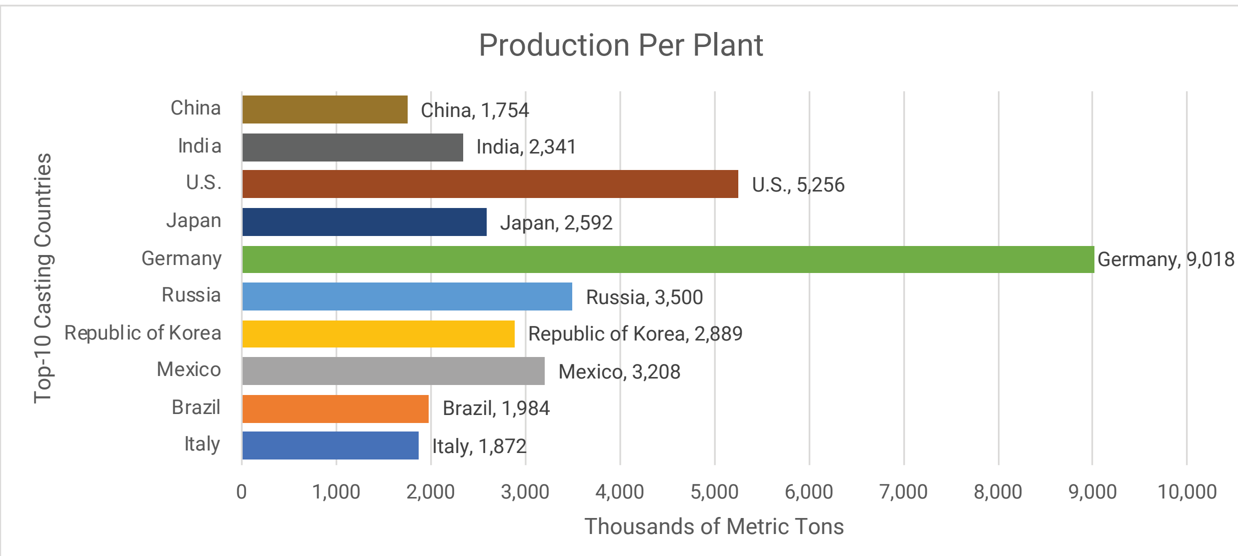

Figure 6: Metalcasting Production, Per Plant 2015 (Metric Tons)
Source: Modern Casting 2016[44]

In 2015, China accounted for 44% of the world's casting production and the U.S. and India combined accounted for 20%.[45] *For more of the global metalcasting statistics, see Modern Casting's December 2016 report:* [50th Census of World Casting Production - 2015](#).

2.1.5 U.S Metalcasting Industry 2016

Tonnage: The U.S. shipped a total of 9,395,305 metric tons in 2016.[46] Here's the U.S. 2016 tonnage, by metals cast:

Gray Iron	Ductile Iron	Malleable Iron	Steel	Copper Base	Aluminum	Magnesium	Zinc	Other NonFe	Total
3,210,350	2,490,970	40,515	1,245,790	205,440	1,686,230	142,740	322,230	51,040	9,395,305

Figure 7: U.S. 2016 Casting Production (Metric Tons)
Source: World Foundry Organization 2018[47]

Number of Facilities: There were 1,952 facilities operating in 2016, with an industry capacity of 15.2 million tons.[48]

Revenues, Per Metal: U.S. metalcasting industry sales were estimated to be $30.6 billion in 2016.[49]

The American Foundry Society provided the above information for inclusion in the World Foundry Organization's WFO Global Foundry Report 2018.

2.1.6 U.S Metalcasting Industry 2018-2019

Revenues
AFS reports the total value of *all* castings produced in the U.S. in 2019 was estimated to be $44 billion, up from an estimated value of $33 billion in 2018.[50]

Increased revenues do not necessarily translate into more jobs, however. The state of Arkansas in 2018 declared foundries to be among the ten fastest declining industries in that state, in terms of employment. Arkansas expects the number of foundry jobs to drop from 1,590 jobs in 2018 to 1,330 in 2028, an expected drop of 16.35% from 2018 to 2028.[51]

Trends
Plant acquisitions, expansions, modernizations, and retrofits have been ongoing trends in the metalcasting industry. Specific examples can be found in Modern Casting's 2019 Year in Review. And stories of recent acquisitions specific to the Investment casting segment are available from the Investment Casting Institute here.

2.1.7 Automotive Metalcasting Sector 2015-2017

As current market revenues have been skewed by the impact of the worldwide pandemic, looking at older, pre-pandemic market projections may be insightful in trying to determine where the metalcasting market is headed. Market reports on the metalcasting industry tend to narrowly focus on a specific application sector or type of metal cast, rather than presenting the metalcasting market as a whole. As the automotive sector is the largest metalcasting application, looking at pre-pandemic revenues and predictions for that sector can be useful in trying to predict what the post pandemic industry may look like. Market research firm MarketsandMarkets (MnM), in its December 2017 metal casting market report specifically focuses on the automotive sector (including passenger and light and heavy commercial vehicles). This report includes predictions through 2025, made before the unexpected worldwide pandemic. A summary of the U.S. and global MnM market analysis follows.

U.S. Automotive Component Metalcasting Market 2015-2025

In December 2017, the U.S. automotive component metalcasting *tonnage was predicted to* grow from 1,482 thousand metric tons in 2015 to 2,633 thousand metric tons by 2025. [*This tonnage figure covers the key automotive components shown in the table below that are manufactured using the casting process, but not other small components as their revenues were considered insignificant*.] [52]

Application	2015	2016	2017-e	2019-p	2022-p	2025-p	CAGR (2017–2025)
Body Assemblies	440.6	458.5	490.1	553.1	671.9	827.0	6.76%
Engine Parts	708.5	733.5	778.3	864.3	1,024.0	1,229.1	5.88%
Transmission Parts	333.1	344.5	365.5	405.9	480.8	577.3	5.88%
Total	**1,482.2**	**1,536.5**	**1,633.9**	**1,823.3**	**2,176.6**	**2,633.3**	**6.15%**

e: Estimated; p: Projected

Figure 8: U.S. Automotive Metalcasting Market 2015–2025 (Thousand Metric Tons)
Reprinted with the permission of MarketsandMarkets.[53]

The U.S. automotive component metalcasting market *revenues were predicted to* grow from $2,622 million in 2015 to $5,374 in 2025. [*This figure covers the key automotive components shown in the table below that are manufactured using the casting process, but not other small components, as their revenues were considered insignificant*.] [54]

Application	2015	2016	2017-e	2019-p	2022-p	2025-p	CAGR (2017–2025)
Body Assemblies	854.8	890.1	964.3	1,113.0	1,417.9	1,832.6	8.36%
Engine Parts	1,187.5	1,223.8	1,326.1	1,505.6	1,874.8	2,374.2	7.55%
Transmission Parts	580.2	599.4	649.5	737.5	922.1	1,167.6	7.61%
Total	**2,622.4**	**2,713.3**	**2,939.9**	**3,356.2**	**4,214.8**	**5,374.4**	**7.83%**

e: Estimated; p: Projected

Figure 9: U.S. Automotive Metalcasting Market 2015–2025 (USD Million)
Reprinted with the permission of MarketsandMarkets[55]

Global Automotive Component Metalcasting Market for Ice and EV/Hybrid

Looking at the global market, MarketsandMarkets' analysts projected that the global automotive component metalcasting market will reach $39.94 billion by 2025, up from $20.23 billion in 2017, at a CAGR of 8.87%. The ICE metalcasting market was estimated to be $18.99 billion in 2017 and was projected to reach $34.41 billion by 2025. The electric & hybrid vehicles metalcasting market for was $1.24 billion in 2017 and was projected to reach $5.53 billion by 2025, at a CAGR of 20.51%. MnM expected factors such as growing stringency in emission & fuel regulations and lack of alternative manufacturing processes for components would propel the growth of the automotive metalcasting market. However, MnM reports that the high cost of casting materials such as aluminum and magnesium as compared with iron is one of the key concerns of this market.[56]

2.2 The Impact of the Worldwide Pandemic on Metalcasting Production

In 2020, the COVID-19 pandemic negatively impacted the production of metalcastings worldwide, except in China (China showed production *gains* of 6%).[57] In 2019, U.S. metal casting production was 11,305,302 metric tons.[58] For 2020, U.S. metalcasting production dropped 13.7 % from 2019, to 9,748,811 metric tons[59], placing it third in production behind China and India (India dropped 1.5 %). Statista reports the U.S. showing a year-on-year decrease of 13.8 % from 2018 to 2020.[60]

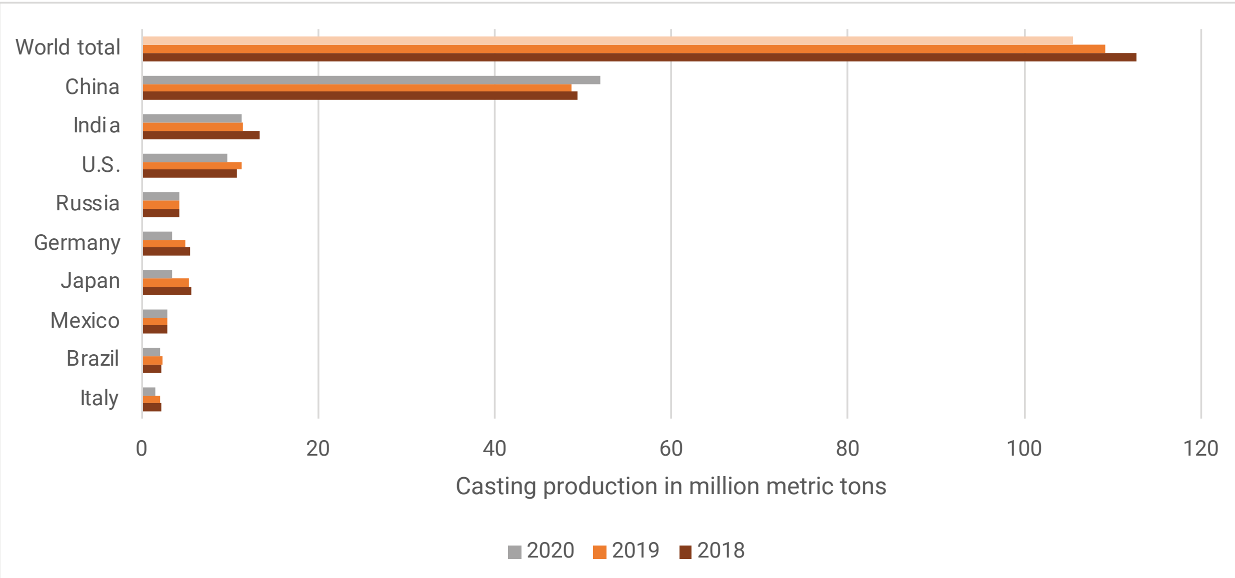

Figure 10: Casting Production, 2018 to 2020 (in million metric tons)
Source: Statista 2022[61]

This table, from Modern Casting's most recent census, [Census of World Casting Production (Dec.2021)](), shows worldwide metal casting production for 2020, by metal:

