Industry of the Future 2002 Annual Report

February 2003

Metals & Mining

Industrial Technologies Program - Boosting the productivity and competitiveness of U.S. industry

U.S. Department of Energy
Energy Efficiency and Renewable Energy

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Executive Summary

The Industries of the Future (IOF) strategy was designed to foster government-industry partnerships in economically imperative, energy intensive U.S. industries, including metal casting. Industries of the Future represent the base of the 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 (DOE), Office of Energy Efficiency and renewable Energy (EERE), cost-shares precompetitive research to improve energy efficiency in metal casting. It fosters industry research partnerships and has been credited as the driving force behind many significant technical advances that have helped to improve energy efficiency in the metal casting industry.

Industry participation in the Metal Casting IOF industry partnership is managed by the Cast Metals Coalition, which is composed of the American Foundry Society (AFS), North American Die Casting Association (NADCA), and Steel Founders' Society of America (SFSA). Collectively, this coalition represents approximately 80% of the U.S. metal casting industry. To guide its research, the industry developed visions and roadmaps, establishing long-term goals for the future and charting the research and development (R&D) pathways to achieve these goals. They have formed the basis for open and competitive solicitations for pre-competitive, cost-shared R&D addressing energy efficiency goals outlined in the *National Energy Policy*, as well as industry research priorities. This successful government-industry partnership has now evolved to a point where it is focusing upon high-impact research to make revolutionary improvements in the energy efficiency of metal casting processes.

The following briefly summarizes major highlights and accomplishments during 2002 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. The research is developing computer-based design tools, sensors, new casting techniques, and new advanced technologies to improve casting productivity. It is expanding engineers' and designers' knowledge of material properties and improving process controls in the casting process. (See page 15)

- The current portfolio of metal casting research is being performed in partnership with three hundred and twenty-five industry, university, and national laboratory partners across the United States. The involvement of industry on the ground floor accelerates technology transfer and dissemination of research results. Involvement of universities is exposing hundreds of students to the field of metal casting and enabling the industry to have access to the technical expertise available at the universities. (See page 13)

- The current portfolio addresses a cross section of priorities outlined in the Metal Casting Technology Roadmap with sixty-six percent of research funding going toward improvements in manufacturing processes, where the greatest opportunities for energy savings exist. Additional research funding is going to improvements in material performance, thereby reducing scrap and increasing yield, as well as to address environmental needs such as recycling of foundry spent sand. (See page 14)

- Beyond the Metal Casting IOF research funding of $23 million received between 1997 and the present, EERE has leveraged an additional $19 million on current research and technical assistance relevant to metal casters. (See page 17)

2002- Highlights and Accomplishments

- The metal casting industry is applying the results of cutting edge IOF research (See pages 21-24). Examples are listed below.

  - ♦ Steel foundries are making improvements in gating systems, including shrouded pouring. They are reducing scrap and heat treatment requirements in the production of their castings.

  - ♦ Research has improved yield by 10-25% through development of new feeding distance rules for risering and pressurization of risers that reduce shrinkage.

  - ♦ Researchers have developed a mathematical tool that will allow an analytical approach to systematically design EPS pattern molds that will produce higher quality patterns with reduced lead-time and expenses.

  - ♦ Researchers have developed cost effective non-incineration techniques that will significantly reduce VOC emissions from foundries.

  - ♦ Research has led to the development of modifications of die steel chemical composition and heat processing, resulting in die life improvements of 20-30% and higher.

  - ♦ Researchers have developed a database explaining the effects of key elements on the properties of the die cast product, permitting a tailoring of alloy components to optimize die castings for specific applications.

- Through the CMC, the metal casting industry has updated its long-term vision. The new vision became the basis for the new technology roadmap that will be made available in late 2003. (See page 24).

- EERE BestPractices and Industrial Assessment Centers are providing hands-on technical assistance that metal casters can apply immediately, saving them millions annually (See page 25).

  - ♦ MetLab in Wyndmoor, Pennsylvania, with assistance from BestPractices, has developed a plan that will produce an annual savings of $528,400. One recommendation included using proper loading and scheduling, and reevaluating soak times for heat treating processes for long cycles.

  - ♦ A plant-wide assessment at the AMCAST Wapakonet, Ohio plant identified recommendations that would result in annual savings of $3.7 million. As implementation began AMCAST identified other cost savings resulting in an annual savings, of $6 million.

- In 2002, the Metal Casting IOF released the *Gateway to Metal Casting Resources* CD-ROM. This CD-ROM is designed to assist metal casting plant managers, engineers, and designers to quickly find information on technical R&D results, technical assistance, financial assistance, training, and other assistance that OIT can provide metal casters (See page 26). It complements the range of other technology transfer activities of the partnership including technical articles in trade journals, conferences, project review meetings, society/DOE websites, and other means.

- In conjunction with Eppich Technologies and industry, the metal casting IOF initiated the Energy Footprint Study of the U.S. Metal Casting Industry. This study will benchmark energy use in the various types of metal casting facilitates (See page 27). In addition, in the fall of 2002, KERAMIDA Environmental, Inc. began to conduct a study to evaluate energy requirements for various metal casting processes for the Metal Casting IOF (See page 27).

CONTENTS

EXHIBITS

Page

INTRODUCTION

Metal casting is one of the most energy intensive industries in the United States. It is critical to the U.S. economy as 90% of all manufactured goods contain one or more cast metal components. Metal castings are integral in U.S. transportation, energy, aerospace, manufacturing, and national defense.

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. Public-private research partnerships, such as the Cast Metals Coslition (CMC), have proven vital for performing long-term research needed to maintain a productive and healthy U.S. metal casting industry.

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Office of the Industrial Technologies Program (OIT), supports these partnerships by providing cost-shared R&D funding to improve energy efficiency in metal casting. This partnership is managed by OIT's Metal Casting Industry of the Future (IOF) program in collaboration with 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. This annual report summarizes the major goals, highlights, and accomplishments of the Metal Casting Industry of the Future during 2002.

The partnership emphasizes university-based research with strong industry participation. This strategy taps the technical resources of our nation's educational institutions and positions industry partners to quickly apply the results of metal casting research--thereby saving energy and improving competitiveness in world markets. The involvement of industry in the early R&D stages 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. The Metal Casting IOF research partners represent the diversity of the metal casting industry including suppliers, end-users, designers, ferrous and nonferrous foundries, and die casters. 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.

Successful Strategy for Partnership

The Industries of the Future strategy was designed to foster government-industry partnerships in economically-imperative, energy-intensive U.S. industries, including metal casting. This strategy has fostered industry partnership and created the impetus for industry to develop long-term visions and roadmaps. Visions establish long-term goals for the future, while roadmaps outline the research and development (R&D) pathways to achieve Vision goals. The Metal Casting vision and roadmap have been 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. This successful government-industry partnership has now evolved to a point where it is focusing upon high-impact research to make revolutionary improvements in the energy efficiency of the metal casting process.

The program has been successful in improving energy efficiency and market competitiveness in the industry. For example, research in lost foam casting, co-funded by the program and in partnership with the Lost Foam Casting Consortium, has resulted in significant improvements in the lost foam process and results have been implemented throughout the industry. The program is now targeting additional opportunities for high-impact research. In doing so the Metal Casting IOF is conducting in-depth analysis to map energy consumption in the industry by selectively evaluating energy demand in each of the various processes and technologies used in metal casting. It is also analyzing the theoretical minimum energy use that may be achievable in the industry. The results of this analysis will assist the Metal Casting IOF in identifying future areas of focus for high-impact research, setting the groundwork for a Grand Challenge research solicitation.

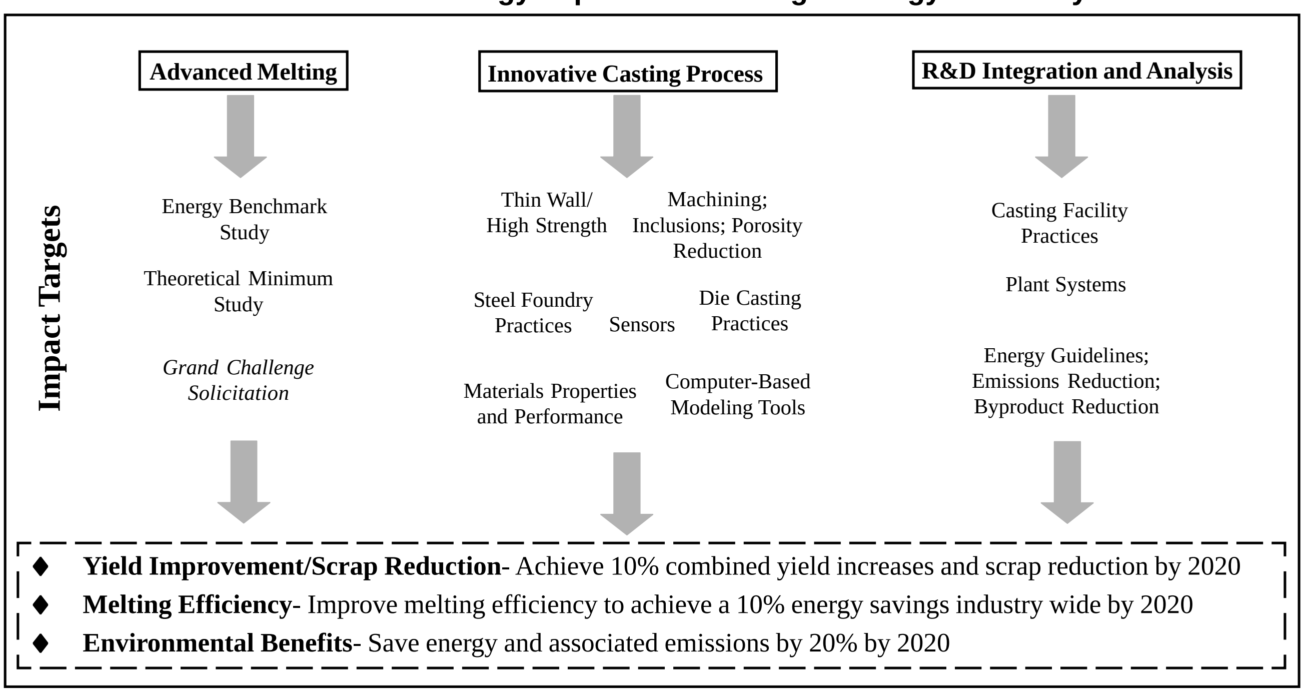
Evolution of the Metal Casting IOF

The success of the Metal Casting IOF is the result of a strong partnership between the Cast Metals Coalition (CMC) and the EERE. In the future, this partnership will direct its efforts to address high-impact research to make revolutionary improvements in energy efficiency in metal casting. Research is grouped into three categories:

- **Advanced Melting:** Research to establish new melting technology processes and practices and significantly improve upon the energy efficiency of melting.
- **Innovative Casting:** Research which advances energy efficient casting processes and practices that will increase yield and reduce scrap, thereby reducing remelting requirements.
- **R&D Integration and System Analysis:** Integration of applicable OIT technologies for improving energy efficiency and reducing emissions in metal casting practices.

As it transitions to a portfolio of fewer, yet larger high-impact projects, the Metal Casting IOF is organizing its research portfolio in three categories: Advanced Melting, Innovative Casting Processes, and R&D Integration and Analysis. Exhibit 1 shows the target areas of each of these research categories.

Exhibit 1
Process & Technology Improvements Target Energy Efficiency



THE CHALLENGE

Metal casting is one of the most energy-intensive industries in the U.S. manufacturing sector. It is also one of the only major U.S. manufacturing industries that is dominated by small businesses. These unique characteristics have helped drive the need for public-private R&D collaboration.

Energy-Intensive Industry

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. (Energy Use in Metal Casting, page 7). The Metal Casting Industry of the Future is funding research to improve energy efficiency in these processes. This research is improving yield, extending die and mold life, and reducing post-cast energy requirements. A 2002 analysis of current Metal Casting IOF research projects estimates that the current R&D portfolio will save 23.4 trillion Btu annually in 2010. This is estimated to increase to 101 trillion Btu in 2020.

Metal casting R&D is a component of the overall EERE strategy to improve energy efficiency nationwide and to contribute to the goals outlined in the *National Energy Policy*. It is contributing to the EERE mission "to strengthen America's energy security, environmentally quality, and economic vitality through public-private partnerships that:

1. promote energy efficiency and productivity;
2. bring clean, reliable, and affordable energy technologies to the marketplace; and
3. make a difference in the everyday lives of Americans by enhancing their energy choices and their quality of life."[3]

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 fewer than 100 people, 14% employ between 100 and 250 people, and only 6% employ more than 250 people. Industry-wide, an estimated 225,000 people are employed in metal casting. Moreover, the industry is widely dispersed throughout the country, eliminating opportunities for geographic based intra-industry coordination. In fact, metal casters are located throughout all 50 states. The industry is vital to the economic well being of the communities where they are located. Although the industry is found nationwide, ten states account for 84% of metal castings shipments. These states are Ohio, Indiana, Wisconsin, Alabama, Michigan, Pennsylvania, Illinois, Tennessee, California, and Texas.[4]

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[1] *1998 Manufacturing Consumption of Energy Report,* U.S. Department of Energy, Energy Information Administration Tables N.11.1, and *Survey 1998 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] U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Organization Mission and Functions, 2002, pg.1

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

Because metal casting is an industry dominated by small businesses, 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 cost and risk involved in long-term, pre-competitive research. Coalition-building is helping the industry to improve yield and reduce scrap rates, increase process control, improve material technologies, and reduce energy and environmental impacts. For example, researchers at the University of Ohio have developed a simple visualization technique software package for die casting part and design called *CastView*. This software has enabled 20% reduction in scrap and enabled first time success in the construction of complex dies. In short, Metal Casting IOF research is helping the U.S. metal casting industry remain innovative and efficient in today's highly competitive world marketplace.

