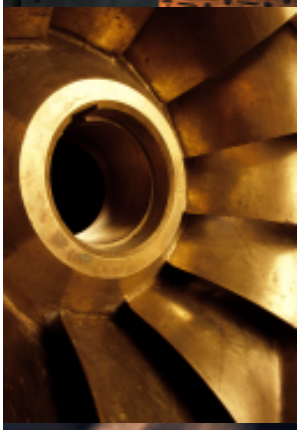
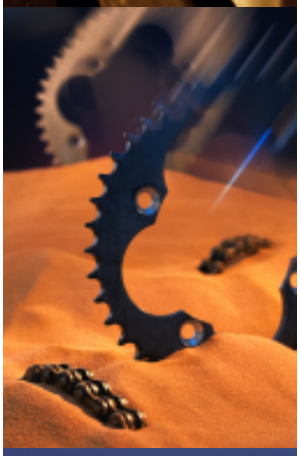


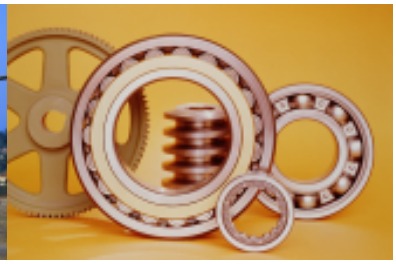


Metal Casting Industry Of the Future

Annual Report 2001

March 2002

Metal Casting Industry of the Future
Energy Efficiency and Renewable Energy
U.S. Department of Energy

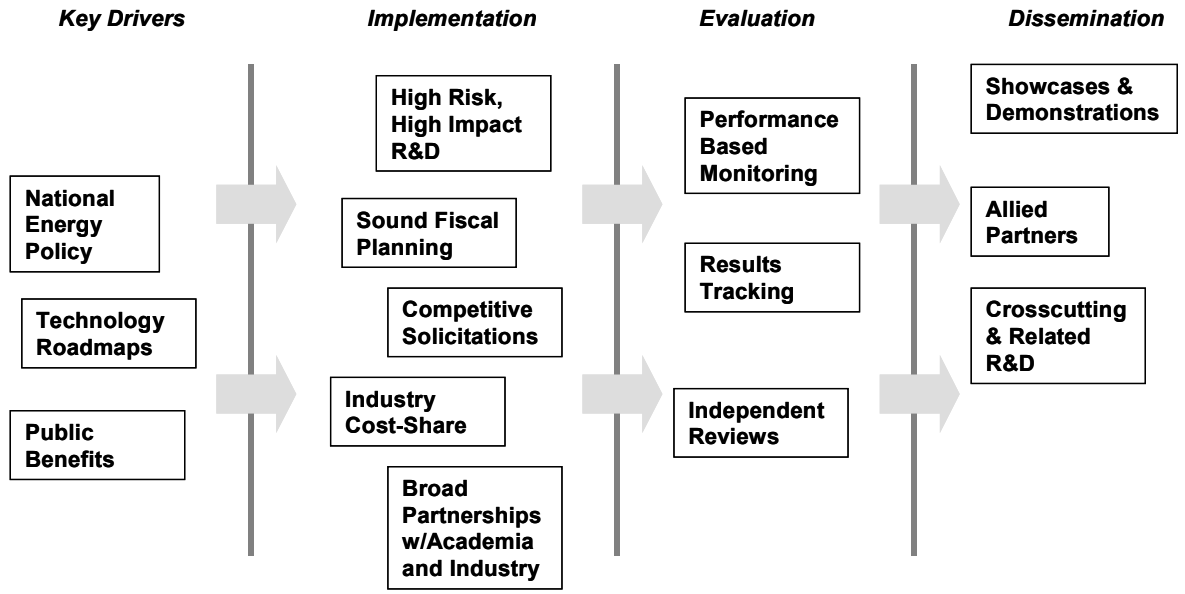


EXECUTIVE SUMMARY

The Industries of the Future (IOF) strategy works with the nine most energy intensive industries in the U.S., including metal casting. The Industries of the Future represent the base U.S. manufacturing industries vital to our economy and our national security. The Metal Casting Industry of the Future, part of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, cost-shares precompetitive research to improve energy efficiency in metal casting.

The program emphasizes pre-competitive research that addresses public and industry energy efficiency needs as outlined in the *National Energy Plan* and technology roadmaps. It fosters research partnerships between universities, industry, laboratories, and state and federal agencies that leverages technical expertise and ensures broad dissemination of research results. The program monitors research progress and tracks technical successes through performance based metrics. It also communicates technical and financial assistance opportunities available from a range of crosscutting research and BestPractices programs. Key characteristics of the program are illustrated in Exhibit E-1.

Exhibit E-1
Metal Casting Industry of the Future: Key Characteristics



The following briefly summarizes major highlights and accomplishments during 2001 and provides a snapshot of the program's research portfolio.

RESEARCH PORTFOLIO

- In cooperation with the Cast Metals Coalition (CMC), the program funds a diverse portfolio of research focused on manufacturing, materials, and energy/environmental technologies. This research is developing computer-based design tools, sensors, and other advanced

technologies to improve casting productivity. It is expanding knowledge of casting materials, and improving process control.

- The current portfolio of metal casting research is being performed in partnership with 285 industry, university, and national laboratory partners across the U.S. The involvement of universities is exposing hundreds of students to the field of metal casting. The large number of industry participants is ensuring broad application and dissemination of metal casting research.

- The current research portfolio addresses a cross-section of priorities outlined in the Metal Casting Industry Technology Roadmap with over half of research funding going to improvements in manufacturing processes, where opportunities for energy savings are the greatest. Additionally, research is being performed to improve materials performance, thereby reducing scrap, as well as to address environmental needs.

- Beyond Metal Casting IOF research, the Industrial Technologies Program has leveraged approximately $27 million in recent research and technical assistance for metal casters.

2001 - HIGHLIGHTS AND ACCOMPLISHMENTS

- Through the CMC, the metal casting industry began updating its long-term *Vision* during 2001 to establish long-term goals for the industry. The new vision will form the basis for a new technology roadmap, being developed in 2002, to guide Metal Casting IOF research (See page 21).

- The National Research Council performed an extensive analysis of the program's investment in lost foam casting. It validated DOE's role as a "catalyst for bringing industry together to perform pre-competitive" research that will remove barriers to the energy benefits available through lost foam casting (See page 26).

- The metal casting industry is applying the results of cutting edge IOF research (See Page 23). Examples include:

  - ✔ *Industry-university partnerships on improved microstructure in aluminum alloys are being disseminated and are enabling innovations in high speed computers, revolutionary wheelchairs and other advanced technologies.*

  - ✔ *New software, Arena-Flow ™, assists in design and trouble shooting for the lost foam casting process.*

  - ✔ *Research to reduce riser length is demonstrating yield improvements of up to 30% in steel foundries.*

  - ✔ *Modeling research is pushing casting simulation to new levels. Industry applications have demonstrated scrap reductions of at least 20% and significant energy savings.*

- ✔ *Research to optimize process parameters is enabling the application of permanent mold casting to produce lead-free copper-base castings.*

- ✔ *Research in mold materials now allows for die casting of copper motor rotors. Tests have shown that this is improving energy efficiency in motors by 14%.*

- EERE BestPractices and Industrial Assessment Centers are providing hands-on technical assistance that metal casters can apply immediately (See page 22). This assistance is saving companies millions per year:

  - ✔ *Indianapolis Casting Corporation optimized its compressed air system resulting in an annual savings of 7,225,000 kWh. Energy cost savings were $325,000 per year.*

  - ✔ *A plant assessment at the AMCAST Wapakonet, OH plant identified recommendations that would results in $3.7 million in savings per year.*

  - ✔ *RCM Industries and NADCA are identifying opportunities for implementing advanced technologies to save energy and reduce scrap at RCM. They will then disseminate the results to industry.*

- In 2001, the Metal Casting IOF began identifying organizations to participate as Allied Partners. Allied Partners will help to spread the word on how industry can save energy, demonstrate energy savings, and leverage greater participation in metal casting research.

- The reach of Metal Casting IOF partnerships is expanding through the State IOF strategy. Wisconsin and Massachusetts are developing Metal Casting State Roadmaps. Other states emphasizing metal casting include: Illinois, Indiana, Iowa, Michigan, New Hampshire, Ohio, Oregon, Pennsylvania, and South Carolina.

- The involvement of universities in metal casting research is exposing hundreds of students to the industry, who are pursuing and obtaining careers in the industry (See page 26).

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INTRODUCTION

The U.S. metal casting industry is diverse, employing a variety of casting processes and alloys to make a wide range of products. Because the majority of metal casters are small businesses, many lack the resources to perform high-risk, high-impact research on their own. Instead they are participating in research consortia and public-private partnerships. These collaborations are proving to be successful methods for performing research for the industry.

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Office of the Industrial Technologies Program (OIT), Metal Casting Industry of the Future (IOF) supports these partnerships by providing cost-shared R&D funding to improve metal casting. The program emphasizes university-based research, tapping the technical and knowledge resources of our nation's educational institutions. Industry partners are applying the results of metal casting research, saving energy, and improving competitiveness in world markets. The partnership is also introducing hundreds of students to the industry. Ensuring a well-educated, and well-trained work force is imperative for the metal casting industry to remain innovative and competitive in world markets.

This report summarizes the major goals, highlights and accomplishments of the Metal Casting Industry of the Future during 2001.

Successful Strategy for Partnership

The Industries of the Future strategy fosters government-industry partnerships in economically imperative, energy-intensive U.S. industries, including metal casting. Through the IOF strategy, EERE helps bring industry together and facilitates the development of unified Visions and Roadmaps. Visions establish long-term goals for the future, while Roadmaps outline the research and development (R&D) pathways to achieve the goals set forth in the Vision.

The Vision and the Roadmap form the pillars for open and competitive solicitations for pre-competitive R&D that address both energy efficiency goals outlined in the National Energy Policy as well as industry research priorities.

The program monitors research progress and tracks technical successes through performance based metrics. It also communicates "direct and relevant" technical and financial assistance opportunities available from a range of crosscutting research and BestPractices programs. Key elements of the program are illustrated in Exhibit 1.

A DYNAMIC VISION FOR THE FUTURE

To maintain a dynamic vision and build upon their accomplishments, the metal casting industry leaders began a process to update their industry vision which was originally developed in 1995.

A Future Think Forum was held during the DOE 4th Industrial Energy Efficiency Symposium and Exposition in February 2001. Dwight Barnhard, Executive Vice President of the American Foundry Society, and Paul Mikkola, Chief Operating Officer & Executive Vice President of Operations of Hitchiner Manufacturing, led a discussion of the major challenges facing the industry over the next 25 years. A two-day Vision workshop was held in October, 2001, at Ohio State University where leaders from industry, DOE, Environmental Protection Agency, and U.S. Department of Defense identified common challenges and goals in several areas. These included:

- improved design capabilities
- process advances
- communicating the importance of metal casting to society
- attracting students and employees to the field of metal casting.

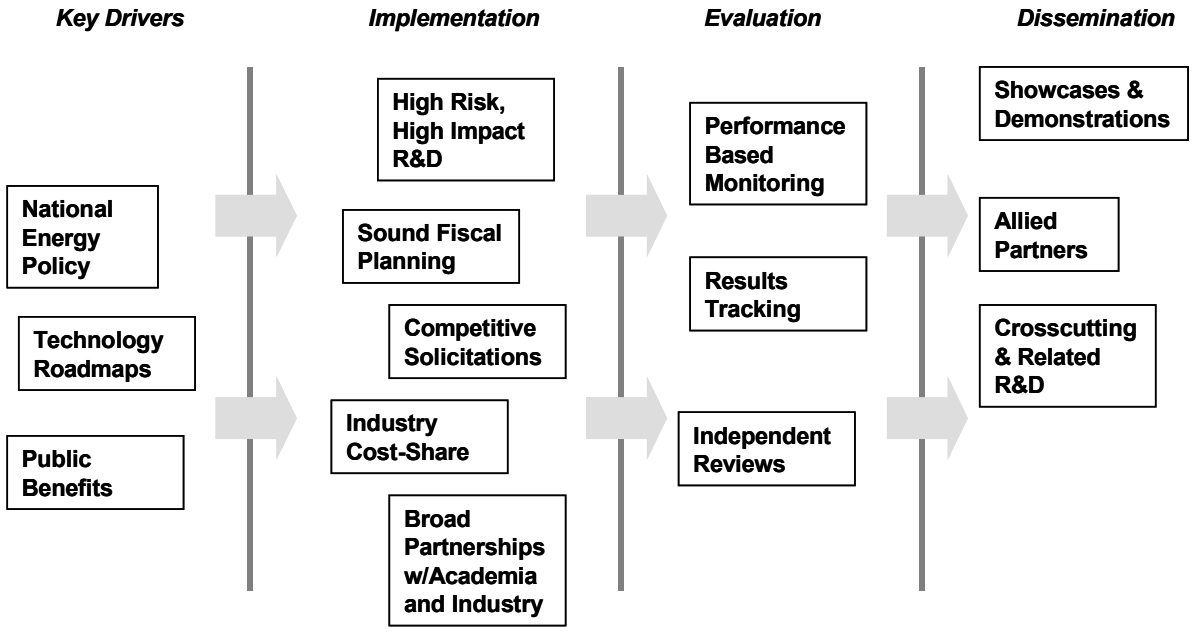
The Vision received broad industry review.

The success of the Metal Casting Industry of the Future has been the result of a highly effective partnership between DOE and the Cast Metals Coalition (CMC). The CMC is composed of the American Foundry Society (AFS), the North American Die Casting Association (NADCA), and the Steel Founders' Society of America (SFSA). Collectively, this coalition represents approximately 80% of the U.S. metal casting industry.

The involvement of industry on the ground floor helps to speed the pace of technology transfer. Strong industry involvement ensures direct application of research results and gives evidence to the importance of this cost-shared research partnership. Metal Casting Industry of the Future research partners represent the diversity of the metal casting industry including suppliers, end-users, designers, ferrous and non-ferrous foundries, die casters, and others. Collectively, these industry partners employ a wide range of metal casting techniques and supply a broad range of end-use markets. Furthermore, this approach to private-public partnership ensures the strategic allocation of limited resources for the R&D of new technologies and the enhancement of the metal casting process. It is through these partnerships that results are tested, disseminated and implemented throughout the industry.

Allied Partners are another key element in the EERE strategy to increase the implementation of energy efficient practices in metal casting. Allied Partners help to demonstrate and disseminate research results and information on how metal casters can save energy and improve the bottom line.

Exhibit 1
Metal Casting of the Future: Key Characteristics



THE CHALLENGE

Metal casting is critical to the U.S. economy with 90% of all manufactured goods containing one or more cast metal components. Metal castings are integral in U.S. transportation, energy, aerospace, manufacturing, and national defense. However, the industry faces a number of challenges, driving the need for a government-industry research partnership. These challenges are being addressed through the Metal Casting Industry of the Future research partnership.

Energy-Intensive Industry

Metal casting was identified as an Industry of the Future because it is one of the nine most energy-intensive industries in the manufacturing sector. In 1998, the U.S. metal casting industry (NAICS 3315) spent $1.2 billion purchasing an estimated 235 trillion Btu. The amount of energy used by the metal casting industry is equivalent to that used by residents in New Hampshire, New Mexico, Rhode Island, Wyoming, and Hawaii combined.[1] If captive foundries are included, the estimated energy consumption for metal casting increases to 328 trillion Btu.[2]

Energy intensive processes in metal casting include melting, mold making, core making, and other activities. (For more information on energy use in Metal Casting, see Industry Overview, page 5). The Metal Casting Industry of the Future is funding research to improve energy efficiency in these processes. This research is helping to improve yield, extend die and mold life, and reduce post-cast energy requirements. A 2001 analysis of current Metal Casting IOF research projects estimates that the current R&D portfolio will save 35 trillion Btu annually in 2010. This is estimated to increase to 75 trillion Btu in 2020.

Metal casting R&D is a component of the overall EERE strategy to respond to energy efficiency goals outlined in the *National Energy Plan*. In addition, it is contributing to the EERE Industrial Technologies goal to achieve "a 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the vision industries by 2010" and "a 35 percent improvement in energy efficiency and 50 percent reduction in emissions for the vision industries by 2020." [3]

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[1] Source: *1998 Manufacturing Consumption of Energy Report,* U.S. Department of Energy, Energy Information Administration Tables N.11.1, and *Survey1998 Annual Energy Review,* U.S. Department of Energy, Energy Information Administration, Table 1.6

[2] Using *AFS 2002 MetalCasting Forecast & Trends*, the ratio of metal casting shipments (NAICS 3315) to captive foundry casting production was calculated. This ratio was applied to industry energy consumption for NAICS 3315,*1998 Manufacturing Consumption of Energy Report,* U.S. Department of Energy, Energy Information Administration Tables N.11.1 , to estimate energy consumption in captive foundries.

[3] Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of Industrial Technologies, *Strategic Plan: A Work in Progress*, 1999, pg 1.

Small Business Industry with a Nationwide Impact

The majority of metal casters are small businesses. Eighty percent of the estimated 2,950 metal casting facilities employ less than 100 people, fourteen percent employ between 100 and 250 people, and only six percent employ more than 250 people. Industry-wide, an estimated 225,000 people are employed in metal casting.[4]

As a small business industry, it is difficult for many metal casters to assume the high cost and risk associated with R&D -- particularly long-term R&D. Research partnerships and consortia such as those fostered by DOE and CMC share the risk involved in long-term, pre-competitive research. The coalition-building is helping the industry to improve yield rates, increase process control, improve material technologies, and reduce energy and environmental impacts. For example, collaborative research in lost foam is demonstrating a 27% energy savings compared to conventional sand casting. In short, Metal Casting IOF research is striving to help the U.S. metal casting industry remain innovative and efficient in today's highly competitive world market place.

To maintain a healthy, vibrant U.S. metal casting industry, it is important that small and large companies alike attract a well-trained, well-educated workforce. Because the majority of metal casting research is performed at universities, undergraduate and graduate students are actively participating in the R&D. The majority are pursuing careers in the industry where they are able to apply their knowledge and experience directly on the plant floor.

[4] www.afsinc.org/Trends/FactsandFigures.htm

INDUSTRY OVERVIEW

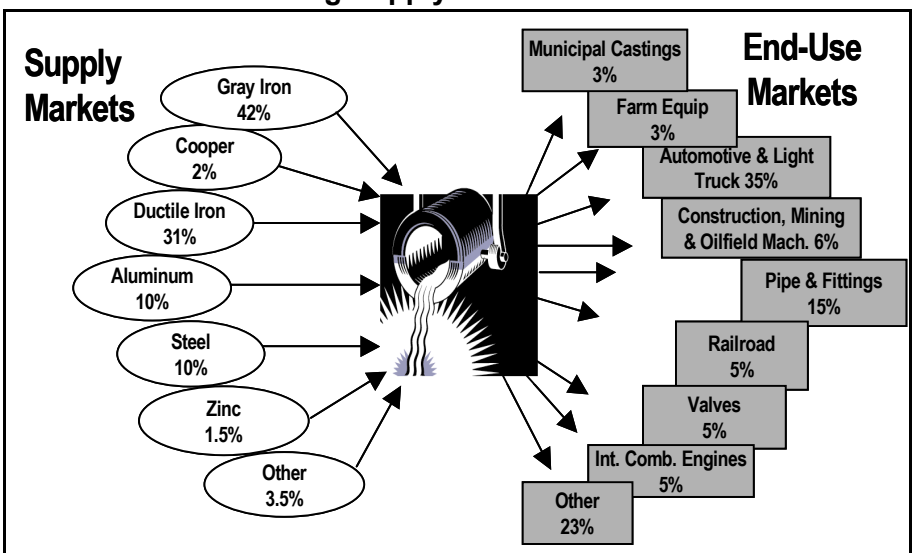
The metal casting industry took form in the United States in 1642 and metal casters were present at the signing of the *Declaration of Independence* in 1776. The metal casting industry has been integral to U.S. growth and has helped the U.S. to become the world benchmark in manufacturing, science, medicine, aerospace, and many other fields. Now this small business industry is helping to fuel the nation's prosperity into the 21st Century.

Metal Casting In Brief

Metal casting enables the production of simple and complex parts that meet a wide variety of needs. Nearly all manufactured goods contain one or more components. Major end-uses include power generation equipment, defense systems and machinery, motor vehicles, transportation equipment, oil field machinery, pipelines, industrial machinery, construction materials, and other products vital to our economic and national security. Exhibit 2 illustrates supply and end use markets for metal castings.

There are various methods used to cast metals as described in Exhibit 3. The basic process consists of pouring molten metal into a mold containing a cavity of the desired shape. The most commonly used method for small-and-medium sized castings is green sand molding. Other methods include: shell molding, permanent molding, investment casting, die casting, lost foam casting, and squeeze casting. Markets for metal castings are increasingly competitive and casting customers are placing greater emphasis on high-quality, competitively priced castings. There is increasing demand for lighter-weight, high-strength ferrous and nonferrous cast metal components as well as castings that meet demanding design specifications. Casting process must continually evolve and improve to remain competitive in today's market place.