Country	Gray Iron	Ductile Iron	Malleable Iron	Steel	Copper Base	Aluminum	Magnesium	Zinc	Other Nonferrous	Total
Austria	33,400	91,700	-	9,600	-	106,798	4,504	-	-	246,002
Belgium	43,000	3,900	-	5,500	-	-	-	-	-	52,400
Brazil	1,148,123	468,952	-	269,512	20,524	160,464	4,534	1,064	-	2,073,173
Canada	330,841	-	-	90,091	14,237	211,374	-	-	-	646,543
China	21,750,000	15,300,000	630,000	6,350,000	870,000	6,800,000	-	-	250,000	51,950,000
Croatia	19,465	6,161	-	120	202	65,606	-	-	131	91,685
Czech Republic	117,000	64,500	-	41,000	16,000	77,400	300	800	-	287,000
Denmark	28,900	58,100	-		1,188	2,224	-	-	112	90,524
Finland	17,300	23,100	-	6,700	2,415	1,730	-	-	-	51,245
France	431,900	593,600	-	41,900	16,118	293,529	-	18,880	2,180	1,398,107
Germany	1,618,700	957,100	-	138,000	46,076	652,738	20,489	49,761	19	3,482,883
Hungary	16,500	58,000	-	2,000	729	118,900	250	1,662	99	198,140
India	7,911,763	1,095,522	50,000	912,893	-	1,344,182	-	-	-	11,314,360
Indonesia	77,783	42,060	86,940	128,724	46,086	182,586	-	-	25,600	589,779
Italy	534,400	300,600	-	58,000	38,168	540,296	3,676	75,834	1,235	1,552,209
Japan	1,598,113	1,169,743	29,438	153,000	57,019	343,651	-	13,792	82,146	3,446,903
Korea (Republic	881,400	670,700	-	150,000	24,100	642,200	12,000			2,380,400
Mexico	816,160	560,270	-	336,250	215,500	832,770	-	79,500	15,200	2,855,650
Norway	8,800	22,300	-	-	-	6,526	-	-	-	37,626
Pakistan	181,000	24,540	-	48,750	14,200	21,200	-	-	2,730	292,420
Poland	360,000	124,000	-	40,000	4,800	272,000	-	6,000	2,400	809,200
Portugal	26,100	76,100	-	4,100	16,203	31,966	-	2,165	-	156,634
Romania	15,000	1,500	-	3,500	3,000	60,000	2,000	250	90	85,340
Russia	2,184,000	-	-	1,134,000	117,600	588,000	75,600	-	100,800	4,200,000
Slovenia	59,300	39,800	-	17,600	990	44,618	-	7,477	-	169,785
South Africa	-	-	-	-	-	-	-	-	-	443,000
Spain	283,100	582,800	-	65,300	15,279	101,317	-	7,304	683	1,055,783
Sweden	126,000	51,000	-	20,200	-	56,400	-	-	-	253,600
Switzerland	8,400	11,900	-	2,500	2,023	10,815	-	762	-	36,400
Taiwan (ROC)	543,617	179,697	-	55,007	27,368	481,593	6,237	-	-	1,293,519
Turkey	617,300	854,700	-	192,000	24,851	449,503	761	31,644	-	2,170,759
Ukraine	-	-	-	-	-	-	-	-	-	1,560,000
U.K.	128,400	195,600		416,000	83,000	102,522	2,000	7,300	-	485,722
U.S.	7,616,824	-	-	-	304,279	1,425,120	-	47,786	354,802	9,748,811
World Total	**49,532,589**	**23,597,945**	**796,379**	**10,317,847**	**1,907,255**	**16,028,028**	**132,351**	**352,773**	**383,227**	**105,505,602**

Figure 11: 2020 Casting Production (Metric Tons)
Source: Modern Casting December 2021[62]

2.2.1 State of the U.S. Metalcasting Industry in 2021/2022

Despite mergers and acquisitions, AFS survey results indicate that the metalcasting industry is still made up of mostly small businesses. In 2022, only 10-17% of AFS survey respondents report having over 300 employees.[63, 64] 60-75% of companies report having less than 100 employees.[65]

Modern Casting, in its January 2022 Industry Outlook, expected to see growth in both revenues and number of facilities in 2022, as summarized below.

Industry Revenues ($ Millions)

$44,290 in 2019
$36,716 in 2020
$43,362 in 2021
$47,317 in 2022 (forecasting 9.1% growth)[66]

Number of Facilities

1,765 in 2019
1,731 in 2020
1,725 in 2021
1,770 in 2022 (forecasting 2.6% growth)[67]

Revenue Per Facility ($ Thousands)

$25,093 in 2019
$21,205 in 2020
$25,144 in 2021
$26,740 in 2022 (forecasting 6.3% growth)[68]

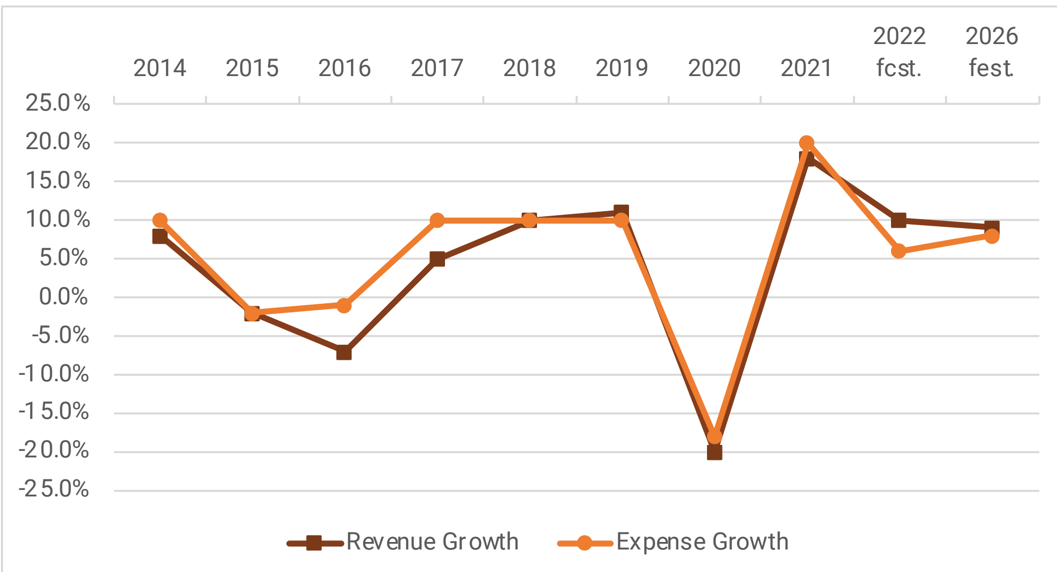

Figure 12: Revenue Growth per Facility vs. Operating Expense Growth per Facility
Source: Modern Casting 2022[69]

2.3 Number and Location of Foundries Today

The number of U.S. metalcasting facilities has continually declined, however, as noted in the previous section, some industry observers expect to see an increase in the number of facilities in 2022 to 1770.[70]

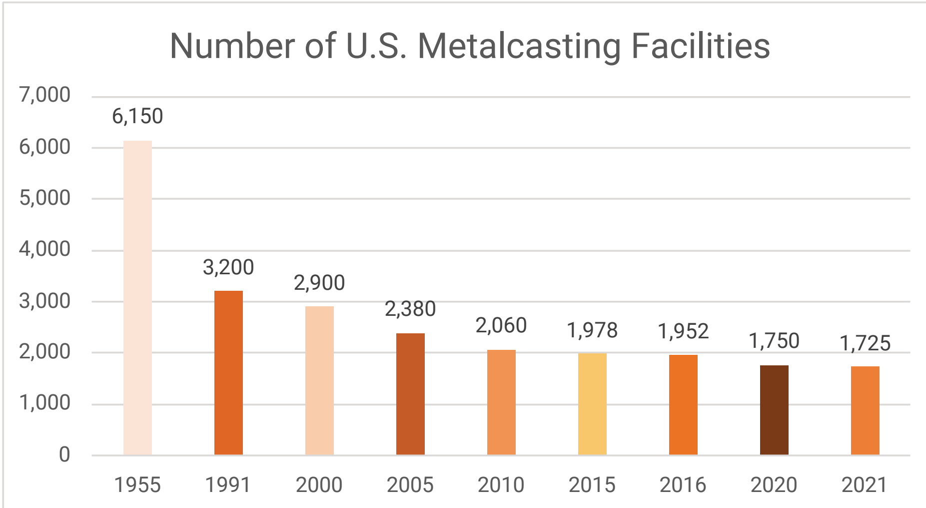

Figure 13: Number of U.S. Metalcasting Facilities

While industry observers note that the decline in facilities reflects both closings and consolidations, research finds no breakdown for how many companies were acquired/merged, as opposed to shuttered.

The states with the largest number of metal casting facilities, as of 2020, were:

Ohio
California
Michigan
Pennsylvania
Wisconsin
Illinois
Texas
Indiana
Minnesota
Missouri
New York
Washington
Alabama
Iowa
Oregon
Tennessee[71]

2.4 Foundry Employment and Output Expectations Through 2030

The industry has witnessed a decline in metalcasting jobs but is expected to increase jobs and output slightly over the course of this decade. In 2006 the U.S. metalcasting industry employed just over 160,000 workers. By May 2019 the Bureau of Labor Statistics (BLS) reported the foundry industry had less than 120,000 workers,[72] and by May 2021 foundry jobs dropped to 100,960.[73]

Prior to the pandemic, the foundry job outlook was quite hopeful for the end of the decade. In a 2019 report, DATA USA cited BLS statistics that show foundry jobs continuing to decline through 2026, then return to 2019 levels by 2029.This growth was attributed to an expected overall increase in the national workforce from 2019 to 2029.[74] However, as seen in the 3rd figure below, BLS adjusted its expectations downward in 2022, reporting 103,100 jobs in 2020 and expecting an increase of only 300 jobs by 2030, to 103,400, resulting in a projected overall job growth of .3% from 2020 to 2030.[75]

The industry has witnessed a decline in metalcasting jobs, but is expected to increase jobs and output slightly over the course of this decade.