> Representative James P. McGovern of Massachusetts highlighted the importance of the metal casting industry to the economy in an address to participants of the Massachusetts State Industries of the Future Metals Processing Symposium. He stated that maintaining a strong industrial infrastructure and manufacturing base in the United States is integral to our nation's success, our economic stability, and our national security. In particular, the congressman stated that metal casting is critical to the U.S. manufacturing base and is important in medical technology, computer technology, aerospace technology and the nation's defense. The congressman recognized the important role that the Metal Casting IOF plays in supporting cost-shared research that would be unapproachable for small businesses and the significant impact it has in exposing students to the industry through university-based research efforts calling the Industries of the Future program "a program for the 21st Century."

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 work force. 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.

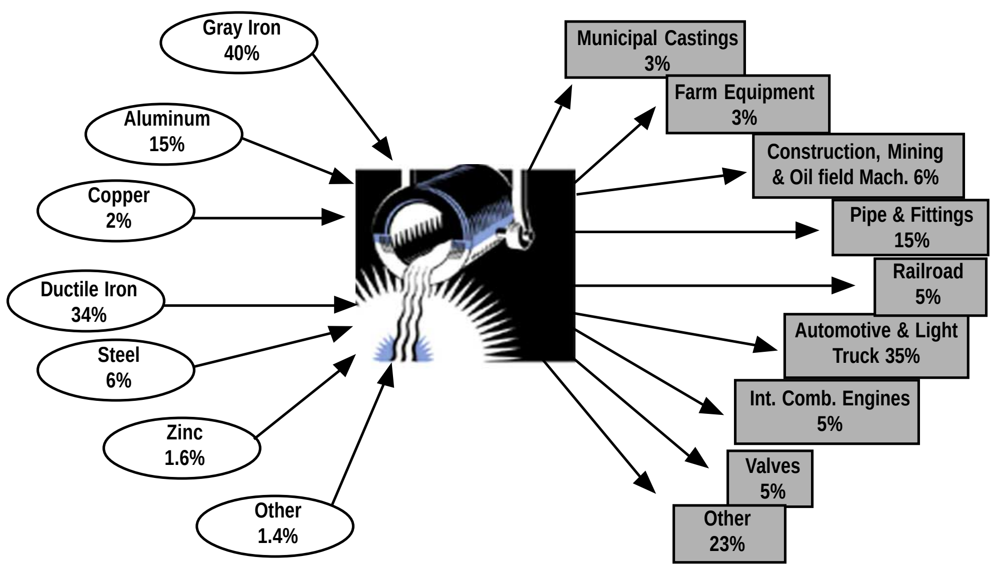
INDUSTRY OVERVIEW

Everyday tasks such as turning on a light, starting a car, or using a computer would not be possible without metal casting. The metal casting industry has been integral to U.S. growth and has helped the U.S. become the world benchmark in fields such as manufacturing, science, medicine, and aerospace. Now this small business industry continues to fuel the nation's prosperity and national defense 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 cast 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. Oil field machinery and equipment sales alone represent $259 million in casting sales per year.[5] Exhibit 2 illustrates raw material supplies and end use markets for metal castings.

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 and American Foundry Society *Facts & Figures About the U.S.Foundry Industry*, http://www.afsinc.org/trends/factsandfigures.htm

Exhibit 3 describes the various methods used to cast metals. The basic metal casting process consists of pouring or injecting molten metal into a mold or die containing a cavity of the desired shape. The most commonly used method for small-and medium-sized castings is green sand molding, accounting for approximately 60% of castings produced. Other methods include die casting, shell molding, permanent molding, investment 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 processes must continually evolve and improve to remain competitive in today's marketplace.

[5] Lessiter, Michael J. *Modern Casting* "Oil Field Equipment & Machinery," November 2002, pg. 36.

Exhibit 3
Examples of Metal Casting Processes

Process	Description	Advantages
Green Sand Molding[6]	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[7]	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.[8]
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.	• Has economical benefits with economies of scale. • Suitable for relatively low melting point metals.
Lost Foam Casting[9]	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[10]	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[11]	In this process, molten metal is introduced into a permanent metallic mold die cavity and pressure is applied as it solidifies.	• Castings do not undergo dimensional shrinkage. • Castings have excellent surface finishes.[12]
Centrifugal Casting[13]	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.

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

[7] Ibid. pg. 8

[8] www.myb2o.com

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

[10] www.myb2o.com

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

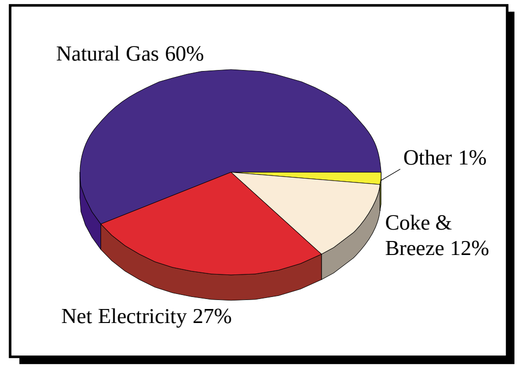
[12] www.myb2o.com

[13] Ibid

Energy Use in Metal Casting

The metal casting industry consumes an estimated 328 trillion Btu annually.[14] This includes 235 trillion Btu consumed by metal casters classified under NAICS 3315 as well as an estimated 93 trillion Btu consumed in captive foundries. As shown in Exhibit 4, 60% 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.[15]

Exhibit 4
Metal Casting Industry Energy Consumption-1998



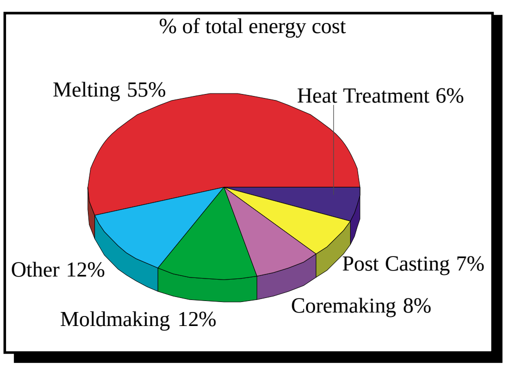
Source: U.S. Department of Energy, Energy Information Administration, 1998 Manufacturers Energy Consumption, Table N1.2 "First Use of Energy for All Purposes, NAICS code 3315; 331511; 331521; 331524.

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 2000, the industry spent $1.2 billion on purchased fuels and electricity. On average, energy purchases represented 10% of the material cost. This was highest in iron foundries where energy purchases represented about 12% of materials costs and lowest in nonferrous die casting foundries where energy purchases represented 6% of material costs (See Exhibits 6 and 7). Purchased fuels and electricity, on average represented about 6% of the value of shipments for 2002.

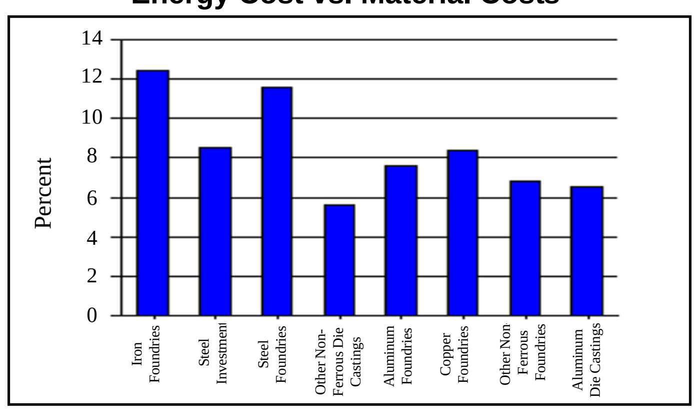
During 2002, the Metal Casting Industry of the Future in conjunction with the Cast Metals Coalition initiated an *Energy Footprint Study* to analyze energy use in metal casting processes and to develop better benchmarks for measuring improvements in energy efficiency. Additional details are provided in section "2002-Highlights and Accomplishments."

Exhibit 5
Process Energy Cost



Source: U.S. Department of Energy Energy Efficiency and Renewable Energy, Office of Industrial Technologies, Metal Casting Industry of the Future, *Energy and Environmental Profile of the U.S. Metal Casting Industry*, 1999, pg 10.

Exhibit 6
Energy Cost vs. Material Costs



Source: U.S. Department of Commerce, U.S. Census Bureau, 2000 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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[14] 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.

[15] U.S. Department of Energy, Energy Information Administration, 1998 Manufacturers Energy Consumption, Table N1.2 "First Use of Energy for All Purposes, NAICS code 3315; 331511; 331521; 331524.

Exhibit 7
Energy Costs for the Metal Casting Industry, 2000
(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)	$224.7	$414.7	$639.4	$5,121.4	12%	9,163,634
Steel Investment Foundries (331512)	22.0	54.3	76.3	894.9	9%	974,932
Steel Foundries (except Investment) (331513)	43.4	103.7	147.1	1,269.3	12%	2,015,405
Nonferrous (except Aluminum) Die Casting Foundries (331522)	14.8	33.0	47.8	856.6	6%	562,983
Aluminum Foundries (except Die Casting) (331524)	60.2	79.6	139.8	1848.0	8%	1,580,592
Copper Foundries (except Die Casting) (331525)	9.7	21.2	30.9	365.2	8%	358,406
Other Non-Ferrous Foundries (except Die Casting) (331528)	5.5	12.5	18.0	266.3	7%	217,562
Aluminum Die Casting Foundries (331521)	46.2	70.6	116.8	1,796.8	7%	1,418,288
Total (3315)	**$426.5**	**$789.6**	**$1,216.1**	**$12,418.5**	**10%**	**16,291,802**

Source: U.S. Department of Commerce, U.S. Census Bureau, 2000 Annual Survey of Manufactures, Manufacturing Industry Series, Tables 2 and 4, Detailed Statistics by Industry: 2000 for NAICS codes 3315, 331511, 331512, 331513, 331524, 331525, 331528, 331521, and 331522.

Metal Casting Industry Shipments

In 2001, the metal casting industry shipped a total of 12.2 million short tons of nonferrous and ferrous castings valued at $16.9 billion. This was a 13 percent decrease in total tonnage shipped the value of castings shipped declined by 11 percent when compared to 2000.

From 2000 to 2001 tonnage of nonferrous castings shipments declined by 12 percent. Over the same period the value declined 10 percent, the first decrease in over five years. The value and quantity of aluminum and aluminum- based alloy casting shipments decreased in both tonnage and value by 9 percent between 2000 and 2001.[16]

In 2001, a total of 9.9 million short tons of ferrous castings valued at $9.5 billion were shipped. Both the value and quantity of shipments declined 12 percent between 2000 and 2001. Ductile iron castings decreased 9 percent based on both tonnage shipped and total value of shipments.[17]

As shown in Exhibit 8, the quantity of casting shipments decreased by an average of 3 percent over the period 1996 to 2001. This was led by a drop in steel and gray iron shipments. Steel shipments decreased at an average annual rate of 9 percent between 1996 and 2000. Production in 2001 was 778 thousand short tons. The biggest share of the decline is was caused by gray iron dropping 1.3 million tons.[18]

Declines in total metal casting shipments over the past five years have been offset by the five year trend of generally increased demand for nonferrous castings. Aluminum and aluminum-based casting shipments increased at an average annual rate of 4 percent between 1996 and 2001 reaching 1.8 million short tons in 2001. Markets for nonferrous castings are expected to continue to remain strong in response to increased demand for lightweight materials.

Shipments value data are provided in Exhibit 9. Throughout the period between 1996 and 2001 the value of nonferrous castings rose by 2 percent. Ferrous castings declined in value over the same period by 3 percent, whereas total casting shipments value declined by 1 percent. This is roughly the same trend that occurred in the tonnage of castings shipped.[19]

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[16] 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.

[17] Ibid.

[18] Ibid.

[19] Ibid.

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

Nonferrous Castings	1996	1997	1998	1999	2000	2001	Avg. % change (96-01)
Aluminum and aluminum-based alloy	1,521,081	1,593,876	1,921,137	1,976,343	2,037,213	1,817,283	4%
Copper and copper-base alloy	284,560	276,480	286,360	310,449	273,739	250,170	-2%
Magnesium and magnesium-base alloy	25,724	19,257	20,741	21,956	29,599	24,346	1%
Zinc and zinc-base alloy	221,543	228,933	239,169	225,058	225,528	191,601	-3%
Sub-Total Nonferrous	2,052,908	2,118,546	2,467,407	2,533,806	2,566,079	2,283,400	3%
Ferrous Castings	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**Avg. % change (96-01)**
Ductile Iron	4,312,000	4,325,000	4,583,000	4,658,000	4,599,000	4,161,000	-1%
Gray Iron	6,198,000	5,938,000	6,047,000	5,955,000	5,606,000	4,813,000	-5%
Malleable Iron	263,000	272,000	247,000	207,000	186,000	135,000	-12%
Steel[1]	1,271,000	1,218,000	1,325,000	1,202,000	972,000	778,000	-9%
Sub-Total Ferrous	12,044,000	11,753,000	12,202,000	12,022,000	11,363,000	9,887,000	-4%
Total Nonferrous and Ferrous	**14,096,908**	**13,871,546**	**14,669,407**	**14,555,806**	**13,929,079**	**12,170,400**	**-3%**

Exhibit 9
Value of Shipments of Nonferrous and Ferrous Castings ('000 dollars)

Nonferrous Castings	1996	1997	1998	1999	2000	2001	Avg. % change (96-01)
Aluminum and aluminum-based alloy	$4,724,290	$5,172,590	$5,669,532	$5,556,386	$6,028,183	$5,428,376	3%
Copper and copper-base alloy	983,955	991,974	1,053,833	1,120,292	1,089,881	1,001,316	1%
Magnesium and magnesium-base alloy	272,842	225,685	256,852	245,677	256,274	203,325	-5%
Zinc and zinc-base alloy	809,127	818,963	914,648	928,341	873,831	765,108	-1%
Sub-Total Nonferrous	$6,790,214	$7,209,212	$7,894,865	$7,850,696	$8,248,169	$7,398,035	2%
Ferrous Castings	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**Avg. % change (96-01)**
Ductile Iron	$3,971,500	$4,148,900	$4,428,400	$4,299,000	$4,381,100	$3,928,800	0%
Gray Iron	4,463,000	4,719,500	4,635,100	4,446,000	4,406,200	3,817,900	-3%
Malleable Iron	266,100	272,400	257,900	238,000	229,400	176,300	-7%
Steel[1]	2,295,600	2,343,500	2,499,000	2,161,000	1,806,800	1,587,200	-7%
Sub-Total Ferrous	$10,996,200	$11,484,300	$11,820,400	$11,144,000	$10,823,500	$9,510,200	-3%
Total Nonferrous and Ferrous	**$17,786,414**	**$18,693,512**	**$19,715,265**	**$18,994,696**	**$19,071,669**	**$16,908,235**	**-1%**

[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(01)-1, and Non-Ferrous Castings, MA331E(01)-1.