Exhibit 2
Metal Casting Supply and End-Use Markets



Source: U.S. Department of Commerce, Bureau of Census, Current Industrial Reports MA331E(00) and MA331A(00)-1

Exhibit 3
Examples of Metal Casting Processes

Process	Description	Advantages
Green Sand Molding[5]	This process is the most common metal casting technique, using silica sand as a medium for the mold. The sand is coated with a mixture of clay and water and pressed manually or mechanically around the pattern to be cast.	• Most ferrous and nonferrous metals can be used. • Low pattern and materials costs.
Permanent Molding[6]	In this process, the mold is prepared in two sections from cast iron or steel and the casting can be poured in a horizontal or vertical position. Castings are generally of aluminum alloys.	• Produces dense, uniform castings with high dimensional accuracy. • Fast production rate along with a low scrap rate.[7]
Die Casting	In this process, molds are made of metal and considered permanent, and are used to produce small- to medium-sized castings in large volume. Molten metal is injected into the mold under high pressure.	• Has economical benefits with economies of scale. • Suitable for relatively low melting point metals.
Lost Foam Casting[8]	In this process, a mold is made of expandable polystyrene patterns and surrounded by unbonded sand. The metal poured into this mold vaporizes the foam pattern and takes the shape of that pattern.	• Reduces operating costs. • No binders required along with other additives. • No core required.
Investment Casting[9]	This process uses heat disposable patterns made of materials such as wax. It invests a three-dimensional pattern to produce one destructible mold into which molten metal will be poured.	• Excellent flexibility in design. • Good for alloys that are difficult to machine.
Squeeze Casting[10]	In this process, molten metal is introduced into a permanent metallic mold die cavity and pressure is applied as it solidifies.	• Castings have little to no porosity. • Castings have excellent surface finishes.[11]
Centrifugal Casting[12]	In this process, the mold is spun at very high speeds as the metal is poured, producing hollow cylinders and tubes of different lengths and wall thickness.	• Improves both homogeneity and accuracy of the casting. • Able to sustain a rapid production rate.

[5] U.S. Department of Energy, Office of Industrial Technologies, *Energy and Environmental Profile of the U.S. Metal Casting Industry*, September 1999, pg 7

[6] Ibid pg. 8

[7] www.myb2o.com

[8] La Rue, James P. *Basic Metalcasting*, American Foundry Society, Des Plaines, Illinois 1989 pg.259.

[9] www.myb2o.com Ibid

[10] U.S. Department of Energy, Office of Industrial Technologies, *Energy and Enviromental Profile of the U.S. Metal Casting Industry*, September 1999, pg. 8.

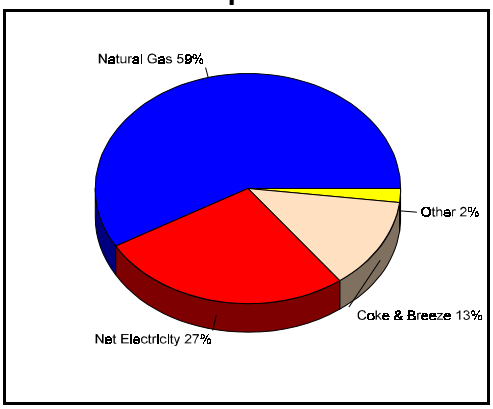
[11] www.myb2o.com

[12] Ibid

Energy Use in Metal Casting

The metal casting industry consumes an estimated 328 trillion Btu annually.[13] This includes 235 trillion Btu consumed by metal casters classified under NAICS 3315 as well as an additional 93 trillion Btu consumed in captive foundries.

Exhibit 4
Metal Casting Industry Energy Consumption- 1998



As shown in Exhibit 4, 59% of the industry's energy consumption is supplied by natural gas and 27% from electricity. The remainder includes other fuel sources such as coke and breeze.[14]

Major energy-consuming processes in metal casting include: melting, coremaking, moldmaking, heat treatment, and post-cast activities. As shown in Exhibit 5, the most energy- intensive of these processes is melting of metal. Melting accounts for an estimated 55% of process energy cost.

In 1998, the industry spent $1.2 billion on purchased fuels and electricity. On average, energy purchases

Exhibit 5
Process Energy Cost

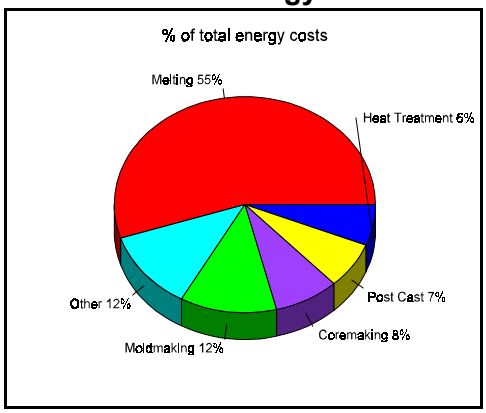
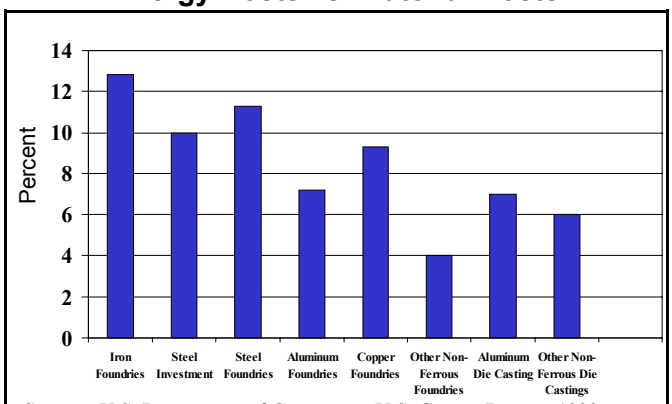


Exhibit 6
Energy Costs vs. Material Costs



Source: U.S. Department of Commerce, U.S. Census Bureau, 1999 Annual Survey of Manufactures, Manufacturing Industry Series, Tables 2 and 4, Detailed Statistic by Industry: 1999 for NAICS codes 3315, 331511, 331512, 331513, 331524, 331525, 331528, 331521, 331522.

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[13] Using *AFS 2002 MetalCasting Forecast & Trends*, the ratio of metal casting shipments (NAICS 3315) to captive foundry casting production was calculated. This ratio was applied to industry energy consumption for NAICS 3315,*1998 Manufacturing Consumption of Energy Report,* U.S. Department of Energy, Energy Information Administration Tables N.11.1 , to estimate energy consumption in captive foundries.

[14] Source: U.S. Department of Commerce, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, Table 3, Detailed Statistics by Industry, 1997

represented 10% of the material costs. This was highest in iron foundries where energy purchases represented about 13% of materials costs and lowest in non-ferrous foundries where energy purchases represented 4% of material costs (See Exhibits 6 and 7). In looking at energy costs in relation to the value of shipments, purchased fuels and electricity represented about 6% of the value of shipments in 1998.

During 2001, the Metal Casting Industry of the Future in conjunction with the Cast Metals Coalition initiated an *Energy Footprint Study* to analyze energy use in metal casting processes and to develop better benchmarks for measuring improvements in energy efficiency. Additional details are provided in the "2001-Highlights and Accomplishments," section of this report.

Exhibit 7
Energy Costs for the Metal Casting Industry, 1998
(million dollars except as noted)

	Cost of Fuels	Cost of Purchased Electricity	Cost of Fuels + Purchased Electricity	Total Cost of Materials	Energy Costs as a % of Material Costs	Electricity Purchased for Heat & Power ('000 kWh)
Iron Foundries (331511)	$215.2	$416.1	$631.3	$4,918.4	13%	9,060,820
Steel Investment Foundries (331512)	21.0	50.4	71.4	711.6	10%	880,524
Steel Foundries except Investment (331513)	36.8	98.6	135.4	1,196.8	11%	2,060,881
Nonferrous (except aluminum) Die Casting Foundries (331522)	19.8	37.2	56.9	942.6	6%	580,415
Aluminum foundries (except Die Casting) (331524)	53.7	73.2	126.9	1,756.7	7%	1,469,585
Copper Foundries (except die casting) (331525)	8.8	23.3	32.1	346.2	9%	373,410
Other Non-Ferrous Foundries except Die Casting (331528)	3.8	10.2	14.0	354.4	4%	220,768
Aluminum Die Casting foundries (331521)	56.3	77.4	133.7	1,908.7	7%	1,427,377
Total (3315)	**$415.4**	**$786.4**	**$1,201.7**	**$12,135.4**	**10%**	**16,073,780**

Source: U.S. Department of Commerce, U.S. Census Bureau, 1999 Annual Survey of Manufactures, Manufacturing Industry Series, Tables 2 and 4, Detailed Statistics by Industry: 1999 for NAICS codes 3315, 331511, 331512, 331513, 331524, 331525, 331528, 331521, and 331522.

Metal Casting Industry Shipments

In 2000, the metal casting industry shipped 11.5 million tons of ferrous castings valued at $10.9 billion and 2.5 million tons of nonferrous castings valued at $7.8 billion. As shown in Exhibit 8, the quantity of casting shipments decreased slightly over the period 1995 to 2000 on average. This was led by a drop in steel and gray iron shipments. Steel shipments decreased at an average annual rate of 2% between 1995-2000. Production in 2000 was 1.10 million short tons. Gray iron declined at an average annual rate of return of 2% between 1995-2000. Production in 2000 was 5.75 million short tons. These declines were offset due to continued growth in ductile iron castings for pipes, automotive castings and other applications. Ductile iron shipments increased at an average annual rate of 1% between 1995-2000. Production in 2000 was 4.57 million short tons.

Overall declines in metal casting shipments were also offset by increased demand for nonferrous castings. Ton of aluminum and aluminum-based casting shipments increased at an average annual rate of 5% between 1995-2000 reaching 1.96 million short tons in 2000. Copper and copper-based alloys increased at an average annual rate of 1% over the period, reaching 305,042 short tons in 2000. Markets for non-ferrous castings are expected to continue to remain strong in response to increased demand of for lightweight materials.

The value of metal casting shipments in 2000 was $18.7 billion. Value of shipments data are provided in Exhibit 9. Although there was a slight decrease in the quantity of shipments over the period 1995-2000, the value of shipments increased at an annual average rate of 2%. This is due in part to an increase in the value per ton of castings shipped for ductile iron castings. The value of ductile iron casting shipments increased at an average annual rate of 4% over the period 1995 - 2000 whereas the quantity of shipments increased at an average annual rate of 1% over that same five year period.[15] The value of ductile iron castings increased 6% on a dollar per ton basis from 1995 to 2000.

[15] Source: U.S. Department of Commerce, U.S. Census Bureau, *Current Industrial Reports*, Iron and Steel Castings 2000, MA331A(00)-1, Table 3; Non-Ferrous Castings 2000, MA331E(00)-1, Table 1.

Exhibit 8
U.S. Producers' Shipments of Non-ferrous and Ferrous Castings (short tons)

Non-ferrous Castings	1995	1996	1997	1998	1999	2000	Avg. % change (95-00)
Aluminum and aluminum-based alloy	1,565,071	1,521,081	1,593,876	1,921,137	1,976,343	1,955,721	5%
Copper and copper-base alloy	286,385	284,560	276,480	286,360	310,449	305,042	1%
Magnesium and magnesium-base alloy	24,162	25,724	19,257	20,741	21,956	25,432	2%
Zinc and zinc-base alloy	208,699	221,543	228,933	239,169	225,058	222,735	1%
Sub-Total Non-ferrous	2,084,317	2,052,908	2,118,546	2,467,407	2,533,806	2,508,930	4%
Ferrous Castings	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Avg. % change (95-00)**
Ductile Iron	4,304,000	4,312,000	4,325,000	4,583,000	4,658,000	4,569,000	1%
Gray Iron	6,260,000	6,198,000	5,938,000	6,047,000	5,955,000	5,752,000	-2%
Malleable Iron	293,000	263,000	272,000	247,000	207,000	186,000	-8%
Steel[1]	1,160,000	1,271,000	1,218,000	1,325,000	1,202,000	1,040,000	-2%
Sub-Total Ferrous	12,017,000	12,044,000	11,753,000	12,202,000	12,022,000	11,547,000	-1%
Total Non-ferrous and Ferrous	**14,101,317**	**14,096,908**	**13,871,546**	**14,669,407**	**14,555,806**	**14,055,930**	**-0.02%**

Exhibit 9
Value of Shipments of Non-ferrous and Ferrous Castings ('000 dollars)

Non-ferrous Castings	1995	1996	1997	1998	1999	2000	Average% change (95-00)
Aluminum and aluminum-based alloy	$4,760,858	$4,724,290	$5,172,590	$5,669,532	$5,556,386	$5,615,655	4%
Copper and copper-base alloy	922,557	983,955	991,974	1,053,833	1,120,292	1,135,803	4%
Magnesium and magnesium-base alloy	224,318	272,842	225,685	256,852	245,677	230,946	2%
Zinc and zinc-base alloy	770,201	809,127	818,963	914,648	928,341	862,820	2%
Sub-Total Non-ferrous	$6,677,934	$6,790,214	$7,209,212	$7,894,865	$7,850,696	$7,845,224	3%
Ferrous Castings	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Average% change (95-00)**
Ductile Iron	$3,664,600	$3,971,500	$4,148,900	$4,428,400	$4,299,000	$4,343,000	4%
Gray Iron	4,503,000	4,463,000	4,719,500	4,635,100	4,446,000	4,368,000	-1%
Malleable Iron	270,900	266,100	272,400	257,900	238,000	229,000	-3%
Steel[1]	2,179,100	2,295,600	2,343,500	2,499,000	2,161,000	1,927,000	-2%
Sub-Total Iron and Steel	$10,617,600	$10,996,200	$11,484,300	$11,820,400	$11,144,000	$10,867,000	1%
Total Non-ferrous and Ferrous	**$17,295,534**	**$17,786,414**	**$18,693,512**	**$19,715,265**	**$18,994,696**	**$18,712,224**	**2%**

1. Does not include steel investment castings.

Sources: U.S. Department of Commerce, U.S. Census Bureau, *Current Industrial Reports*, Iron and Steel Castings, MA331A(00)-1, and Non-Ferrous Castings, MA331E(00)-1.

World Casting Production

The U.S. continues to lead the world in ferrous casting production with 20% of the world market. Exhibit 10 illustrates world ferrous casting production for 2000 based on tons produced. Within markets for ferrous castings, China produces the most gray iron, malleable iron, and steel castings worldwide. China is the second largest producer of ferrous castings with 14.9% of the world market. Other major producers of ferrous castings are Russia, Germany, Japan, and India.[16]

Exhibit 10
2000 World Ferrous Casting Production
(Share of Tonnage Produced)

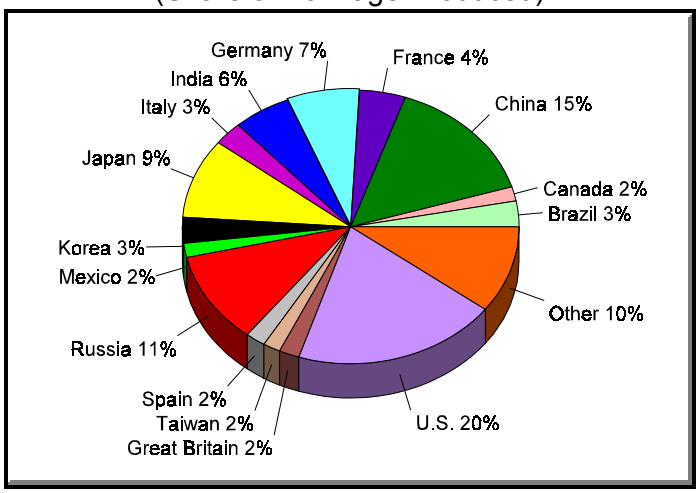
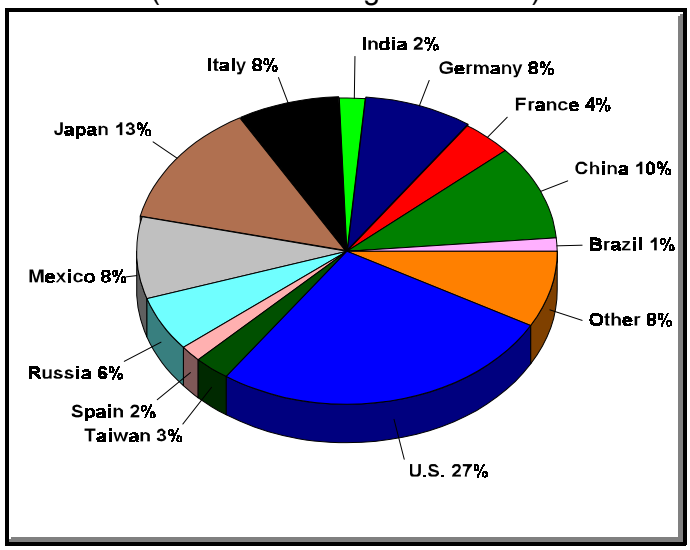


Exhibit 11 illustrates world non-ferrous casting production for 2000 based on tonnage produced. The U.S. led in non-ferrous castings across nearly all alloy types with 26.7% of the world market share. Japan followed the U.S. at 13.2% of world market share with a bulk of their shipments being aluminum. China held 10.2% of the world market. Mexico has significantly increased its production of non-ferrous casting with 8.5% of the world market share. This is a sharp increase from 1995 when Mexico held 2.9% of the world market share. Other leading producers of non-ferrous castings include: Germany, Russia, and Italy.[17]

Exhibit 11
2000 World Nonferrous Casting Production
(Share of Tonnage Produced)



Although the U.S. is the largest producer of metal castings, it is still dependent upon imports to meeting casting demand. In 2002 the U.S. will rely on imports to meet 18% of demand for gray castings and 12% of demand for steel castings. Moreover, the U.S. relies on imports to meet 17.9% of its total demand for aluminum castings and 16.6% of its requirements for copper castings.[18]

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[16] Source: "35th Census of World Casting Production- 2000" *Modern Castings,* December 2001 p. 39.

[17] Ibid

[18] AFS, *AFS Metalcasting Forecast & Trends 2002*, American Foundry Society, Inc, Des Plaines, IL 2001, pg. 9-24

METAL CASTING RESEARCH PORTFOLIO

The Metal Casting Industry of the Future supports a diverse portfolio of cost-shared, pre-competitive research. Research projects address high-risk/high-impact needs that have broad application throughout the metal casting industry.

All metal casting research projects are selected through a competitive review process. Metal Casting IOF research must address both the priorities outlined in the *Metal Casting Industry Technology Roadmap* as well as DOE's national energy efficiency goals. Solicitations are announced in trade society publications and meetings, the *Commerce Business Daily, FedBizOpps*, the Metal Casting IOF Web site and industry Web sites.

Maintaining a strong and well-balanced portfolio requires careful attention throughout the competitive solicitation, evaluation and selection process. The 2001 Metal Casting IOF research portfolio consists of 46 active projects, addressing the diverse research needs of the industry. Many of the projects in the portfolio have applications across various casting processes and alloys. All projects address the need to improve energy efficiency in the industry.

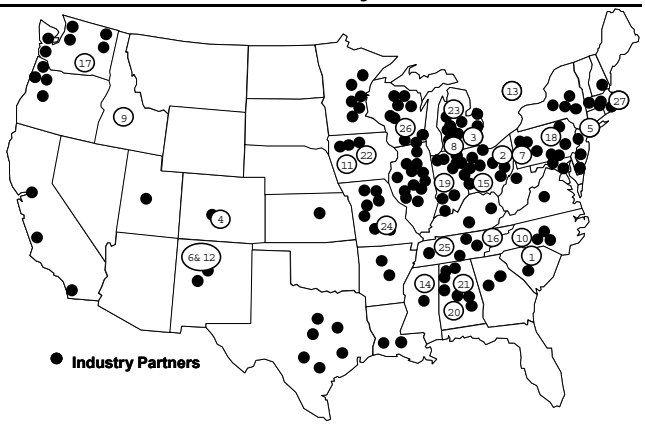
Broad Industry Partnership

One of the strengths of the metal casting research portfolio is the large participation of both industry and universities, providing both cost-share and in-kind support. Currently, the program is partnering with 285 industry, university and national laboratory partners in 33 states across the U.S. The geographic reach of the program's partnership is illustrated in Exhibit 12.

Exhibit 12
Broad Industry Partnership
Metal Casting Research Performers and Project Partners

Primary Research Performers

1. Advanced Technology Institute
2. Case Western Reserve University
3. Climax Research Services
4. Colorado School of Mines
5. Copper Development Assoc., Inc.
6. Flow Simulation Services, Inc.
7. GKS Engineering Services
8. Hayes Lemmerz
9. Idaho National Engineering and Environmental Laboratory
10. Intl. Lead Zinc Research Organization
11. Iowa State University
12. Los Alamos National Laboratory
13. Materials Technology Laboratory
14. Mississippi State University
15. Oak Ridge National Laboratory
16. Ohio State University
17. Pacific Northwest National Laboratory
18. Pennsylvania State University
19. Tri-State University
20. University of Alabama
21. University of Alabama - Birmingham
22. University of Iowa
23. University of Michigan
24. University of Missouri - Rolla
25. University of Tennessee
26. University of Wisconsin - Milwaukee
27. Worcester Polytechnic Institute



The Metal Casting Industry of the Future is partnering with 285 university, industry, and laboratory partners in 33 states across the U.S.

Appendix A provides a listing of program partners by state. The involvement of industry on the ground floor accelerates technology transfer and dissemination of research results. Industry partners represent the diversity of the metal casting industry and include suppliers, end-users, designers, ferrous and non-ferrous foundries, die casters, and others. Because it emphasizes university-based research, the program's portfolio also enables the industry to have direct access to technical expertise available at our universities and national laboratories.

A Diverse Research Portfolio

Exhibit 13 illustrates program R&D funding by both primary roadmap category. Exhibit 13 illustrates program funding by alloy. As shown, the portfolio addresses each of the key areas of the *Metal Casting Industry Technology Roadmap* -- manufacturing, materials, and environment. Because many of the key opportunities for improving energy efficiency are in the area of manufacturing technologies, a larger portion of program funding goes to research in this category. It should be noted that although projects are categorized by the primary roadmap category they address, the majority of projects respond to research priorities in multiple roadmap categories.