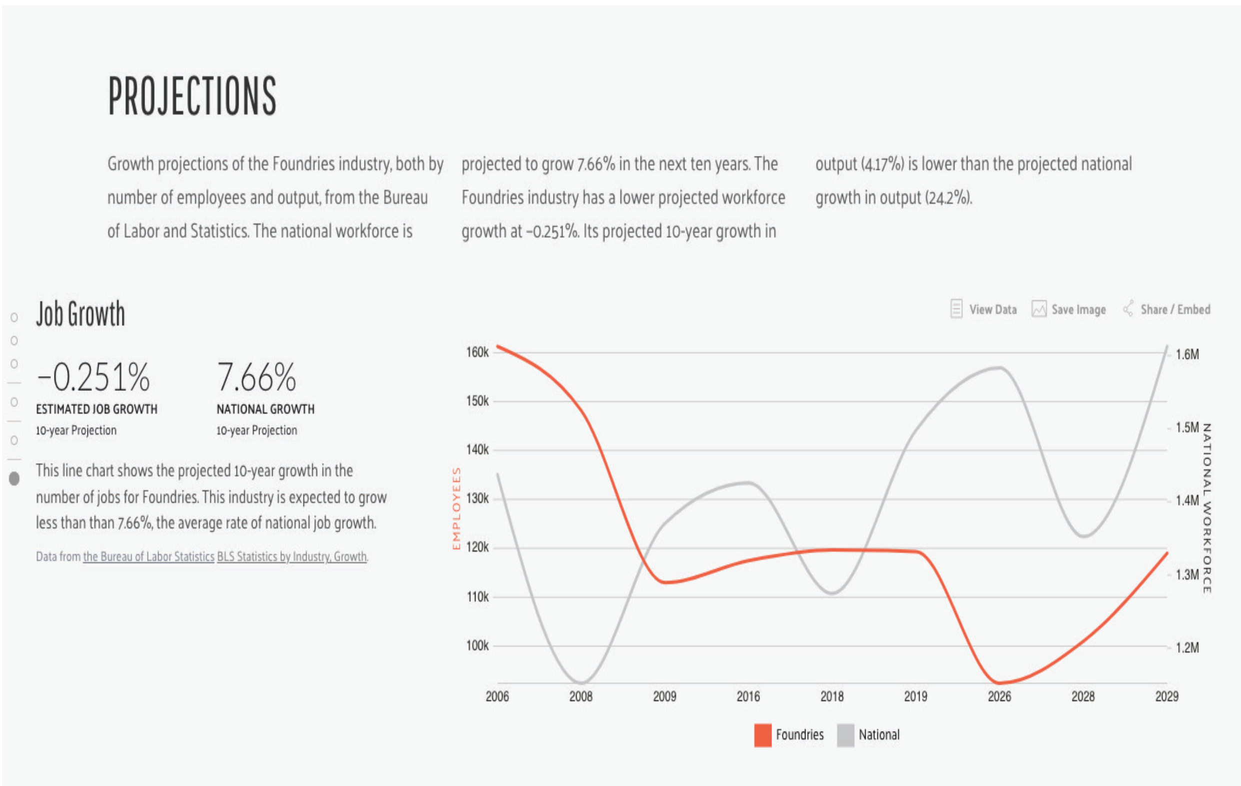

Figure 14: U.S. Foundry Job Outlook in 2019

Source: Data USA 2019[76]

YEAR	INDUSTRY JOBS	BLS INDUSTRY FLAT
2029	119k	Foundries
2028	101k	Foundries
2026	92.4k	Foundries
2019	119k	Foundries
2018	120k	Foundries
2016	118k	Foundries
2009	113k	Foundries
2008	148k	Foundries
2006	161k	Foundries

Data from the Bureau of Labor Statistics [BLS Statistics by Industry, Growth](#).

Figure 15: U.S. Foundry Job Outlook in 2019
Source: DATA USA[77]

Industry	2017 NAICS	Employment 2010	Employment 2020	Employment 2030	Employment change 2010-20	Employment change 2020-30	Employment CAGR of change 2010-20	Employment CAGR of change 2020-30
Total		141,926.7	153,533.8	165,413.7	11,607.1	11,879.9	0.8	0.1
Foundries	3315	111.8	103.1	103.4	-8.7	0.3	-0.8	0

Figure 16: Foundry Employment Expectations in 2022
(Employment in thousands of jobs; Output in billions of chained 2012 dollars)
Source: Bureau of Labor Statistics 2022[78]

The industry has witnessed a decline in metalcasting jobs, but is expected to increase jobs and output slightly over the course of this decade.

In terms of industry Output, in 2019, DATA USA, citing BLS data, reported a drop in foundry industry output from $41 billion in 2006 to $31.2 billion in 2019. At that time, output was expected to continue to drop through 2026, then gradually regain some of that loss, to reach about $32.5 billion in 2029, resulting in a projected overall growth of 4.17% for the ten year period of 2018 to 2028.[79] However, as seen above, actual output for 2020 was down to 27.8 billion, and output is only expected to reach 31.4 billion by 2030, resulting in a projected overall growth of only 1.2% from 2020 to 2030.[80]

2.5 Summary of Changes in Tonnage and Number of Foundries

2.5.1 Changes in Tonnage, U.S. and Worldwide

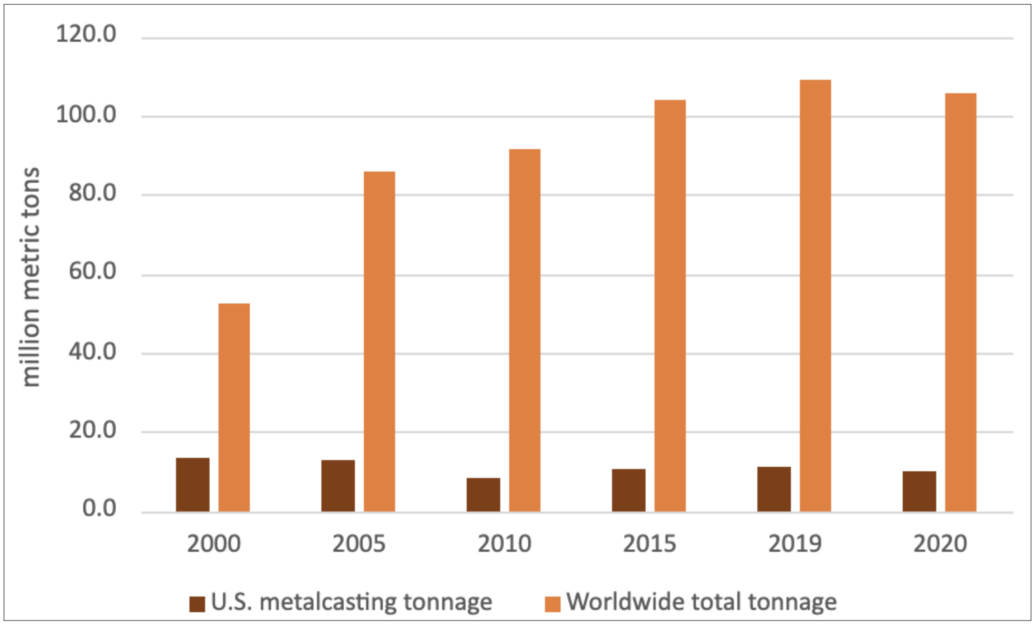

Figure 17: Global Changes in Tonnage, 2000-2020 (Million Metric Tons)

For a closer look at the current annual sales of the [Top Ten U.S. Foundries, By Sales], the NAICS Association provides these company snapshots on its public website:

Top U.S. Foundries, by Annual Sales

Company DUNS#: 00-902-7970	
Corporate Name: Precision Castparts Corp	**Tradestyle Name:** PCC
Point of Contact: Restricted	**Title:** Restricted
Address: 4650 SW Mcdam Ave Ste 300, Portland OR 97239	
Telephone: Restricted	
URL: www.precast.com	
Total Employees: 30,100	**Employees On Site:** 150
Sales Volume: $8,152,598,554	
Public/Private: Public	**Year Started:** 1949
Latitude: 45.4891943	**Longitude:** -122.6729013
NAICS 1: 331512	Steel Investment Foundries
NAICS 2: 331529	Other Nonferrous Metal Foundries (except Die-Casting)
SIC 1: 33249901	Aerospace investment castings, ferrous
SIC 2: 33690000	Nonferrous foundries, nec
Number of Family Members: 6436	

Company DUNS#: 05-196-4583	
Corporate Name: Pace Industries LLC	**Tradestyle Name:**
Point of Contact: Restricted	**Title:** Restricted
Address: 481 S Shiloh Dr, Fayetteville AR 72704	
Telephone: Restricted	
URL: www.paceind.com	
Total Employees: 2,800	**Employees On Site:** 60
Sales Volume: $1,205,702,729	
Public/Private: Public	**Year Started:** 2007
Latitude: 36.05858	**Longitude:** -94.1986634
NAICS 1: 331523	Nonferrous Metal Die-Casting Foundries
NAICS 2:	
SIC 1: 33630000	Aluminum die-castings
SIC 2:	
Number of Family Members: 32	

Figure 18: Foundries, by Annual Sales:
Precision Castparts Corp and Pace Industries LLC
Source: NAICS Association 2022[81]

Company DUNS#: 05-216-9310	
Corporate Name: Chicago Bridge & Iron Co Del	**Tradestyle Name:**
Point of Contact: Restricted	**Title:** Restricted
Address: 2103 Research Forest Dr, The Woodlands TX 77380	
Telephone: Restricted	
URL: www.cbi.com	
Total Employees: 26,510	**Employees On Site:** 268
Sales Volume: $5,056,952,236	
Public/Private: Public	**Year Started:** 1979
Latitude: 30.1752388	**Longitude:** -95.4695724
NAICS 1: 331513	Steel Foundries (except Investment)
NAICS 2: 332111	Iron and Steel Forging
SIC 1: 33250000	Steel foundries, nec
SIC 2: 34620000	Iron and steel forgings
Number of Family Members: 212	

Company DUNS#: 05-017-1381	
Corporate Name: Kpi Intermediate Holdings Inc	**Tradestyle Name:**
Point of Contact: Restricted	**Title:** Restricted
Address: 481 S Shiloh Dr, Fayetteville AR 72704	
Telephone: Restricted	
Total Employees: 2,800	**Employees On Site:** 6
Sales Volume: $1,205,702,729	
Public/Private: Public	**Year Started:** 2008
Latitude: 36.05858	**Longitude:** -94.1986634
NAICS 1: 331523	Nonferrous Metal Die-Casting Foundries
NAICS 2: 331110	Iron and Steel Mills and Ferroalloy Manufacturing
SIC 1: 33630000	Aluminum die-castings
SIC 2: 33120803	Tool and die steel
Number of Family Members: 32	

Figure 19: Foundries, by Annual Sales:
Chicago Bridge & Iron Co Del and Kpi Intermediate Holdings Inc
Source: NAICS Association 2022[82]

Company DUNS#: 00-523-8183	
Corporate Name: Newell Operating Company	**Tradestyle Name:** Newell
Point of Contact: Restricted	**Title:** Restricted
Address: 29 E Stephenson St, Freeport IL 61032	
Telephone: Restricted	
URL: www.newellbrands.com	
Total Employees: 9,800	**Employees On Site:** 250
Sales Volume: $2,265,204,120	
Public/Private: Public	**Year Started:** 1903
Latitude: 42.2985757	**Longitude:** -89.6188744
NAICS 1: 331524	Aluminum Foundries (except Die-Casting)
NAICS 2: 339994	Broom, Brush, and Mop Manufacturing
SIC 1: 33650101	Cooking/kitchen utensils, cast aluminum
SIC 2: 39910201	Paint rollers
Number of Family Members: 958	

Company DUNS#: 00-637-0357	
Corporate Name: Koch Enterprises Inc	**Tradestyle Name:** Koch Enterprises
Point of Contact: Restricted	**Title:** Restricted
Address: 14 S 11th Ave, Evansville IN 47712	
Telephone: Restricted	
URL: www.kochenterprises.com	
Total Employees: 2,365	**Employees On Site:** 7
Sales Volume: $1,001,734,000	
Public/Private: Public	**Year Started:** 1873
Latitude: 37.977124	**Longitude:** -87.5971167
NAICS 1: 331523	Nonferrous Metal Die-Casting Foundries
NAICS 2: 423730	Warm Air Heating and Air-Conditioning Equipment and Supplies Merchant Wholesalers
SIC 1: 33630000	Aluminum die-castings
SIC 2: 50750101	Air conditioning equipment, except room units, nec
Number of Family Members: 31	