World Casting Production

In 2001, the U.S. dropped to second in world ferrous casting production with 16% of the world market. Exhibit 10 illustrates world ferrous casting production for 2001 based on tonnage produced. China leads the world in ferrous casting production with 24% of the world market. In 2000 and 2001, China experienced a 10% and 7% growth in ferrous casting shipments respectively while the U.S. experienced nearly a 10% decline in casting shipments in 2001. Other major producers of ferrous castings are Russia, Germany, Japan, and India.[20]

Exhibit 11 illustrates world nonferrous casting production for 2001 based on tonnage produced. The U.S. was the leader in nonferrous castings across nearly all alloy types with 24% of the world market share, down slightly from 27% during 2000. Japan followed the U.S. with 12% of the world market. Aluminum represented 90% of Japan's nonferrous casting shipments, whereas the U.S. was more diversified with aluminum accounting for 68% of the nonferrous casting shipments. China held 11% of the world market. Mexico continued to have strong nonferrous production with 8% of the world market share. This is a significant increase from 1995 when Mexico held only 2.9% of the world market share. Other leading producers of nonferrous castings include: Germany, Russia, and Italy.[21]

Exhibit 10
2001 World Ferrous Casting Production
(Share of Tonnage Produced)

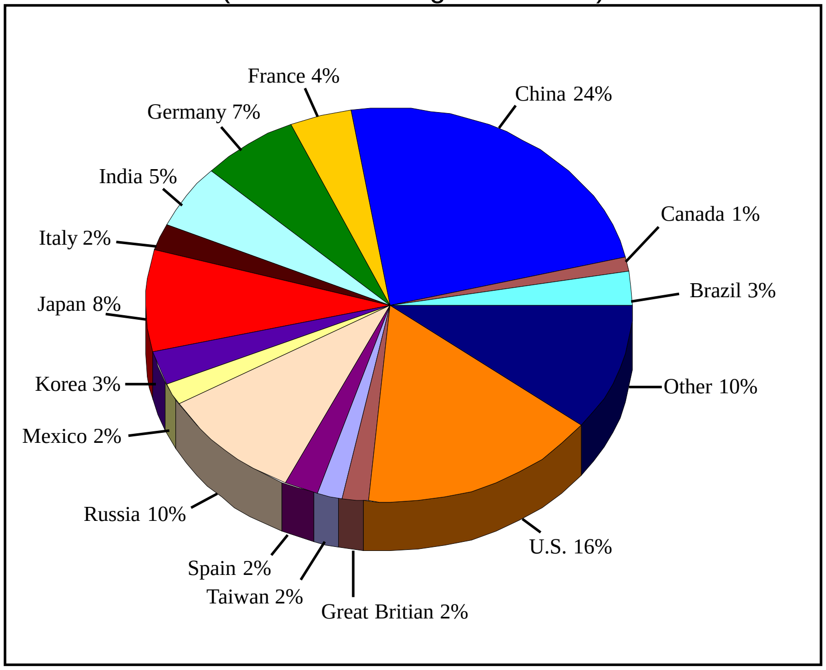
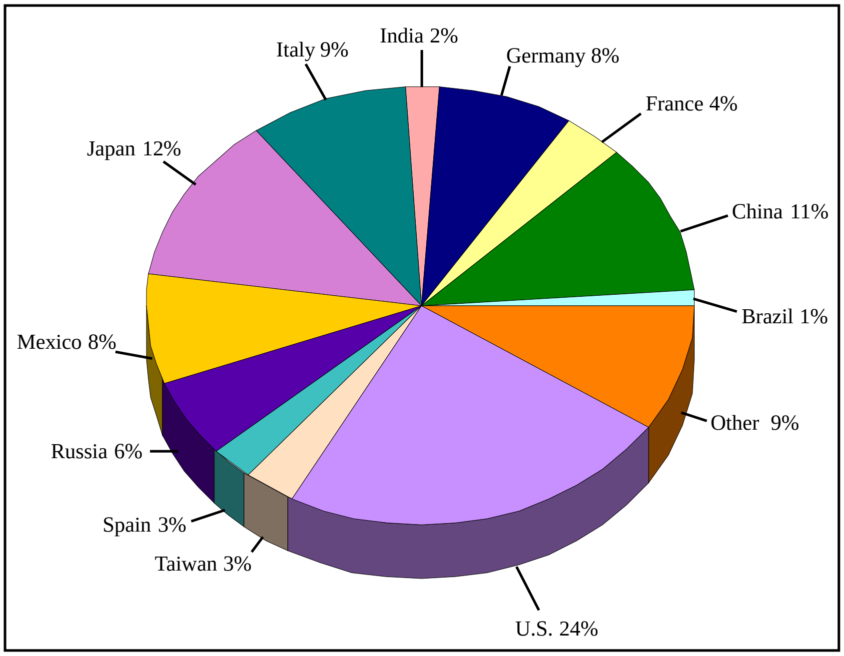


Exhibit 11
2001 World Nonferrous Casting Production
(Share of Tonnage Produced)



[20] Staff Writer, "36th Census of World Casting Production- 2001" *Modern Castings*, December 2002 p. 23.
[21] Ibid

Although the U.S. is one of the largest producers of metal castings, its manufacturing sector is dependent upon imports to meeting casting demand. It is estimated that in 2003 the U.S. will rely on imports to meet 15% or 2.2 million tons of its total casting demand. The U.S. will rely on imports to supply 20.3% of its gray iron casting demand, and 13.6% to meet its steel casting demand. Moreover, the U.S. will rely on imports to meet 17.5% of its total demand for aluminum castings and 18.6% of its requirements for bronze castings.[22]

[22] Kirgin, Kenneth H. "Casting Imports: What to Expect in 2003" *Modern Castings*, September 2002 p. 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. In 2003 and beyond, the metal casting portfolio will transition to larger projects that will have the opportunity to produce revolutionary improvements in metal casting energy efficiency.

Maintaining a strong and well-balanced portfolio requires careful attention throughout the competitive solicitation, evaluation, and selection process. The 2002 Metal Casting IOF research portfolio consists of 47 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.

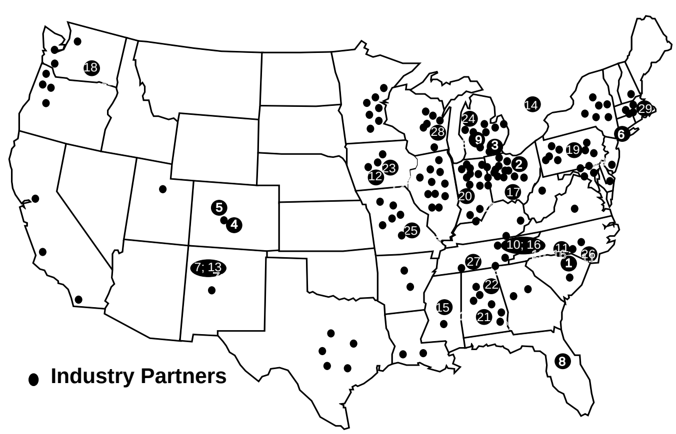
Broad Industry Partnership

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 325 industry, university and national laboratory partners in 35 states across the U.S. The geographic reach of the program's partnership is illustrated in Exhibit 12. Appendix A provides a listing of program partners by state.

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 Colorado State University
6 Copper Development Assoc., Inc.
7 Flow Simulation Services, Inc.
8 GKS Engineering Services
9 Hayes Lemmerz
10 Industrial Analytics Corporation
11 Intl. Lead Zinc Research Organization
12 Iowa State University
13 Los Alamos National Laboratory
14 Materials Technology Laboratory
15 Mississippi State University
16 Oak Ridge National Laboratory
17 Ohio State University
18 Pacific Northwest National Laboratory
19 Pennsylvania State University
20 Tri-State University
21 University of Alabama
22 University of Alabama - Birmingham
23 University of Iowa
24 University of Michigan
25 University of Missouri – Rolla
26 University of North Carolina-Charlotte
27 University of Tennessee
28 University of Wisconsin - Milwaukee
29 Worcester Polytechnic Institute



The Metal Casting Industry of the Future is partnering with 325 university, industry, and laboratory partners in 35 states across the U.S.

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 nonferrous 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 roadmap category. Exhibit 14 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 have crosscutting applications and respond to research priorities in multiple roadmap categories.

As illustrated in Exhibit 14, the program maintains a healthy balance of research targeted to both ferrous and nonferrous 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 in Appendix B.

Exhibit 13
Research Funding by Roadmap Category

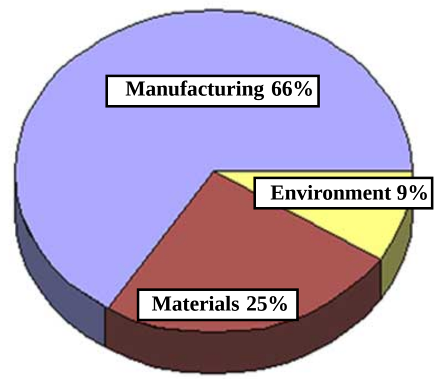


Exhibit 14
Research Funding by Primary Alloy

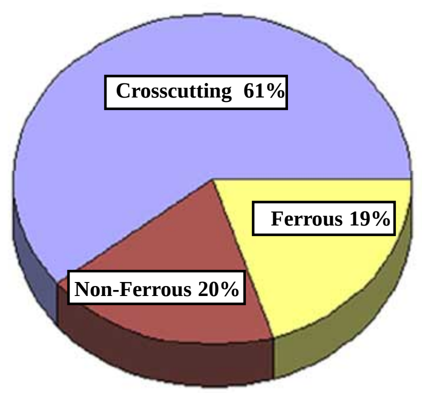


Exhibit 15
Metal Casting Portfolio by Roadmap Category

Manufacturing

- Development of Computational Fluid Dynamics Tool for Modeling the Blowing and Steaming of Expandable Polystyrene (EPS) Patters for Lost Foam Castings **(Arena, LLC)**
- Optimization of Squeeze Casting Process for Aluminum Alloy Parts **(Case Western Reserve University)**
- Effects of Die Design & Dimensional Features on Thermal Fatigue Cracking of Die Casting Dies **(Case Western Reserve University)**
- Gating of Permanent Mold Aluminum Casting (Phase II) **(Case Western Reserve University)**
- Integration of RSP Tooling with Rapid Prototyping for Die Casting Applications **(Colorado State University)**
- Quantification and Standardization of Pattern Properties for the Lost Foam Casting Process **(Industrial Analytics Corporation)**
- 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)**
- Predicting Pattern Tooling and Casting Dimensions for Investment Casting - Phase II **(Oak Ridge National Laboratory)**
- Control of Soldering and Thermal Fatigue During Die Casting **(Oak Ridge National Laboratory)**
- Sensors for Die Casting **(Oak Ridge National Laboratory)**
- Castability Assessment and Data Integration for Die Casting Design **(Ohio State University)**
- Prediction of Part Distortion in Die Casting (Phase III) **(Ohio State University)**
- Energy Consumption of Die Casting Operations **(Ohio State University)**
- Understanding the Relationship Between Pattern Filling and Part Quality in Die Casting **(Ohio State University)**
- Computer Modeling of the Mechanical Performance of Die Casting Dies **(Ohio State University)**
- Improvements in Sand/Mold/Core Technology: Effects on Casting Finish **(Ohio State University)**
- Investment Shell Cracking **(Tri-State University)**
- Thin Wall Cast Iron: Phase 2 **(University of Alabama)**
- Advanced Lost Foam Casting, Phase V **(University of Alabama - Birmingham)**
- Clean Cast Steel Technology, Phase IV **(University of Alabama - Birmingham)**
- Advanced Steel Casting Technology **(University of Alabama-Birmingham)**
- Yield Improvement and Defect Reduction in Steel Castings **(University of Iowa)**
- Investigation of Heat Transfer at the Mold/Metal Interface in Permanent Mold Casting of Light Alloys **(University of Michigan)**
- Determination of Bulk Dimensional Variation in Castings **(University of North Carolina at Charlotte)**
- Semi-Solid Metals Processing Consortium **(Worcester Polytechnic Institute)**
- Manufacture of Semi-Solid Metals (SSM) Feedstock **(Worcester Polytechnic Institute)**