As also illustrated in Exhibit 14, the program maintains a healthy balance of research targeted to both ferrous and non-ferrous alloys. However, the majority of research in the program's portfolio crosscuts all alloy types, further leveraging research investments.

A list of the current portfolio of metal casting projects, organized by Roadmap category, is shown in Exhibit 15. Lead research organizations are also shown. Exhibit 16 lists upcoming project milestones. Project descriptions and partners are provided by Roadmap category in Appendix B.

Exhibit 13
Research Funding By Roadmap Category

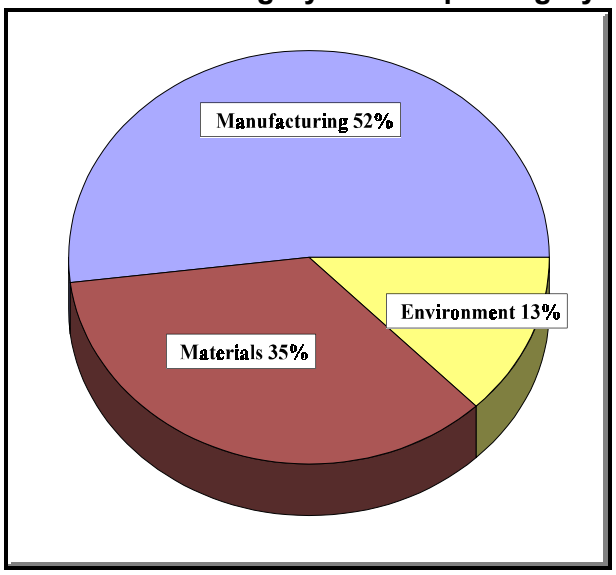


Exhibit 14
Research Funding By Primary Alloy

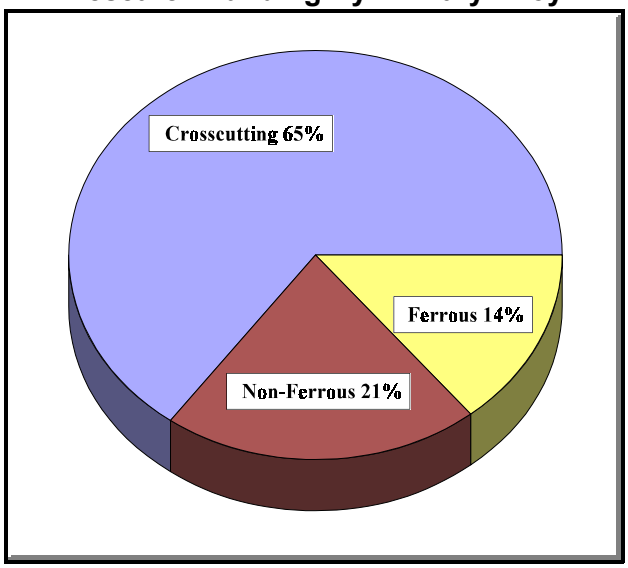


Exhibit 15
Metal Casting Portfolio by Primary Roadmap Category

Manufacturing

- *Development of Computational Fluid Dynamics Tool for Modeling the Blowing and Steaming of Expandable Polystyrene Patters for Lost Foam Castings* **(Arena, LLC)**
- *Effects of Die Design & Dimensional Features on Thermal Fatigue Cracking of Die Casting Dies* **(Case Western Reserve University)**
- *Gating of Permanent Mold Aluminum Casting* **(Case Western Reserve University)**
- *Mold Materials for Permanent Molding of Aluminum Alloys* **(Case Western Reserve University)**
- *Optimization of Composition and Heat Treating of Die Steels for Extended Lifetime* **(Case Western Reserve University)**
- *Optimization of Squeeze Casting Process for Aluminum Alloy Parts* **(Case Western Reserve University)**
- *Integration of RSP Tooling with Rapid Prototyping for Die Casting Applications* **(Colorado State University)**
- *Ergonomic Improvements for Foundries* **(Iowa State University)**
- *Reduction in Energy Consumption and Variability in Steel Casting* **(Iowa State University)**
- *Effects of Applied Pressure During Feeding on the Fatigue Properties of Critical Cast Aluminum Alloy Components* **(Mississippi State University)**
- *Control of Soldering and Thermal Fatigue During Die Casting* **(Oak Ridge National Laboratory)**
- *Predicting Pattern Tooling and Casting Dimensions for Investment Casting - Phase II* **(Oak Ridge National Laboratory)**
- *Sensors for Die Casting* **(Oak Ridge National Laboratory & Hayes Lemmerz, Inc.)**
- *Castability Assessment and Data Integration for Die Casting Design* **(Ohio State University)**
- *Computer Modeling of the Mechanical Performance of Die Casting Dies* **(Ohio State University)**
- *Energy Consumption of Die Casting Operations* **(Ohio State University)**
- *Improvements in Sand/Mold/Core Technology: Effects on Casting Finish* **(Ohio State University)**
- *Qualitative Reasoning for Additional Diecasting Design Applications* **(Ohio State University)**
- *Understanding the Relationship Between Pattern Filling and Part Quality in Die Casting* **(Ohio State University)**
- *Prediction of Part Distortion in Die Casting* **(Ohio State University)**
- *Investment Shell Cracking* **(Tri-State University)**
- Thin Wall Iron Castings **(University of Alabama)**
- *Advanced Lost Foam Casting* **(University of Alabama – Birmingham)**
- *Clean Cast Steel Technology* **(University of Alabama – Birmingham)**
- *Yield Improvement in Steel Castings* **(University of Iowa)**
- *Heat Transfer at the Mold/Metal Interface in Permanent Mold Casting of Aluminum Alloys* **(University of Michigan)**
- *Semi-Solid Metals Processing Consortium* **(Worcester Polytechnic Institute)**

Materials

- *Die Materials for Critical Applications and Increased Production Rates* **(Case Western Reserve University)**
- *Evaluation of Heat Checking and Washout of Heat Resistant Superalloys for Die Insert Applications* **(Case Western Reserve University)**
- *Metallic Reinforcement of Direct Squeeze Die Cast Aluminum Alloys for Improved Strength and Fracture Resistance* **(Case Western Reserve University)**
- *Development of a Fatigue Properties Data Base for Use in Modern Design Methods* **(Climax Research Services)**
- *Prevention of Porosity in Iron Casting* **(Climax Research Services)**
- *Development of Surface Engineered Coatings for Die Casting Dies* **(Colorado School of Mines)**
- *Grain Refinement of Permanent Mold Cast Copper Base Alloys* **(Copper Development Association)**
- *Development Program for Natural Aging Aluminum Alloys* **(GKS Engineering Services)**
- *Creep Resistant Zinc Alloy Development* **[International Lead Zinc Research Organization, Inc. (ILZRO)]**
- *Effects of Externally Solidified Product on Wave Celerity and Quality of Die Cast Products* **(Ohio State University)**
- *Heat Treatment Procedure Qualification for Steel Castings* **(Pennsylvania State University)**
- *Age Strengthening of Gray Cast Iron* **(Tri-State University)**
- *Metallic Recovery and Ferrous Melting Processes* **(Tri-State University)**
- *Clean, Machinable, Thin-Walled Gray and Ductile Iron Casting Production* **(University of Alabama – Birmingham)**
- *Service Performance of Welded Duplex Stainless Steel Castings and Wrought Materials* **(University of Tennessee)**
- *Systematic Microstructural Corrosion Performance Evaluation of CN-3MN and CK-3MCUN High Molybdenum Stainless Steel* **(University of Tennessee)**

Environmental

- *Development of Technical Data to Validate Performance of Foundry Byproducts in Hot-mix Asphalt and Controlled Low-Strength Material* **(Pennsylvania State University)**
- *Non-incineration Treatment to Reduce Benzene and V.O.C. Emissions from Green Sand Molding Systems* **(Pennsylvania State University)**
- *Steel Foundry Refractory Lining Optimization: Electric Arc Induction Furnace* **(University of Missouri – Rolla)**

Exhibit 16
Technical Milestones

2002
AFS
- Lost Foam Casting – Referee Materials Produced to Compare Machinability with Other Casting Processes
- Computational Fluid Dynamics Lost Foam Casting - Steaming Module Commercialized
- Foundry Sand Density Guidelines for Surface Finish In Aluminum Castings
- Metal Matrix Composites – Tensile Property Database For Preliminary Design
- Thin Wall Iron Casting - Guidelines to Critical Process Variables In Molding Accuracy
- Iron Fatigue – Low Cycle Fatigue Database For 18 Cast Iron Grades
- Guideline for Gating Molds With And Without Filters
NADCA
- Die Materials - Recommendations for Productivity Improvement
SFSA
- Re-engineering Casting Production Systems-Reorganizing the finishing operation to use robotic finishing to improve productivity and safety
2003
AFS
- Lost Foam Casting – Publish Pattern Metrics For Quality Control
- Computational Fluid Dynamics Lost Foam Casting – Release Full Blowing And Steaming EPS Pattern Designer Software Tool
- Sand Visualization Tool - Active Integration
NADCA
- Die Deflection - Enhanced Tolerances
- Die Coatings- Multi-layer System Recommendation
SFSA
- Yield - Radiographic Standards; Production Approval (30% scrap reduction)
2004
AFS
- Lost Foam Casting – Publish lost foam casting gating rules based on real-time radiography
NADCA
- Sensors in Die Casting - Vibration Signatures for Die Casting Process Control
- Creep Resistant Zinc - New Die Casting Alloys
- Die Design - Design guidelines for reduced thermal fatigue cracking

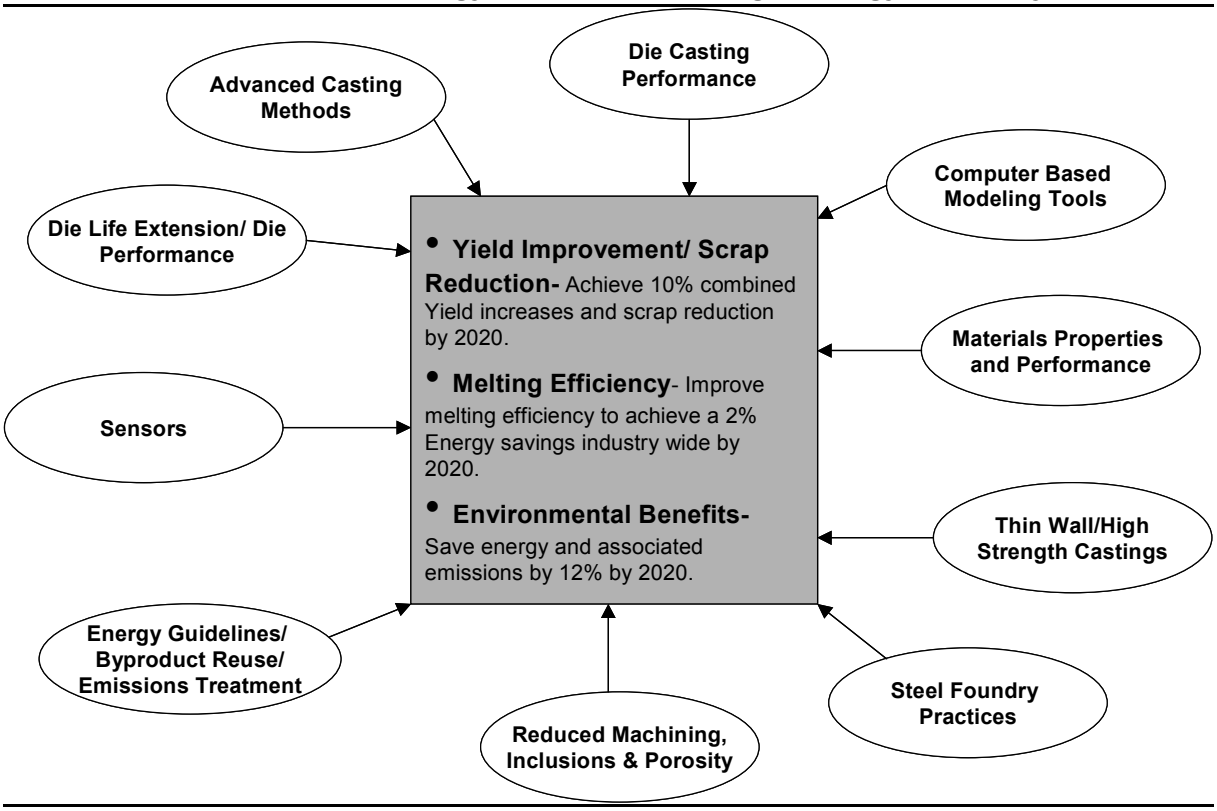
Process and Technology Improvements to Increase Energy Efficiency

As illustrated in Exhibit 17, the Metal Casting IOF program is focusing upon a number of areas of technology and process improvements. These include computer-based modeling tools, material properties and performance, sensors, reductions in machining requirements, and a number of other key areas. The program evaluates projects against performance based metrics to ensure that projects remain on-track and lead to energy savings in the industry.

Specifically, the program is targeting research that will reduce scrap and improve productivity to a level where yield rates increase 10%. Improved yield will reduce the ammount of metal which must be melted per ton of casting shipped, thereby significantly reducing energy requirements. Similarly, the program is emphasizing R&D to improve melting efficiency and reduce post-cast energy requirments.

Looking at the long term, an analysis of the Metal Casting IOF 2001 R&D portfolio indicates that the portfolio will save an estimated 35 trillion Btu annually by 2010 and 75 trillion Btu annually by 2020. This analysis is performed annually in response to the Government Performance and Results Act (GPRA). Results are reported to Congress.

Exhibit 17
Process & Technology Improvements Target Energy Efficiency



Integrated Technical Assistance for the Metal Casting Industry

The EERE Industrial Technologies Program Office has strategically designed its organizational structure to provide industry with an integrated array of assistance for saving energy. This includes:

1) regularly disseminating information on “direct and relevant” research and technical assistance available to the industry
2) hands-on technical assistance, software and other resources for near-term energy savings provided through BestPractices and Industrial Assessment Centers
3) research on leading edge enabling technologies, including Sensors & Controls, Industrial Materials, Combustion and others
4) risk sharing on industry-specific pre-competitive long-term, high-impact research available through the Industries of the Future programs

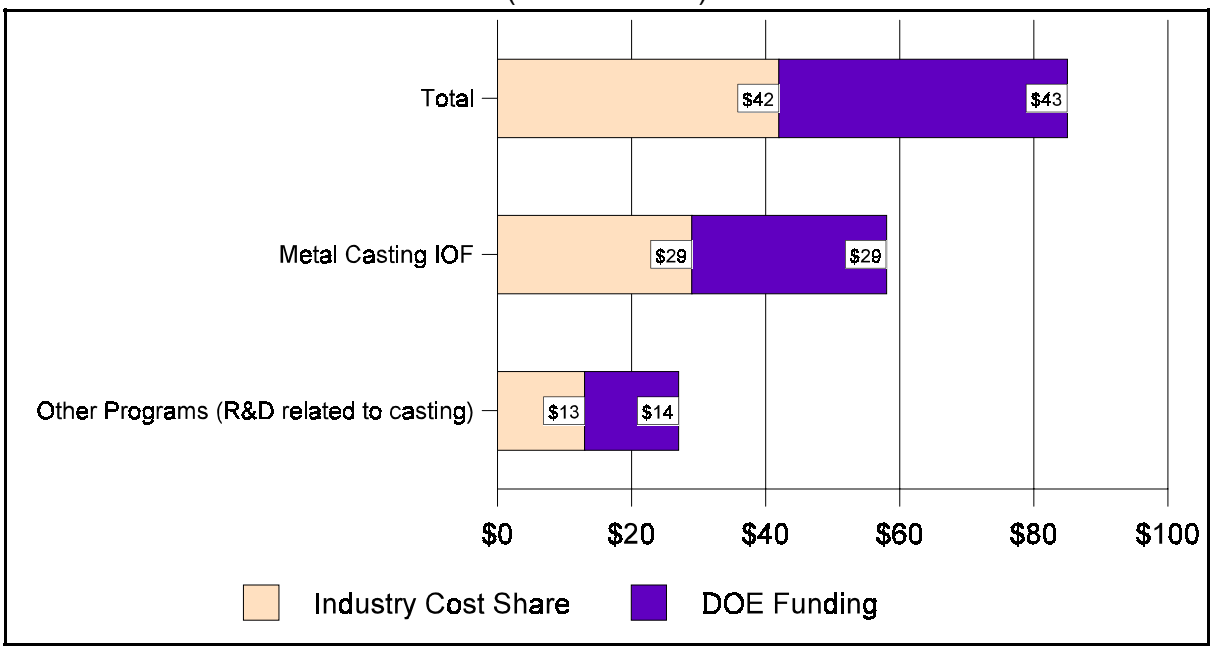
5) financial assistance for innovative energy efficiency concepts and demonstrations, available through the Inventions & Innovation and NICE[3] programs
6) financial assistance for small businesses through Small Business Innovative Research grants

Beyond the research funding provided by the Metal Casting IOF program, virtually all programs and services are available to the metal casting industry to improve energy efficiency and competitiveness in casting processes.

As illustrated in Exhibit 18, the Industrial Technologies Program Office has provided approximately $14 million in funding on current research and technical assistance relevant to metal casters and leveraged an additional $13 million in cost-share. This is in addition to the approximately $29 million in Metal Casting IOF funded research, and matching cost-share, over the period 1992 to the present, and planned through 2004.

Exhibit 19 lists recent examples of research above and beyond that performed through the Metal Casting IOF that is relevant to the metal casting industry. In addition, the Metal Casting Industry of the Future is working with Allied Partners to help deploy the results of metal casting research and improve energy efficiency in the industry.

Exhibit 18
Leveraging Funding for the Metal Casting Industry
(Million Dollars)



Allied Partners are manufacturers, trade associations, industrial service and equipment providers, utilities, and other organizations that agree to help promote increased energy efficiency and productivity for those industries that participate in the Industries of the Future strategy. The metal casting industry is working with the technical societies, state casting associations, research institutes and others to formalize Allied Partnership agreements. Through Allied Partners, EERE will be better able to deliver the results of research programs and technical assistance.

Exhibit 19
Additional Industrial Technologies Research Related to Metal Casting

Financial Assistance

- A Ceramic Composite Die for Metal Casting (Inventions & Innovation)
- Highly Efficient Rapid Tooling Using Optimized Cooling Passages (Inventions & Innovation)
- Nickel Based Superalloy with Improved Weldability and Oxidation Resistance (Inventions & Innovation)
- Lost Foam Casting Quantifier Program (Inventions & Innovation)
- Filtering Molten Metal (Inventions & Innovation)
- Titanium Matrix Composite Tooling Material for Enhanced Manufacture of Aluminum Die Castings (Inventions & Innovation)
- Development of Energy Efficient High-Temperature Natural Gas-fired Furnace (Inventions & Innovation)
- A Process to Recover and Reuse Sulfur Dioxide in Metal Casting Operations (NICE^3)
- Reducing Foundry Emissions and Green Sand Waste (NICE^3)
- Energy Conserving Tool for Combustion Dependent Industries (NICE^3)
- Enhanced Application Control of Die Casting Lubricants (NICE^3)
- Commercial Demonstration of an Improved Magnesium Thixomolding Process (NICE^3)
- Die Casting Copper Motor Rotors (NICE^3)
- Novel Method to Process Electric Arc Furnace Dust Into Saleable Chemical Products (NICE^3)
- Improvement of the Lost Foam Casting Process (NICE^3)

Crosscutting Applications

- Improved Grain Refinement (Aluminum)
- Innovative Vertical Flotation Melter and Scrap Dryer (Aluminum)
- Removal of Residual Elements in the Steel Ladle (Steel)
- Optical Sensor for Post-Combustion Control in Electric Arc Steelmaking (Steel)
- In Situ Real Time Measurement of Melt Constituents in the Aluminum Glass and Steel Industries (Steel)
- Advanced Intermetallic Alloy for Ethylene Reactors (Chemicals)
- Sensing and Control of the Cupola Furnace (Sensors & Controls)

Technical Assistance

- BestPractices - Plant Assessments and Hands-on Technical Assistance
  - AMCAST
  - Indianapolis Casting Corporation
  - RCM Industries
- Industrial Assessments
  - Over $11.6 million in energy saving recommendations implemented in the metal casting industry since 1992

2001 - HIGHLIGHTS & ACCOMPLISHMENTS

The Metal Casting Industry of the Future program posted a number of important technical accomplishments in 2001. It was also a year in which the industry took stock of past accomplishments. The following describes accomplishments during the year in several key areas including:

- A New Vision for the Future
- Improving Energy Efficiency Today
- Applying R&D Results
- Partnership Highlights
- Technology Transfer
- New Project Awards

A New Vision for the Future

Broad-based partnerships and technology roadmapping are key elements of the IOF strategy. Since 1995, the Metal Casting IOF has been guided by *Beyond 2000: A Vision for the American Metal Casting Industry*. Recognizing the need to maintain a dynamic vision and build upon past lessons and accomplishments, industry leaders began a process to update their industry Vision. It started with the *Future Think Forum*. The Forum was held in conjunction with the Department of Energy's Office of Industrial Technologies *4th Industrial Energy Efficiency Symposium and Exposition* in February 2001. Dwight Barnhard, Executive Vice President of the American Foundry Society, and Paul Mikkola, Chief Operating Officer & Executive Vice President of Operations of Hitchiner Manufacturing, led a discussion of the major challenges facing the industry over the next 25 years. It was followed by a two-day workshop held in October 2001 at Ohio State University. At the workshop, leaders from the metal casting industry, U.S. Department of Energy, Environmental Protection Agency, and U.S. Department of Defense identified common challenges and goals in several areas. These included improved design capabilities, process advances, communicating the importance of metal casting to society, and attracting students and employees to the field of metal casting.