Figure 20: Foundries, by Annual Sales:
Newell Operating Company and Kock Enterprises Inc
Source: NAICS Association 2022[83]

Company DUNS#: 00-657-5799		
Corporate Name: Howmet Holdings Corporation	**Tradestyle Name:**	
Point of Contact: Restricted	**Title:** Restricted	
Address: 1 Misco Dr, Whitehall MI 49461		
Telephone: Restricted		
URL: www.arconic.com		
Total Employees: 10,000	**Employees On Site:** 1	
Sales Volume: $1,658,557,494		
Public/Private: Public	**Year Started:** 1970	
Latitude: 43.3970484	**Longitude:** -86.3493991	
NAICS 1: 331512	Steel Investment Foundries	
NAICS 2: 333517	Machine Tool Manufacturing	
SIC 1: 33249902	Commercial investment castings, ferrous	
SIC 2: 35420000	Machine tools, metal forming type	
Number of Family Members: 314		

Company DUNS#: 00-213-6117		
Corporate Name: Victaulic Company	**Tradestyle Name:** Victaulic Company of America	
Point of Contact: Restricted	**Title:** Restricted	
Address: 4901 Kesslersville Rd, Easton PA 18040		
Telephone: Restricted		
URL: www.victaulic.com		
Total Employees: 3,000	**Employees On Site:** 900	
Sales Volume: $769,043,069		
Public/Private: Public	**Year Started:** 1925	
Latitude: 40.7589924	**Longitude:** -75.2313716	
NAICS 1: 331511	Iron Foundries	
NAICS 2: 332911	Industrial Valve Manufacturing	
SIC 1: 33219902	Ductile iron castings	
SIC 2: 34910000	Industrial valves	
Number of Family Members: 18		

Figure 21: Foundries, by Annual Sales:
Howmet Holdings Corporation and Victaulic Company of America
Source: NAICS Association 2022[84]

Company DUNS#: 00-434-1533		
Corporate Name: Matthews International Corp	**Tradestyle Name:**	
Point of Contact: Restricted	**Title:** Restricted	
Address: 2 N Shore Ctr Ste 200, Pittsburgh PA 15212		
Telephone: Restricted		
URL: www.matw.com		
Total Employees: 11,000	**Employees On Site:** 50	
Sales Volume: $1,602,580,000		
Public/Private: Public	**Year Started:** 1850	
Latitude: 40.446	**Longitude:** -80.0109	
NAICS 1: 331529	Other Nonferrous Metal Foundries (except Die-Casting)	
NAICS 2: 236220	Commercial and Institutional Building Construction	
SIC 1: 33669902	Bronze foundry, nec	
SIC 2: 15429904	Mausoleum construction	
Number of Family Members: 189		

Company DUNS#: 00-905-6037		
Corporate Name: Consolidated Metco Inc	**Tradestyle Name:** Conmet	
Point of Contact: Restricted	**Title:** Restricted	
Address: 5701 SE Columbia Way, Vancouver WA 98661		
Telephone: Restricted		
URL: www.conmet.com		
Total Employees: 2,000	**Employees On Site:** 100	
Sales Volume: $705,890,830		
Public/Private: Public	**Year Started:** 1964	
Latitude: 45.613456	**Longitude:** -122.611836	
NAICS 1: 331524	Aluminum Foundries (except Die-Casting)	
NAICS 2: 331523	Nonferrous Metal Die-Casting Foundries	
SIC 1: 33650200	Aluminum and aluminum-based alloy castings	
SIC 2: 33630000	Aluminum die-castings	
Number of Family Members: 56		

Figure 22: Foundries, by Annual Sales:
Matthews International Corp and Consolidated Metco Inc
Source: NAICS Association 2022[85]

2.5.2 Changes in Number of Foundries

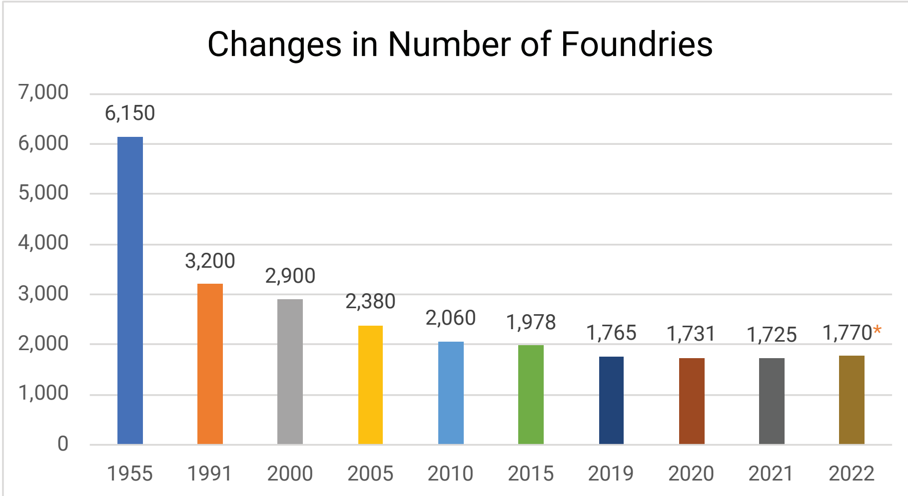

Figure 23: Changes in Number of Foundries

Not all sources agree on facility numbers. While the above estimates come from various metalcasting organizations and publications, the NAICS Association reports very different 2022 foundry numbers (2611 in 2022), based on business entities that fall under NAICS code 3315 – Foundries.

Codes	Titles	US Business Entities
3315	Foundries	2,611
331511	Iron Foundries	474
331512	Steel Investment Foundries	232
331513	Steel Foundries (except Investment)	276
331523	Nonferrous Metal Die-Casting Foundries	423
331524	Aluminum Foundries (except Die-Casting)	442
331529	Other Nonferrous Metal Foundries (except Die-Casting)	764

Figure 24: Number of U.S. Businesses That Fall Under 3315 - Foundries
Source: NAICS Association 2022[86]

2.5.3 2022 Expectations of Industry Players and Investors

The vast majority (75-90%) of AFS 2022 survey respondents have a positive outlook for the near future and expect sales to increase from June 2022 to June 2023. About 60-70% of U.S. foundries expect to add employees in 2022. This is despite an overall expectation that the country will enter a recession either in 2022 or 2023.[87, 88]

Investment banker CIBC Cleary Gull, in its Quarter 1 2022 U.S. casting industry report, Foundry & Forging Newsletter Q1 2022, predicts steadily increasing metalcasting market revenues.

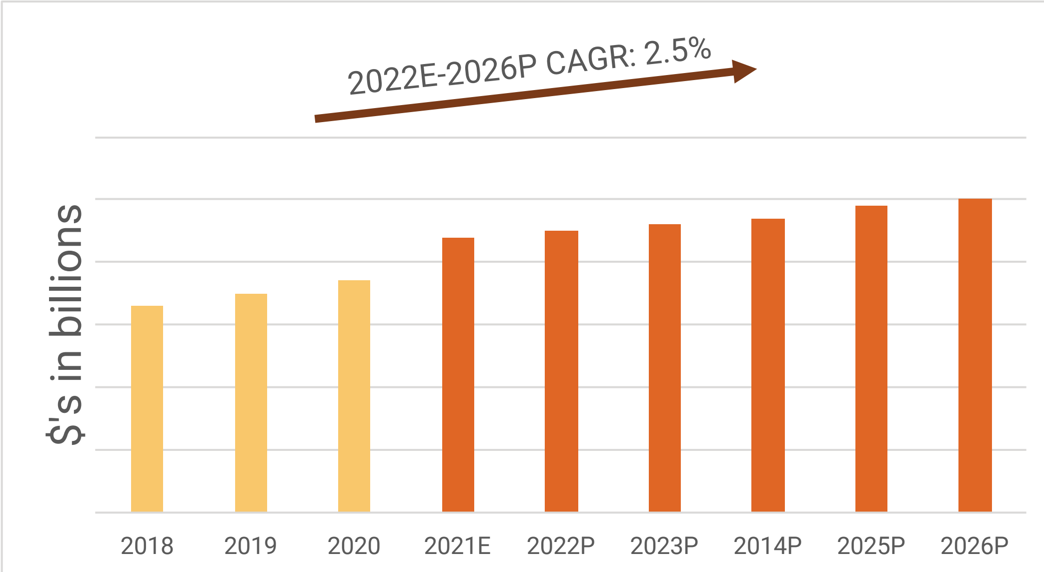

Figure 25: Metalcasting Industry Growth 2018-2026
Source: CIBC Cleary Gull 2022[89] *(Citing AFS and IBIS World Reports)*

The Investment Casting Institute's INCAST magazine published an ICI members-only 2022 Forecast, which is available for purchase, at reduced rates to some universities and other affiliates.

2.5.4 Where Industry is Investing in 2022

Over 90% of respondents to the AFS Q1 2022 industry survey plan to make some capital investment between March 2022 and March 2023. About 35% plan to spend over $1 million. As seen in the survey results below, much of the spending is earmarked for traditional casting equipment, but 30% expect to invest in robotics in 2022; 7% plan to purchase simulation software; and 16% expect to buy 3D printing technology in 2022.[90]

Air Compressors	23.26%	10
Blast Cleaning Equipment	16.28%	7
Conveyors	25.58%	11
Coremaking Machines	13.95%	6
Cranes or Hoists	25.58%	11
Design Technology	4.65%	2
Environmental Controls	23.26%	10
Grinding Equipment	41.86%	18
Heat Treating Equipment	11.63%	5
Inspection/Testing Equipment	11.63%	5
Lab Equipment	18.60%	8
Machine Tools	23.26%	10
Melting Equipment	23.26%	10
Molding Equipment	27.91%	12
Permanent Mold Systems	0.00%	0
Pouring Systems	13.95%	6
Power Control Technology	0.00%	0
Robotics	30.23%	13
Sand Prep Equipment	13.95%	6
Sand Reclamation Technology	11.63%	5
Simulation Software	6.98%	3
3D Printing Technology	16.28%	7
Total Respondents: 43		

Figure 26: Intended Equipment Purchases 2022
Source: AFS Q1 2022 Metalcasters Quarterly Outlook Survey[91]

3.0 Challenges Faced by Small Foundries Today

3.1 Industry's Biggest Concerns: Labor / Materials & Energy Costs / Shortages

Results of the Q1 and Q2 2022 AFS surveys indicate that the top concerns of U.S. metalcasting executives in 2022 are, in order of priority:

- Labor issues (labor shortages, wage inflation, workforce training)
- Inflated costs of chemicals, materials, and energy
- Component shortages [92]

Back in 2000, the three most significant threats cited by industry executives were:

- Increasingly stringent government regulations
- Competition from imported castings
- Lack of skilled workers[93]

Interestingly, in Q2 2022, out of 37 respondents, when asked "Which of these issues are the top 3 concerns or priorities for your company at this time?" NONE considered offshore competition to be a top concern or priority.[94]