Materials

- Evaluation of Heat Checking and Washout of Heat Resistant Superalloys for Die Insert **(Case Western Reserve University)**
- Die Materials for Critical Applications and Increased Production Rates **(Case Western Reserve University)**
- Metallic Reinforcement of Direct Squeeze Die Cast Aluminum Alloys for Improved Strength and Fracture Resistance **(Case Western Reserve University)**
- Prevention of Porosity in Iron Casting **(Climax Research Services)**
- Development of a Fatigue Properties Data Base for Use in Modern Design Methods **(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.)**
- 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 Phase III **(Tri-State University)**
- Metallic Recovery and Ferrous Melting Processes **(Tri-State University)**
- Clean, Machinable, Thin-Walled Gray and Ductile Iron Casting Production, Phase III **(University of Alabama - Birmingham)**
- Service Performance of Welded Duplex Stainless Steel Castings and Wrought Materials **(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 Furnace **(University of Missouri - Rolla)**

Exhibit 16
Technical Milestones

2003
American Foundry Society • 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 **North American Die Casting Association** • Die Deflection - Enhanced tolerances • Die Coatings- Multi-layer system recommendation • Casting Characteristics of Aluminum Die Casting Alloys- Processing guidance for die cast aluminum alloys with enhanced properties **Steel Founders' Society of America** • Yield Improvement in Steel Castings - Radiographic standards; production approval
2004
American Foundry Society • Gating- Rules for permanent mold castings **North American Die Casting Association** • Sensors – Vibration signatures for die casting process control • Creep Resistant Zinc – New die casting alloy • Die Design- Design guidelines for reduced thermal fatigue cracking • RSP Tooling- Rapid tooling technique for short lead-time die casting tool **Steel Founders' Society of America** • Advance Steel Casting- Determine the decomposition kinetics of ferrite into austenite in two duplex stainless steel
2005
American Foundry Society • Metallic Recovery - Improved charge determination and composition control • Grain Refinement- Permanent mold casting grain refinement **North American Die Casting Association** • Castability Assessment- Design guidance for die casting die cooling line placement and geometry for low stress **Steel Founders' Society of America** • Reduction in Energy Consumption- Improved overall efficiency of steel foundry

Process and Technology Improvements to Increase Energy Efficiency

The Metal Casting IOF evaluates projects against performance based metrics to ensure that projects remain on track and lead to energy savings for the industry. Specifically, it is targeting research that will reduce scrap and improve productivity to a level where yield rates increase by 10%. Improved yield will reduce the amount 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 requirements.

An analysis of the Metal Casting IOF 2002 R&D portfolio indicates that the portfolio will save an estimated 23.38 trillion Btu annually by 2010 and 101.01 trillion Btu annually by 2020. This analysis is performed each year in response to the Government Performance and Results Act (GPRA). Results are reported to Congress.

In 2003, the Metal Casting IOF program will focus upon three research areas. These areas include:

- **Advanced Melting:** Research in this category will establish new melting technologies and practices to dramatically improve the energy efficiency of melting. Melting represents approximately 55 percent of the overall energy costs in metal casting operations. Improvements in the melting process will have a large impact on energy consumption and cost savings for metal casters.

- **Innovative Casting Processes:** This area of the portfolio includes research that advances energy efficient casting processes as well as practices that increase yield and reduce scrap, thereby reducing the amount of metal which must be remelted. Casting processes include, for example, lost foam, die casting, investment casting, semi-solid casting, permanent mold, and next generation ferrous castings. Innovations in these casting processes are being made through developments in sensors, material properties and performance, computer-based modeling tools, and reduction in machining requirements.

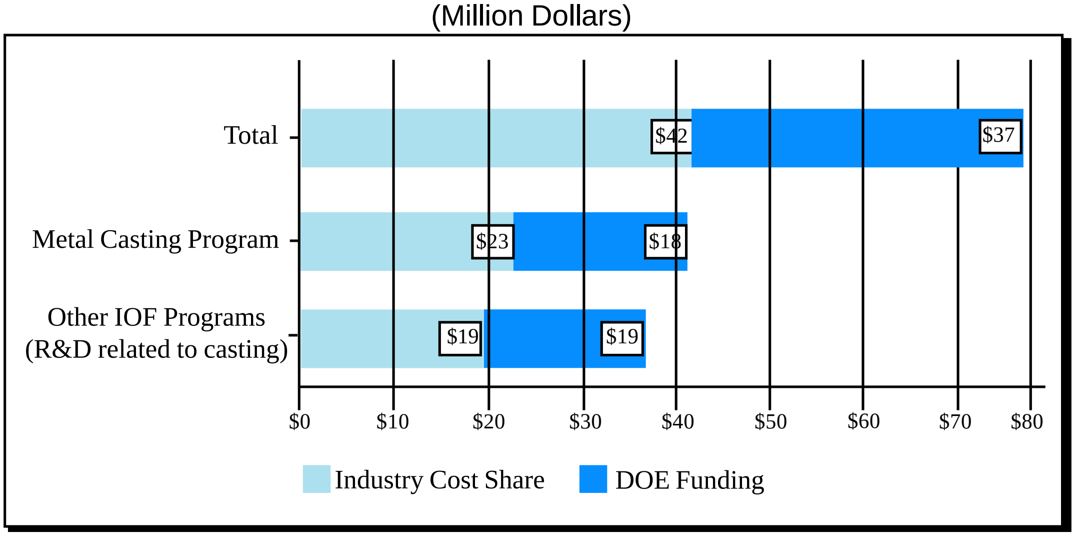
- **R&D Integration and Analysis:** This area of the portfolio includes research and technical assistance that integrates applicable OIT technologies for improving energy efficiency and reducing emissions in metal casting practices. Research in this area includes improvements to the general energy efficiency of plant operations through BestPractices and Industrial Assessments as well as research to identify new uses for casting byproducts.

Integrated Assistance for the Metal Casting Industry

As illustrated in Exhibit 17, the Metal Casting IOF has funded $18 million in research with an additional $23 million provided by industry cost-share over the period of 1997 to the present.

A number of other EERE programs have performed research related to metal casting. These include NICE[3], Inventions & Innovations, and the Aluminum and Steel IOFs. Combined, they have provided approximately $19 million in funding on current research and technical assistance relevant to metal casters and leveraged an additional $19 million in cost-share.

Exhibit 17
Leveraging Funding for the Metal Casting Industry
(Million Dollars)



Beyond the research funding provided by the Metal Casting IOF, many EERE technical and financial assistance programs and services are available to the metal casting industry to improve energy efficiency and competitiveness in casting processes. Exhibit 18 describes several examples of EERE program assistance. 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 to those programs listed in Exhibit 18, EERE provides research on leading edge enabling technologies, including Sensors & Controls, Industrial Materials, Combustion and others. The program enables risk sharing on industry-specific pre-competitive long-term, high-impact research available through the Industries of the Future such as Aluminum and Steel. The program also provides financial assistance for small businesses through Small Business Innovative Research grants. FreedomCar, a program within EERE, funds research on materials to make automobile more fuel efficient. For example *Improved A206 Alloy May Lead to Better, More Cost Effective Automotive Suspension Components* is one of the materials projects in their portfolio.

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.

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 18
Examples of EERE
Technical and Financial Assistance

- **NICE^3:** National Industry Competitiveness through Energy, Environment, Economics (NICE^3) provides funding to state and industry partnerships (large and small businesses) for projects that develop and demonstrate advances in energy efficiency and clean production technologies.

- **I&I:** Inventions and Innovation (I&I) provides financial assistance at two levels: up to $40,000 (Category 1) or up to $200,000 (Category 2)- for conducting early development and establishing technical performance of innovative energy saving ideas and inventions.

- **IAC:** Industrial Assessment Centers enables eligible small and medium-sized manufacturers to have comprehensive industrial assessments performed at no cost to the manufacturer.

- **States EERE Partnerships:** Deliver the accomplishments of the national Industries of the Future strategy to the local level to expand the opportunities to a larger number of partners and reach smaller businesses and manufacturers that were not initially involved in the IOF effort.

Throughout DOE there are other programs that fund research that is relevant to the metal casting program. Fossil Energy (FE) conducts advanced materials and metallurgical processes research in their electric power R&D portfolio. One such project in their portfolio is *Advanced Austenitic Alloys-Development of a Modified 310 Stainless Steel*. This project is evaluating structural alloys for improved performance of high-temperature components in advanced combined-cycle, coal combustion systems, and components needed for advanced processes.

Exhibit 19
Additional Industrial Technologies Research Related to Metal Casting

Financial Assistance

- Ceramic Composite Die for Metal Casting (Inventions & Innovation)
- High-Frequency Eddy-Current Separator for Foundry Sand (Inventions & Innovation)
- Computer Process Model for the Cupola Furnace (Inventions & Innovation)
- Casting Quality Measurements for Polystyrene Foam Patterns (Inventions & Innovation)
- A New “Pour In-Mold” (DPI) Technology for Producing Ductile and Compacted Graphite Iron Castings (Inventions & Innovation)
- Demonstration of a Vanadium Carbide Coating/Enhancing Wear Resistance ($NICE^3$)
- Reducing Foundry Emissions and Green Sand Waste ($NICE^3$)
- Rapid Heat Treatment of Cast Aluminum Components ($NICE^3$)
- Enhanced Application Control of Die Casting Lubricants ($NICE^3$)
- Commercial Demonstration of an Improved Magnesium Thixomolding Process ($NICE^3$)
- Die Casting Copper Motor Rotors ($NICE^3$)
- Improvement of the Lost Foam Casting Process ($NICE^3$)

Crosscutting Applications

- A Bubble Probe for Optimization of Bubble Distribution and Minimization of Splashing/Droplet Formation (Aluminum)
- Continuous Severe Deformation Processing of Aluminum Alloys (Aluminum)
- Coolant Characteristics and Control in Direct Chill Casting (Aluminum)
- Degassing of Aluminum Alloys Using Ultrasonic Vibrations (Aluminum)
- Development of an Innovative Vertical Floatation Melter and Scrap Dryer (Aluminum)
- Development of a Two-Phase Model for the Hot Deformation of Highly-Alloyed Aluminum (Aluminum)
- Effect of Impurities on the Processing of Aluminum Alloys in Casting, Extrusion, and Rolling (Aluminum)
- Energy Efficient Isothermal Melting (Aluminum)
- Fundamental Studies of Structural Factors Affecting the Formability of Continuous Cast Aluminum Alloys (Aluminum)
- Gating of Permanent Mold Aluminum Casting Phase-II (Aluminum)
- High Efficiency, Low-Dross Combustion System for Aluminum Remelt Reverberatory Furnaces (Aluminum)
- Improved Energy Efficiency in Aluminum Melting (Aluminum)
- Molten Aluminum Treatment by Salt Fluxing with Low Environmental Emissions (Aluminum)
- Reduction of Annealing Times for Energy Conservation in Aluminum Processing (Aluminum)
- Reduction of Oxidative Melt Loss of Aluminum and its Alloys (Aluminum)
- Selective Absorption of Salts from Molten Aluminum (Aluminum)
- Surface Behavior of Aluminum Alloys Deformed Under Various Processing Conditions (Aluminum)
- Alloys for Ethylene Cracker (Chemicals)
- Improving the Efficiency of Electric Arc Furnace in the United States (Steel)
- Optical Sensors for Post Combustion Control in electric Arc Steelmaking (Steel)

Technical Assistance

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

2002- Highlights & Accomplishments

The Metal Casting Industry of the Future posted a number of important accomplishments in 2002 with energy efficiency improvements to be transferred to and applied in industry. The following describes accomplishments in several key areas including:

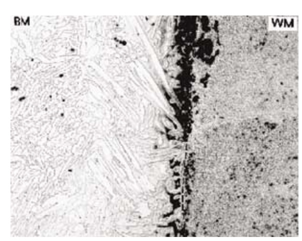
- Applying R&D Results
- Partnership Highlights
- Improving Energy Efficiency Today
- Disseminating Research Results to Industry
- Energy Analysis - Targeting Energy Efficiency

Applying R&D Results

Industry is adopting Metal Casting IOF research results rapidly in their casting operations. The following provides examples of metal casting research developments and applications.

- ***Clean Cast Steel Technology -*** Researchers at the University of Alabama- Birmingham developed a method 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 project was a multi-task effort to reduce the amount of surface macroinclusions and improve the machinability of steel castings. The results of this research program are new improvements in gating systems, including shrouded pouring. By reducing scrap and heat treatment requirements, an estimated 5 percent savings of the energy used in steel casting could be achieved as a result of this research. Due to the participation of steel foundries in the research program, technology transfer was facilitated quite easily. Currently, three steel foundries -Falk Corporation, Atlas Foundry & Machine, and Harrison Steel Casting- have implemented the results of this study. To learn more, please visit http://www.oit.doe.gov/factsheets/metalcast/pdfs/uab_cleansteel.pdf.

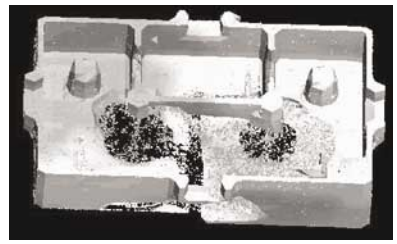
- ***Service Performance of Welded Duplex Stainless Steel Castings and Wrought Materials –*** Research at the University of Tennessee has revealed that the corrosion performance of the solution treated cast materials is equivalent to that of their wrought counterparts across the full range of compositions. A follow-on study has been initiated to continue to examine the corrosion performance of weld filler materials for cast and wrought duplex stainless steel. This research program has fostered the growing recognition of uses for duplex stainless steels. It has also lead to growing market penetration, particularly when lighter castings in corrosive environments are used. This project increases yield thus saving the energy associated with remelting. A specification for cast duplex stainless steel is balloted for inclusion in ASTM A923. For more information, please visit http://www.oit.doe.gov/metalcast/factsheets/ut_welded_duplex.pdf.