Achieving the goals set forth in the Vision will contribute to improved productivity and energy efficiency in the industry and quicken the development and application of advanced, clean technologies in metal casting processes. The industry plans to release the Vision for broad industry review in Spring 2002 and publish it shortly thereafter. The updated Vision represents the goals and challenges, as identified by industry leaders, that must be addressed over the next 20 years.

Improving Energy Efficiency Today

Although the majority of Metal Casting IOF research focuses on mid- to long-term research, there are a number of Industrial Technology Program products and services that help industry to save energy immediately. These include BestPractices and Industrial Assessment Centers as well as software, training, and other energy saving resources. For example, since 1992, over $11.6 million in energy saving recommendations have been implemented in the metal casting industry as a result of recommendations for the Industrial Assessment Centers.

Learn how to save energy today through BestPractices, <www.oit.doe.gov/bestpractices>, and Industrial Assessment Centers, <www.oit.doe.gov/iac>.

The following describes several recent examples of activities to improve energy efficiency in the metal casting industry.

- **Improving Compressed Air Systems Saves Energy and Costs at Indianapolis Casting Corporation** - The BestPractices Program worked with the Indianapolis Casting Corporation (ICC) to optimize their compressed air system. The result was an annual savings of 7,225,000 kWh, or $325,000, and a reduction in maintenance costs of $70,000. Payback on capital investment is just over two years. Following an extensive evaluation of the ICC compressed air system and day-to-day requirements, the compressed air profile was stabilized and pressure was reduced to the lowest level necessary to satisfy production requirements in the foundry. In addition, leaks in the system were identified and repaired. In the powerhouse, two new dryers were installed to eliminate the moisture carryover and lower the operating and maintenance costs of air treatment.

- **Industrial Energy Assessment has Potential to Save Company $3.7 Million Annually** - A plant-wide assessment performed by the BestPractices Program for AMCAST Industrial Corporation in Wapakoneta, OH identified 12 plant and process modifications that would result in an annual savings of $3.7 million per year. A $1 million investment would be required to implement the 12 recommendations, resulting in a payback of just over 3 months. Several of the recommendations were:
  - using electric infrared heaters instead of gas torches to preheat permanent molds, reducing scrap and saving approximately $850,000 per year.
  - using exhaust heat from reverbatory melting furnaces in heat treating furnaces, potentially saving $157,000 per year in natural gas costs.
  - using exhaust heat from heat treating furnaces in aging ovens, savings an additional $93,000 per year.

- **Plant-wide Assessment and Technology Transfer Project Launched at RCM Industries** - This assessment will identify new/emerging technologies that are high priority to industry and define a dissemination strategy to make the industry aware of the technologies. The activity involves three principal activities: 1) The North American Die Casting Association (NADCA) will compile a list of new/emerging technologies of potential interest to the metal casting industry. These technologies will include both those in the Industrial Technologies portfolio and those being developed by industry.

2) NADCA and RCM will assemble a team of technical experts from the industry to assess the applicability/impact of the identified technologies. It is expected that the assessment and implementation of economically justifiable recommendations will result in 10-20% energy savings, 10% increase in productivity, 30-40% improvement in die life, and 10-15% reduction in scrap. 3) The results of the assessment will then be communicated to the industry through final reports published in NADCA's bimonthly magazine, *Die Casting Engineer*, and on the NADCA website.

- **Energy Footprint Study** - In conjunction with industry, the Metal Casting IOF initiated an Energy Footprint Study of the U.S. metal casting industry. The purpose of the study is to benchmark energy use in various metal casting processes and for various types of metal casting facilities. When complete, the results will be used to help measure the effectiveness of process and technology improvements in saving energy. Types of information being gathered from participating facilities include amount and type of energy consumed, including coke and oxygen. A wide range of alloys and common metal casting processes will be included in the analysis.

Applying R&D Results

The Metal Casting Industry of the Future and its partners achieved a number of important research accomplishments during 2001. Research performed through EERE Financial Assistance programs has also posted important successes. Industry is applying these research findings on a real-time basis in their casting operations. The following provides several examples of metal casting research developments and applications.

- **Arena-flow™ - A New Software Package for Foam Pattern Filling Engineering -** Research performed on a new and innovative computational fluid dynamics formulation using a multi-phase particle-in-cell was applied to the complex granular flow behavior controlling sand core blowing. This physics-based approach developed by Flow Simulation Services will capture important fluid phenomena and sand size distribution effects on blowing complex high-quality cores on a production basis. *The result of this research was Arena-flow™ , a math based, engineering software package that can assist in all stages of designing and trouble-shooting not only sand cores but also lost foam patterns.* A graphical user interface includes a mesh generator to easily set up models or run existing models. Answers to "what if" questions are possible with calculations that can be completed in a day, helping to:

  - Visualize the foam filling process
  - Locate and size blowtubes and vents
  - Optimize blow parameters
  - Optimize arrangement of cores on blowplate
  - Eliminate filling problems
  - Reduce tool wear
  - Make "good patterns
  - Optimize gas cycle

- **Yield Improvement in Steel Castings** - *Research to reduce riser length is demonstrating yield improvements of up to 30% for a low implementation cost.* In research at the University of Iowa and in conjunction with industry partners, three casting trials were performed comparing three inches thick by six inches wide plate castings produced with and without riser pressurization. In each trial, a slightly different technique or schedule was used to apply the pressure. Computer simulations were performed to assist in both the design of the trials and the analysis of the trial results. The results of the trials showed that a system capable of applying pressure to the riser could be developed from materials that many foundries already have at hand.

- **Clean Steel Casting** - Clean Steel Casting research has changed the notion of gating and pouring throughout the casting industry. It is resulting in significant yield improvements in steel casting with application to other materials including iron and aluminum. *The use of shrouding with proper guidelines is significantly reducing reoxidation and inclusions in steel castings. Some industry partners are seeing inclusions drop by 30 to 60 percent.* Because gating systems are eliminated, thus reducing steel, labor, and gating system costs, and yield is higher, there is no net cost for shrouds. Industry partners on the University of Alabama - Birmingham estimate that 20 percent of the steel casting market could eventually use shrouds. It will take an estimated 5 to 10 years to penetrate that portion of the market, but will have significant improvements in yield, reduced scrap associated with gating, and reduced melting requirements. *Industry partners have said that shrouds are reducing casting costs by 15 - 20 percent.*

- **Die Casting Copper Conductors for Induction Motor Rotors** - Motor manufacturers have long realized that replacing the aluminum conductor structure of the rotor with pure copper would significantly increase the electrical energy efficiency of the motor. Motor modeling had shown that motors with copper-containing rotors would yield overall loss reductions from 15% to 20% compared to the aluminum counterpart. Conventional tool molds were not adequate for casting higher melting point metals such as copper. A durable and cost-effective mold material was needed. A multi-disciplinary team of motor manufacturers, die casting equipment manufacturers, the Copper Development Association, International Copper Association, design and materials companies came together to solve the problem. A grant from OIT's NICE[3] program to Trex Enterprises at the onset of the program was the catalyst to the successful development mold materials suitable for die casting copper motor rotors. *Following a series of tests and in-depth analyses, researchers identified the INCONEL alloys, 601, 617 and 625 operated in the 600-650°C temperature range as very promising mold materials for die casting copper motor rotors.* Copper motor rotors were pressure die cast and evaluated in motor tests by participating motor manufacturers. The tests showed that the process for pressure die casting copper motor was very robust and allows for a wide range of machine parameters. *Motor manufacturers tested the motor rotors and found energy efficiency improvements on the order of 14% and higher*.[19]

- **Process Parameters for Lead-Free Copper-Base Engineering Alloys** - Currently about 25% of lead-free copper-base engineering alloys are produced using the permanent mold process and about 75% are produced using sand casting. The market demand for lead-free alloys is increasing and permanent mold casting will be needed to ensure these castings have the desired dimensional accuracy and material properties. *This research, at the Materials Technology Laboratory, is optimizing process parameters such as mold materials, mold coating, casting fluidity, grain refinement and gating design in permanent mold lead-free copper alloys. Considerable success has been achieved in producing these castings using the permanent mold process and the share of lead free copper-base alloys casting using permanent mold is increasing rapidly.* The project is resulting in large electricity savings as well as large carbon dioxide emission reductions. Results are being publicized by AFS and the Copper Development Association.

- **Qualitative Reasoning for Die Casting Design Application** - Modeling research being performed at Ohio State University through the Metal Casting IOF is pushing casting industry simulation modeling to new levels. This specific project is extending current reasoning methods to: 1) visualize fill in squeeze casting as well as low-pressure casting, and gravity casting; 2) provide a relative equilibrium temperature distribution in the part and die (cooling line placement); and 3) to provide qualitative shrinkage/distortion predictions for the part and ejector pin locations. It has produced a qualitative technique that generates results approximating mathematical models. It gives relative results, but not exact quantitative results, and is enabling alternative simulations to minimize shrinkage and distortion. *NADCA has published case studies on industry applications of the model. These applications show no added cost or time for tooling; a minimum 20% reduction in scrap; and energy savings of 4 x 10^7 Btu per year for one company on one part alone.* By using qualitative methods up-front, alternative design simulations can be performed in the design stage and potential flaws can be captured. In addition, the use of qualitative reasoning requires less

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[19] *Die Casting Engineer,* "Materials & Modifications to Die Cast the Copper Conductors of the Induction Motor Rotor", September 2001, p. 38.

technical expertise for evaluating the results, thus the simulation outputs can be used and interpreted by a larger number of people.

- **Enhancements in Magnesium Die Casting** - This project is designed to improve the impact properties of die cast magnesium parts. Experimental results to date have confirmed a strong relationship between the aluminum content of the magnesium alloys and the mechanical properties. *The results of this research can be used by die casters of magnesium to optimize the properties attained. Good impact properties of magnesium are best obtained with fine grained AM50 and AM60 alloys.* The castings should be produced with a minimum of porosity, impurities and Mg17A112 in the matrix. These properties are obtained from alloys that are transferred from the melt with a small amount of metal damage and solidified rapidly in the die casting die. Tensile properties of 30 ksi and Charpy V-notch impact of 5 foot pounds are feasible under these casting conditions.[20]

- **Re-engineering Casting Production Systems** - Research performed through the Steel Founders' Society of America and Iowa State University set out to reduce work-in-progress and lead times in steel foundries. *By reducing work-in-progress, metal casters can reduce casting inventory, save valuable floor space, and reduce in-plant transportation requirements (fork truck, conveyor, etc.).* Researchers analyzed 21 foundries and made a number of findings that can be implemented in all types of foundries. Recommendations include: development of flowpaths to evaluate current procedures and identify opportunities to optimize those procedures; reduce material handling by moving people to castings rather than moving castings to people; perform sorting at shakeout to reduce unnecessary sorting; and assign personnel to be responsible for reducing material handling.

- **Improve Metal Flow in Lost Foam Casting** - Research partners involved in the lost foam casting project have developed new findings on the effect of the gating design on metal flow and defect formulation in aluminum. *Test results showed that untapered, hollow ceramic sprue, using the least amount of glue possible and a filter was beneficial in reducing pyrolosis defects*. This was the result of tests on various gating arrangements to measure metal velocity, maximum metal temperature during fill, and the number and location of pyrolysis defects. Variables tested were the sprue type (foam versus untapered hollow ceramic), filters, overflows, number and location of gates, and pattern contraction.[21]

During 2001, the Metal Casting IOF reviewed past and current Industrial Technologies Program research projects relevant to the industry to identify those which are having commercial success or are emerging as a potential commercial success. A list of these projects is shown in Exhibit 20. For more information on these projects, visit the metal casting web site at: <www.oit.doe.gov/metalcasting>.

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[20] *Die Casting Engineer,* "Research & Development Dips into Alloys", September 2001, p. 56.

[21] *Modern Casting*, "Optimizing Metal Control, Quality", June 2001, p. 65.

Exhibit 20
Commercial and Emerging Successes from Metal Casting Research

Commercial Technologies	Emerging Technologies
• Cupola Furnace Process Model • Laser-based Laminated Object Manufacturing • Meta-lax Stress Relief Process • Precision Pattern Production, Multiple Station Air Gauge • Reactive Sintered Nickel Aluminide • CastView: Simple Visualization Tools for Part and Die Design	• Highly Efficient Rapid Tooling Using Optimized Cooling Passages • Intelligent Control of the Cupola Furnace • Lost Foam Casting Technology • Process to Recover and Reuse Sulfur Dioxide in Metal Casting Operations • Rapid Heat Treatment of Cast Aluminum • Three-dimensional Objects by Photosolidification

Partnership Highlights

There were a number of important events during 2001 that highlighted the partnership between industry, states, universities and others through the Metal Casting IOF program. These included:

- **New Assistant Secretary Meets with Industry Leaders, Sees Metal Casting Research in Action** - DOE's Assistant Secretary for Energy Efficiency and Renewable Energy, David Garman, attended the North American Die Casting Association's 21st International Die Casting Congress and Exposition, October 2001 in Cleveland, Ohio. The event proved to be an excellent opportunity for the Assistant Secretary to meet one-on-one with leaders from the metal casting industry including industry CEOs and the Cast Metals Coalition executive leadership. Plant tours illustrated how Metal Casting IOF research is saving energy and improving competitiveness for U.S. metal casters.

  Tours included Willard Industries, a small business in Cincinnati, where implementation of lost foam casting research results is having a dramatic impact in improving energy efficiency, productivity and competitiveness. Another tour to CastFab, a gray and ductile iron foundry illustrated the benefits of machinability research in reducing scrap and saving energy. During the Congress, Metal Casting IOF research represented 14 of the 60 technical papers. Many of the programs partners exhibited at the Expo showing posters describing the quantitative and qualitative benefits of specific research projects.

- **National Research Council Answers Question: "Was it Worth it" for Lost Foam Casting** - In 2001, the National Research Council performed an extensive review of several U.S. Department of Energy fossil energy and energy efficiency research programs for the purpose of evaluating whether the payback in energy efficiency and productivity improvements was worth the federal R&D investment. Among the R&D programs evaluated was the Metal Casting IOF lost foam casting research. The National Research Council review validated that DOE sponsorship of lost foam research removed a number of important technical barriers that had been impeding commercialization. This research contributes to the industry's ability to benefit from the significant energy savings available through lost foam casting. The Council also

validated the role of DOE as a "catalyst for bringing industry together to address pre-competitive" research needs.[22]

- **Collaborative R&D Enables Technology Innovation** - Revolutionary improvements in product performance are often hindered by technical barriers too large for one company to overcome alone. This is particularly true in metal casting where the majority of companies are small businesses. Collaborative efforts are enabling industry, universties, and technical societies to come together to identify innovative methods for addressing common barriers. One such barrier has been an effective method for managing heat output in motors and other heat generating products. Research conducted at Worcester Polytechnic Institute evaluated microstructural performance interaction of aluminum alloys. A number of industry partners shared knowhow and data as well as provided cost-share on this research. The results have been broadly disseminated to the industry and in a recent innovation, were used to cast metal heat sink molds. These molds have made possible unprecedented leaps in new technologies:

  - The Independence 3000 IBOT Transporter gives unprecedented mobility and access to wheel chair users through a rotating four-wheel base that is gyro-balanced and controlled by computers, sensors and actuators. The unusually high rate of heat generated by these components had to somehow be managed. WPI research results contributed to a custom die-cast heat sink that helped to make this revolutionary wheelchair possible.

  - A similar thermal management problem faces CPU manufacturers. As the demand for faster computers increases, so does the need for new methods for thermal management in the CPU. NEC Computers, Inc. needed to find a heat sink capable of protecting a CPU running at 600 megahertz. Using the results of WPI research, a heat sink was designed specifically for managing the thermal loads of the faster CPU.

- **State IOF Expands Outreach to Metal Casters -** The State Industries of the Future program is designed to translate the national IOF strategy to the state level in order to address local needs and reach a larger number of customers. A number of new states received IOF grants in 2001 and plan to target metal casting companies. These State IOF activities will help to transfer the results and impact of the national metal casting IOF to the local level. It will help in both outreach and targeted assistance to address local needs of metal casters. State IOFs with a metal casting emphasis include: Indiana, Massachusetts, Ohio, South Carolina, Iowa, Michigan, New Hampshire, Pennsylvania, Wisconsin, Illinois, and Oregon. In particular, Wisconsin and Massachusetts are developing State Metal Casting Roadmaps.

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[22] National Research Council, *Energy Research at DOE: Was it Worth It?*, 2001.

Using the framework of the State IOF strategy, metal casters in West Virginia worked with state government agencies and legislators to develop a new policy that would allow beneficial reuse of foundry sand. The new policy was signed June 1, 2001 by the West Virginia Department of Environmental Protection permitting a number of useful applications for spent sand. This policy not only reduces the demand on landfills, it saves foundries money by reducing landfilling costs. For example, since the new policy was signed, one foundry has saved $500,000 by using its sand for structural fill rather than having it landfilled.

- **University-based Research** – Since its inception, the Metal Casting Industry of the Future has emphasize university-based research. This emphasis has several important benefits:

  - It leverages the extensive technical resources and knowhow available at our nation's universities
  - It encourages partnerships between industry and universities
  - It helps to sustain and grow university-based curricula in technical fields related to casting and materials sciences
  - By exposing students to the field of metal casting, it addresses one of the industry's primary concerns – the shortage of a qualified workforce entering the industry

  During 2001, the program supported cost-shared research at over a dozen universities around the U.S. This has proven to be a mutually beneficial relationship for the students and industry. It is providing students the opportunity to learn the latest advances in metal casting technology and carry that knowledge with them as they pursue careers in the industry. In 2001, the program began to track the status of students that had participated in program-funded research. Exhibit 21 shows the preliminary status of students who have participated in metal casting research. As illustrated, 73% (136 of 186) of students who have graduated, have pursued careers in the industry. The remaining 27% are either pursuing advanced degrees or have taken positions in other fields. The data shown in Exhibit 20 are preliminary and do not include all of the universities that the program has worked with since its inception.

- **Outreach at the High School Level** -During 2001, the Metal Casting IOF program began to reach out to high school level students to expose them to the field of metal casting as they prepare for college. The program sponsored a high school metal casting competition with the Junior Engineering Technical Society (JETs). Almost 16,000 high school students from around the country participated in the test which included questions regarding metal casting as well as the other Industries of the Future. The metal casting section of the test was developed by metal casting researchers from Iowa State University and Ohio State University. The winning team, the Arts and Sciences Academy in Saginaw, Michigan, came to Washington, D.C. and gave a poster presentation on their results during the 4th OIT International Symposium and Exposition.

Exhibit 21
Metal Casting Graduates: Preliminary Data

University	Metal Casting IOF Research Alumni	Graduates Known to be in the Industry
University of Alabama	24	10
University of Alabama - Birmingham	12	8
University of Missouri - Rolla	11	9
Ohio State University	46	36
Worcester Polytechnic Institute	23	18
University of Tennessee	1	1
Iowa State University	2	2
Penn State University	19	17
Tri-State University	2	2
University of Iowa	4	4
Case Western Reserve University	42	29
Preliminary Total	**186**	**136**

Note: Data do not include students currently participating in Metal Casting IOF research. Data are not available from all universities participating from the inception of the program in 1990.

Technology Transfer

NADCA, AFS and SFSA continued to excel in getting the word out on technical R&D accomplishments. Dozens of articles were published in the trade press including *Die Casting Engineer, Modern Casting, Engineered Cast Solutions* and *Links* magazines. Metal Casting researchers from universities, laboratories and industry presented technical results of metal casting R&D at technical conferences sponsored by AFS, NADCA and SFSA. EERE Metal Casting program staff gave presentations at numerous meetings and conferences including the 2001 ACEEE Summer Study as well as State IOF meetings in Wisconsin, Michigan, Ohio, and Tennessee. Additional technology transfer activities in 2001 included:

- **Utah Technology Showcase -** In August 2001, the program participated in the *Utah Technology Showcase*, which highlighted energy savings measures implemented as a result of BestPractices and IOF research in the metal casting, aluminum, mining and petroleum industries. Over 400 participants attended, taking plant tours to see first hand how industrial facilities are improving energy efficiency and saving costs. The Executive Vice President of AFS spoke before a Congressional Panel on the importance of the metal casting industry to the U.S. Technical sessions were held on recent results in metal casting research.

- **Allied Partners Extend Outreach for Implementing Energy Savings** - In 2001, the Metal Casting IOF began identifying organizations to participate as Allied Partners and help transfer and implement energy-saving technologies and practices in the metal casting industry. Research organizations, technical societies, state and regional casting associations are all potential Allied Partners. They can help the program transfer both BestPractices and R&D results to metal casting.

- **Gateway to Metal Casting Resources-** In October 2001, the Metal Casting IOF launched a beta version of its Gateway to Metal Casting Resources CD-ROM. The CD is designed to help metal casting plant managers quickly find information on technical R&D results, technical assistance, financial assistance, training, and other assistance specifically for metal casters. The final version will be released in Spring 2002.

New Project Awards

The program's solicitation for competitive cost-shared research proposals resulted in twelve new awards in 2001. They are listed in Exhibit 22. These projects, along with the remainder of the metal casting research portfolio, respond to both industry research priorities as well as national energy efficiency goals.