3.2 Foreign Competition Issues

As revealed in the historic section of this report, U.S. metalcasters of all sizes face ongoing competition from metalcasters in other countries, especially China. Even DoD has to sometimes count on China and other foreign sources for very large cast products used in some defense systems and many machine tools and manufacturing systems in which the military is reliant. DoD says that multiple U.S. sources have told DoD that China and other foreign suppliers can often deliver a completed item for the same cost that a U.S. forge will pay for the raw materials needed to produce the parts of an item.[95]

DoD describes some of the reasons the domestic metalcasting industry cannot meet the defense department's needs:

> The Military Services have experienced casting and forging capability and capacity challenges that can be attributed in part to the impacts of offshoring and waves of industry consolidation since the mid-20th century. For example, the United States has only one foundry that can produce the large titanium castings required for some key systems. The Army has also identified shortfalls in production and heat treatment of specialty alloys that are mission critical. The Navy has documented C&F capacity and quality issues affecting many facets of shipbuilding ... A government-only 2021 analysis for the Navy reported the need for reliable production of extremely large C&F parts is such a high concern to DoD that the Navy added an NTIB firm to produce large cast shapes for shipbuilding due to domestic suppliers' capacity and quality issues … The Air Force has identified needs for the ability to cast single crystal turbine blades and large thin-wall titanium components, an additional source for an extrusion press used for powder nickel super alloy billets, and downstream post-processing capacities and capabilities—including heat treating, coating, hole drilling, machining, and hot isostatic pressing to help eliminate unwanted voids and provide increased strength in cast products. Although some suppliers have updated equipment over time in an attempt to meet the Services' needs, many commercial and OIB C&F plants have aging equipment or are limited by existing facilities, infrastructure, and, for commercial firms, state and federal operating permits.[96]
>
> *[The OIB (Organic Defense Industrial Base) includes government-owned government operated (GOGO) and government-owned contractor-operated (GOCO) facilities that provide specific goods and services for the DoD.*][97]

3.3 Competing With Larger U.S. Firms

Despite closures and acquisitions, the majority of U.S. metalcasting firms are still small businesses with less than 100 employees. These foundries face challenges in competing with the larger foundries, for various reasons, as described by the investor group CIBC Cleary Gull below.

> Industry participants have left the market due to inefficiencies or acquisitions, and the number of facilities will continue to decrease. Foundries are producing more on a facility basis and that is occurring through expansion and efficiency initiatives. Industry trends drive many factors, including the advantages of scale. Large foundry operations can absorb fixed overhead and regulatory costs better than smaller ones. In general, larger foundries benefit from greater purchasing power, enjoy earnings stability through diversification by industry and customer, and can use resources more effectively by flexing or redeploying them with demand. Although many small foundries still exist, they are rapidly being acquired.[98]

Recently the Department of Defense noted that many U.S. firms cannot afford improvements to equipment and processes and limited access to capital for America's small and medium size producers has hindered their ability to invest in the necessary technologies, including the adoption of innovative processes and complementary technologies such as AM/3D printing equipment and training, robotic automation, and digital engineering to support reverse engineering of aging parts.[99]

3.4 Challenges of Working with Military Customers

Even when domestic metalcasters have the technology to meet the needs of the military customer, these firms are challenged by complex contracting processes, burdensome accounting system requirements, small and unreliable demand, non-standard technical data packages, and a slow Government sales cycle.[100] DoD is aware of these hurdles, describing them in detail below:

> The U.S. C&F industry faces challenges related to capability and capacity, workforce, and U.S. Government policies. Like all businesses, domestic producers need predictable demand, costs, and returns to compete successfully for global market share. In some cases, DoD product needs involve specialized, often low-density requirements that can only be addressed by a small portion of the casting and forging market. Furthermore, the variability of DoD funding (timing and amount) creates challenges for businesses trying to satisfy DoD needs. Industry currently prefers to pursue commercial work. Obstacles to expanding DoD's sources of supply in this area lie in the complex Federal contracting process, the need for improved technical data requirements, and the requirement to modify plant capabilities to support the manufacturing of products that meet military specifications.[101]
>
> Low-volume work driven by U.S. Government and DoD procurement practices incurs high startup costs and produces limited profits. Many small and medium sized manufacturers find it challenging to create sustainable businesses or production lines in this space. Although many trade policy actions are conducted pursuant to specific authorities and designed to remedy injury to domestic industry and respond to unfair or unreasonable foreign trade practices, participants in DoD industry listening sessions reported that tariffs on raw materials used in U.S.-made C&F parts made U.S. products significantly more expensive than parts made in China, driving U.S. suppliers out of business.[102]

DoD has several paths to address these challenges, as expanded on in the Solutions section of this report.

3.5 3D Printing Alternatives to Casting

Additive manufacturing/3D printing processes can present a competitive challenge to traditional Metalcasters. Some companies within the industry, such as Xometry and MetalTek are using 3D printing technologies to complement their traditional metalcasting part production services. With 3D printing, such companies can, in some cases, offer to produce more affordable parts faster than with traditional metalcasting. So, 3D printing can be a solution to cost and time constraints of metalcasting, but foundries that don't add 3D printing to their processes may lose business to the firms that do. This is expanded on in the Solutions section to follow.

3.6 Electric Transport and Lightweighting Impact

E-mobility is presenting challenges to the traditional casting industry, but also opportunities. The increasing adoption of electric vehicles will significantly impact the casted parts industry over time and the casting industry will need to change and adapt to meet the different requirements of E-mobility. The EV industry is currently dealing with two pain points: the power-to-weight ratio; and expensive component supply issues.[103] With EVs, not only do parts need to be made from lighter weight metals, but the type of parts that go into an EV are dramatically different from an internal combustion engine, as described by Anchor Harvey's Kerry Kubatzke:

> To understand the disruptions and opportunities in the coming shift from the internal combustion engine (ICE) to electric vehicles (EVs), it is important to first discern the differences between the two systems ... In an electric vehicle, the fuel tank is replaced by a battery pack, and the internal combustion engine is replaced with one or more electric motors. Similarly, the ICE vehicle's multi-geared transmission and clutch are replaced with a fixed, single-gear gearbox. EVs also do not require any form of onboard emissions control because they do not produce any carbon emissions.
>
> The result is that EVs have far simpler motors than ICEs in terms of both their operations and manufacturability due to EV powertrains having fewer moving parts and less mechanical complexity. According to UBS, the electric motor on Chevy's Bolt has three moving parts, which is in sharp contrast to the 113 moving parts in the internal combustion engine of a Volkswagen Golf. Despite having fewer components and reduced intricacy, EVs nevertheless present new challenges that major automotive institutions and startup companies have yet to solve. Currently, the difficulties being faced fall into two primary areas: power-to-weight ratio and expensive component supply... Due to their large lithium-ion battery packs, EVs are hefty vehicles. In some cases, they can be heavier than their traditional ICE competitors ... Range anxiety – the concern that a vehicle may have insufficient range to reach its intended destination – remains one of the most significant obstacles to the widespread adoption of electric vehicles.[104]

Metalcasting companies can help to reduce EV range anxiety through the manufacture of high-strength, lightweight components. This is expanded on in the Solutions section to follow.

3.7 Issues in Providing Very Large Castings

While very large iron and steel castings are needed for some military systems, as well as for wind turbines, large-scale hydropower turbines, and nuclear reactor components, it is challenging for a foundry to be able to successfully service the need for very large castings. Equipment investment is high, and often needs to be specific to just one or a few end products. For example, molds and tooling for large wind blades can cost upward of $10 million and the production process is time-intensive – time to market for blades is 16–20 months.[1] The lifespan of large castings can be quite long (nearly 20 years for a wind turbine[2]). So there needs to be quantity demand and assured long term demand. And such foundries often need to be located close to where the casting will be installed in the end system, due to transport challenges. For example, GE Renewable Energy is locating a new turbine plant in northeast England to serve the vast offshore wind potential of the North Sea. This facility will produce GE's 107-meter-long offshore wind turbine blades. [3] China, which leads the wind energy market with the highest installations[4] and also has a huge nuclear energy footprint, presents the type of opportunity needed for a company to launch a large-castings foundry.[5]

Foundries also have to consider what the future demand will be for large castings. Large-casting customer sectors, such as nuclear, large-scale hydropower, and wind power, can see fluctuations in demand, depending on a nation's energy needs and a nation's energy source options and preferences. Currently, the U.S. has seen a declining interest in large nuclear power facilities, trending towards small modular reactors; and increased private and public investment in wind power. While small hydropower is expanding in the U.S.[6], large-scale hydropower dams are on the decline in Europe and the U.S., with possibly more now being dismantled than installed.[7] In addition to environmental concerns, drought conditions in California and the Pacific Northwest, where the majority of U.S. hydropower capacity is located, also threaten the market for large-scale hydropower turbines.[8]

Where an industry, such as wind power, is in its infancy, the government has to be willing to support efforts to get that industry up and running – which is currently happening for wind power in the U.S. The Biden Administration and 11 east coast states have launched an Offshore Wind Partnership to boost offshore wind supply chains and grow the offshore wind industry. To meet its goal of 30 GW of offshore wind capacity, the White

1 Wind Turbine Casting Market - Industry Analysis, Market Size, Share, Trends, Application Analysis, Growth and Forecast 2022-2027. Industry ARC. August 2022
2 Wind Turbine Casting Market - Industry Analysis, Market Size, Share, Trends, Application Analysis, Growth and Forecast 2022-2027. Industry ARC. August 2022
3 Wind Turbine Casting Market - Industry Analysis, Market Size, Share, Trends, Application Analysis, Growth and Forecast 2022-2027. Industry ARC. August 2022
4 Wind Turbine Casting Market - Industry Analysis, Market Size, Share, Trends, Application Analysis, Growth and Forecast 2022-2027. Industry ARC. August 2022
5 Heavy Manufacturing of Power Plants. World Nuclear association, March 2021
6 U.S. Small Hydropower Market Size, Share & Trends Analysis Report By Capacity (Up To 1 MW, 1-10 MW), By Type (Micro, Mini), By Component (Electromechanical Equipment, Civil Construction), And Segment Forecasts, 2021 - 2028. Grand View Research, 2021
7 Large hydropower dams 'not sustainable' in the developing world, M. McGrath. BBC News, November 5, 2018
8 U.S. hydropower generation to decline 14% in 2021 amid drought, EIA reports. E. Ingram. Hydro Review, September 23, 2021

House estimates 2,100 wind turbines will be needed.[9] To that end, the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy has funded research at the University of Maine Advanced Structures and Composites Center to develop a rapid, low-cost additive manufacturing solution for fabricating large, segmented wind blade molds. If successful, this technology is expected to reduce the time and cost of mold creation, lowering new blade development costs by 25% to 50% and accelerating time to market by at least 6 months.[10] Learn more.

However, the threat of innovative replacement technologies is also a restraint to the development of large castings foundries. Looking to wind blades again, Orbital Composites, aiming to solve transportation issues for large 100+ meter-long onshore and offshore wind blades, is working on developing mobile containerized robotic 3D printers that will bring blade manufacturing closer to the installation site. However, this project's focus is on an alternative to metalcasting, as it seeks to develop 3D printed rotor blade tips, using low-cost reinforced thermoplastics. This project has also received DOE funding.[11] If similar composite technologies prove able to match the quality of cast metal blades, while reducing time, cost, and transport issues, such efforts could diminish the need for new large-casting foundries.