Weld fusion boundary pitting corrosion sensitive material ASTM A890-4A (2205 type).

- ***Yield Improvement and Defect Reduction in Steel Casting*** - Advancing technology in yield improvement and defect reduction will result in decreased scrap and rework, along with an increase in yield and higher quality steel castings produced with less iteration. Researchers at the University of Iowa have developed new feeding distance rules for risering and pressurization of risers that will reduce shrinkage and increase yield in steel castings. This research program has also assisted in the development of solidification models to quantify solidification shrinkage. The ASTM E07.02 Committee has accepted the need for a new set of radiographic standards for steel castings, and this research program is forming the basis for those standards. The results of this research are expected to improve yield by 10-25% with an equal reduction in melt energy requirements. To learn more, please visit http://www.oit.doe.gov/metalcast/factsheets/ui_yield_def.pdf.

- ***Development of a Computational Fluid Dynamics Tool for Modeling the Blowing and Steaming of Expandable Polystyrene (EPS) Patterns for Lost Foam Casting*** - Researchers at Flow Simulation Services, Inc. have developed a mathematical tool that will allow, for the first time, an analytical approach to systematically design EPS pattern molds that will produce higher quality patterns with reduced lead-time and expense. These math-based tools solve equations that model physical phenomena important to the pattern production process. Both a bead blowing and bead expansion module was created. The bead blowing module became available in December 2001. A second version of the module was released in October 2002, for purchase by foundry engineers. In December of 2002 the first release of the bead expansion module became available. These software packages are being used by a major automobile manufacturer to address manufacturing design issues as well as to solve bottlenecks. This research is expected to achieve significant defect reductions resulting in yield improvements of about 10% with an equal reduction in melting requirements. To learn more, please visit http://www.arena-flow.com.



Box Pattern Filling

- ***Non-Incineration Treatment to Reduce Benzene and VOC Emissions for Green Sand Molding System*** **-** 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 gas are costly to operate and difficult to maintain. Researchers at Pennsylvania State University have been researching methods to develop a cost effective non-incineration technique that will significantly reduce VOC emissions from foundries. They have been conducting Advanced Oxidants (AO) emissions and sand performance trials at the university and at five participating foundries. All five of these foundries have adopted or are in the process of adopting the AO system. The research has shown that Benzene and VOC emissions can be reduced by 10-75%; sand system premix consumption can be reduced by 15-42%; foundry smoke is reduced; and AO Technology is scalable for small, medium, and large foundries. For more information, please visit http://www.oit.doe.gov/metalcast/factsheets/voc_psu.pdf.

Advanced oxidation processing has reduced smoke, odor and emissions in foundries.

- ***Investigation of Heat Transfer at the Mold-Metal Interface in Permanent Mold-Casting of Light Alloys*** **-** Researchers at the University of Michigan have focused their work on improving the design functions supporting production of light alloy castings produced by permanent mold casting processes. This work provides the basis for the production of castings having thinner walls, lighter weight, higher integrity, and improved mechanical properties. Their research has developed and experimentally verified a new approach to estimating interfacial heat transfer in Indirect Squeeze Casting and Low Pressure Permanent Mold Casting. This new method takes into account variations within the mold as well as time dependent variations of interfacial heat transfer. It provides a range of heat transfer parameters that will aid the optimization of the design of the mold to meet the quality and productivity goals with a short lead-time. Further work in this research will extend the rules for heat transfer in simple geometries to more complex geometries. Accurate modeling of the heat transfer will reduce scrap rates, production lead-time, tooling costs, and delivery times. These benefits are expected to result in an energy savings of 8%. For more information, please visit http://www.oit.doe.gov/metalcast/factsheets/cda_grain_refinement.pdf.

- ***Iron Fatigue Design Properties -*** The lack of a comprehensive strain-life database jeopardizes the application of iron casting to improve the value of engineered components for transportation equipment, power generation, industrial machinery, gearing, and other markets. Approximately 90 percent of the cost and energy of a product is fixed in the design of the product. Researchers at Climax Research Services (CRS) have developed a first-of-its-kind listing of twenty-two cast irons (gray, ductile, austempered ductile, and compacted gray iron) strain controlled fatigue properties along with the structure that is found in typical sections that are common in the metal casting industry. This database is available to original equipment designers. Without the appropriate strain-life fatigue data and the corresponding structure, cast iron is virtually invisible to the designer. This database permits meaningful concurrent engineering between the metal casting process engineer and the OEM design engineer to enable the design and production of parts through the manufacturing process. This database enables the production of lighter weight castings that require less melting thus reducing the energy required. To learn more, please visit http://www.oit.doe.gov/metalcast/factsheets/crs_fatigue.pdf.

- ***Simple Visualization Techniques for Die Casting Part and Die Design -*** Research conducted at Ohio State University has helped the die casting industry to identify and resolve die casting design problems while still in the design phase. A simple qualitative method has been developed to visualize design problems in die casting. The software, *CastView,* is intended to help minimize flow-related problems, thermal problems in the die casting die, and solidification-related defects in the cast part. This software is now available commercially. This fast running flow simulation program is being used to solve problems with existing die casting designs and during the initial stage through the evaluation of candidate gate, vent, and overflow locations. For the first time, this software enables designers to compare candidate designs to select the most viable designs with success. Reports by users of this software say that they have experienced scrap reduction of 20% and first-time successes have been made. One customer has seen returns decrease 30% and realized savings of $100,000. To learn more, please visit http://www.oit.doe.gov/metalcast/factsheets/vistool.pdf or http://www.diecasting.org/.

- ***Effects of Composition and Processing of High Performance Die Steels -*** Research conducted at Case Western Reserve University was focused on determining how the composition and processing of various die steels affect their thermal fatigue resistance. Various die steels of varying compositions were compared using thermal fatigue immersion tests. Results from this study indicated that specifically processed die steels of selected compositions are superior in performance to other die steels that have been employed in the past. Mechanisms of thermal fatigue have become better understood due to this study. Modification of die steel chemical composition and heat treatment processing have resulted in die life improvements of 20-30% and higher, significantly reducing energy use associated with die replacement and testing as well as reducing die replacement costs. Die life improvements of 30-100% were seen by companies such as General Motors, Ford, and Metaldyne Light Metals Division. In one case, a new steel composition yielded an improvement of 30% over Premium Grade H-13. The level of improvement resulted in $150,000 less die steel purchased and heat treated each year, a 5% scrap reduction and 0.5% productivity improvement, plus a 1 % decrease in downtime for repair. It is estimated that results from this project will have an energy savings of 4.6 billion Btu annually. To learn more, please visit http://www.oit.doe.gov/metalcast/factsheets/cwru_die_life_optimal_comp.pdf.

- ***A Study of Aluminum Alloy Microstructure Performance Interaction -*** Researchers sought to gain an understanding of the relationship between the mechanical and physical properties and chemistry of aluminum die casting alloys. As a result, an enhanced level of understanding of the effects of various alloying elements on the properties of aluminum die casting alloys has been achieved. Additional properties as well as trend equations for improving properties have been developed. The result of this study have been compiled in a book published by NADCA entitled *Microstructures and Properties of Aluminum Die Casting Alloys*. The die caster now has available a database explaining the effects of key elements on the properties of the die cast product. This permits a tailoring of alloy compositions to optimize die castings for specific applications. Die casters have utilized the information to improve heat sinks by enhancing the thermal capability of an alloy and to increase the strength of an alloy. The increased strength led to reduced section thickness and 7% less alloy needed per casting. For more information about the publication, please visit http://www.diecasting.org/.

- ***RSP Tooling*** – The Rapid Solidification Process (RSP™) was developed at the Idaho National Engineering and Environmental Laboratory under grants from DOE. This process is designed to allow die casters to build production tooling in the time it usually takes to make prototype tooling. The RSP™ Tooling process makes high quality production tooling from virtually any existing tooling metal, for any tooling process. The technique eliminates the need for any CNC milling, sink EDM, benching, polishing, engraving and heat treatment. An early application of the technology was the production of low-carbon steel strip, the industry's highest volume commodity. A major advantage of using the RSP™ for producing strip is the significant reduction in energy use. Producing the strip directly from the molten metal with accuracy would eliminate the need for hot rolling unit operations, saving time, money, and energy. The invention received an *R&D 100 Award* in 1998 and the *Federal Laboratory Consortium Award* in 2001. In 2002, RSP™ Tooling, LLC was formed to design, build, use, and sell machines that manufacture tooling using this process. To learn more, please visit http://www.oit.doe.gov/metalcast/factsheets/csu_rsp_tooling.pdf.

As-deposited H13 tool steel die for die casting applications.

Exhibit 20
Commercial and Emerging Successes from Metal Casting Research

Commercial Technologies	Emerging Technologies
• Computational fluid dynamics lost foam casting • Foundry sand density guidelines for surface finish in aluminum casting • Tensile properties database for preliminary design of metal matrix composites • Guidelines for critical process variables in molding accuracy (TWIG) where developed • Low Cycle fatigue database for 22 cast iron grades • Guidelines for gating molds with and without filters	• Demonstrate increase in beneficial reuse of foundry byproducts • Deployment of RSP Tooling Technology • Squeeze casting techniques more widely deployed • Radiographic standards developed

In 2002, the Metal Casting IOF reviewed its portfolio to identify those technologies that are having commercial success or are emerging as a potential commercial success. IOF "commercial" technologies are those technologies currently being used in the commercial industry as a result of program funding. Emerging technologies are those technologies that have achieved laboratory or in-plant success and are ready to be deployed commercially. Exhibit 20 lists both commercial and emerging successes from the Metal Casting IOF research.

<u>Partnership Highlights</u>

- **A New Vision for the Future -** In July of 2002, the Cast Metals Coalition (CMC) published its new vision, *A Vision for the U.S. Metal Casting Industry 2002 and Beyond*. A new vision was created to build upon the past lessons and accomplishments of the program and maintian a dynamic vision. 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 the metal casting industry. The updated vision represents the goals and challenges, as identified by industry leaders, that must be addressed over the next 20 years. It is available online at: www.oit.doe.gov/metalcast/pdfs/mcvision.pdf. The CMC is currently working with DOE and industry to develop a technology roadmap for achieving goals set forth in the vision.

Improving Energy Efficiency Today

The Metal Casting IOF funded research focuses on mid- to long-term research. Within OIT there are other services to assist industry in beginning to save energy today. These include software tools, training and other energy saving resources from EERE BestPractices and Industrial Assessment Centers. Recommendations by these groups have the potential to save metal casters millions of annually. To learn more about the BestPractices IOF please visit www.oit.doe.gov/bestpractices; for more information about Industrial Assessment Centers visit www.oit.doe.gov/iac. The following are a few examples of successful implementation of BestPractices recommendations in Metal Casting.

- **Metlab Industrial Energy Assessment Recommendations:** A plant-wide assessment of energy efficiency, emissions, and productivity was performed in 2001 at Metlab in Wyndmoor, Pennsylvania. Metlab uses large gas-fired furnaces to perform metal heat treating operations such as surface hardening, surface coatings, tempering, and annealing on many critical parts used by the commercial and defense sector. The assessment included a comprehensive survey and assessment of energy use, emissions, and production practices at the plant. Based on the results published in August 2002, Metlab plant management has set goals to reduce energy use and associated emissions by 20 to 30 percent, reduce plant discharges by 50 percent, and increase productivity by 10 to 20 percent. To achieve these goals, Metlab has prepared a plan that will produce an annual savings of $528,400; with a capital cost of $820,000. A payback in 1.8 years. Some of the recommendations made to achieve their goals include:

    - selecting the proper furnace, using proper loading and scheduling and reevaluating soak times for heat treating processes for long cycles. These suggested actions would create an annual savings of $126,000.
    - installing and maintaining an upgrade insulation for furnaces, which would result in an annual savings of $53,100.
    - installing and maintaining proper furnace seals, which would result in an annual savings of $53,100.

- **AMCAST Industrial Energy Assessment Results:** In 2001, a plant-wide assessment performed by the BestPractices program for AMCAST Industrial Corporation in Wapakoneta, Ohio 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 in just over three months. Some of the recommendations include using a electric infrared heaters instead of gas torches to preheat permanent molds, reducing scrap and saving approximately $850,000 per year, using exhaust heat from reverberatory melting furnaces in heat treating furnaces and saving $157,000 per year, and using exhaust heat from heat treating furnaces in aging ovens, saving $93,000 per year.

    As implementation occurred during 2002, additional energy savings opportunities were identified by AMCAST. The actual saving experienced by the plant was close to $6 million per year. In addition, AMCAST has embarked on a program to replicate the projects at their other North American facilities. This ambitious action will result in a total corporate savings of $36 million.