Exhibit 22
2001 Metal Casting Research Awards

Project Title	Performing Organization
Yield Improvement and Defect Reduction in Steel Casting	The University of Iowa
Prediction of Part Distortion in Die Casting	The Ohio State University
Metallic Recovery and Ferrous Melting Processes	Tri-State University/University of Missouri -Rolla
Reduction in Energy Consumption and Variability in Steel Foundry Melting and Casting Operations	Iowa State University
Advanced Steel Casting Technology	University of Alabama-Birmingham
Development Program for Natural Aging Aluminum Casting Alloys	GKS Engineering Services
Determination of Bulk Dimensional Variation in Castings	The University of North Carolina at Charlotte
Low Cost and Energy Efficient Methods for The Manufacturing of Semi Solid Feedstock	Worcester Polytechnic Institute
Thin Wall Cast Iron: Phase II	The University of Alabama
Improved Design, Operation and Durability of Shot Sleeves	Case Western Reserve University
Quantification and Standardization of Pattern Properties For Control of the Lost Foam Metal Casting Process	Industrial Analytics Corporation
Investigation of Heat Transfer at the Mold/Metal Interface in Permanent Mold Casting of Light Alloys	The University of Michigan

Appendix A

Current Metal Casting Research Partners By State

Appendix A
Current Metal Casting Research Partners By State

Bold italics denotes project lead

Alabama
ABC Coke, Birmingham
ABC Rail Products, Calera
Alexander City Casting, Alexander
American Cast Iron Pipe Co., Birmingham
American Centrifugal, Birmingham
Auburn University, Auburn
Citation Corporation, Birmingham
Foseco-Morval Inc., Bessemer
Mueller Corp., Albertville
Southern Alloy Corporation, Sylacauga
University of Alabama-Birmingham

Arkansas
Sloan Valve Company, Augusta

California
ABI, Oakland
Alloy Tool Steel, Santa Fe Springs
Pacific Steel Castings Company, Berkley

Colorado
Colorado School of Mines, Golden
Colorado State University, Fort Collins

Georgia
Georgia Iron Works, Grovetown
Tecpro Corp., Atlanta

Iowa
Iowa State University, Ames
Keokuk Steel Casting, Keokuk
Sivyer Steel Corporation, Bettendorf
University of Iowa, Iowa City

Idaho
Idaho National Engineering and Environmental Laboratory, Idaho Falls

Illinois
A. Finkle & Sons, Chicago
ABC-NACO, Cicero
ABC-NACO, Downers Grove
ABC-NACO, Lombard
AECCO, Champaign
Alloy Rods, Champaign
American Foundry Society, Des Plaines
American Steel Foundries, East Chicago
American Steel Foundries, Granite City
Arrow Aluminum Castings Co. Inc., Woodstock
Austin Associates, Quincy
Brass and Bronze Ingot Manufacturers, Chicago
Caterpillar Inc., Peoria
Chicago White Metal, Basenville
CMI Novacast, Inc., Elk Grove Village
FPM Heat Treatment, Elk Grove
General Kinematics Corp., Barrington
H. Kramer & Co., Chicago
Heick Die Casting Corp., Chicago
Illinois Cast Metals Association, North Pekin
Ingersoll Cutting Tools, Rockford
K&P Agile, Inc., Naperville
Kirit Dave (Consultant), Naperville
Magma Foundry Technologies, Inc., Arlington Heights
Miller & Co., Rosemont
National Castings, Cicero
North American Die Casting Association, Rosemont
PrimeCast, South Beloit
Q.I.T. America, Chicago
Rio Tinto Iron & Titanium, Rosemont
R. Lavin & Sons, Inc., Chicago
R&S Design, Bloomingdale
Spartan Light Metal Products, Sparta
Steel Founders' Society of America, Barrington
Superior Graphite, Chicago
U.S. Environmental Protection Agency, Chicago

Indiana
ABC Rail Products, Anderson
Auburn Analytical, Auburn
Bohn Aluminum Corporation, Butler
Bosch Breaking Systems, South Bend
CMW, Indianapolis
Cummins Engine, Columbus
Daimler Chrysler Corporation, Indianapolis
Dalton Corporation, Kendallville
Dalton Corporation, Warsaw
Delaware Machine, Muncie
Electric Steel Castings, Indianapolis
GM Bedford, Bedford
Hard Chrome, Evansville
Harrison Steel Castings Company, Attica
Hiler Industries, LaPorte
Indiana Cast Metals Association, Indianapolis
Intat Precision, Rushville
Maco Corp., Huntington
Matrix Technologies, Muncie
Omnisource Corporation, Fort Wayne
Ryobi Die Casting (USA), Inc., Shelbyville
Shenango, Terre Haute
Technalysis, Indianapolis
Tri-State University, Angola

Kansas
Atchison Casting Corp., Atchison

Kentucky
Carrollton Casting Center, Carrollton
Furness-Newburge, Inc., Versailles
M. Argueso & Co., Mamaroneck

Louisiana
Carbo Ceramics, Iberia
Hendrix Manufacturing, Mansfield

Massachusetts
Cambridge Tool and Manufacturing, North Billerica
Company, Inc., North Billerica
EO Associates, Mill River
Johnson & Johnson, Raynham
Kennedy Die Castings, Inc., Worcester
Metal Processing Institute, Worcester
Palmer Foundry, Inc., Palmer
Wollaston Alloys, Inc., Braintree

Maryland
Black and Decker, Baltimore
UES, Inc., Annapolis

Michigan
A-CMI, Michigan Casting Center, Fruitport
Amcast Industrial Corporation, Southfield
Applied Process, Livona
Arvin Meritor Automotive, Troy
Bay Cast, Inc., Bay City
Chem-Trend, Inc., Howell
Climax Research Services, Wixom Hills
CMI- Michigan Casting Center, Cadillac
CMI-Tech Center, Ferndale
Dynamic Metal Treating, Canton Twp.
Ford Motor Company, Dearborn
Ford-Rawsonville Plant, Ypsilanti
Foundry Association of Michigan, Lansing
General Motors Corporation, Pontiac
GM Advanced Development Laboratory, Saginaw
GM Powertrain, Pontiac
GM Powertrian Ypsilanti, Ypsilanti
GM Worldwide Facilities Group Environmental Services
Division, Detroit
Grand Rapid Aluminum Casting, Grand Rapids
Hayes Lemmerz International, Inc., Ferndale
Hickman Williams & Co., Livonia
Howmet Corp., Whitehall
Lost Foam Technologies, Sheboygan
Metalloy Corporation, Hudson
NEMAK, Southfield
Premier Tool & Die Cast Corporation, Berrien Springs
Prince Machine, Holland
S. Katz Associates, W. Bloomfield
SIMTEC, Inc., Grand Rapids
Simpson Technologies, Jackson
SPX Contech Division, Portage
Thixomat, Ann Arbor
TRW Automotive, Livonia
UBE Machinery, Ann Arbor
University of Michigan, Ann Arbor

Minnesota
Buhler, Inc., Minneapolis
Hitchcock Industries, Inc., Minneapolis
Nicollet, Minneapolis
Progress Casting Group, Plymouth
Superior Industries International, Inc., Morris
Tool Products, Minneapolis
United Machine and Foundry, Winona

Missouri
Carondelet Corporation, Pevely
Die Makers, Monroe City
Hubbel Power Systems, Centralia
Missouri Steel Castings, Joplin
Monett Metals, Monett
St. Clair Die Casting, St. Clair
St. Louis Precision Casting, St. Louis
Stahl Specialty Company, Kingsville
University of Missouri-Rolla, Rolla

Mississippi
Mississippi State University, Mississippi State
Southern Cast Products, Meridian

New Jersey
Metallurg Aluminum, Newfield
HC Stark, East Rutherford

New Mexico
Arena, LLC, Albuquerque
Flow Simulation Services, Inc., Los Alamos
Los Alamos National Laboratory, Los Alamos

New York
Copper Development Association, New York
Eastern Alloys, Maybrook
International Copper Association Ltd., New York
Welding Research Council, New York

North Carolina
Allvac, Monroe
Consolidated Diesel, Whitakers
International Lead Zinc Research Organization, Inc. (ILZRO), Research Triangle Park
Selee Corporation, Hendersonville
Southeastern Foundry Products, Greensboro
University of North Carolina- Charlotte, Charlotte

Ohio
Alotech, Cleveland
Amcast Industrial Corporation, Dayton
A-Mold, Mason
Ashland Chemical Co., Cuyahoga Heights
Blaze Technical Sensors, Stowe
Borden Chemical, Inc., Toledo
Bradken Marion Corp, Marion
Brost Foundry Company, Cleveland
Brush Wellman, Cleveland
Buckeye Steel Castings, Columbus
Case Western Reserve University, Cleveland
Copeland Corporation, Sidney

CSM Industries, Cleveland
DCD Technologies, Cleveland
Edison Materials Technology Center, Dayton
Electroalloys Corp., Elyria
Elkam Metals Co., Ashtabula
Eluclid Heat Treat, Cleveland
Fairmont Minerals, Chardon
Foseco, Cleveland
General Die Casters, Inc., Peninsula
Global Metal Technologies, Inc., Solon
Humtown Products, Columbiana
ITT Automotive, Cleveland
Kowalski Heat Treating, Cleveland
Kurtz Brothers, Inc., Groveport
Lester Precision Die Casting, Twinsburg
Lindberg Heat Treat, Solon
Metaldyne, Bedford Hieghts
Ohio Cast Metals Association, Columbus
Ohio State University, Columbus
Precision Metalsmiths, Inc., Cleveland
Procast, Dayton
Ross Aluminum Foundries, Sidney
Sawbrook Steel Casting, Lockland
Thyssen, Cleveland
United Foundries, Canton

Oregon
Albany Research Center, Albany
Columbia Steel Castings, Portland
Consolidated Metco, Clackamas
Northwest Aluminum Company, The Dalles
PED Manufacturing, Oregon City
Varicast, Inc., Portland

Pennsylvania
Advanced Cast Products, Inc., Meadville
Aluminum Company of America, Alcoa Technical Center
Baker, Refractories, York
Blue Ridge Pressure Castings, Lehighton
Durametal Corporation, Muncy
Erie Bronze & Aluminum, Erie
Esab Welding & Cutting Products, Hanover
Frogswitch, Carlisle
GKS Engineering Services, Johnstown
Heraeus Electro-Nite Company, Philadelphia
J.S. McCormick, Pittsburgh
Latrobe Steel Company, Latrobe
McConway & Torley Corporation, Pittsburgh
North American Refractories, State College
Nova Precision, Auburn
Pennsylvania Foundry Group, Myerstown
Pennsylvania Foundrymen's Association, Plymouth Meeting
Pennsylvania State University, University Park
Pennsylvania Steel, Hamburg
PIAD Precision Casting Corporation, Greensburg
Process Recovery Corp., Sinking Spring
Quaker Alloy, Inc., Myerstown

South Carolina
Advanced Technology Institute, Charleston
IonBond, Duncan
Sulzer Pumps, Easley

Tennessee
Accu-Cast, Inc., Chattanooga
AEMP Corporation, Jackson
American Magotteaux, Pulaski
MINCO, Inc., Midway
Oak Ridge National Laboratory, Oak Ridge
Saturn Corp., Spring Hill
Teksid Aluminum Foundry, Inc., Dickson
University of Tennessee, Knoxville
Wheland Foundry, Chattanooga

Texas
GH Hensley Industries, Dallas
KO Steel Foundry, San Antonio
Southwest Steel Castings Co., Longview
Styrochem International, Ft. Worth
Texaloy Foundry, Floresville
Texas Steel Company, Fort Worth

Utah
Maca Supply, Springville

Virginia
Intermet Corporation, Lynchburg

Washington
Atlas Foundry and Machine, Tacoma
Kaiser Aluminum and Chemical Corporation, Spokane
Spokane Steel Foundry Co., Spokane

Wisconsin
American Colloid, Berlin
Albany Chicago Co., Kenosha
Badger Metal Technology, Menomonee Falls
Badger Mining Corporation, Berlin
Bay Engineered Castings Inc., De Pere
Briggs & Stratton Corporation, Wauwatosa
Briggs Die Casting, Wauwatosa
Brillion Iron Works, Brillion
Falk Corporation, Milwaukee
Grede Foundries, Inc., Reedsburg
Harley-Davidson Motor Company, Milwaukee
IMA USA, Inc., Sheboygan
International Truck and Engine Corp. Waukesha
J.L. French International, Sheboygan
Kohler Company, Kohler
Madison-Kipp Corporation, Madison
Maynard Steel Casting Co., Milwaukee
Mercury Marine, Fond Du Lac
Milwaukee Steel, Milwaukee
Neenah Foundry Company, Neenah
Outboard Marine Corp., Waukesha
Payne & Dolan, Inc., Waukesha
Pelton Casteel, Milwaukee
Stainless Foundry & Engineering, Milwaukee
Starline Mfg. Co., Inc., Milwaukee
University of Wisconsin, Madison
Walkington Engineering, Cottage Grove

West Virginia

Ormet Corporation, Wheeling

Appendix B

Current Metal Casting Research Projects and Partners: By Roadmap Area

Appendix B

Current Metal Casting Research Projects and Partners: By Roadmap Area

Manufacturing Technologies

Effects of Die Design & Dimensional Features on Thermal Fatigue Cracking of Die Casting Dies, **Case Western Reserve University-** The objective of the project is to identify and evaluate the effect of design factors such as size and location of cooling lines, sudden changes in cross-section, and sharp radii on the life of die casting dies. The study will provide die designers with computer tools that allow them to predict the thermal stresses in dies, and a method to relate these stresses with thermal fatigue cracking. These tools can be applied towards mitigating or eliminating design related problems and their adverse effect on die life. The study will develop a new approach in design of dies for thermal fatigue resistance. This approach is designed to identify potential hot spots (thermal) and high stresses in the design by minimizing them by modifying the dimensions of the inserts and the location and size of the cooling lines. It includes 1) computer aided design of the die with all geometrical details, including location of cooling lines, 2) couple finite element modeling of flow/thermal/stress of the die, and 3) thermal fatigue immersion testing to determine the actual effect of the maximum design temperatures and stresses on the heat checking damage.

North American Die Casting Association- Rosemont, IL
DCD Technologies, Cleveland, OH
General Die Casters, Peninsula, OH
Procast, Dayton, OH
Lester Precision Die Casting, Solon, OH
Thyssen, Cleveland, OH
Latrobe Steel Company, Latrobe, PA
PAFPM Heat Treatment, Chicago, IL
A. Finkyl & Sons, Chicago, IL
CSM Industries, Cleveland, OH
Brush Wellman, Cleveland, OH
Alloy Tool Steel, Santa Fe Springs, CA
Hayes-Tech Center, Ferndale, MI
Chem-Trend, Howell, MI
Badger Metal Technology, Menomonee Falls, WI

Gating of Permanent Mold Aluminum Casting (Phase II), **Case Western Reserve University**- The objective of this project is to provide a basis for improved gating design for vertically-parted aluminum permanent mold castings. The design of gating for conventional gravity-fed vertically-parted permanent mold castings is a task which is performed daily throughout the foundry industry, but for which there is a great deal of dissatisfaction with the current design methodology and recommended gating designs. Basic gating design has remained essentially unchanged since the mid 1950's. This program will examine the gating of vertically-parted aluminum permanent mold castings through a combination of experiments and computer simulations to develop improved gating designs. The improved gating systems will aim to eliminate molten metal surface turbulence during mold filling in order to reduce casting defects, maximize thermal gradients during solidification to aid metal feeding, provide necessary risers as a source of feed metal, and maximize casting yield by minimizing gating and riser size. Through improved gating design, castings can be produced with higher casting yields, lower scrap rates, lower defect contents, and with fewer initial design iterations. Real-time x-ray radiography will be used to visualize the filling of molten aluminum into a set of vertically-parted permanent molds. Experiments will be performed with the same gating designs in specially instrumented permanent molds to measure the thermal history of the casting during mold filling and solidification. The combinations of radiography and thermal measurements will be used as benchmarks to verify a computer model of the permanent mold casting process. This heat and fluid flow model will be based on a commercial finite element or computational fluid dynamics code modified to reflect the aluminum / metal mold casting system. The verified model will then be used to examine a large number of gating and process variations to develop an improved set of gating recommendations and designs. The improved designs will be verified with experiments (including x-ray radiography) and plant trials on industrial castings.

American Foundry Society, Des Plaines, IL
CMI- Michigan Casting Center, Cadillac, MI
Hayes Lemmerz, Ferndale, MI
Foseco, Inc., Cleveland, OH
UES, Inc., Annapolis, MD
Stahl Specialty Co., Kingsville, MO
St. Louis Precision Casting, St. Louis, MO
Bohn Aluminum Corp., Butler, IN
Amcast Automotive, Southfield, MI
Grand Rapid Aluminum Casting, Grand Rapids, MI
Arrow Aluminum Castings Co. Inc., Woodstock, IL
DCD Technology, Cleveland, OH

Mold Materials for Permanent Molding of Aluminum Alloys, **Case Western Reserve University**- The primary goals of this project are to extend the life and improve the quality of permanent molds utilized in casting aluminum. The relative mold life under the thermal conditions that prevail in permanent molds that experience exposure to molten aluminum will be determined for a range of materials such as gray iron (Meehanite), ductile iron, and compacted graphite iron. These materials may be used plain or alloyed to provide microstructures with different life and stabilities at elevated temperatures. Other candidate materials are cast and wrought 4140 type steels, and cast and wrought H-13 steels. An additional goal is to reduce the cost of the molds and improve the surface and soundness quality of the aluminum castings by selective application of coatings. Different coatings can control the rate at which heat is dissipated into the mold material. This heat transfer is a function of the diffusivity of the mold material, but the heat transfer in a metal mold is controlled to a large extent by the heat transfer at the interface of the mold with the casting. The coating, or mold washes employed in the industry, exert a direct effect on the surface heat transfer coefficient. In this project, state of the art coatings used in the permanent mold industry will be evaluated and compared. The heat transfer coefficients will be determined and correlated to the thickness of the coating.

American Foundry Society, Des Plaines, IL
Amcast Industrial Corporation, Southfield, MI
Arrow Aluminum Casting, Woodstock, IL
Bohn Aluminum Corporation, Butler, IN
DCD Technology, Cleveland, OH
Foseco, Inc., Cleveland, OH
Grand Rapid Aluminum Casting, Grand Rapids, MI
Hayes Lemmerz-CMI, Ferndale, MI
Progress Casting Group, Plymouth, MN
Stahl Specialty Company, Kingsville, MO
St. Louis Precision Castings, St. Louis, MO
UES, Inc., Annapolis, MD

Optimization of Composition and Heat Treating of Die Steels for Extended Lifetime, **Case Western Reserve University-** The overall objective of the program is to extend the life of die materials utilized in aluminum die casting by 50%. It will: further evaluate the effect of controlled changes in steel chemistry on the resistance to heat checking, develop a new fast interrupted oil-quenching cycle, and verify the results of the laboratory tests with in-plant trials using production die casting machines.

North American Die Casting Association, Rosemont, IL
Latrobe Steel Company, Latrobe, PA
FPM Heat Treatment, Elk Grove Village, IL
Alloy Tool Steel, Santa Fe Springs, CA
Hayes Lemmerz International, Inc., Ferndale, MI
DCD Technology, Cleveland, OH
Chem-Trend, Howell, MI
Badger Metal Technology, Menomonee Falls, WI

Optimization of Squeeze Casting Process for Aluminum Alloy Parts, **Case Western Reserve University-** The objective of this project is apply fundamental heat and mass transfer principles to the squeeze casting process to optimize the variables and improve the quality of the castings manufactured by this process. Squeeze casting is a new and developing casting process suitable for manufacturing light-weight structural aluminum castings needed for the production of advanced components in applications such as the automotive industry. Because squeeze casting is a relatively new process, much work needs to be done to better understand the fundamentals of the process in order to optimize the variables. In this project, fundamental heat and mass transfer principles will be applied to the squeeze casting process, with experimental work performed on an industrial-scale 315 metric tonne squeeze caster. The specific objectives that will be accomplished over the 3-year duration of this project include the following: Conduct a detailed experimental study of metal flow and heat transfer in the squeeze casting process; Analyze the relationships between the design of the part, the squeeze casting system, the processing variables, and the soundness of the squeeze cast part; Generate an integrated flow-heat transfer computer model for design of squeeze castings; Provide detailed guidelines for the design of squeeze cast components and the dies for manufacturing them; Demonstrate implementation of the design guidelines and computer model in the production of sound, high strength, aluminum components.

North American Die Casting Association, Rosemont, IL
Blaze Technical Sensors, Stowe, OH
DCD Technologies, Cleveland, OH
Euclid Heat Treat, Cleveland, OH
Ford Motor Company, Dearborn, MI
Hayes-Lemmerz-CMI, Ferndale, MI
ITT Automotive, Cleveland, OH
Latrobe Steel Company, Latrobe, PA
Lindberg Heat Treat, Solon, OH
Nicollet, Minneapolis, MN
UBE Machinery, Ann Arbor, MI

Integration of RSP Tooling with Rapid Prototyping for Die Casting Applications, **Colorado State University-** Die casting can quickly produce intricate, high quality metal components in high volume. However, die casting dies continue to be manufactured through the use of machining practices, materials, and heat treatment practices developed many years ago. This project will improve the turnaround time of tooling for making prototypes, and to develop a better understanding of the microstructure, chemistry, and heat treatment of hot forming die steels that lead to die life extension. In this project, a new and unique Rapid Solidification Process (RSP) technology will be introduced to the die casting industry that will reduce lead time for prototyping and producing die casting tooling. In addition to productivity increase, use of RSP tooling technology will also result in a substantial reduction in energy use and scrap than conventional machining practices. RSP tooling is a spray forming technology tailored for producing molds and dies. The approach combines rapid solidification processing and net-shape materials processing in a single step. The concept involves converting a mold design described by a CAD file to a tooling master using a suitable rapid prototyping technology such as stereolithography. This is followed by spray forming a thick deposit of tool steel on the pattern to capture the desired shape, surface texture and detail. The resultant metal block is cooled to room temperature, separated from the pattern, and squared up to fit a standard holding block. The turnaround time for die casting tooling is significantly less than traditional tooling.