4.0 Potential Solutions to Industry Challenges

AFS considers new product development, exports, reshoring, and **conversions** to be the primary ways to fuel the growth of the U.S. metalcasting industry.[105]

4.1 New Technologies

Some of the new technologies the U.S. industry is adopting are:

- Automated machine and production monitoring for real time evaluation and predictive and preventive maintenance to reduce downtime, reduce capital expenditures, lower repair cost
- Virtual training and augmented reality headsets to reduce training costs
- Computer controlled melt shop technology
- Foundry management software
- Metal reclaiming technology for zero waste
- 3D printing/additive manufacturing for tooling-less casting, cost-efficient design
- Casting simulation software
- Robotics and digital manipulators

9 Report Outlines Supply Chain Needs to Achieve Offshore Wind 2030 Goal. U.S. Department of Energy, March 28, 2022

10 UMaine awarded $2.8 million to accelerate wind blade development through additive manufacturing. The University of Maine, January 28, 2021

11 Composites AM research targets wind energy. The University of Maine, July 30, 2021

Examples of some of the foundries embracing these technologies can be found in Modern Casting's publication State of the Art Foundry 2022. Interestingly, a brief review of this source found that none of the companies profiled appeared to be adopting technologies that address energy use issues.

4.2 Reshoring

Bloomberg reported in July 2022 that reshoring and nearshoring, the process of returning a business operation that was moved overseas back to the company's home country or at least closer, is increasingly being considered by U.S. manufacturing companies, as mounting geopolitical tensions, the ongoing pandemic, soaring fuel costs, parts shortages, and shipping delays all continue to disrupt global supply chains.[106] But for the U.S. metalcasting industry, the costs and availability of labor in the U.S. may serve as a restraint to reshoring.

AFS is a strong advocate of reshoring and promotes it as one of four primary ways to fuel growth of the U.S. metalcasting market.[107] AFS encourages its members to use the Total Cost of Ownership Estimator™ (TCO), developed by the Reshoring Initiative and promoted by the U.S. Department of Commerce, to help companies make more accurate sourcing decisions.

The Reshoring Initiative provides a full 2021 Company List of manufacturing companies that have chosen to reshore or not offshore work, as of January 31, 2022. The list includes foundries, such as Intel Foundry Services, Kimura Foundry America, Brillcast Inc., Chicago White Metal Casting, Dicastal North America Inc., and others.[108] The Reshoring Initiative's founder, Harry Moser, delivered a reshoring workshop at CastExpo 2022.[109] The Investment Casting Institute published this presentation, How To Buy or Sell Investment Castings Using TCO. In his presentation, Mr. Moser described how four U.S. metalcasting firms have embraced reshoring:

- KSM Castings brought automotive component production from Germany to North Carolina, creating 80 jobs.
- PC Production Castings, Inc. convinced their customer Dazor to reshore or stay onshore, resulting in Dazor reshoring 90% of their parts.
- Hubbardton Forge regularly calculates TCO if the Chinese price of die castings is within 50% of the U.S. price.
- LA Aluminum Casting Company helped customers to reshore molds and castings from offshore manufacturers, shortening supply chains and increasing quality.[110]

4.3 Metalcasting Adopting 3D Printing

Industrial 3D printers are used in some foundries for making sand molds for metal casting or plastic melt-off models for investment casting.[111] MarketsandMarkets, in its December 2021 *Industrial 3D Printing Market* analysis, describes 3D printing as an "established technology" in the global foundries industry:

> With the increasing significance of additive manufacturing, 3D has emerged as an established technology in the foundry industry. Fine and sand casting companies are particularly benefiting from this production technology. Sand casting can be done without the manual production of model plates or core boxes with the 3D printer. In investment casting, classic wax castings, which are generally produced with conventional injection molds, are being replaced by 3D-printed plastic models. While the production of casting molds or prototypes can take several weeks or months, the printing process only takes 1–2 days, depending on the size of the component.
>
> Whether foundries use sand molds for metal casting or plastic melt-off models for investment casting, in both cases, they benefit from many advantages of additive manufacturing. For many years, many foundries have considered sand casting molds and cores produced with a 3D printer as the standard. This technology is well established in the iron and metal casting field and is used wherever it is beneficial. While these applications primarily lie in the areas of prototypes and small batches, the focus is increasingly shifting toward mass production as the performance of the 3D printing systems is constantly improving.[112]

This expansion of 3D printing from prototyping into the actual manufacturing process is reflected in the following revenue tables. Although 3D printing has yet to achieve large scale adoption, it has seen strong growth in the global metalcasting industry, and this is expected to accelerate, showing an overall CAGR of 18% from 2021 to 2026.

Application	2017	2018	2019	2020	CAGR (2017-2020
Prototyping	96.0	119.0	148.0	121.0	0.1
Manufacturing	70.0	93.0	122.0	106.0	0.1
Total	166.0	211.0	269.0	227.0	0.1

Figure 27: Global 3D Printing Foundry Market, By Application 2017-2020 ($ Millions)
Reprinted with the permission of MarketsandMarkets.[113]

Application	2021	2022	2023	2024	2025	2026	CAGR (2021-2026)
Prototyping	126.0	134.0	147.0	167.0	200.0	254.0	15.10%
Manufacturing	115.0	129.0	148.0	178.0	224.0	299.0	21.00%
Total	241.0	263.0	295.0	345.0	423.0	553.0	18.00%

Figure 28: Global 3D Printing Foundry Market, By Application 2021-2026 ($ Millions)
Reprinted with the permission of MarketsandMarkets.[114]

3D printing has seen increased adoption in the U.S. foundry industry (especially for molding and casting), growing at a CAGR of 10% from 2017 to 2020, according to MarketsandMarkets. The U.S. foundry and forging industry market for 3D printing technology in 2021 was $76 million (mostly foundry) and is expected to reach a value of $180 million in 2026, at a CAGR of almost 19%. Some of the key 3D printing companies active in the U.S. foundry industry include GE Additive, Stratasys, ExOne, HP, Protolabs, Optomec, Desktop Metal, Formlabs, Carbon, and Markforged.[115]

4.3.1 Advantages and Disadvantages of 3D Printing in Metalcasting

Frost & Sullivan reports AM has yet to achieve large scale adoption in the global foundry industry due to high cost and the need for precision surface finishing. [116] MetalTek's Dave Kirmse, a Senior Manufacturing Engineer at MetalTek's Wisconsin Centrifugal Division, agrees, writing in his May 6, 2022 blog, 3D Metal Printing and Metal Casting:

> 3D metal printing has additional progress to make before it represents a true threat to metal casting processes such as investment casting and sand casting. For most applications 3D metal printing is currently best suited for complex geometries, low weights, and low production volumes.
>
> Only when it becomes more cost effective will 3D metal printing represent a larger threat to metal casting.[117]

Kirmse lists the following casting industry advantages and disadvantages of 3D metal printing:

Advantages of 3D Metal Printing:

- Low volume: 3D metal printing can have cost advantages compared to metal castings for extremely low volume production (e.g., a one-off part).
- Complex geometry: small, complex shapes that are difficult and/or cost prohibitive to tool or machine as metal castings. This will reduce or even eliminate associated tooling costs.
- Lead times: 3D metal printed parts can generally be produced much more quickly than metal castings. Customer delivery can take place in as little as 10 days.
- Testing: 3D metal printing can quickly produce a prototype for customer review.[118]

Disadvantages of 3D Metal Printing

- Cost: 3D metal printing is expensive, from the cost of metal powder to machine time. Parts can cost upwards of thousands of dollars.
- Limited part size: 3D metal printing build envelopes are generally smaller than metal castings. Producing a 1,000-pound metal part using 3D metal printing is simply not possible under current conditions. Even parts around 100-pounds can be a significant challenge for current build envelopes.
- Limited high-volume production: 3D metal printing technology cannot produce extremely high volumes of metal parts quickly enough to meet customer expectations.[119]

Kirmse believes that investment castings and sand castings will likely be the first metal casting methods to feel the full commercial impact of 3D printing, and that projects in the 5-to-10-pound range will be the first to convert to 3D metal printing when it becomes scalable.[120]

4.3.2 3D Printing Sand Molds: Benefits and Limitations

Foundry-Planet.com notes the following benefits of sand casting with 3D printed molds and cores:

- 3D printed sand casts and cores facilitate the creation of gating systems and risers that result in high-performance metal parts with fewer internal defects and up to 15 percent higher material strength.
- Additive manufacturing eliminates the need for hard tooling and casting patterns and the associated geometry restrictions. This benefit facilitates the production of high-performance, optimized parts with complex geometry.
- 3D printing and other digital manufacturing technologies help transform the image of the traditional foundry, attracting young talent and new workforce to the field.[121]

While digital manufacturing and 3D printed sand molds can enable foundries to produce complex parts rapidly, Foundry-Planet.com notes the following limitations of sand casting with 3D printed molds and cores:

- As with every new technology, access to knowledge and design expertise is still limited. Elusive best practices and design guidelines stop engineers and manufacturers from getting the most out of this new technology.
- The current availability of industrial sand 3D printers is limited, and the cost of manufacturing 3D printed molds are relatively high. For reference, sand 3D printing costs approximately $0.1 per cubic inch, while a traditional foundry usually charges between $10-20k for a mold.
- Part design should still follow the restrictions imposed by the casting process and the 3D sand printing systems. These design considerations include wall thickness, changes in part cross-section, and wall-to-wall thickness. [122]

MarketsandMarkets reports that 3D printing can be bad for the environment, in terms of energy use and byproducts.

> Plastic filament is a widely used material for 3D printing. While it is relatively inexpensive, its byproduct ends up in landfills. The widespread use of 3D printing can lead to a significant release of byproducts, which can affect the environment. Another issue regarding 3D printing is energy use. 3D printers consume about 50–100 times more electrical energy than traditional injection molding when making an item of the same weight. Laser direct metal deposition, on the other hand, uses more than 100 times the electricity as traditional foundry machines. 3D printers for industrial applications must be equipped with exhaust ventilation or filtration accessories and be used in an adequately ventilated environment.[123]

See the "Upcoming Conferences" section at the end of this report for information on the AFS 2022 Sand Casting Conference in September 2022.

4.3.3 Current and Innovative Types of AM Processes

There are currently seven different types of 3D printing technology acknowledged by ASTM and ISO standards (at least five can be used with metals):

- **Binder Jetting (BJT):** It is a process where powder materials are joined using a selectively deposited liquid bonding agent.

- **Applications:** BJT is used in polymers, metals, ceramics, and sand to produce figurines, small industrial parts, or sand molds.

- **Direct Energy Deposition (DED)**: This process uses focused thermal energy to fuse materials by melting them during depositing.
- Applications: DED is used to produce end-use structural metal parts for the aerospace and defense industry.
- Technologies: Laser Engineered Led Shaping (LENS), Direct Metal Deposition (DMD), Electron Beam Additive Manufacturing (EBAM).

- **Material Extrusion (MEX):** In this process, the material is selectively dispensed through a nozzle or orifice.
- Applications: MEX is used to produce rapid prototypes in thermoplastic or composite materials.
- Technologies: Fused Deposition Modeling (FDM).