Disseminating Research Results to Industry

The Metal Casting IOF performs various outreach activities to disseminate R&D results and enable the U.S. metal casting industry to implement energy saving practices and technologies. This includes participating in trade shows and maintaining an up-to-date web site that highlights the Metal Casting IOF activities. In addition, through trade publications such as *Die Casting Engineer* and *Modern Casting,* research funded by the Metal Casting IOF is often highlighted, exposing metal casters to research that can save them energy and reduce their costs. In 2002 articles, Metal Casting IOF research was published. Examples of 2002 outreach include:

- **Industry Conferences and Expositions:** CMC partners continued to host successful conferences to disseminate the results of metal casting IOF research. From May 4-7, 2002 over 6,530 foundrymen from across the world gathered in Kansas City for CastExpo '02 and the 106th AFS Casting Congress. The show featured more than 325 exhibits and 56 technical and management sessions covering technological and technical advances for the industry. Many Metal Casting IOF-funded research projects were presented as papers at the expo that covered both ferrous and nonferrous metals and various casting processes.[23] Examples of some of the projects that were presented include *Manufacture of Semi-Solid Metals (SSM) Feedstock*, *Determination of Bulk Dimensional Variation in Castings*, *Development of Computational Fluid Dynamics Tool for Modeling the Blowing and Steaming of Expandable Polystyrene (EPS) Patterns for Lost Foam Castings*, and *Heat Treatment Procedure Qualification for Steel Castings*. More information is available on these projects in Appendix B of this report. To learn more about future CastExpo and Casting Congress, please visit AFS at http://www.afsinc.org/. NADCA held the Die Casting Toward the Future Conference and Exposition September 30 through October 2, 2002 in Rosemont, Illinois. More than 425 registrants had the opportunity to visit 80 exhibits and hear presentations on 30 technical papers. These technical papers covered a variety of topics such as, computer modeling and simulation, cast materials, die materials and coatings, and process engineering.[24] Many of these projects were cost shared with DOE funding. To learn more about upcoming NADCA Conferences and Expositions, please visit http://www.diecasting.org/. SFSA held their Technical and Operating Conference November 6-9, 2002 in Chicago, Illinois. At this conference, a number of Metal Casting IOF research projects were presented such as "Heat Treatment Procedure Qualification Trails at Steel Foundries." To learn more about upcoming events from SFSA, please visit http://www.sfsa.org/.[25]

- **The *Gateway to Metal Casting Resources* CD-ROM:** In the spring of 2002 the Metal Casting IOF released the *Gateway to Metal Casting Resources* CD-ROM. This CD-ROM is designed to assist metal casting plant managers, engineers, and designers to quickly find information on technical R&D results, technical assistance, financial assistance, training, and other assistance that the Office of Industrial Technologies can provide to metal casters. The CD-ROM also contains final reports on Metal Casting IOF-funded research. The program is organized in a user-friendly manner for both foundries and die casters. It includes foundry and die casting plant layouts to help industry to identify research results by each stage of the metal casting process. It also contains links to software that can be downloaded to assist plant managers in improving their energy efficiency today. To receive your copy please e-mail Ehr-Ping HuangFu, of the Metal Casting IOF at Ehr-ping.huangfu@ee.doe.gov or obtain it on-line at http://www.oit.doe.gov/metalcast/.

[23] Staff Reporter, "Foundrymen Gather in 'Heart of America' for CastExpo '02" *Modern Casting*, June 2002, pg 50-67.
[24] Peterson, Donna "Wrap It Up! DCE Reports on 2002's *Toward the Future* Show " *Die Casting Engineer* , November 2002, pg 28.
[25] http://www.sfsa.org/

- **Metal Casting IOF Web Site:** The Metal Casting IOF website is another tool utilized to disseminate information on research activities. In 2002 this website was visited 90,000 times. The website is a valuable resource to keep up-to-date on Metal Casting IOF activities, have access to IOF publications, and learn about upcoming solicitations. The web site also contains a "What's News" section that provides articles on recent events in the Metal Casting IOF and updates on research successes. To view the website please visit: http://www.oit.doe.gov/metalcast/.

Energy Analysis - Targeting Energy Efficiency

The Metal Casting IOF is performing an in-depth analysis of energy use in the metal casting industry to identify energy intensive processes/technologies and to identify where major energy savings can be achieved. These will be the basis for a new grand challenge for high-impact research to be performed by the Metal Casting IOF in the coming years.

- **Energy Footprint Study:** In conjunction with Eppich Technologies and industry, the Metal Casting IOF initiated an Energy Footprint Study of the U.S. metal casting industry. This study will benchmark energy use in the various types of metal casting facilities. The results will help measure the effectiveness of the processes and technology improvements in energy saving. This study has taken a sample of foundries in the metal casting industry that are representative of the overall industry including green sand, die casting, lost foam, investment, permanent mold, and squeeze casting foundries. Researchers are gathering information at these foundries pertaining to the types of energy consumed, including coke and oxygen, in each step of the casting process. A wide range of casting processes and alloys are being evaluated in this study. This study will help the Metal Casting IOF and the CMC to direct efforts to high-impact, revolutionary processes research.

- **Theoretical Minimum Study:** In October 2002 KERAMIDA Environmental, Inc. began to conduct a study to evaluate energy requirements for various metal casting processes for the Metal Casting IOF. This study will evaluate the theoretical minimum and practical potential for reducing energy requirements to produce 1 ton of molten metal (cast iron, steel, aluminum, magnesium, zinc, and copper) in metal casting operations. This study will examine several casting processes including: green sand, chemically bonded sand, lost foam, investment, permanent mold, and die casting. Research will address several melting processes, including cupola, electric induction, electric arc, gas fired crucible, and gas fired revebatory furnaces.

  The theoretical minimum for each process or operation is defined as the absolute theoretical minimum energy required without regards to energy loss or practical operational consideration. The best practice minimum energy requirement for each process would take into account what is possible under actual operational conditions utilizing best practices in the industry. The practical minimum energy requirement would be the minimum energy usage being achieved in practice in industry. Potential waste heat recovery options will be identified in this study. The influence of scrap levels and yield on energy requirements will also be evaluated for each named process.

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 Rail Products, Calera
Alexander City Casting, Alexander
American Cast Iron Pipe Co., Birmingham
American Centrifugal, Birmingham
Auburn University, Auburn
Citation Corporation, Birmingham
EFP Corp., Decatur
Foseco, Inc., Bessemer
Foundry Coatings, Inc., Birmingham
Mueller Corp., Albertville
Southern Alloy Corporation, Sylacauga
University of Alabama, Tuscaloosa€
University of Alabama-Birmingham, Birmingham€
Vulcan Engineering, Helena

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
Formcast, Inc., Denver

Connecticut

Crane Valve Co., Stamford

Florida

GKS Engineering Services, Dunedin

Georgia

Georgia Iron Works, Grovetown
Summit Adhesives, Stone Mountain

Idaho

Idaho National Engineering and Environmental Laboratory, Idaho Falls

Illinois

A. Finkle & Sons, Chicago
ABC-NACO, Cicero
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 Group, LLC, 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
HA International, LLC, Westmont
Heick Die Casting Corp., Chicago
Illinois Cast Metals Association, North Pekin
Ingersoll Cutting Tools, Rockford
Kirit Dave (Consultant), Naperville
Magma Foundry Technologies, Inc., Arlington Heights
National Castings, Cicero
NACO, Lombard
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
Steel Founders' Society of America, Barrington
U.S. Environmental Protection Agency, Chicago
Unimun Corp., Belvedere
Wagner Castings Company, Decatur

Indiana

ABC Rail Products, Anderson
Auburn Analytical, Auburn
Bohn Aluminum Corporation, Butler
Bosch Breaking Systems, South Bend
Bremen Castings, Bremen
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
Harrison Steel Castings Company, Attica
Hiler Industries, LaPorte
Indiana Cast Metals Association, Indianapolis
Maco Corp., Huntington
Omnisource Corporation, Fort Wayne
PAHard Chrome Evansville
Ryobi Die Casting (USA), Inc., Shelbyville
Technalysis, Indianapolis
Tri-State University, Angola
Wabash Alloys, Wabash
Wells Manufacturing, Woodstock

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

Kansas
Atchison Steel Casting & Machining, Atchison
Viking Engineering Cast Products, Witchita

Kentucky
Furness-Newburge, Inc., Versailles
Gibbs Die Casting, Henderson
M. Argueso & Co., Mamaroneck

Louisiana
Carbo Ceramics, Iberia
Hendrix Manufacturing, Mansfield

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

Massachusetts
Cambridge Tool and Manufacturing, North Billerica
Capacitec, Ayer
Dynamet Technology Inc., Burlington
EO Associates, Mill River
Johnson & Johnson, Raynham
Kennedy Die Castings, Inc., Worcester
Metal Processing Institute, Worcester
Palmer Foundry, Inc., Palmer
Wollaston Alloys, Braintree
Worcester Polytechnic Institute, Worcester
Wyman Gordan Investment Castings, North Grafton

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
Daimler Chrysler, Auburn Hills
Dock Foundry, Three Rivers
Dynamic Metal Treating, Canton Twp.
EKK, Walled Lake
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
Grede Foundries, Inc., Kingsford
Hayes Lemmerz International, Inc., Ferndale€
Hickman Williams & Co., Livonia
Howmet Corp., Whitehall
Intermet, Troy
LECO, St. Joseph
Metalloy Corporation, Hudson
NEMAK, Southfield
Premier Tool & Die Cast Corporation, Berrien Springs
Prince Machine, Holland
S. Katz Associates, W. Bloomfield
SIMTEC, Inc., Grand Rapids
SPX Contech Division, Portage
Thixomat, Ann Arbor
TRW Automotive, Livonia
UBE Machinery, Ann Arbor
University of Michigan, Ann Arbor
West Michigan Steel Foundry, Muskegon
Zoller, Ann Arbor

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

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

Missouri
Carondelet Corporation, Pevely
Die Makers, Monroe City
Diversified Plastics Corp., Centralia
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
Wellsville Fire Brick Co., Wellsville

New Hampshire
Metal Casting Technology, Inc., Milford
Watts Industries, Inc., Franklin

New Jersey
HC Stark, E. Rutherford
Kulite Tungsten Corp., E. Rutherford
Metallurg Aluminum, Newfield

New Mexico
Arena, LLC, Albuquerque
Flow Science, Inc., Santa Fe
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
Charlotte Pipe and Foundry Company, Charlotte
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

ACM Coldwater, Coldwater
Alotech, Cleveland
Amcast Industrial Corporation, Dayton
A-Mold, Mason
Ashland Chemical Company, Troy
Ashland Chemical, Cleveland
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
Cadic Technologies, Dublin
Case Western Reserve University, Cleveland
Copeland Corporation, Sidney
CSM Industries, Cleveland
DCD Technologies, Cleveland
Electroalloys Corp., Elyria
Eluclid Heat Treat, Cleveland
The Edison Materials Technology Center, Dayton
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
Rex-Buckeye Corp., Cleveland
Ross Aluminum Foundries, Sidney
Sawbrook Steel Casting, Lockland
Thyssen, Cleveland
United Foundries, Canton
Visi-Trak Corporation, Cleveland
Wahl Refractories, Fremont
Willard Industries, Cinncinnati
ZMD Mold and Die, Mentor

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
Alcoa, Alcoa Technical Center
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
Heraeus Electro-Nite Company, Philadelphia
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
VAW, Inc., Pittsburgh

South Carolina

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

Tennessee

Accu-Cast, Inc., Chattanooga
AEMP Corporation, Jackson
American Magotteaux, Pulaski
Industrial Analytics Corporation, Oak Ridge
Lodge Manufacturing, South Pittsburg
MINCO, Inc., Midway
Mueller Company, Chattanooga
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
Kirby West, Andrews
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
J.L.J. Technologies, Inc., Richmond

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

West Virginia
Ormet Corporation, Wheeling

Wisconsin
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
Delta-HA, Milwaukee, WI
Eck Industries, Manitowock
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
Waukesha Foundry Co. Inc., Waukesha
Waupaca Foundry, Inc., Waupaca
Wisconsin Cast Metals Association, Milwaukee
Wisconsin Centrifugal, Waukesha
Wisconsin Invest Cast, Watertown
Wright Products, Rice Lake

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 the 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 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. Recent work has focused on disseminating information from literature and permanent mold foundries on current practices of gating of vertical permanent molds for cast aluminum. The objective is to apply the lessons learned in the project by conducting real-time X-ray experiments side by side with computer cumulations to improve the existing guidelines and current practices in industry.

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

Improved Design, Operation, and Durability of Shot Sleeves, **Case Western Reserve University** - Research being performed at Case Western Reserve University will improve the design, operating conditions, and longevity of shot sleeves for use in aluminum die casting. This research will make improvements in the die casting machine that will eliminate or significantly reduce the need for repair or replacement of shot sleeves, thus facilitating a smoother operation of the die casting machine than feasible at present. This project does not target a specific shot sleeve, but rather a generic improvement in shot sleeve design and operation by the application of advanced materials. This research program will examine ways of correcting the dimensional changes that produce warping of the shot sleeve. Researchers will examine the addition of high melting point, stable inserts, or weldments in the shot sleeve directly under the pour hole. Tests will be conducted on a material with a very high stability and small amount of thermal expansion for use in the area under the pour hole. Finally, researchers will examine the use of a low thermal conductivity liner inside the shot sleeve, to retain the heat in molten aluminum and prevent premature solidification.

North American Die Casting Association, Rosemont, IL
A. Finkle & Sons, Chicago, IL
Brush Wellman, Cleveland, OH
Castool Precision Tooling, Scarborough, ONT
CMW, Indianapolis, IN
Dynamet Technology Inc., Burlington, MA
FPM Heat Treatment, Elk Grove, IL
Kulite Tungsten Corp., East Ritherford, NJ
Latrobe Steel Company, Latrobe, PA
Rex-Bucheye Corp., Cleveland, OH

Optimization of Squeeze Casting Process for Aluminum Alloy Parts, **Case Western Reserve University -** Squeeze casting is a new and developing casting process suitable for manufacturing lightweight 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 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 conducting a detailed experimental study of metal flow and heat transfer in the squeeze casting process; analyzing the relationships between the design of the part, the squeeze casting system, the processing variables, and the soundness of the squeeze cast part; generating an integrated flow-heat transfer computer model for design of squeeze castings; providing detailed guidelines for the design of squeeze cast components and the dies for manufacturing them; demonstrating 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. The need for innovation in die casting is reflected in recent R&D projects. This project seeks to 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 shorter than that of traditional tooling.