North American Die Casting Association, Rosemont, IL
Global Metal Technologies, Inc., Solon, OH
Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID

Development of Computational Fluid Dynamics Tool for Modeling the Blowing and Steaming of Expandable Polystyrene (EPS) Patterns for Lost Foam Castings**, Flow Simulation Services, Inc.**- The lost foam casting process produces clean, high quality castings with close tolerances. The most important advantage is that no cores (with binders) are required. One challenge in lost foam casting is maintaining the uniformity and quality of the expandable polystyrene (EPS) pattern. This has often been the cause of defects in casting. It is estimated that 60% of lost foam defects can be attributed to the pattern, or the so-called "white-side." Foam molds are complex, and beads must flow through complex passages to completely fill the mold. The process is further complicated by the expansion of the beads. In this project, Arena, LLC in conjunction with the American Foundry Society and the metal casting industry will extend existing flow modeling software to simulate the air-driven blowing of pre-expanded beads into a mold, and the subsequent steaming (expansion) of beads as they form a lost foam pattern. They will develop a CFD modeling tool for improving design and development of expandable polystyrene patterns for lost foam castings.

American Foundry Society, Des Plaines, IL
Auburn University- Auburn, AL
GM Advanced Development Laboratory, Saginaw, MI
Mercury Marine- Fond Du Lac, WI
StyroChem- Ft. Worth, TX
Vulcan Engineering- Helena, AL

Ergonomic Improvements for Foundries, **Iowa State University-** Manual operations remain an important part of many metal casting operations, due to the diverse products produced. This diversity makes automation infeasible. Ergonomics is the science of fitting workplace conditions and job demands of the working population. This project will take a reactive and proactive approach to solving ergonomic problems which lead to poor product quality, poor productivity, and poor lead times. The purpose of this project is to introduce ergonomic thinking into the foundry industry. It will involve student training, mini-workshops and evaluations, and off-site assessments of process evaluations. Process improvements and ergonomic improvements will be identified. The project team will work with participants through training and workshops to introduce improvements on to the foundry floor. This work will be conducted in conjunction with previous research at Iowa State "Re-engineering Casting Production Systems." The Re-Engineering project made improvements in the areas of scheduling, inspection and rework practices, plant layout and material handling.

Steel Founders' Society of America, Barrington, IL
AECCO, Champaign, IL
Atchison Casting, Atchison, KS
American Steel Foundries, East Chicago, IL
Bay Cast, Inc., Bay City, MI
Buckeye Steel Castings, Columbus, OH
Carondelet Corporation, Pevely, MO
Durametal Corporation, Muncy, PA
Erie Bronze & Aluminum, Erie, PA
Falk Corporation, Milwaukee, WI
Harrison Steel Castings Company, Attica, IN
Hendrix Manufacturing, Mansfield, LA
Magotteaux Pulaski, Pulaski, TN
Maynard Steel Casting Co., Milwaukee, WI
McConway & Torley Corporation, Pittsburgh, PA
Monett Metals, Monett, MO
NACO, Lombard, IL
Pacific Steel Casting, Berkeley, CA
Pennsylvania Foundry Group, Myerstown, PA
PrimeCast, South Beloit, IL
Sawbrook Steel Castings Co., Lockland, OH
Sivyer Steel Corporation, Bettendorf, IA
Southern Alloy Corporation, Sylacauga, AL
Southern Cast Products, Meridian, MS
Southwest Steel Castings Co., Longview, TX
Spokane Steel Foundry Co., Spokane, WA
Sulzer Pumps, Easley, SC
Texas Steel Company, Fort Worth, TX
United Machine and Foundry, Winona, MN
Varicast, Inc., Portland, OR
Waukesha, Delavan, WI
West Michigan Steel Foundry, Muskegon, MI
Wisconsin Centrifugal, Waukesha, WI
Wollaston Alloys, Braintree, MA

Reduction in Energy Consumption and Variability in Steel Casting, **Iowa State University**- The goals of this R&D project are to reduce energy consumption, reduce variability, and improve overall efficiency of steel foundry melting and casting operations. This project will also provide steel foundries with the necessary understanding, technologies, and expertise to make the required melting and castings changes to improve energy consumption, enhance economic competitiveness, and reduce environmental impacts.

Steel Founders' Society of America, Barrington, IL
Iowa State University, Ames, IA
ABC-NACO Technologies
Atchison Steel Casting & Machining, Atchison, KS
Durametal Corporation, Muncy, PA
Grede Foundries, Inc., Reedsburg, PA
Harrison Steel Castings Company, Attica, IN

Effects of Applied Pressure During Feeding on the Fatigue Properties of Critical Cast Aluminum Alloy Components, **Mississippi State University-** The objective of this three-year program is to determine the effect of applied pressure during feeding on the distribution, level, and morphology of porosity, and subsequently on the fatigue behavior of critical permanent mold cast aluminum components. Recently, there has been a renewed interest in a feeding technique capable of minimizing this porosity. The technique involves a highly localized pressurization of the feed metal within the risers of the casting. The method leads to improved mechanical properties , increased casting yield, reduced energy use and environmental impact. Many components used in safety-critical systems in automobiles and aircrafts, are of complex shape and lend themselves to casting to minimize costs. Many of the alloys used in these applications freeze over a long temperature range and are prone to dispersed porosity defects. Dispersed porosity in aluminum alloy castings has profound effects upon mechanical properties of engineered components produced this way. Both static properties (ductility, tensile strength, etc.) and dynamic properties (fatigue strength, and properties associated with the time dependence of fatigue crack initiation and growth) are affected. Although rigorous techniques of degassing and riser design can partly alleviate this situation, the effects of residual porosity are serious.

American Foundry Society, Des Plaines, IL
A-CMI, Michigan Casting Center, Fruitport, MI
Bohn Aluminum Corporation, Butler, IN
CMI Novacast, inc., Elk Grove Village, IL
Ford Motor Company, Dearborn, MI
Foseco, Cleveland, OH
GM Powertrain, Pontiac, MI
Metalloy Corporation, Hudson, MI

Control of Soldering and Thermal Fatigue During Die Casting, **Oak Ridge National Laboratory**- The objective of the project is to apply capabilities and technologies developed at ORNL to control soldering and thermal fatigue of dies used in die casting. A new high-density infrared (HDI) processing capability will be developed to apply coatings and surface treatments on die casting dies to prevent soldering and thermal fatigue. Thermodynamic models of soldering during die casting will be developed for use as a tool to predict soldering during die casting.

North American Die Casting Association, Rosemont, IL

Predicting Pattern Tooling and Casting Dimensions for Investment Casting - Phase II, **Oak Ridge National Laboratory**- The goal of this project is to develop computational tools that can be used to accurately predict the tooling dimensions for an investment casting prior to the first casting run, eliminating the trial-and-error step inherent in the design of the casting process. Computer models will be developed for the prediction of dimensional changes occurring during each step in the investment casting process. This includes the wax contraction during its solidification in the pattern die, to shell deformation during dewaxing, firing, and casting, and alloy deformation during its solidification and cooling to room temperature in the shell mold. The tools will be implemented in the commercial casting code ProCAST and complement the existing stress module. A simplified version of the tools will also be available in an easy-to-use spreadsheet format. The project will test the model extensively under production conditions, establish training manuals and procedures for their use by industry and develop a simplified PC version of the tools for foundries that do not have access to computational software and engineering workstations.

American Foundry Society, Des Plaines, IL
Accu-Cast, Inc., Chattanooga, TN
Howmet Corp., Whitehall, MI
Johnson & Johnson, Inc, Raynham, MA
M. Argueso & Co., Mamaroneck, KY
MINCO, Inc., Midway, TN
PED Manufacturing Ltd., Oregon City, OR
Precision Metalsmiths, Inc., Cleveland, OH
Spokane Industries, Spokane, WA
UES, Inc., Annapolis, MD

***Sensors for Die Casting*, Oak Ridge National Laboratory and Hayes Lemmerz, Inc.-** The objective of the project is to develop a sensor to improve the quality and consistency of aluminum die castings. A vibration sensor (accelerometer) for machine diagnostics will be used to allow problems to be detected and solved during the casting cycle, leading to less scrap, improved surface finish, higher dimensional repeatability, and improved internal integrity. Vibration diagnostics often provides insight into the normal operational characteristics of equipment and can detect many anomalous operational characteristics as well as provide monitoring of the operational characteristics over their normal ranges. Vibration sensors can be used to measure plunger characteristics due to normal operation of off-normal operation such as "sticking." After development, the technology will be validated in a production environment at the facilities of an industrial partner. The use of aluminum alloy castings for automotive applications is rapidly increasing due to the need for weight savings leading to a reduction in fuel consumption and emission levels. The replacement of a ferrous component by an aluminum alloy component typically results in mass savings of 50%. Since a large proportion of automotive castings are made by die casting, technologies that improve the quality and consistency of aluminum die castings will increase their application.

North American Die Casting Association, Rosemont, IL
A-CMI, Michigan Casting Center Fruitport, MI
Bohn Aluminum Corporation Butler, IN

***Castability Assessment and Data Integration for Die Casting Design,* Ohio State University**- Castability assessment requires the development of methods that help users to measure the overall castability of a design and to evaluate the trade-offs inherent in configuring the die casting die. This research will develop simple mathematical models, scaling methods, and decision support aids. A set of indicators, such as the variance in wall thickness, will be extracted from the CastView data for input to the decision support model. Researchers will define data requirements for evaluation, and develop and test extraction techniques. The research also will address methods to deal with geometric data that is defined using CastView. Geometric features are important information for the toolmaker. Exporting this information from CastView can accelerate the die design process. Researchers will develop and implement methods to export the data in a form that can be imported into a CAD system.

North American Die Casting Association, Rosemont, IL
Albany Chicago Co., Kenosha, WI
AMCAN
Briggs & Stratton Corporation, West Allis, WI
Chicago White Metal, Basenville, IL
Citation Corporation, Birmingham, AL
DCD Technologies, Cleveland, OH
Exco Engineering, New Market, Ontario, Can
Flow Science, Inc.,
Ford-Rawsonville Plant, Ypsilant, MI
General Die Casters, Inc., Peninsula, OH
GM Power Train, Ypsilanti, MI
JL French Corporation, Sheboygan, WI
Lester Precision Die Casting, Twinsburg, OH
Magma Foundry Technologies, Inc., Arlington Heights, IL
Prince Machine, Holland, MI
R&S Design, Bloomingdale, IN
Ryobi Die Casting (USA), Inc., Shelbyville, IN
SIMTEC, Inc., Grand Rapids, MI
Tool Products, Minneapolis, MN
UES, Annapolis, MD
Walkington Engineering, Inc., Cottage Grove, WI
Wright Products, Rice Lake, WI

***Computer Modeling of the Mechanical Performance of Die Casting Dies,* Ohio State University**- The majority of die casting computer modeling work focuses on thermal or filling issues including solidification. Although the simulation of mechanical and thermal load effects is critical for high pressure die casting and for squeeze casting it is not yet addressed by commercial casting design packages. In an attempt to resolve this, stress analysis packages for the casting are beginning to be used. But they are based on the nominal part geometry (as defined by the CAD model) and not the actual part shape at ejection. This is not a reasonable assumption for die casting. Due to the clamping and operating pressure involved, the mechanical performance of the die and machine must be considered in order to better understand the part ejection conditions. As a direct extension of an existing project "Die Deflection Modeling: Empirical Validation and Technology Transfer", researchers from Ohio State University will further advance the state of the art in computer modeling and simulation to solve die casting design problems in practical ways. Key relationships among the design variables will be determined, and a design methodology will be established. This work will lead to a better understanding of how to design dies to meet clamping, thermal, and pressure loads. The goal of this project is to assemble data and report results on development methods which can be applied to design better running die casting dies. By incorporating design methods and computer modeling in the design phase, the goal of this project is to reduce the number of test-rework-repair iterations necessary to put a new die into service.

North American Die Casting Association Rosemont, IL
Briggs & Stratton Milwaukee, WI
GM Bedford, Bedford, IN
Lester Precision Diecasting Solon, OH
Visi-Trak Corporation Cleveland, OH
Walkington Engineering Cottage Grove, WI

Energy Consumption of Die Casting Operations, **Ohio State University-** The objective of the project is to examine energy consumption as a cost of die cast products. The use of life cycle assessment (LCA) to compare the environmental impacts of materials and energy inputs and waste outputs for various components for automotive, appliances, and electronic products is an emerging trend. Several companies will participate in this study and will supply information on energy and equipment. The U.S. die casting industry needs to characterize their energy usage to identify opportunities for energy savings and to compare usage with other industries. To facilitate implementation of energy audits by die casters who will help identify energy drivers, additional templates are needed to disaggregate a facility's energy use and allocate it to specific activities. The award research has two main objectives. Phase I includes a pre-survey and focus energy audit standard to examine the die casting industry to determine current energy management practices and adapt an energy audit standard to focus on characterization of energy use by die casting activity. Phase II includes a database development, statistical analysis, and recommendations. The focussed energy audits will quantify energy drivers in U.S. die casting operations. The database will be based on current U.S. die casting energy use by categories for equipment, process configuration, and alloys. Statistical analyze will be used to examine U.S. die casting industry usage data by contrasting the data by categories for equipment age, type, fuel source, insulation, and coverage, process configuration, and alloys. The energy use will be compared between the data accumulated against reported energy use in other sectors. Recommendations will be developed for energy conservation and energy management practices that may provide cost savings for the die casting industry.

North American Die Casting Association, Rosemont, IL
Premier Tool & Die Cast Corporation, Berrien Springs, MI
GM Powertrain, Bedford, IN

Improvements in Sand/Mold/Core Technology: Effects on Casting Finish**, Ohio State University-** The goal of this project is to improve casting surface finish in sand mold/core technology. Specifically, it will develop a predictive understanding of how density variations control sand structure and casting surface finish and to identify when and how this results in severe penetration. In addition, it will develop a predictive understanding of how binder content and mixing controls both density variations and surface finish. This research also will analyze the behavior of manufactured binders and binder additives at the mold-metal interface. X-Ray Computed Tomography is required to separate the performance of these organics from the effects of density variations. This research, being conducted by the Ohio State University in conjunction with the American Foundry Society and industry, is examining the issues of surface finish and thermal reclamation costs resulting from the use of sand molds/cores. The results will provide an in-depth understanding of the influence of binder content on density variations that correlate to surface finish. The results will allow metal casters to improve both casting surface finish and net shape capabilities in sand mold/core technology. This will enable metal casters to reduce time and cost associated with surface cleaning and finishing operations as well as surface finishing metal losses. It also will reduce the amount of binder used each year.

American Foundry Society, Des Plaines, IL
Edison Materials Technology Center, Dayton, OH
Ross Aluminum Foundries, Sidney, OH
Humtown Products, Columbiana, OH
Watts Industries, Inc., Franklin, NH
Alotech, Cleveland, OH
Amcast Industrial Corporation, Dayton, OH

Qualitative Reasoning for Additional Diecasting Design Applications, **Ohio State University-** This project builds off a previous effort developing Simple Visualization Tools, using CastView, to improve die design. The goal of this research is to develop design tools for die casting that can be used to promote the compatibility between the design and the die casting. Specific goals are to reduce part development lead time by at least 15% and reduce tryout and setup time by at least 30%. The project will address extensions to the CastView program in the following areas: Extending the fill analysis to include lower velocity flow present in low pressure die casting, squeeze casting and gravity casting; Thermal/temperature extensions to provide a relative, equilibrium temperature distribution in the part and die, and; Qualitative shrinkage/distortion predictions for the part. The research will extend the thickness-based depiction of heat in the part and die currently used in CastView to provide an indication of the relative temperature pattern in equilibrium. To improve the characterization of the flow in the runner system and the flow in lower velocity processes, such as squeeze castings, reasoning methods will be extended to include: differentiation of flow in runner and cavity; consideration of shot profile; consideration of slower filling processes; and qualitative methods to account for pressure, head and resistance to flow. The research will also extend the ability of CastView to enable the characterization and visualization of the warpage tendencies of a part.

North American Die Casting Association Rosemont, IL
EXCO Engineering, New Market, Ontario
Ford Motor Company, Dearborn, MI
General Motors Powertrain, Pontiac, MI
ITT Industries, Auburn Hills, MI
J.L. French Corporation, Sheboygan, WI
Ryobi Die Casting, Inc., Shelbyville, IN
Spartan Light Metal Products, Sparta, IL
Tool Products, Minneapolis, MN
Walkington Engineering, Cottage Grove, WI

Understanding the Relationship Between Pattern Filling and Part Quality in Die Casting, **Ohio State University-** The objective of this project is to understand the phenomena involved in the filling of the die cavity and the relationships between fill parameters and part quality. The affects of gate geometry at part entry, gate velocity, and slow-to-fast shot acceleration on filling patterns in die casting, and ultimately part quality, will be explored. The results should produce a better understanding of the die filling phenomena under a variety of gate entry geometries, selected common cavity geometries, and gate velocities. The speed of fill in the die casting process and the fact that the die cavity is encased in a large envelope of steel presents some severe challenges for observing and measuring die fill. The use of physical analog (water, ferrometal) modeling with high speed video photography will be the primary technique used to observe fill patterns. The technique is limited however and must be supplemented with additional measurements and trials. Researchers will attempt to use real-time x-ray with high speed video on a limited number of trials with zinc and an aluminum die. Additional measurement trials will be explored. The laboratory and analog studies will be followed by casting trials. The casting trials will allow researchers to test the effects on quality of the design recommendations resulting from the lab studies. Numerical simulations will be performed for both the production and the experimental cases. This work will enable improvements in productivity and quality. Energy and emissions savings arise primarily due to scrap reduction including reductions due to faster startup, less die tryout, and a better understanding of the relationship between fill and part quality. An outcome of the research will be a computer program that would predict die casting quality level given a set of pre-defined gate geometry and processing variables. This will greatly assist industry to improve productivity and reduce lead time.

North American Die Casting Association, Rosemont, IL
General Die Casters, Peninsula, OH
GM Bedford, Bedford, IN
Lester Precision Die Casting, Solon, OH
Walkington Engineering, Cottage Grove, WI

Prediction of Part Distortion in Die Casting**, Ohio State University**- The goal of this project is to develop techniques for die casting part designers and die designers to consistently predict the shape of the part after cooling to room temperature and to develop the corresponding techniques to use the results to modify the die geometry. This capability will allow them to compensate for the part distortion during die design with greater accuracy than is possible with current techniques.

North American Die Casting Association, Rosemount, IL
Albany Chicago Co., Kenosha, WI
Chicago White Metal, Basenville, IL
DCD Technologies, Cleveland, OH
Exco Engineering, Ontario, Can
Flow Science Inc., Los Alamos, NM
General Die Casters, Inc., Peninsula, OH
General Motors, Detroit, MI
JL French Corporation, Sheboygan, IN
Kirby
Lester Precision Die Casting Inc.,Solon, OH
Magma Foundry Technologies, Inc., Arlington Hieghts, IL
Prince Machine, Holland, MI
Ryobi Die Casting (USA), Inc., Shelbyville, IN
Simtec, Inc., Grand Rapids, MI
SPX Contech, Portage, MI
UES , Annapolis, MD
Walkington Engineering, Inc., Cottage Grove, WI
Wright Products Corp., Rice Lake, WI

Investment Shell Cracking**, Tri-State University**- Investment casting is growing in North America and is seen as a means for steel casting to penetrate high value added markets and high production markets such as automotive. The purpose of this project is to investigate and reduce the occurrence of investment shell cracking defects in investment casting. Shell cracking may occur during dewaxing or pouring. The dewaxing problem is one of superposition of stresses due to constraint of free strain of the wax by the shell. The wax will have a higher thermal expansion coefficient than the refractory shell. Robustness of the shell in dewaxing and thermal shock resistance during pouring may depend on strength and/or on plane strain critical stress intensity of more exactly critical crack extension force. It is our concept that the appropriate bench scale control tests coupled with manufacturing evaluations will reveal methods to control the process for lower scrap rates. The scope of work includes developing bench scale tests for ceramic shells and wax (polymer) pattern materials and designing a standard test casting. Then we would apply those tests to production materials collected four to size times from participating foundries with concurrent evaluation of defect occurrence from selected worst example case history castings and standardized test casting. The bench test results would then be correlated with the manufacturing results. After that, researchers will examine process parameters which can be used to achieve the desired trend or range for the bench test parameters and run confirmation tests to determine that the desired results are achieved in manufacturing.

Steel Founders' Society of America Barrington, IL
Spokane Steel, Spokane, WA
ABC-NACO, Cicero, IL
Stainless Foundry, Milwaukee, WI
Wisconsin Centrifugal, Waukesha, WI
Wisconsin Invest Cast, Watertown, WI
PED Manufacturing, Oregon City, OR
Nova Precision, Auburn, PA

Thin Wall Iron Castings, **University of Alabama-** Today's foundries are confronted with a continuous demand of manufacture high-quality, cost- effective cast products. Those specializing in automotive castings have the added pressure of developing new processes and materials that reduce overall car weight to meet federally mandated fuel economy standards, without sacrificing performance. In order to meet these needs, automakers have increasingly turned to lighter weight materials, and castings continue to be a prime target. This explains why some ferrous castings markets have been lost in the past 15 years, as aluminum displaced cast iron for parts such as cylinder heads, engine blocks and steering components. A closer examination actually reveals that ferrous castings are, in many cases, superior to -- or at least competitive with -- aluminum-based alloys. For instance, ductile iron is not only cheaper, it is also superior to aluminum in many cases in terms of relative weight per unit of yield strength. Similar analyses can be made for gray iron and compacted graphite iron. European automakers have made significant progress in the replacement of aluminum castings with iron castings. However, for cast iron to regain the lost market from aluminum, it must be better engineered to achieve its full potential. At present time, iron castings can not be routinely produced in sand mold with thickness less than 3 mm. In addressing this need, research is being carried out at the University of Alabama, to develop the technology for producing commercial iron castings with wall thickness less than 3 mm. The project will also investigate both the metallurgical treatment required for molten iron, and the mold and core making techniques needed to reach the project goals.