- **Material Jetting (MJT)**: Droplets of feedstock material are selectively deposited in this process.
- Applications: MJT is mostly used to produce prototypes in polymers. Technologies: Drop on Demand (DOD), Nanoparticle Jetting (NPJ).
- **Powder Bed Fusion (PBF):** This process uses thermal energy to selectively fuse regions of a powder bed.

- **Applications:** PBF has a wide range of applications, but its most common uses include metal structural parts and plastic medical equipment.
- Technologies: Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Electron Beam Melting (EBM), Direct Metal Laser Sintering (DMLS),
- Multi Jet Fusion (MJF).
- **Sheet Lamination (SHL)**: In this process, sheets of material are bonded to form a part.
- Applications: SHL is used in polymers, metals, and paper to produce visual prototypes and sand mold casting.
- Technologies: Laminated Object Manufacturing (LOM), Ultrasonic Additive Manufacturing (UAM)

- **Vat Photopolymerization (VPP)**: In this process, light-activated polymerization is used to selectively cure a liquid photopolymer in a vat.
- Applications: VPP is used to produce accurate visual prototypes and casting patterns in photopolymers.
- Technologies: Stereolythography (SLA), Digital Processing (DLP), Continuous Liquid Interface Production (CLIP), Daylight Polymer Printing (DPP).[124]

Some U.S. foundries, such as MetalTek, use 3D printing as a compliment to their metalcasting processes, for “rapid manufacturing.”

> MetalTek does not use 3D metal printing to directly produce metal components. Instead, it uses 3D metal printing to complement its existing metal casting processes. This is commonly referred to as “rapid manufacturing.” With the use of rapid manufacturing MetalTek can eliminate tooling, lower costs, and reduce lead times. In other words, 3D printing can improve the metal casting process.[125]

MetalTek primarily uses three different 3D metal printing technologies to support its existing metal casting capabilities. MetalTek uses the Rapid Sand Casting 3D printing method, also referred to as rapid prototyping sand casting, to quickly produce molds for sand casting. MetalTek also uses fused deposition modeling (FDM) to support investment casting, and Stereolithography Apparatus (SLA) to replace traditional wax patterns for the investment casting process.[126]

In addition to the above-mentioned 3D printing processes, the development of novel metal AM processes is ongoing. A UK startup, Enable Manufacturing, has developed a new metal casting process called Additive Casting®, which is a hybrid process that combines 3D printing and traditional casting. As the cost of production using this novel process is reduced in comparison to other 3D printing technologies such as direct metal laser sintering, market analysts at Frost & Sullivan expect this process to find high growth opportunities in the automotive and aerospace sectors.[127] Here's a snapshot of the technology and company:

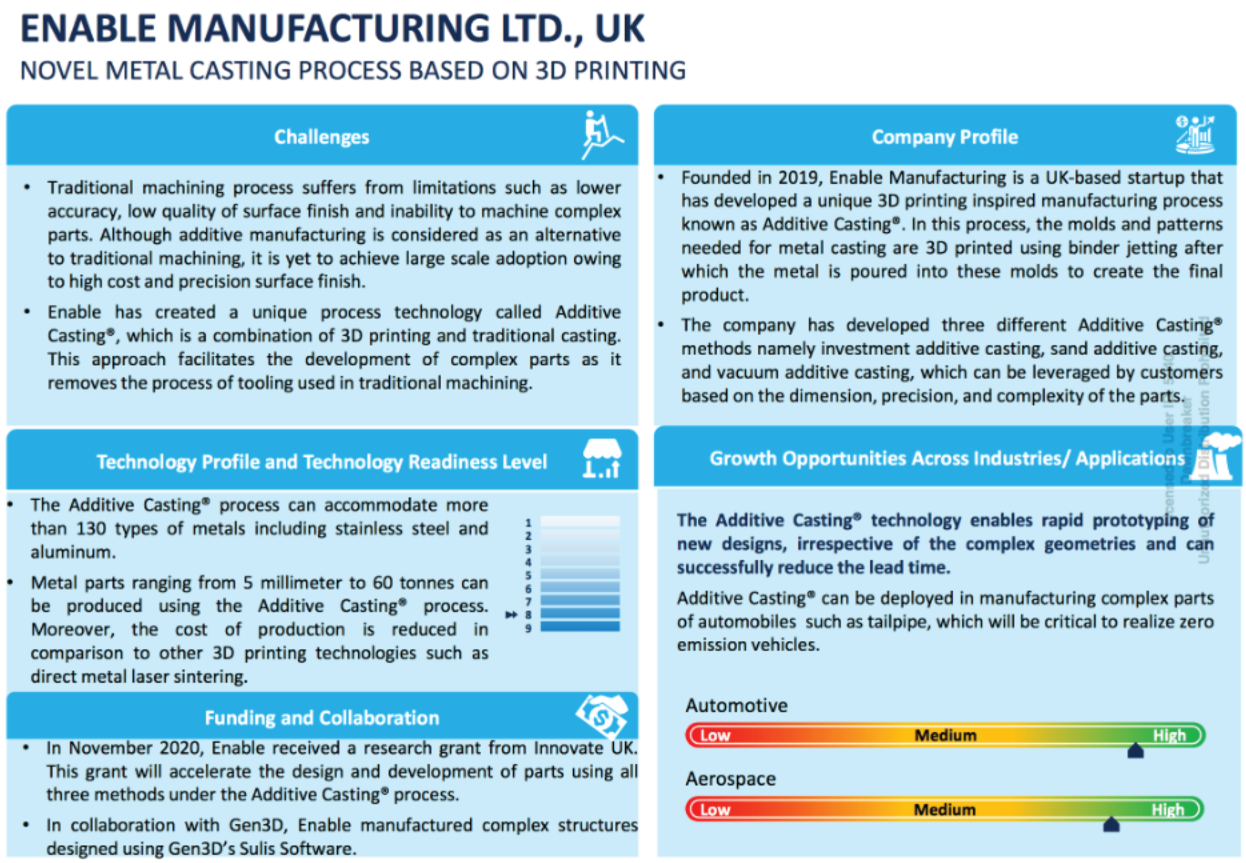

Figure 29: Enable Manufacturing's Additive Casting® Process

Reprinted with the permission of Frost & Sullivan[128]

To address the need to produce complex metal parts with compact geometries, such as are needed in some medical applications or jewelry designs, Holo, a U.S.-based metal 3D printing start-up spun out of Autodesk in 2017, has developed its proprietary PureForm™ metal AM platform, based on the process of Vat Photopolymerisation.[129]

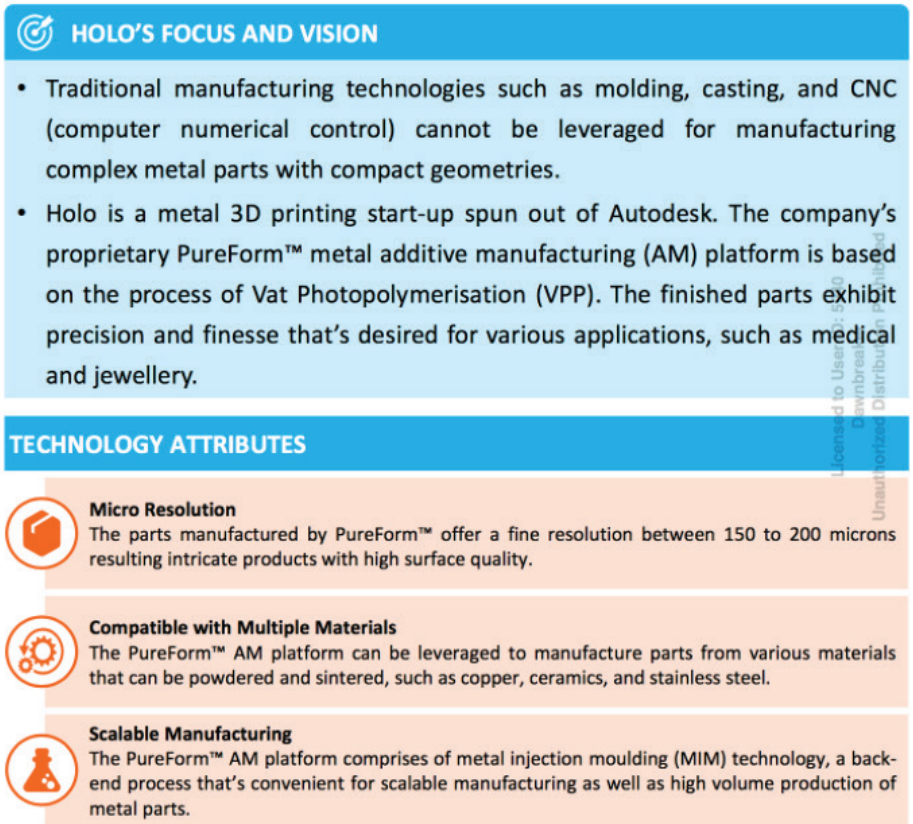

Figure 30: Holo's Micro Metal AM Technology

Reprinted with the permission of Frost & Sullivan[130]

4.3.4 Metal AM Could Benefit from AI/ML

Applications of artificial intelligence and machine learning could benefit metal additive manufacturing. The manuscript [Applications of artificial intelligence and machine learning in metal additive manufacturing] focuses on the application of AI in powder bed processes for metals.

4.4 "Microwave Casting" Faster Alternative to 3D Printing

A New Zealand-based startup, Foundry Lab, has developed microwave casting technology that has captured the interest of investors and the automotive industry, as their process enables same-day turnaround of metal castings.

> These production-identical parts have applications in mass manufacturing industries where metal 3D printing cannot reach. Existing casting systems like investment casting, 3D printed sand molds and die-casting require a 1-6 week production time. Recently, brake shoes cast by Foundry Lab went from CAD files to cast aluminum parts in less than 8 hours. Foundry Lab's Digital Metal Casting (DMC) system allows users to create metal parts in any casting alloy for functional testing before mass production … "3D printing is great for look-alike parts, but the world runs on real parts, and metal printing can never

produce a real casting," says Foundry Lab CEO and founder David Moodie. The team's focus on production-identical metal castings is being proved out with the successful production of parts like brake shoes. "We're able to work at speeds 3D printing can only dream of."[131]

4.5 Addressing Labor Issues

In addition to automating some processes, and utilizing technologies like augmented reality headsets for training, in 2022, AFS suggested these government solutions to address the labor issues:

- Expand Pell Grant eligibility to high-quality, short-term workforce programs
- Expand tax credits for employers that provide training to employees
- Create and expand tax benefits to incentivize individuals to pursue training and technical education
- Increase investments in technical and community colleges[132]

4.6 Addressing Shortages and Supply Chain Issues

Regarding shortages and supply chain issues, AFS would like to see efforts to strengthen domestic semiconductor manufacturing, as the metalcasting industry is impacted by semiconductor shortages when foundry customers have to suspend operations due to chip shortages. AFS also reports that metalcasters have faced significant delays in obtaining key foundry materials and minerals through U.S. ports and have also been impacted by skyrocketing ocean freight rates, trucking fuel prices, and truck driver shortages.[133] In addition to addressing transport delays, the industry also wants to see efforts to bolster the domestic critical minerals supply chain, stating:

> Metalcasters support strong federal investment to support domestic critical mineral and material processing, recycling, extraction, and high-level supply chain mapping included in the America COMPETES Act. In particular, the increase in critical mineral funding for agencies like the National Science Foundation, as well as the directive to advance critical mineral mining processing and recycling technologies, will improve critical mineral lifecycles and scale these technologies for broad market use. [134]

4.7 Addressing Energy Costs

The cost of energy is a major concern to the industry and AFS believes that the solution is to expand domestic energy production to bring down the price of energy. AFS would like to see an increase in domestic production of oil and natural gas, as well as renewable energy production – noting that the metalcasting industry produces castings vital to both the oil and gas industry and the renewable energy industry and electric vehicle markets.[135]

A 2015 article, Seven Steps to Energy Efficiency for Foundries, notes that energy costs for foundries are around 15% of the cost of castings, and 75 to 80% of the costs are in the melting process. As foundries became more energy aware, many installed energy meters with on-line energy monitoring systems to report energy consumption. The authors noted in 2015 that "a 10% saving in energy efficiency is equivalent to a saving of US $1.5 Billion along with substantial reduction in harmful greenhouse gas emissions."[136]

4.8 Addressing Foreign Competition

To address foreign competition, the industry, through AFS, has indicated a need for comprehensive supply chain mapping and monitoring. And the industry has expressed a need for initiatives that support re-tooling and adding new technologies, to build supply chain resilience.[137] The industry wants to see updated U.S. trade laws to ensure that the metalcasting industry will have remedies to address new and evolving unfair trade practices by China and others, and also make it harder for U.S. companies to illegally import competing foreign products, as explained by AFS:

> China's government continues to heavily subsidize its companies; many, in fact, are state-owned or controlled, which means they can price their goods far below fair market value. In addition, AFS urges consideration of legislation that would more effectively punish U.S. importers that mask the true country of origin of illegally imported products and their customers that repeatedly facilitate trans-shipment schemes.[138]

The industry also feels that China is further advantaged by less restrictive mining regulations of metals and other materials needed by metalcasters, as well as their manufacturing and energy sector customers.[139]

4.9 Addressing Lightweighting Needs

4.9.1 Casting Aluminum, Magnesium, and Zinc Instead of Cast Iron and Steel

In the automotive sector, increasing demand for fuel efficiency and stringent government emissions regulations are driving automotive OEMs to use components made of more lightweight materials, especially aluminum, but also magnesium, and zinc, instead of cast iron and steel. Traditionally, components such as engine blocks, engine heads, intake manifold, differential cover housing, gearbox housing, and transmission housing were made using cast iron. Increasingly, many of these components, along with body assembly parts, are being manufactured using aluminum to reduce weight.[140] Aluminum used in cars can also be successfully recycled at end-of-life, further driving the use of this metal. Automotive end-of-life recyclability is of particular concern in Europe. According to the European Aluminium Association (EAA), a 2006 car contained approximately 4 to 6% aluminum and a 2020 car contains 7 to 20% aluminum, depending on the OEM.[141] EAA notes that Tesla, Jaguar, Land Rover, Audi, BMW, and Daimler are all using well-made aluminium car parts that are considered as safe and strong as steel but up 40% lighter.[142] However, the high cost of aluminum and magnesium is a restraint for some OEMs.[143]

4.9.2 Ductile Iron Castings Opportunities for Lightweighting

Researchers in Ann Arbor Michigan are working on new and better ductile iron alloys for lighter, less expensive components. These researchers expect ductile iron will be able to compete technically and economically with aluminum, steel, and titanium castings, forgings, and weldments.[144] See Opportunities for Ductile Iron Castings in Lightweighting of Vehicles.

4.10 Solutions for Working with Defense Customers

To address the technical data ownership issues, DoD is exploring creating Government-developed technical data. Efforts at Oak Ridge National Lab's Manufacturing Demonstration Facility indicate that this can:

- Expand the supplier base by licensing on a non-exclusive basis to as many manufacturers as needed, resulting in more competitive pricing.
- Increase speed and reduce the cost of first-part certification and acceptance (requires the IP to include a manufacturing recipe which manufacturers must follow scrupulously). This reduces barriers to entry for new and smaller suppliers, increasing the supplier base that can afford to compete for defense work, thereby reducing prices and vendor lock.
- Contribute to development of a creative, competent workforce able to deliver next-generation solutions efficiently.[145]

DoD has developed a recommended plan of action to address all the casting and forging supply chain challenges, starting with the development of a cross-service C&F strategy, to be published no later than the end of Q2 of FY 2023. This strategy will make recommendations concerning the following:

- Establishing C&F centers of excellence.
- Identifying other specific measures to improve the OIB's capabilities.
- Prioritizing DoD research into:
    - New C&F processes.
    - Alternatives to C&F, such as new subtractive and hybrid methods.
    - Expanding use of additive manufacturing and digital production capabilities as a tool to enhance traditional methods, such as 3D printing sand cores, and for direct manufacturing.
    - Identify specific opportunities requiring the development of Government-owned technical data.[146]

Based on the finalized strategy, DoD then plans to:

- Invest in the C&F industrial base, creating a working group that will address sub-tier supplier and workforce development, competition to enable affordable production, and designs and procurements that optimize synergies within the DIB.
- Expand its existing partnerships (such as ORNL) and develop new interagency and organization relationships, such as with the American Metalcasting Consortium and the Forging Defense Manufacturing Consortium
- Identify and develop allied and partner nations' C&F capabilities
- Engage the NIST's Manufacturing Extension Partnership to expand its understanding of industry's perspectives on building commercially viable domestic capacity.[147]

The American Metalcasting Consortium's CAST-IT (Casting Advanced Systems Technology - Integration Team) links government and industry to support procurement success and offers metal casting solutions to the Defense Logistics Agency (DLA).[148]

4.10.1 Metalcasting Technology Research of CAST-IT]

The American Metalcasting Consortium provides support to the Defense Logistics Agency (DLA) through new technology, improved processes, and technical expertise.

> AMC integrates the nation's top academic metalcasting researchers with the CAST-IT team of industry experts and the four leading metalcasting industry associations and their members to solve supply chain management issues and support DLA's mission. AMC membership includes 95% of U.S. Metalcasters and 25 leading metals research universities.[149]

CAST-IT technology success stories are available here.

5.0 Summary and Conclusions

This report introduces a significant, but often behind-the-scenes segment of the U.S economy –
the metalcasting industry. As metalcastings are found in 90% of durable goods, the stability of the U.S. metalcasting industry is critical to the supply chains of many other industry sectors. This report begins with an historic overview of the changes that the U.S. foundry industry has experienced over the past two decades, regarding its fluctuating production and revenue levels, and declining plant and employee numbers. While every effort has been made to present industry data accurately, the reader should be mindful that the source of this data is not the U.S. government, as there is no federal census of the foundry industry. Instead, statistics are gathered by domestic and international industry associations that compile data gathered through survey/census efforts or from reports voluntarily submitted by each industry-active country. Survey participation levels can vary from year to year and survey methods and specific respondent information are often not shared publicly. Worldwide totals can also be skewed, depending on which countries volunteer data in any given year, and there is no method for verifying accuracy of any reported data. Within the U.S., while there is a specific NAICS code for foundries, companies that cast metals and then further process their castings into finished products are counted under a different NAICS code – so NAICS data does not always agree with casting association data. With all of these factors in mind, this report has attempted to present an accurate picture of the evolving U.S. metalcasting industry.

With the historical review serving as a backdrop, the ongoing industry challenges were reviewed, including, among others, labor issues, costs of modernization, and the impact that electric mobility will have on this transportation intense industry. The report then presents some solutions being discussed or adopted within the industry to help foundries survive and thrive - including reshoring, adoption of new technologies such as additive manufacturing, and introducing high strength light weight metals. Real world stories of innovative solutions, from both established players and startups, are shared and linked for further investigation. As this critical industry moves forward, the U.S. government should consider developing a comprehensive census that will accurately follow its evolution and clearly show how the U.S. foundry industry is fairing, at home and abroad.

APPENDIX A: Universities That Support the Foundry Industry

The following is a list of U.S. universities certified by the Foundry Educational Foundation (FEF)[150] and the key professor contact for each.

ALABAMA - BIRMINGHAM, UNIVERSITY OF
Dept of Materials Science & Engineering
1150 10th Ave South - EEC 254
Birmingham, AL 35294

205.996.7390

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APPENDIX B: Cast Industry Organizations & Directories

American Foundry Society (AFS)

1695 North Penny Lane
Schaumburg, IL 60173
Tel: +1-800/537-4237, +1-847/824-0181
cusserv@afsinc.org

Investment Casting Institute (ICI) and ICI Member Directory

Investment Casting Institute
1 Paragon Drive, Suite 110
Montvale, NJ 07645
(201) 573-9770
ici@investmentcasting.org

ICI, with the European Investment Castors' Federation (EICF) provides a downloadable directory of members. All the U.S. investment foundry member companies, with points of contact, can be accessed here. The database offers an Advanced search that allows filtering results by state or searching using keywords. ICI/EICF European members can be found here. A printable directory, of all members, updated in February 2022, (see sample image below) is available here.

North American Investment Casters

ACRA CAST, INC.
1837 First Street
Bay City, MI 48708 USA
(989) 893-3961 .... Fax: (989) 893-0241
Email: dmaine@acracast.com
www.acracast.com

AEROTEC ALLOYS, INC.
10632 Alondra Blvd.
Norwalk, CA 90650 USA
(562) 809-1378 .... Fax: (562) 402-8363
Email: dfranklin@aerotecalloys.com
www.aerotecalloys.com

AMERICAN CASTING COMPANY
205 Apollo Way, Suite A
Hollister, CA 95023 USA
(831) 637-5641 .... Fax: (831) 636-8390
Email: cstjohn@americancastingco.com
www.americancastingco.com

ARTCAST, INC.
14 Armstrong Avenue
Georgetown, Ontario L7G 4R9 CANADA
(905) 877-5455 .... Fax: (905) 877-0205
Email: marcus@artcast.com
www.artcast.com
WINNER

ATLANTIC C & E CORPORATION
810 Bloomfield Avenue
Clifton, NJ 07012 USA
(973) 779-2450 .... Fax: (973) 779-2854
Email: rzebick@atlantic-ce.com
www.atlantic-ce.com

AURORA CASTING & ENGINEERING, INC.
1790 E. Lemonwood Dr.
Santa Paula, CA 93060 9510 USA
(805) 933-2761
Email: a.penrose@auroracasting.com
www.auroracasting.com

AVALON PRECISION METALSMITHS
15583 Brookpark Road
Brook Park, OH 44142 USA
(216) 362-4100 .... Fax: (216) 362-4108
Email: jsmith@avalon-castings.com
www.avalon-castings.com

Figure 31: ICI/EICF Member Directory
Source: INCAST, Feb. 2022[151]

American Metalcasting Consortium (AMC)

https://amc.ati.org/

The American Metalcasting Consortium provides direct support to the Defense Logistics Agency (DLA) through new technology, improved processes, and technical expertise in the procurement of metalcastings to ensure warfighter readiness.

AMC integrates the nation's top academic metalcasting researchers with the CAST-IT team of industry experts and the four leading metalcasting industry associations and their members to solve supply chain management issues and support DLA's mission. AMC membership includes 95% of U.S. metalcasters and 25 leading metals research universities.[152]

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