North American Die Casting Association, Rosemont, IL
RSP Tooling LLC., 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 Tool for improving design and development of expandable polystyrene patterns for lost foam castings. Both a bead blowing and a bead expansion module are created. The first release of the bead-blowing module became available in December 2001. A second release of the bead-blowing module was available in October 2002 for purchase. The first release for the bead expansion module became available in December 2002. This software is being used by a major automobile manufacture to address design for manufacturing issues as well as to solve production bottlenecks.

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

***Quantification and Standardization of Pattern Properties for the Lost Foam Casting Process*, Industrial Analytics Corporation -** The lost foam casting process is a relatively new metal casting process that is beginning to see increased application for casting near net shape complex parts. Much of the engineering and scientific development of the lost foam casting process to date is based on the assumption that foam patterns have uniform properties. However, recent studies by Industrial Analytics Corporation and The University of Tennessee indicate that the pattern properties such as local structure, density, and fusion level are not uniform and have a significant impact on metal fill and casting quality. The goal of this project is to develop effective measurement techniques for improved understanding of the relationships between pattern properties and casting quality. The results of this investigation will be critical for process optimization of lost foam casting. The research results from this project will be used by industry to properly and consistently control pattern properties.

The University of Tennessee, Knoxville, TN
American Foundry Society, Des Plaines, IL
Ashland Chemical, Cleveland, OH
Austin Group, LLC, Quincy, IL
Capacitec, Ayer MA
Delaware Machinery and Tool Company, Inc., Muncie, IN
Diversified Plastics Corp., Centralia, MO
EFP Corp., Decatur, AL
Flow Science, Inc., Santa Fe, NM
Foseco-Morval, Inc., Ontario, Can.
Foundry Coatings, Inc., Birmingham, AL
GM Powertrain, Saginaw, MI
HA International, LLC, Westmont, IL
Kurtz North America, Plymouth, WI
Metal Casting Technology, Inc., Milford, NH
The Mueller Company, Chattanooga, TN
Quintek Measurement Systems, Inc., Knoxville, TN
Southeastern Foundry Products, Inc., Birmingham, AL
StyroChem International, Fort Worth, TX
Summit Adhesives, Stone Mountain, GA
UES Software, Annapolis, MD
Vulcan Engineering, Helena, AL

***Reduction in Energy Consumption and Variability in Steel Casting*, Iowa State University** - This project is a follow-up project of previous work being conducted at Iowa State University in a project named "Ergonomic Improvements for Foundries." The goal of that research was to introduce ergonomic thinking into the foundry industry. That project took a reactive and proactive approach to solving ergonomic problems. 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 operational changes to improve product and process controls. Two student researchers collected 24 weeks of production data from three participating steel foundries during the summer of 2002. These foundries represented a large range of production processes, casting types and casting sizes. The data collection methodology was refined. The data is being analyzed to determine trends between casting quality and processing times.

Steel Founders' Society of America, Barrington, IL
Iowa State University, Ames, IA
Atchison Steel Casting & Machining, Atchison, KS
Durametal Corporation, Muncy, PA
Grede Foundries, Inc., Reedsburg, PA
Harrison Steel Castings Company, Attica, IN
Maynard Steel Casting Co. Milwaukee, WI
ME International, Inc., Duluth, MN
Missouri Steel Castings, Joplin, MO
Monett Steel Castings, Monett MO
Varicast, Inc., Portland, OR
Waukesha Foundry Co. Inc., Waukesha, WI
West Michigan Steel Foundry, Muskegon, MI

Effects of Applied Pressure During Feeding on the Fatigue Properties of Critical Cast Aluminum Alloy Components, **Mississippi State University -** 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. Dispersed porosity in aluminum alloy castings has profound effects upon mechanical properties of engineered components produced. 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 and is the cause for renewed interest in a feeding technique capable of minimizing this effect. The techniques involve 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. 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.

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 to 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. Recently, the HDI coating process was demonstrated on room temperature sprayed and HDI-fused Cr2C3 coatings with nickel-based binders on H13 steel pins for testing of soldering resistance. The coated core pins were tested under industrial conditions at the facilities of TTE Casting Technologies, Oak Ridge, Tennessee. In this study, the coated pin performed significantly better than an uncoated pin even though it was subjected to significantly higher temperatures due to its position in the die cavity. Also, during this and numerous other tests, no spalling of the HDI coating has ever been observed, suggesting that cermet coatings have inherent advantages over PVD coatings in resisting spalling.

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 provide 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. Researchers have demonstrated that vibration signatures can identify shot profile parameters and provide insights into the flow characteristics of the metal. The identification of flow characteristics is the first step in correlating the vibration signature with part quality. As researchers refine the analysis of the vibration signature, they will be able to identify the vibration characteristics that will correlate with part quality. Once these characteristics have been identified, they can be incorporated into real-time machine diagnostics for use on the production floor to instantly differentiate between good and bad parts.

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 will also 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 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. Currently, the work is producing surprising results that suggest conventional practices may not be optimal with respect to minimizing the die distortion and, ultimately, the final part shape and size. 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 proposed research has two main objectives. During Phase I (Year 1), a pre-survey and focus energy audit standard will be completed. The survey will examine the die casting industry to determine current energy management practices and adapt a Griffith's energy audit standard to focus on characterization of energy use by die casting activity. During Phase II (Year 2), surveys will be conducted to develop a database, data will be statistically analyzed, and recommendations will be developed. The focussed energy audits will be used to 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 analysis 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, coverage, process configuration, and alloys. The energy use will be compared to 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 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. 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.

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

***Prediction of Part Distortion in Die Casting (Phase III)*, 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. The project extends previous efforts on modeling part distortion. The earlier work developed geometric techniques that can be used to relate the meshes used independently model the part and die. This technique enables an approximate representation of the distorted state of the part at ejection and therefore provides a better prediction of the final state. This is an approximation of the effects on the part of the thermal and mechanical loads that exist in die-casting. This capability is required to be able to back calculate the required cavity shape at room temperature so that the distortion in the part after cooling will be minimized. Researchers at Ohio State University had good success in constructing realistic, but approximate, finite element models to simultaneously track the part and die response while the casting solidifies. The current work focuses on verifying the models and improving understanding of the part/die interface.

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

***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 effects 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. However, the technique is limited 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. Casting trials will follow the laboratory and analog studies. 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 will 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, Rosemount, IL
General Die Casters, Peninsula, OH
GM Bedford, Bedford, IN
Lester Precision Die Casting, Solon, OH
Walkington Engineering, Cottage Grove, 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, designing a standard test casting; and applying those tests to production materials collected four to six 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 will 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 (Phase II),* University of Alabama -** This project will enable the consistent production of higher strength, lighter weight ferrous castings. Production processes and material composition and treatment sensitivity will be explored for ductile iron castings (walls as thin as 2.0 to 2.5 mm), and compacted graphite iron castings (walls as thin as 4 mm). Thin-wall iron castings, used in domestic cars and trucks, should result in a savings of 5% in gasoline consumption annually and will allow cast iron to compete with light metals in transportation systems. Techniques developed through this project (control in melting, metal treatment, pouring, and mold accuracy) can be transferred throughout the foundry industry for other markets where consistent properties and high stiffness, or elevated temperatures strength, is important. The research being conducted has focused on evaluating the influence of process variables on microporosity and inverse chill. It will establish feeding distance rules and evaluating the tendency to form inverse chill for selected cases. It will correlate mechanical properties with local cooling rate and microstructure, and investigate the effects of surface roughness on the static mechanical properties of ductile and compacted graphite iron castings.

American Foundry Society, Des Plaines, IL
Ashland Sepcialty Chemical Co., Cuyahoga Hieghts, OH
Cadic Technologies,
Caterpillar, Inc., Mapleton, IL
Climax Research Services, Wixom Hills, MI
Crane Valve Co., Stamford, CT
Cummins Engine Co, Inc., Columbus, IN
Heraeus Electro-Nite Co., Philadelphia, PA
Lodge Manufacturing, South Pittburgh, TN
Magma Foundry Technologies, Inc., Arlington Heights, IL
Rio Tinto Iron & Titanium Inc., Rosemont, IL
Superior Graphite, Chicago, IL

***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. A major focus will be to continue to develop a database 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

***Advanced Steel Casting Technology,* University of Alabama - Birmingham** -This Steel Casting Technology program is a consortium effort directed by the Steel Founders Society of America and conducted by the University of Alabama-Birmingham and companies in the metal casting industry. The work conducted by the consortium focuses on understanding the relationship between material properties and steel casting performance. A second task of the consortium is to utilize dilatometry and heat treatment techniques, supplemented with metallographic examinations, to determine the decomposition of ferrite into austenite and other phases in two duplex stainless alloys. The first task will develop a relationship between micro-porosity, a modeling parameter such as Niyama criteria, and material properties. Ductility can be significantly affected by micro-porosity. A pathfinder trial on micro-porosity effects on carbon steel tensile properties was conducted by UAB in the past year. Careful analysis of the data showed an effect of micro-porosity on yield strength. The population for the high micro-porosity specimens had a skewed normal distribution compared to a normal distribution in the low micro-porosity specimens. UAB will extend the research to four commercially interesting alloys, conduct simulations of selected casting geometries, produce the castings, evaluate the predictions, evaluate casting soundness, and modify the code if necessary to provide more accurate predictions of porosity and mechanical properties. Research to determine the transformation diagrams for duplex stainless steel is being conducted by Iowa State University. In this task of the project researchers at Iowa State University will determine isothermal transformation diagrams, continuous cooling transformation diagrams. They will then interpret these diagrams and develop an empirical model of diagrams based on their results.

Steel Founders' Society of America, Barrrington, IL
American Steel Foundries, Granite City, IL
Arena, Albuquerque, NM
Atchison Casting Corp., Atchison, KS
Dominion Castings Ltd., Ontario, Can
Falk Corporation, Milwaukee, WI
Harrison Steel Castings, Attica, IN
National Castings, Inc., Cicero, IL
The Sawbrook Steel Casting, Lockland, OH
Sivyer Steel Corp., Bettendorf, IA
Southern Cast Products, Meridian, KS
Viking Engineering Cast Products, Witchita, KS

***Clean Cast Steel Technology, Phase IV,* University of Alabama-Birmingham** - The objective of this 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. 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 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. Additional clean/dirty heat trials will be conducted at interested foundries. The ability of a foundry to reduce the incidence of macroinclusions through modification of the melting process can reduce energy usage and post-casting cost and generally adds no cost to the melting process. This will provide foundries with melting guidelines that will reduce the incidence of macroinclusions. Research also will continue working with the steel foundry industry to produce a set of guidelines on how to properly gate a steel casting that will minimize macroinclusion formation. Finally, research will identify metallurgical factors that affect machinability and conduct designed foundry trials to verify the improvement in machinability.

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 and Defect Reduction in Steel Castings, **University of Iowa** - Steel casting yield improvement and defect reduction are two research areas that will have a high impact on the steel casting industry. Advancing technology in these areas will result in decreased scrap and rework, increased yield, and higher quality steel castings produced with less iteration. Considerable prior research has been performed in the areas of yield improvement and defect reduction. As part of two previous yield improvement programs funded by the DOE, researchers at the University of Iowa developed a new set of riser feeding distance rules for low alloy steels; in fact, the success of those new rules prompted the current development of an analogous set of rules for high alloy steels. Also as part of the previous yield improvement programs, researchers investigated novel casting techniques such as mold stacking, which proved successful in improving the yield of the parts chosen for that study (spring caps). In a similar manner, researchers at the university of Iowa are currently investigating two novel casting methods: (1) riser pressurization, which was shown in a pilot study that was performed to increase feeding distances and thus increase yield, and (2) mold tilting, done to reduce reoxidation inclusions in castings. Finally, there is a wealth of literature regarding prior modeling of various stages of inclusion formation, including aspects such as nucleation, growth, particle motion, etc. However, no one has ever modeled the complete process for steel casting, from nucleation through determination of the final location, composition, and number density of particles. This is the intent of the third task in this study.

Steel Founders' Society of America, Barrington, IL
ABC-NACO, Downers Grove, IL
Alcan International Limited, Montreal, Can
American Steel Foundries, Granite City, IL
Harrison Steel Castings, Attica, IN
Keokuk Steel Castings
Missouri Steel Castings, Joplin, MO
Pennsylvania Foundry Group, Myerstown, PA
Sivyer Steel Corporation, Bettendorf, PA
Stainless Foundry, Milwaukee, WI

Heat Transfer at the Mold/Metal Interface in Permanent Mold Casting of Light Alloys (Phase II), **University of Michigan-** The objective of this research work is to markedly improve the design functions supporting production of light alloy castings produced by permanent mold casting processes. This project will provide the basis for the production of castings having thinner walls, lighter weight, higher integrity, lower cost and improved mechanical properties. In 2002 researchers at the University of Michigan developed and experimentally verified a new approach to estimating interfacial heat transfer in indirect squeeze casting and low pressure permanent mold casting. This method takes into account variations within the mold as well as time dependent variations of interfacial heat transfer. It provides a range of heat transfer parameters that will aid in optimizing the design of the mold to meet quality and productivity goals with a short lead-time. Future work will extend the rules for heat transfer in simple geometries to more complex geometries. Accurate modeling of heat transfer will reduce production lead-time, tooling cost, and delivery time.