University of North Carolina - Charlotte, Charlotte, NC
American Foundry Society, Des Plaines, IL
ABC Coke, Birmingham, AL
American Colloid, Berlin, WI
Badger Mining, Berlin, WI
Brillion Iron Works, Brillion, WI
Caterpillar, Inc., Mapleton, IL
Carrollton Casting Center, Carrollton, KY
Chrysler Foundry, Indianapolis, IN
Citation Corp., Birmingham, AL
Elkam Metals Co., Ashtabula, OH
Fairmont Minerals, Chardon, OH
Ford Motor Co., Dearborn, MI
Foseco, Inc., Cleveland, OH
Georg Fischer DISA A/S, Denmark
GM Powertrain, Saginaw, MI
Hickman Williams & Co., Livonia, MI
Intat Precision, Rushville, IN
Intermet Technical Service, Lynchburg, VA
K&P Agile, Inc., Naperville, IL
Magma Corp., Arlington Heights, IL
Miller & Co., Rosemont, IL
Rio Tinto Iron & Titanium, Rosemont, IL
Simpson Technologies, Jackson, MI
Superior Graphite, Chicago, IL
UES Software, Annapolis, MD

Advanced Lost Foam Casting - Phase V, **University of Alabama - Birmingham**- The overall objective of this program is to advance the theory and application of the lost foam casting technology. This is the fifth phase of ongoing research by UAB in conjunction with an industrial consortium in this area. This project will continue the consortium for three additional years and a major focus will be to advance the Lost Foam Process into steel castings. The objective of the continuation is to develop a data base for pattern degradation properties at typical metal velocities and temperatures. This data, along with coating and sand permeability and thermal property data, will be merged into a commercial fill/solidification code to describe the physical events of metal replacement of lost foam patterns and validated using real time x-ray and instrumented castings. In plant experiments will be conducted to quantify sources of casting distortion and to demonstrate the validity of existing compaction theory and sand thermal expansion theory. Procedures will be developed to measure pattern /bead properties that control the bead pre-expansion and pattern blowing process. New pattern materials that produce less liquid and/or carbon degradation products will be investigated. Coating quality control procedures will be developed which include more robust techniques. Sponsors will be assisted in reducing defects. Technology transfer meetings and in-plant experiments will be conducted.

University of Missouri - Rolla, Rolla, MO
American Foundry Society, Des Plaines, IL
Lost Foam Casting Consortium Partners
Advanced Cast Products, Inc.
Alex City Casting
Ashland Chemical Co.
Austin Associates
Borden, Inc.
Carbo Ceramics
Citation Corp.
Copeland Corp.
Delaware Machine
Flow Science
Foseco-Morval Inc.
General Kinematics Corp.
General Motors
Kohler Company
Kurtz North America
Maco Corp.
Mercury Marine
Montupet Corp.
Mueller Corp.
Nemak
Outboard Marin Corp.
Reference Tool Corp.
Saturn Corp.
Southeastern Foundry Products Styrochem International
UES Inc.
Vulcan Engineering
Willard Industries

Clean Cast Steel Technology, Phase IV, **University of Alabama - Birmingham**- The objective of this program of research is to improve casting product quality by removing or minimizing oxide defects and allowing the production of higher integrity castings for high speed machining lines. The research in past years has focused on macroinclusions that break or chip tool cutters and drills and cause the immediate shut down of machining lines; and on optimizing pouring techniques including metal stream shrouding and ladle design. It also has focused on determining the sources of heat-to-heat variations in metal cleanliness. Research in this phase will be to reduce the amount of surface macroinclusions and improve the machinability of steel castings. Macroinclusions have been identified by industry sponsors as a major barrier to improving the quality and marketability of steel castings.

Steel Founders' Society of America, Barrington, IL
American Magotteaux, Pulaski, TN
American Steel Foundries, Granite City, IL
Atchison Casting Corp., Atchison, KS
Dominion Castings Ltd., Ontario, Can.
Electric Steel Castings, Indianapolis, IN
Falk Corporation, Milwaukee, WI
Flow Technology, Los Alamos, NM
Harrison Steel Castings, Attica, IN
Keokuk Steel Castings, Inc., Keokuk, IA
Maynard Steel Castings, Milwaukee, WI
National Castings, Cicero, IL
Sawbrook Steel Casting, Lockland, OH
Selee Corporation, Hendersonville, NC
Sivyer Steel Corporation, Bettendork, IA
Southern Cast Products, Meridian, MS
Stainless Foundry & Engineering, Milwaukee, WI
Viking Engineering Cast Products, Witchita, KS
Wisconsin Centrifugal, Milwaukee, WI

Yield Improvement in Steel Castings, **University of Iowa**- A previous project at the University of Iowa (UIA) investigated the improvement of yield in steel castings. The work that is being performed under this research will investigate a number of new yield improvement techniques, and continue and expand the transfer of the project results to the steel casting industry. The Yield I project achieved the following: (1) A literature review was conducted of current risering and feeding methods and of other potential yield improvement techniques. (2) A survey was conducted among American steel foundries to determine the current state of casting yield. The average casting yield was found to be only 53%. (3) Extensive computer simulations were conducted to re-examine the SFSA rules that have been used by industry for more than 30 years to determine riser sizes and locations. New rules were established and made available to industry through the SFSA. (4) Extensive casting trials were conducted at five steel foundries to verify the computer simulations and the new rules. (5) New and unconventional yield improvement techniques were analyzed by computer simulation. (6) Case studies were conducted to investigate the yield performance of complex production castings.

Steel Founders' Society of America, Barrington, IL
ABC-NACO, Downers Grove, IL
Quaker Alloy, Myerstown, PA
Waukesha Cherry-Burell, Delevan, WI
Texas Steel, Fort Worth, TX
Pennsylvania Steel, Hamburg, PA
Bay Cast, Bay City, MI
Alcan International Limited, Montreal, Can
Pennsylvania Foundry Group, Myerstown, PA
KO Steel Foundry, San Antonio, TX
Missouri Steel Castings, Joplin, MO
Varicast, Portland, OR
American Steel Foundries, Granite City, IL
Atchison Casting, Atchison, KS
Shenango, Terre Haute, IN
Sivyer Steel Corporation, Bettendorf, PA
Harrison Steel Castings, Attica, IN
Pacific Steel Casting Company, Berkeley, CA
Stainless Foundry, Milwaukee, WI
Electric Steel, Indianapolis, IN
Falk, Milwaukee, WI
American Centrifugal, Birmingham, AL
Keokuk Steel Castings, Keokuk, IN

Heat Transfer at the Mold/Metal Interface in Permanent Mold Casting of Aluminum Alloys, **University of Michigan-** The objective of this project is to evaluate heat transfer between mold and casting in permanent casting of aluminum alloys. Energy savings can be achieved by more precise design of these castings. The design improvements require further understanding of the fundamentals of the process, in particular, interfacial heat transfer including the influence of gap formation and mold coatings, the stress and deformation of the solidifying castings, and the thermal and mechanical behavior of the mold. This project will include modeling and experimental measurements of the parameters to provide a means for the foundry worker to define and predict multidimensional heat flow in permanent mold casting. The resulting design will allow production of castings with closer tolerances, improved properties, higher integrity, and lower weight.

American Foundry Society, Des Plaines, IL
AMCAST Industrial Corporation, Southfield, MI
Hayes Lemmerz Tech Center, Ferndale, MI
Magma Foundry Technologies, Inc., Arlington Heights, IL
UES, Inc., Annapolis, MD

Semi-Solid Metals Processing Consortium, **Worcester Polytechnic Institute**- This program of research will address fundamental technical issues of semi-solid metal (SSM) processing and contribute to the development of a knowledge base for the commercial sector. Semi-solid metal processing is a relatively new technology which offers distinct advantages over other near-net shape manufacturing processes. This process is ideally suited for die casting and a number of automotive components are currently being produced on a prototype basis using SSM. In this process, the raw material is melted and allowed to cool and solidify, while the dendrites formed during solidification are broken up and their morphology is altered using mechanical, electromagnetic or other forces. Subsequently, the specially prepared raw material is remelted to its mushy state, and, while the temperature is kept between the liquidus and solidus isotherms, it is processed to its final shape. The flow of these rheologically complex fluids in shape making operations in a rapid cycle mode is highly unsteady, which significantly influences the overall quality of the final product. In order to develop a better understanding of the process and to optimize the operation, it is important to gain a deeper insight into the underlying theoretical and physical concepts associated with this novel family of thixotropic materials. Process control needs to be based on process understanding; moreover, there is a need for material characterization of SSM processed materials.

North American Die Casting Association, Rosemont, IL
Alcan International Limited, Montreal, Quebec
Aluminum Company of America, Alcoa Technical Center, PA
Aluminum Pechiney, Paris, France
Kaiser Aluminum and Chemical Corporation, Spokane, WA
Northwest Aluminum Company, The Dalles, OR
Ormet Corporation, Wheeling, WV
VAW, Inc., Pittsburgh, PA
Wabash Alloys, Wabash, IN
Suppliers/Equipment Users
Buhler, Inc., Minneapolis, MN
Chem-Trend, Inc., Howell, MI
Foseco, Inc., Bessemer, AL
Heraeus Electro-Nite Company, Philadelphia, PA
Metallurg Aluminum, Newfield, NJ
Prince Machine, Holland, MI
Selee Corporation, Hendersonville, NC
Thixomat, Ann Arbor, MI
Briggs & Stratton Corporation, West Allis, MI
Daimler Chrysler Corporation, Indianapolis, IN
Ford Motor Company, Dearborn, MI
General Motors Corporation, Pontiac, MI
Harley-Davidson Motor Company, Milwaukee, WI
Mercury Marine, Fond Du Lac, WI
A-Mold, Mason, OH
AEMP Corporation, Jackson, TN
Amcast Industrial Corporation, Southfield, MI
Citation Corporation, Birmingham, AL
Cambridge Tool and Manufacturing Company, Inc., North Billerica, MA
Consolidated Metco, Clackamas, OR
Hayes Lemmerz International, Ferndale, MI
Hitchcock Industries, Inc., Minneapolis, MN
Intermet Corporation, Lynchburg, VA
J.L. French International, Sheboygan, WI
Kennedy Die Castings, Inc., Worcester, MA
Madison-Kipp Corporation, Madison, WI
Palmer Foundry, Inc., Palmer, MA
SPX Contech Division, Portage, MI
Stahl Specialty Company, Kingsville, MO
Superior Industries International, Inc., Morris, MN
Teksid Aluminum Foundry, Inc., Dickson, TN
Wyman Gordan Investment Castings, North Grafton, MA

Materials Technologies

Die Materials for Critical Applications and Increased Production Rates, **Case Western Reserve University**- The objective of this project is to double the life of die casting inserts exposed to the most severe die casting conditions by testing, comparing, and providing guidelines for selective use of: (a) high-alloy tool steels, (b) refractory and other nonferrous high temperature die materials, and (c) diffusion coatings. In the die casting process, molten metal is injected at high pressure into a water cooled steel die, where it solidifies as a net shape product. Very complex shapes ranging in size from less than one inch, to fifty inches and more, can be made out of aluminum, magnesium, zinc and copper with no additional machining. Die cast parts have very broad applications in automotive, aerospace, electronics and household consumer products. The design and performance of the steel die is critical in meeting the engineering requirements of the final casting. It controls not only the dimensions and tolerances of the final part but also the surface quality of the products. Many dies end their useful life when tiny cracks develop on the surface, leading to unacceptable marks on the cast part. Improvement of the die steel has a major impact on the dimensional stability, reproducibility, and surface quality of the product. Prior work conducted by Case Western Reserve demonstrated that dies produced from chromium-molybdenum-vanadium steels with about 0.40% carbon and a minimum of inclusions and segregation and heat treated to a Rockwell C range of 45-50 provide good thermal fatigue resistance. With appropriate composition and quality of these steels, optimized austenitizing temperature and fast cooling rate, these studies show that improved die life can be expected in most applications. However, under certain circumstances and specific locations, these good quality tool steels are prone to early failure. The use of special materials for inserts or cores can extend the die life in severe conditions. Specific elements of the study will include: the effect of increased alloy content; an evaluation of non-ferrous high temperature die materials; the effect of diffusion coatings; and productivity improvements.

North American Die Casting Association, Rosemont, IL
Latrobe Steel, Latrobe, PA
FPM Heat Treatment, Elk Grove, IL
A. Finkl & Sones, Chicago, IL
CSM Industries, Cleveland, OH
Brush Wellman, Cleveland, OH
Alloy Tool Steel, Santa Fe Springs, CA
CMI-Tech Center, Ferndale, MI
DCD Technology, Cleveland, OH
Chem-Trend, Howell, MI
Badger Metal Technology, Menomonee Falls, WI

Evaluation of Heat Checking and Washout of Heat Resistant Superalloys for Die Insert Applications, **Case Western Reserve University**- This study will investigate the potential of special types of nickel-base alloys as die casting die materials. The project will also develop a test that will determine the erosion resistance of these materials in a stream of molten 380 aluminum alloy. The mechanisms of thermal fatigue crack nucleation and propagation in superalloys will be studied and compared to thermal fatigue cracking of steels.

North American Die Casting Association, Rosemont, IL
Allvac, Monroe, NC
HC Stark, East Rutherford, NJ
CMW, Indianapolis, IN
Dynamic Metal Treating, Canton Twp., MI
Bohler Uddeholm, Ontario
IonBond, Duncan, SC
St. Clair Dei Casting, St. Clair, MO
Metaldyne, Bedford Heights, OH

Metallic Reinforcement of Direct Squeeze Die Cast Aluminum Alloys for Improved Strength and Fracture Resistance, **Case Western Reserve University**- The goal of this project is to develop feasible methods of reinforcing aluminum die casting components with large size metallic inserts that will provide greater strength, improved impact resistance, and reduced tendency to shatter. This research is a follow-on to earlier research performed by Case Western on direct squeeze casting of aluminum alloys. Planned activities in the current project include: Reinforced Casting Experiments, Bonding Technique, Mechanical Testing , In-plant Implementation. During the reinforced casting experiments aluminum alloys will be selected for the matrix. Lab scale casting experiments with sand molds and squeeze parts will be conducted with simple cast shapes representative of the applications. Plate-like, cylindrical and spherical shapes will be cast initially. For the Bonded Technique tests Interfacial coatings that provide the desired metallurgical bond between the insert and the aluminum alloy matrix will be selected and evaluated. Once that step has been completed, the researchers will begin to analyze the strength of the bond between the matrix and the reinforcing insert will be evaluated by tensile and bending tests. The final action planed will be the Inplant Implementation. Here, after it has been demonstrated that a satisfactory means of holding the reinforcing insert in the die and a strong metallurgical bond has been established for different metallic inserts and aluminum alloys, the industrial partners will use this information to produce actual components for the applications.

North American Die Casting Association, Rosemont, IL
Black and Decker, Baltimore, MD
Briggs Die Casting, Wauwatosa, WI
Cummins Engine, Columbus, IN
Kowalski Heat Treating, Cleveland, OH
Lester Precision Die Casting, Solon, OH
Los Alamos National Laboratory, Los Alamos, NM
ZMD Mold and Die, Mentor, OH
Zoller, Ann Arbor, MI

Development of a Fatigue Properties Data Base for Use in Modern Design Methods, **Climax Research Services**- The objective of this project is to develop a comprehensive database of strain-life fatigue data for graphitic cast irons. Specifically, the structural grades of gray iron, ductile iron, austempered ductile iron and compacted graphitic iron will be included. Each grade will be evaluated with microstructures corresponding to two cast section sizes for comparison, thus resulting in two materials to be described per grade of iron. The purpose is to provide a database of cast iron fatigue properties that is suitable for modern design techniques. This will enable designers to use modern durability modeling to develop more precise and efficient cast iron components. Cast iron producers will benefit by expanded and newly opened markets while end-users will realize cost savings in both component development and manufacture. Iron foundry expenditures will also benefit from the reduced weight of metal in the lighter more efficient component design.

American Foundry Society, Des Plaines, IL
Applied Process, Livona, MI
Arvin Meritor Automotive, Troy, MI
Bay Engineered Castings Inc., De Pere, WI
Caterpillar, Inc., Peoria, IL
Citation Corporation, Birmingham, AL
TRW Automotive, Livonia, MI
Waupaca Foundry Inc., Waupaca, WI
Wheland Foundry, Chattanooga

Prevention of Porosity in Iron Casting, **Climax Research Services**- The goal of this project is to develop a model to help foundries learn the mechanisms of porosity formation and other effects of gases in their iron castings. It will establish a quantitative relationship among the factors affecting porosity formation and better enable foundry operator to reduce/eliminate porosity formation in a production environment. For most foundries, porosity problems occur sporadically, but even occasional outbreaks can be costly. Even a small amount of porosity can significantly reduce the mechanical properties of the castings; as a result, the casting will have to be scrapped. In general, ½ to ¾ of the all-scrap castings are lost to factors related, directly or indirectly, to porosity. Despite the obvious importance of the problem, there is no consensus on how to deal with it. Most porosity in iron castings is believed to be a result of the combination of solidification shrinkage and a decrease in the solubility of gases during solidification. Unfortunately, there are insufficient data to support this theory. Therefore, it is essential for the foundries to learn the mechanisms of porosity formation and other effects of gases in their iron castings. It is also essential to establish a quantitative relationship among the factors affecting porosity formation, in a form that can be used to predict its formation in a production environment.

American Foundry Society, Des Plaines, IL
Briggs & Stratton Corporation, West Allis, WI
Hickman Williams, Livonia, MI
Q.I.T. America, Chicago, IL
Wagner Castings Company, Decatur, IL
Waupaca Foundry, Inc., Waupaca, WI
Albany Research Center, Albany, OR
Borden Chemicals, Toledo, OH
Citation, Birmingham, AL
Columbia Steel Castings, Portland, OR
Durametal, Muncy, PA
Georgia Iron Works, Grovetown, GA
Intermet, Lynchburg, VA
Maca Supply, Springville, UT
Texaloy Foundry, Floresville, TX
United Foundries, Canton, OH
United Machine & Foundry, Winona, MN

Development of Surface Engineered Coatings for Die Casting Dies, **Colorado School of Mines**- The objective of this research program is to develop an optimal "coating system" that minimizes the major mechanisms leading to premature die failure. These mechanisms include: heat checking (thermal cracking), and gross cracking; erosive wear; and soldering and corrosion/oxidation. Ultimately, the goals of this research program are: 1) the achievement of increased die-casting die life; 2) increased surface quality of die-cast components; 3) decreased downtime during scheduled production; 4) increased substitution of aluminum die-cast components for steel and cast iron; and 5) decreased in-process (pre-consumer) scrap. This initial research program will concentrate on developing a coating system for dies used in Die casting aluminum alloys. The measured outcomes from this research will quantify comparisons of the current aluminum die-casting practice with the measured results using the newly developed coating systems. A comparison of cost/performance will also be determined for the new coating systems using current cost data as the base line.

North American Die Casting Association
Rosemont, IL
Blue Ridge Pressure Castings, Lehighton, PA
Hard Chrome, Evansville, IN
Hayes-Lemmerz, Ferndale, MI
SPX Contech, Portage, MI

Grain Refinement of Permanent Mold Cast Copper Base Alloys, **Copper Development Association**- Grain refinement is a well-established process for many cast alloys, especially aluminum, resulting in enhanced casting characteristics and improved mechanical properties. Grain refinement of copper-base alloys in permanent mold casting process is fairly new and is aimed at improving the hot tearing resistance. Preliminary research has shown that the mechanism of grain refinement in copper-base alloys is not well understood. This lack of understanding extends to the interaction between the grain refiner and minor elements present in copper alloys, such as Sn, Al, Bi, Se, and Pb. The evaluation of nuclei formation which causes the grain refinement in copper alloys is also necessary. The Copper Development Association and industry partners will conduct a series of research tasks to understand grain refinement behavior of permanent mold copper-base alloys. This will increase casting fluidity, reduce hot tearing, and increase pressure tightness. This will in turn result in higher casting yield in foundries. The project will greatly improve the ability to produce components for plumbing and other applications while responding to environmental issues surrounding lead in plumbing components and foundry sand.

American Foundry Society, Des Plaines, IL
Kohler Company, Kohler, WI
Starline Mfg. Co., Inc., Milwaukee, WI
Hubbel Power Systems, Centralia, MO
Sloan Valve Company, Augusta, AR
Brost Foundry Company, Cleveland, OH
H. Kramer & Co., Chicago, IL
PIAD Precision Casting Corporation, Greensburg, PA
L. Fazekas Patterns & Models, Inc., Brantford, Ontario, Canada
IMA USA, Inc., Sheboygan, WI
R. Lavin & Sons, Inc., Chicago, IL
International Copper Association Ltd., New York, NY
Brass and Bronze Ingot Manufacturers, Chicago, IL

Development Program for Natural Aging Aluminum Alloys, **GKS Engineering Services**- This R&D project's goals are as follows: 1) to produce commercial parts free of hot cracks, and thereby establish that natural aging alloys are a commercially viable alternative to the casting alloys used today. 2) To eliminate the lack of mechanical property data for these materials, by measuring casting tensile properties, and hot cracking resistance, a function of alloy composition. 3) To provide more detailed scientific knowledge about aging process in these alloys. 4) to provide a knowledge database that may be used to optimize alloy composition for a particular casting.