Mississippi State University, Mississippi State, MS
American Foundry Society, Des Plaines, IL
Alcoa, Alcoa Technical Center, PA
AMCAST Automotive, Southfield, MI
Eck Industries, Manitowock, WI
EKK, Walled Lake, MI
Ford Motor Company, Dearborn, MI
Gibbs Die Casting, Henderson, KY
Intermet Technical Services, Lynchburg, VA
Hayes Lemmerz Tech Center, Ferndale, MI
Magma Foundry Technologies, Inc., Arlington Heights, IL
Metalloy Corporation, Hudson, MI
Stahl Specialty Co., Kingsville, MO
UES, Inc., Annapolis, MD

Determination of Bulk Dimensional Variation in Castings, **University of North Carolina-Charlotte** - The implications of large dimensional variations are significant in terms of energy and raw materials consumption. Casting features are routinely oversized to allow for molding variations. This requires higher alloy and melt energy costs, and increased weight for the final products. Excessive molding variations also result in high scrap rates, increased casting defects, and increased energy used for post casting processes such as machining. Optimizing the green sand molding process will provide more accurate features with tighter tolerances. A reduced dimensional variation reduces the need to "over-design" and the need for extensive finishing to reduce work in progress and lead-time. The research seeks to benchmark current metrology practices, establish an improved methodology for dimensional metrology, and validate the improved best practices. Progress has been made in analyzing the data obtained from the casting round robins. The large numbers of parameters involved in the study have resulted in large spreads in the reported variations. Analysis has shown that the process of shot blasting the castings has added significant variation to the measured parts, and those castings that are sand blasted show the potential for better statistical strength. Progress has also been made in decoupling the parameters and identifying some factors, which seem to have a strong effect on dimensional variation.

American Foundry Society, Des Plaines, IL
Ashland Chemical Company, Troy,OH
Charlotte Pipe and Foundry Company, Charlotte, NC
Citation Corp., Birmingham, AL
Cummins Engine, Cloumbus, IN
Delta-HA, Milwaukee, WI
Unimun Corp., Belvedere, IL
Grede Foundries, Inc., Kingsford, MI
MAGMA Foundry Technologies Inc., Arlington Hieghts, IL
Neenah Foundry Company, Neenah, WI

***Low-Cost and Energy Efficient Methods for the Manufacture of Semi-Solid Metal (SSM) Feedstock*, Worcester Polytechnic Institute** - Previous research at WPI in semi-solid metal (SSM) processing has produced results of fundamental and applied nature, including material characterization, yield stress effects, alloy development, and other SSM results. WPI is investigating alternatives to produce SSM slurries at lower processing costs and with less energy. This project will provide a low cost and an effective means of attaining a non-dendritic, globular SSM structure, which is thixotropic, and can thus be processed in the semi-solid state. The production of cheaper SSM feedstock could lead to a dramatic increase in the tonnage of castings produced by SSM, and will provide end users with lighter, cheaper, and better materials. In addition, less energy will be utilized because special billets will not be required and the off-all or returns will be usable as opposed to separated for reprocessing into special billets. Experiments conducted during this project have demonstrated that the SSM slurry making process developed at WPI is a robust, simple alternative for the production of high-quality SSM slurries. The process has been termed “Continuous Rheoconversion Process (CRP).” The CRP process is unique in the sense that it allows either the continuous or batch production of semi-solid metal slurries containing highly spheroidized primary phase particles that are essentially free of entrapped liquid. The CRP is adequate for semi-solid forming operations that use the rheocast approach and require readily available slurries. Another unique characteristic of the CRP is that the levels of superheating can be varied from values very near the liquidus temperature to values near 1000C, (i.e., it has a large processing window).

North American Die Casting Association Rosemont, IL
Briggs & Stratton Corp., Milwaukee, WI
Daimler Chrysler, Auburn Hills, MI
Formcast, Inc., Denver, CO
Harley-Davidson Motor Co., Wauwatosa, WI
IdraPrince Co., Holland, MI
Intermet, Troy, MI
J.L.J. Technologies, Inc., Richmond, VA
Madison-Kipp Corp., Madison, WI
Mercury Marine, Fond du Lac, WI
Metallurg Aluminum, Newfield, NJ

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. 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. Researchers will study the behavior of these materials from a basic microstructure standpoint and evaluate the relative behavior of candidate materials. Testing will require a thermal fatigue test that is more severe than has been used so far. A new sample design with a small section of 1" x 1" internally water cooled will be utilized to accomplish the more severe conditions. This sample will also cycle in and out of molten 380 aluminum alloy held at 13500F. Possible die materials for these severe applications fall in three categories: increased alloy content steels, refractory and other non-ferrous metals, and diffusion coated components. 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. In the last task of the project, researchers found that a good substrate is essential for the coating to perform in a satisfactory manner. Applying a hard coating on relatively soft substrate does not improve the thermal fatigue behavior. In fact, cracks develop in the coatings and propagate into the substrate. Ideally, both steel and the coatings should be engineered for the highest thermal fatigue resistance. The best steel should be heat treated to 44-46 hours or slightly higher for small parts and a sound, defect-free coating should be applied.

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 .Recent activities have focused on coatings applied by Physical Vapor Deposition. These included CrC coatings applied by Balzers, a popular coating in the die casting industry, another (TiA)N coating from Balzers, a CrN+W coating applied by IonBond, and a CrN from Phygen. The best performer of these coatings as far as soldering was the thick CrC coating. However, this coating is only recommended for relatively small inserts, and is prone to fail in thermal fatigue when applied on large inserts. A feature common to all coatings is the presences pinholes from manufacturing. These tend to become failure sites, by undercutting. The molten aluminum penetrates the coating through the pinhole and creates a crate underneath. The coating loses the support it had from the substrate and fails locally while creating a larger pinhole. A pinhole-free is therefore a pre-requisite for a good coating.

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 project is concerned with strengthening die cast aluminum components with large size metallic inserts that will provide greater strength, improved impact resistance, and reduced tendency to shatter. The investigation will study both the aluminum alloy employed for the parts and the type of reinforcement. The reinforcement will be restricted to metallic materials. At the present time, aluminum die castings frequently do not have sufficient impact strength and resistance to shattering to be employed for many applications, e.g., housings that surround rotating parts such as impellars used in superchargers. Other targets and potential components for reinforcement with metallic inserts include (1) increasing strength of cast aluminum structural, pressure, and chassis parts in automobiles and trucks. This will increase the size of such castings that can be safely used; (2) improving the thermal fatigue resistance of aluminum cast blocks, particularly by incorporating reinforcing inserts in head deck areas between the exhaust parts; (3) providing fracture resistant components for handheld tools such as cutting wheels, chain saws, and lawn equipment. These applications stand to gain most from light weight aluminum while providing the fracture resistance required to protect the operator.

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 all 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 from expanded and newly opened markets while end-users will realize cost savings in both component development and manufacture. Iron foundry will also benefit from producing value-added, 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 ultimate goal of this project is to reduce the losses of the metal casting industry caused by the incidence of porosity in castings. This will be accomplished by developing and understanding the mechanisms for pore formation in castings and developing a model for the use of the metal casting industry. This model will take into account all the factors affecting porosity formation. It will help iron foundries to predict the conditions, that are conducive to porosity formation in castings, and to take measures to prevent porosity. This will be done by surveying participating metal casters for porosity, generating data by conducting experiments for the factors affecting porosity formation, and developing a model which will predict porosity formation in castings prior to pouring. Industrial partners will provide expertise, materials, and industrial trails. Albany Research Center will generate experimental data and participate in development of the model.

American Foundry Society, Des Plaines, IL
Briggs & Stratton Corporation, West Allis, WI
Hickman Williams, Livona, 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) 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 baseline.

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 the 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 tin, aluminum, bismuth, selenium, and lead. 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. Results to date indicate that minor alloy additions such as tin, aluminum, lead, and bismuth have profound effect on the grain size of Cu-36% n alloy. Aluminum, lead and bismuth reduce the grain size of Cu-n alloy with lead having the most significant effect followed by bismuth and aluminum. Tin reduces the amount of grain refiner (boron or zirconium) required for the effective grain refinement. Boron refined yellow brass and EnviroBrass III. It was not effective for silicon brass and silicon bronze. Zirconium was found to be an effective refiner for all the four alloys investigated in this work. In the second year, three issues (hard spot formation, fading, and thermal analysis) were investigated.

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** - Al-n-Mg (7xx) casting alloys have excellent mechanical properties and naturally ages. No high temperature solution treatment is required, in contrast to the high strength casting alloys used commercially today. In spite of the potential cost and energy savings, these alloys are seldom used, due to their reputation for hot cracking during casting. As a consequence, there has been no technical development in these alloys for almost 50 years. This means that no detailed mechanical property data exist and design engineers do not have the information needed to use these alloys, creating another obstacle to their use. This project will remove the two obstacles to commercial use of 7xx casting alloys, by demonstrating that new (low Ti) versions of the alloys have improved hot cracking resistance, and by providing an extensive database of needed design information on the alloys.

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.** - The hot chamber die casting process, which almost all zinc casts alloys are produced, 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. 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, 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 equals 1% or less.

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, and (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. Thus far, the results of this study support the premise that the tensile and fatigue properties of die castings are strongly dependent on the microstructural features present in those products. The microstructural features observed in the die castings produced as part of this study (cold shuts, surface flow marks, ESP/oxide films, and macroporosity) influence the tensile and fatigue properties of the modified 383 aluminum alloy die castings. Of the above four microstructural features, cold shuts were the most detrimental to both the tensile and fatigue properties. The extent of occurrence of the four microstructural features was dependent on the die casting conditions, with cold shuts occurring most frequently with extremely long shot delay times.

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 ensure 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. Steel casting performance can be certified in a similar manner as welds can (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 given casting or family of castings will result in "qualified castings.” Currently, comprehensive heat treatment procedure qualification development trials have been conducted at three SFSA member steel foundries. This has included heat treatment of plain carbon, low alloy, and high alloy steels at various section sizes ranging from 1 in to 6 in. Secondly, modeling work is on going to develop an empirical relationship between heat treatment time and temperature. Finally, initial test results have shown wide variation in process control during comprehensive heat treatment procedure qualification development trials. Results to date demonstrate the validity and robustness of heat treatment procedure qualifications testing methods for identifying heat treatment inadequacies that were not uncovered previously.

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

Metallic Recovery and Ferrous Melting Processes, **Tri-State University** - The goal of this research is to provide statistically significant data on the magnitude of the effects of charge material characteristics and melting procedure on the recovery of specific important alloying elements. This research will provide quantitative information on the effects of melting procedures and briquette formulation on melt loss and recovery of alloying elements from briquetted machining chips. This program will demonstrate the feasibility of a process to reduce the amount of undesirable trace elements in a scrap-melted composition with thermochemical processing rather than dilution. This process will then be developed in a further subsequent effort, after a sufficient understanding is achieved to outline a specific experimental plan. Throughout the course of the research, researchers have realized that metallic charge materials represent the largest cost in the electric furnace production of ferrous castings. The quality and cost of charge materials can vary greatly and thus have a significant impact on the competitiveness of the melting process. Slag generation, metallic recovery and alloy recovery are reported for twenty-one different heats when melted in a coreless induction furnace. Specific ferrous charge materials investigated include pig iron, cast iron scrap, steel scrap, and briquetted cast iron borings. A procedure for determining percent oxide on the scrap was developed for future work and foundry scrap characterization. There were some unexplained metallic losses and work continues at Tri-State University.

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** - 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 has been 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 developed 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. The baseline data is being used to determine reasons for both superior and inferior machining behavior. Companies contributed hard-to-machine castings for analyses. 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
Cummins Engine, Columbus IN
ABI, Oakland CA
Consolidated Diesel, Whitakers NC
Bosch Breaking Systems, South Bend IN
Caterpillar Inc. Peoria IL
Copeland Corporation, Sidney OH
Daimler Chrysler, Indianapolis IN
Wells Manufacturing, Woodstock IL
Ford Motor Co, Dearborn MI
Hiler Industries, LaPorte IN
Ingersoll Cutting Tools, Rockford IL
Kohler, Kohler WI
Mercury Marine, Fond du Lac, WI
Seele Corp, Hendersonville NC
Technalysis, Indianapolis IN
Waupaca Foundry Co. Waupaca WS
Wheland Foundry Co. Chattanooga TN

Age Strengthening of Gray Cast Iron Phase III, **University of Missouri-Rolla** - 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 qualify the relationship between aging and machinability. Previous research 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 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 q 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 the process, and 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

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. Welding processes, which leave behind a fusion zone containing melted base material, most egregiously degrades the corrosion performance. 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, when comparrd 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
Alloy Rods, Champaign, IL
Atlas Foundry and Machine, Tacoma, WA
Keokuk Steel Casting, Keokuk, IA
Quaker Alloy, Myerstown, PA
Stainless Foundry, Milwaukee, WI
Welding Research Council, New York, NY
Wollaston Alloys, 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. The Federal Highway Administration has identified both materials 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. Currently, the database of properties contains more than 1,100 sets of physical and/or chemical data for waste streams sands from 150 individual foundries. The database program has been completed. The project team has selected a series of foundry sand sources for inclusion into the CLSM and HMA studies.

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 further develop cost-effective non-incineration techniques that will significantly reduce VOC emissions from foundries through understanding the physical chemistry. 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 SonoperoxoneTM (SP) treatment systems or a combination of SonoperoxoneTM 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. Advanced oxidants emissions and sand system performance trials have been conducted at Penn State University, at Tecknikon /CERP, and at five production foundries. All five of these foundries have adopted the AO system or in the process of doing so. This program has shown that Benzene and VOC emissions can be reduced by 10-75%; sand system premix consumption can be reduced by 15 to 42%; Foundry smoke and odor is reduced, and AO technology is scaleable for small, medium, and large foundries.

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 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 as 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. 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. 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

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

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as a vital new "energy carrier."

Metals & Mining

Industrial Technologies Program - Boosting the productivity and competitiveness of U.S. industry

U.S. Department of Energy
Energy Efficiency and Renewable Energy