American Foundry Society , Des Plaines, IL
Alcan International Limited, Quebec, Can
Metal Processing Institute, Worcester, MA
Stahl Specialty Co., Kingsville, MO

Creep Resistant Zinc Alloy Development, **International Lead Zinc Research Organization, Inc.**- This program will develop zinc-based die casting alloys suitable for processing by the hot chamber die casting process that have improved creep strength. Many applications such as fasteners in automobile underhood applications require zinc alloys to maintain a minimum load under long term loading. The results of a survey of automotive designers and specifiers has indicated the following target properties for an improved generation of zinc casting alloys: temperature capability of 140 degrees C, however if this could be increased to 160 degrees C then it would encompass 84.5% of respondent desires; creep stress at 4500 psi (31 Mpa); exposure time of 1,000 hours; and maximum creep elongation under the above conditions: 1% or less. The hot chamber die casting process, by which almost all zinc alloys are cast, is known to be a more efficient casting process than the cold chamber technique used to die cast aluminum and other alloys. The lower casting temperature of zinc alloys allows for greater precision in the cast parts, reducing both energy and materials waste. However the capabilities of zinc die castings are limited with respect to sustaining loads for long times at elevated temperatures. Under such conditions, a slow deformation, termed "creep", occurs. Creep is common in all metal alloys under such conditions, but the commonly used zinc casting alloys are less creep resistant than other higher melting temperature alloys, meaning that the cold chamber die casting process must be used to obtain the benefits of higher creep resistance. Recent preliminary research has shown promise for development of higher creep resistant zinc alloys. It is clear that development of such alloys would reduce energy consumption, metal waste and therefore the environmental impacts of the metal casting industry. Improvements of zinc alloy capabilities that can use the hot chamber die casting process will also improve the competitive advantage of die casters that apply the anticipated program results versus other materials. These results will be made available to interested U.S. die casters through the proposed technology transfer program.

North American Die Casting Association, Rosemont, IL | *Die Makers, Monroe City, MO* | *Eastern Alloys, Maybrook, NY*

Effects of Externally Solidified Product on Wave Celerity and Quality of Die Cast Products, **Ohio State University**- The heat and mass transport phenomena which occur in the shot sleeves of cold chamber die casting systems have significant effects on the reproducibility of the die casting process and resulting die cast components. The objective of this project is to increase productivity and improve the quality of die castings. This project will develop an improved understanding of the alloy solidification which occurs in the shot sleeve and its effects on the subsequent filling of both the shot sleeve and die cavity during the injection portion of the die casting process. The project consists of three interrelated activities: 1. The use of transparent physical analog materials to model the solidification and fluid flow phenomena which occur in die casting. 2. The use of the FIDAP computer program to calculate the solidification and fluid flow in shots for both the transparent physical analog experiments and aluminum die casting experiments. 3. The production and characterization of die cast aluminum components with varying levels of externally solidified phase(s) to confirm the validity of the analog modeling and the FIDAP computer modeling. The results of this project will allow improvements to the die casting process and resultant products. The energy and emission savings will arise directly from the reduction in scrap.

North American Die Casting Association, Rosemont, IL | *Briggs & Stratton Corp., Milwaukee, WI* | *Heick Die Casting Corp., Chicago, IL* | *Walkington Engineering, Cottage Grove, WI*

Heat Treatment Procedure Qualification for Steel Castings, **Pennsylvania State University**- The objectives of this project are to develop, test, and validate heat treatment qualification procedures that can be effectively used by steel foundries to assure casting performance for carbon, low alloy and high alloy steels. At the present time, specifications for steel castings do not address the necessary heat treatment procedure control to assure casting performance. This is true for high alloy steel castings where proper heat treatment is the key to obtaining corrosion performance and for carbon and low-alloy steels where proper heat treatment is the key to obtaining mechanical performance. This project will propose simple but robust "heat treatment qualification procedures" that can be performed by foundries to demonstrate and assure casting performance. Steel casting performance can be certified similar to welds (e.g. ASME Boiler and Pressure Vessel Codes and the AWS Structural Welding Code) with the development of simple, appropriate, up-front qualification procedures. These science-based and performance-based test procedures demonstrate that the process control practices used by the foundry can be expected to yield acceptable performance for a class of castings. This will assure the customer that heat treatment controls and specifications for a give casting or family of castings will result in "qualified castings". Heat treatment procedure qualification strategies will be developed for carbon steels, low alloy steels, and high alloy steels. It is expected that the heat treatment qualification concepts developed can also be applied to other heat treatment casting alloy families with further research.

Steel Founders' Society of America, Barrington, IL
American Steel Foundries, Granite City, IL
Frogswitch, Carlisle, PA
The Harrison Steel Castings, Attica, IN
Milwaukee Steel, Milwaukee, WI
Missouri Steel Castings, Joplin, MO
Pacific Steel Castings Company, Berkley, CA
Pennsylvania Foundry, PA
Sawbrook Steel Castings, OH
Stainless Foundry & Engineering, Milwaukee, WI
Varicast, Vancouver, WA
West Michigan Steel Foundry, Muskegon, MI

Age Strengthening of Gray Cast Iron Phase III, **Tri-State University**- This project will identify the age-strengthening mechanism in gray cast iron, quantify the parameters which control the process, measure properties and develop a predictive model, and quality the relationship between aging and machinability. This research is the third phase of a program investigating the age strengthening of gray cast iron. Previous research that was sponsored by the AFS and industry partners has proven the capability of some gray cast irons to increase strength up to 10% of the ultimate tensile strength. The mechanism and control of this phenomenon has not been conclusively quantified. Current research from Phases I and II has indicated that dissolved nitrogen may be the control mechanism There are also indications that these aging phenomena may favorably affect the machinability of gray cast iron. The ability to initiate and control this phenomenon could result in a significant improvement in casting mold yield, casting weight reduction, and possibly improved machining productivity. A 10% increase in strength would allow the production of higher carbon equivalent irons and a corresponding improvement in mold yield along with improved machinability. There is also the potential to reduce casting weight by producing higher strength iron. The scope of work includes four main tasks. The time and temperature effect studies will be done in laboratory environment with irons cast at production foundries. The composition will be varied so that the effect of nitrogen activity and activity coefficient can be evaluated as well as the influence of substitutional elements on the process. This will require about five test-bar casting runs per year in participating foundries. This data will allow us to control and design with the process, but will also contribute to the understanding of the process.

American Foundry Society, Des Plaines, IL
ACM Coldwater, Coldwater, OH
Auburn Foundry, Auburn, IN
Bremen Castings, Bremen, IN Dalton
Dalton Warsaw, Warsaw, IN
Dock Foundry, Three Rivers, MI
Kendallville,Kendallville, IN
LECO, St. Joseph, MI

Metallic Recovery and Ferrous Melting Processes, **Tri-State University**- 1) Provide statistically significant evidence of the magnitude of the effects of charge material characteristics and melting procedure on the recovery of total metal and specific important alloying elements when melting scrap materials. 2) Provide quantitative information on the effects of melting procedures and briquette formulation on melt loss and recovery of alloying elements from briquetted machining chips. 3) Demonstrate feasibility of a process to reduce the amount of undesirable trace elements in a scrap-melted composition by thermo chemical processing rather than dilution. This process would then be developed in a further subsequent effort, after a sufficient understanding is achieved to outline a specific experimental plan.

Steel Founders' Society of America, Barrington, IL
Auburn Analytical, Auburn, IN
Dalton Corporation, Kendaville, IN
Omnisource, Corporation, Fort Wayne, IN
S. Katz Associates, W. Bloomfield, MI

Clean, Machinable, Thin-Walled Gray and Ductile Iron Casting Production, Phase III, **University of Alabama - Birmingham**- This is a continuation of a multi-phase project. All high production foundries experience problems with casting machinability. Some castings are scrapped immediately while others make it to the machine tool line where they cause inordinate tool wear and sometimes break the tools. Premature tool wear forces the line to be slowed or shut down for tool replacement. Not only must new tools or tool inserts be used, but there are high costs associated with line downtime. It has historically been difficult and usually impossible to assign causes to the specific tool wear problem because there was limited data about relations between foundry processes and tool life. That deficiency is being eliminated in this project. The focus of the Phase I study was to develop a consistent method for evaluating the machinability of gray and ductile iron. Test castings were produced in participating foundries, and "hard-to-machine" castings were solicited from both foundries and machine shops. A microcarbide dispersed in the pearlite was found to be a significant cause for poor machinability in both laboratory test procedures and in "hard-to-machine" commercial castings. A large body of data on iron processing, properties, and machinability was developed to provide baseline information relating machinability to microstructural characteristics. Castings submitted in Phase II were examined and compared to the baseline data. The baseline data serves as a reference point for assessing the causes of the difference. The baseline data is being used to determine reasons for both superior and inferior machining behavior. Companies began contributing hard-to-machine castings for examination. Analyses produced findings to improve machinability. The primary focus of the current phase will be to continue to identify and determine how the occurrence of microcarbides, silicides, and other objectionable phases can be controlled within the normal foundry process (rather than by heat treatment). Alloy combinations will be explored that will maintain strength while improving machinability. Machining operations will be extended from drilling to include turning, and data will be obtained with higher performance tools including carbides and ceramics. In addition, properties will be measured on selected classes of irons to provide data for linear elastic stress codes that can be used to design castings for reduced mass.

American Foundry Society, Des Plaines, IL	*Copeland Corporation, Sidney OH*	*Kohler, Kohler WI*
Cummins Engine, Columbus IN	*Daimler Chrysler, Indianapolis IN*	*Mercury Marine, Fond du Lac, WI*
ABI, Oakland CA	*Wells Manufacturing, Woodstock IL*	*Seele Corp, Hendersonville NC*
Consolidated Diesel, Whitakers NC	*Ford Motor Co, Dearborn MI*	*Technalysis, Indianapolis IN*
Bosch Breaking Systems, South Bend IN	*Hiler Industries, LaPorte IN*	*Waupaca Foundry Co. Waupaca WS*
Caterpillar Inc. Peoria IL	*Ingersoll Cutting Tools, Rockford IL*	*Wheland Foundry Co. Chattanooga TN*

Service Performance of Welded Duplex Stainless Steel Castings and Wrought Materials, **University of Tennessee**- Welding can impair the corrosion performance of both wrought and cast materials. It requires that the specifiers must consider the fabrication aspects of the materials and not just rely on published values for the base materials alone. The corrosion performance is most egregiously degraded by welding processes, which leave behind a fusion zone containing melted base material. This melted base metal zone, which is termed the “unmixed zone” in the filler metal added processes, is the region responsible for the degraded corrosion pitting resistance. Further, the phase balance in this zone is influenced by solidification and this phase balance must be restored either by heat treatment or by the selection of filler metals richer in austenite formers such as nickel and nitrogen. However, a paucity of data exists upon which the specifier/engineer can base service performance. Hence, there is the need for a more comprehensive study of the behavior of welded components. The project will develop a suitable database to provide detailed fabrication and service performance guidelines including welding and heat treatment procedures for duplex stainless steel and wrought materials. The database will enable the industry to reduce wastes resulting from improper fabrication and heat treatment methods, to reduce fabrication time due to undocumented fabrication procedures, and to improve service performance of components fabricated from duplex stainless steels, comparing to conventional materials. It is expected that the following types of manufacturing plats are affected: oil refineries, ethylene furnaces, and reformer furnaces. There are 187 oil refineries in the U.S, and it is estimated that there are 450 ethylene furnaces, and 700 reformer furnaces in the U.S.

Steel Founders' Society of America, Barrington, IL	*Atlas Foundry and Machine, Tacoma, WA*	*Stainless Foundry, Milwaukee, WI*
Alloy Rods, Champaign, IL	*Keokuk Steel Casting, Keokuk, IA*	*Welding Research Council, New York, NY*
	Quaker Alloy, Myerstown, PA	*Wollaston Alloys, Braintree, MA*

Systematic Microstructural Corrosion Performance Evaluation of CN-3MN and CK-3MCUN High Molybdenum Stainless Steel **University of Tennessee**- There is a need for a thorough and systematic investigation of the microstructural relationships and corrosion performance of high alloy stainless steel castings. This is of paramount importance because a dearth of information exists for optimum engineering usage of the newer and more corrosion resistant alloy systems. From an on-going study at the University of Tennessee entitled "Improved Process Procedures for Upgrading and Repair of High Alloy and Stainless Castings," being performed for Department of Defense, Defense Logistics Agency, it has been found that there is a significant need to better understand the metallurgy and microstructural evolution during casting processing in order to optimize performance. The DOD/DLA program definitely demonstrated that cast and wrought alloys of the same type and general composition can have significant differences in properties, and , furthermore, the same cast alloy system may vary in response to corrosive environments from supplier to supplier or from one supplier depending on the heat treatment. In this study, the University of Tennessee will systematically document the microstructural phase evolution (constituent type, morphology, extent and distribution) in two types of high molybdenum stainless steel castings as a function of solution heat treatment parameters, and then relate the microstructure to corrosion performance. The nature of the second phase particles and constituents will be thoroughly studied as to the origin of the secondary phases. In particular, the effect of re-oxidation during pouring of a casting will be investigated and the source of the re-oxidation products will be defined by close cooperation with participating foundries. If the second phase particles that affect corrosion performance are associated with re-oxidation, a special effort will be undertaken to define the methodologies for minimization of re-oxidation. The optimum solution heat treatments will be documented and the effect of solution heat treating temperature, time and cooling rate from the solution heat treatment temperature will be defined. Standard corrosion tests will be employed for intergranular attack and pitting resistance assessment. Extensive optical and electron micrographic techniques will be employed for identification of secondary constituents and the degree of alloy segregation and its distribution as a function of thermal treatments will be assessed. Comparable companion wrought alloys will be similarly evaluated. An atlas of microstructures as a function of heat treatment will be produced which will relate the heat treatment variables, the microstructure and corrosion performance.

Steel Founders' Society of America, Barrington, IL	*Esab Welding & Cutting Products, Hanover, PA*	*Quaker Alloy, Inc., Myerstown, PA*
Atlas Foundry and Machine, Tacoma, WA	*Keokuk Steel Casting, Keokuk, IA*	*Welding Research Council, New York, NY*
		Wollaston Alloys, Inc.,Braintree, MA

Environmental Technologies

Development of Technical Data to Validate Performance of Foundry Byproducts in Hot-mix Asphalt and Controlled Low-Strength Material, **Pennsylvania State University**- The goal of this project is to develop technical data to validate performance characteristics of foundry byproducts in hot-mix asphalt and controlled low-strength material. The data will be made publicly available and enable the construction industry to evaluate and use foundry sand as an aggregate for various materials. It is estimated that approximately 8 million tons of foundry sands and slags could be available for reuse every year. Most spent foundry sands and slags have characteristics that allow for reuse as fine and coarse aggregates in a number of engineered applications. However, the engineering specifications and technical performance standards for reuse of foundry sands and slags have not been developed. Additionally, the environmental characteristics of foundry byproducts in reuse applications are not universally understood. Compiling this information is prohibitively expensive for most small foundries. Together, these technical barriers constitute major impediments to foundry byproduct reuse activities. Controlled low strength material (CLSM) and hot mix asphalt (HMA) have been selected as initial targets to address the void of technical data. There are a variety of technical, economic, and environmental arguments that support a focus on these two applications. Both materials have been identified by the Federal Highway Administration as potential uses for foundry byproducts in highway construction applications. The project will develop a national technical database defining the technical parameters for the use of foundry byproducts in CLSM and HMA, as well as design guidelines for CLSM and HMA mix designs.

University of Wisconsin, Madison, WI
American Foundry Society, Des Plaines, IL
Badger Mining Corporation, Berlin, WI
EOAssociates, Mill River, MA
Foundry Association of Michigan, Lansing, MI
GM Worldwide Facilities Group Environmental Services Division, Detroit, MI
Illinois Cast Metals Association, North Pekin, IL
Indiana Cast Metals Association (90 companies), Indianapolis, IN
Kurtz Brothers, Inc., Groveport, OH
Ohio Cast Metals Association (95 companies), Columbus, OH
Payne & Dolan, Inc., Waukesha, WI
Pennsylvania Foundrymen's Association (140 companies),
Plymouth Meeting, PA
Process Recovery Corp., Sinking Spring, PA
U.S. Environmental Protection Agency Chicago, IL

Non-incineration Treatment to Reduce Benzene and V.O.C. Emissions from Green Sand Molding Systems, **Pennsylvania State University**- The goal of this research is to understand and further develop cost-effective non-incineration techniques that will significantly reduce VOC emissions from foundries. Green sand foundries are under increasing pressure to reduce benzene and volatile organic carbon (VOC) emissions during pouring, cooling and shakeout. Conventional incineration systems to treat stack gases are expensive to operate and difficult to maintain. Alternative pollution prevention strategies must be developed to comply with ever more demanding air quality requirements. Full-scale plant trials at green sand foundries have shown that simple non-incineration Sonoperoxone™ (SP) treatment systems or a combination of Sonoperoxone™ Plasma (SPP) treatment can significantly reduce emissions. In SP and SPP treatment systems, sand system baghouse dust is passed through a water slurry that has been pre-conditioned with ozone, hydrogen peroxide, and sonification/plasma treatment. The research project at the Pennsylvania State University is a comprehensive program. It will be conducted to develop a fundamental understanding of SP and SPP processing. Plant trials and laboratory tests will be conducted and processes monitored to further optimize systems that have been already installed at production foundries. As a result of this research effort, the performance characteristics and effectiveness of non-incineration treatments to significantly and cost effectively reduce benzene and VOC emissions for green sand foundries will be demonstrated.

Wisconsin Cast Metals Association (60 companies), Milwaukee, WI
American Foundry Society, Des Plaines, IL
Furness-Newburge, Inc., Versailles, KY
Grede Foundries, Inc., Reedsburg, WI
International Truck and Engine Corp., Waukesha, WI
Neenah Foundry Company, Neenah, WI
Wheeland Foundry, Chattanooga, TN

Steel Foundry Refractory Lining Optimization: Electric Arc Furnace, **University of Missouri - Rolla**- The objective of this project is to improve refractory lining performance in electric arc furnaces used by steel foundries. This objective will be accomplished through (1) careful review of electric arc furnace (EAF) operating practices, including refractory lining and maintenance practices, (2) post-mortem characterization of furnace refractories, and (3) high temperature simulations of operating conditions. The campaign duration of furnace refractory linings used in wrought steel production has been increasing dramatically over the past few decades. In the 1970's, a lining campaign of 2,000 heats was considered excellent while today more than 20,000 heats per lining can be achieved. This lining campaign extension is the result of many factors such improved refractory selection, basic slag chemistry, refractory gunning, and slag splashing. The effects of such changes are most pronounced in basic oxygen furnaces and large electric arc furnaces. Smaller electric arc furnaces, as used in steel foundries, do not afford the potential for such dramatic improvements; however, 4 to 5 fold extensions in lining campaigns are possible. For the past ten years, the researchers at the University of Missouri at Rolla (UMR) have been working with the wrought steel industry to better understand the mechanisms, which govern the wear of furnace refractories. Many new refractory materials have been developed during that same period and have been used successfully by wrought steel producers. But, largely because of elevated costs, these materials have not found widespread usage in steel foundries. In the current project, the researchers at UMR will build on the experience they gained with wrought steel production to assist steel foundries. The main focus of the project is to optimize the refractory systems used in electric arc furnaces (EAFs) in the steel foundries. This will be accomplished by determining the best combinations of refractory materials, slag compositions, and melting practice to increase the refractory life in EAFs. There are nearly twenty industry partners involved in this project from across the U.S.

Steel Founders' Society of America, Barrington, IL
ABC Rail Products, Anderson, IN
ABC Rail Products, Calera, AL
American Cast Iron Pipe Co., Birmingham, AL
Atchison Casting, Atchison, KS
Baker, Refractories, York, PA
Electroalloys Corp., Elyria, OH
The Falk Corporation, Milwaukee, WI
GH Hensley Industries, Dallas, TX
Harrison Steel Castings, Attica, IN
Keokuk Steel Castings, Keokuk, IA
Missouri Steel Castings, Joplin, MO
North American Refractories, State College, PA
Pelton Casteel, Milwaukee, WI
Quaker Alloy, Inc., Myerstown, PA
Varicast, Inc., Portland, OR
Wahl Refractories, Fremont, OH
Wellsville Fire Brick Co., Wellsville, MO

For More Information Contact:

Metal Casting Industry of The Future Web-site:
http://www.oit.doe.gov/metalcast/metalcasting.shtml

Office of Industrial Technologies
Clearinghouse
Phone: (800) 862-2086
Fax: (360) 586-8303
E-mail: Clearinghouse@ee.doe.gov

Additional Resources

Office of Industrial Technologies Web-site:
www.oit.doe.gov

Cast Metals Coalition (CMC) Web-site:
http://cmc.aticorp.org

Industrial Assessment Centers Web-site:
www.oit.doe.gov/iac

Office of Industrial Technologies Solicitations Calendar Web-site:
http://www.oit.doe.gov/working/solicitations.shtml

Office of Industrial Technologies BestPractices Web-site:
http://www.oit.doe.gov/bestpractices/bestpractices.shtml

American Foundry Society (AFS) Web-site:
www.afsinc.org

North American Die Casting Association (NADCA) Web-site:
www.diecasting.org

Steel Founder's Society of America (SFSA) Web-site:
www.sfsa.org