Metalcasting Industry Technology Roadmap

Sponsored by the

Cast Metal Coalition

of the

American Foundrymen's Society
North American Die Casting Association
Steel Founders' Society of America

AMERICAN FOUNDRYMEN'S SOCIETY, INC.

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CHAPTER 1

Executive Summary

Castings are essential building blocks of U.S. industry. More than 90% of all manufactured, durable goods and 100% of all manufacturing machinery contain castings. Suppliers of components to durable goods manufacturing industries exist in a complex and competitive market. A given component may compete not only with castings made using other methods or other metals, but also metal components made using other fabrication techniques and components made of non-metallic materials. In this dynamic environment, existing markets for castings are changing and new ones are expected to emerge. To stay competitive under these conditions, the industry must continue to develop techniques to improve the products and processes it offers its customers.

Partnerships between the metalcasting industry, its suppliers, and its customers will be critical to successfully meeting the competitive challenges of the industry. Technology advancement plays an important role in lowering production costs, improving energy efficiency, enhancing environmental quality, and creating innovative new cast products. Intense competition within the industry for historically low-value-added, low-profit-margin markets, as well as competition with other materials and processes, limits resources for R&D investment. The future competitiveness of the U.S. metalcasting industry requires the combined resources and talents of industry, academia, and government.

Metalcasting industry leaders have been leveraging limited resources with cooperative partnerships as a way of maximizing investments in advanced technologies to solve pre-competitive technical problems and create new applications for castings. In September 1995, the metalcasting industry published its vision for meeting future challenges. This vision entails enlarging the application of metalcasting technology and expanding its usefulness to society through improvements in energy efficiency, cost minimization, and other innovations. *Beyond 2000: A Vision for the American Metalcasting Industry*, provides the framework for the metalcasting industry to become more competitive, productive, and efficient by the year 2020. The industry affirmed its commitment to the goals outlined in this document by making a compact with the U.S. Department of Energy that was signed by Secretary of Energy Hazel O'Leary and representatives from three major metalcasting technical societies in October, 1995.

While *Beyond 2000* identifies major needs of the metalcasting industry, it does not present a detailed technology strategy to achieve the vision. The industry has therefore prepared this *Metalcasting Industry Technology Roadmap* to provide a blueprint of the technology milestones needed to achieve the goals outlined in the vision. The *Roadmap* represents the critical link between the broadly defined strategic goals contained in *Beyond 2000* and the detailed research portfolio that will be pursued through industry/government partnerships and other mechanisms.

In June 1997, the U.S. Department of Energy, the American Foundrymen's Society, the Steel Founders' Society of America, the North American Die Casting Association, and the Cast Metal Coalition sponsored the *Metalcasting Industry Technology Roadmap Workshop*. This event brought together experts from the metalcasting industry, some major customers, academia, and the national laboratories to identify key targets of opportunity, technology barriers, and priority research needs for the metalcasting industry. The core of the workshop was facilitated work sessions in which participants explored in detail the areas of products and markets, materials technology, manufacturing technology, and environmental technology.

The work sessions resulted in over 100 research ideas which were then assigned some level of priority by the industry. Exhibit 1-1 lists the highest priority research needs identified in each of the four major areas. The appropriate time frame—near (0 - 3 years), mid (3 - 10 years), and long (beyond 10 years)—in which the research activity is expected to yield benefits has been noted for each activity. The anticipated role for government (and in some cases, industry) in supporting selected research activities has also been identified. In some of the areas, important interrelationships and linkages among research activities have been identified.

This *Roadmap* document includes the results of the workshop and incorporates material from an earlier roadmap report that was prepared with help from the major metalcasting industry technical societies. The current *Roadmap* contains the following sections:

- Products and Markets
- Materials Technology
- Manufacturing Technology
- Environmental Technology
- Human Resources
- Profitability and Industry Health
- Partnerships and Collaborations
- Relevant Industry R&D Projects (Appendix)

For each of the areas listed above, the *Roadmap* discusses the current situation of the industry, the critical trends and driving forces affecting it, the performance targets given in the *Beyond 2000*, the technical and other barriers preventing the industry from achieving these performance targets, and the research and development activities that the industry has recommended for overcoming the barriers. Instead of listing R&D activities, the last three sections discuss how the issues of human resources, profitability, and partnerships can be integrated with the rest of the *Roadmap*.

Numerous interrelationships exist between the issues discussed in the *Roadmap*. For example, although quality and lead time are discussed under "Manufacturing Technology," they directly impact the industry's ability to maintain existing markets and capture new ones. These interrelationships are noted in the discussions for the appropriate sections.

The research priorities outlined in this *Roadmap* will be used as the basis for making new research investments by government and industry. However, the *Roadmap* is a dynamic document that will be reevaluated at regular intervals to incorporate new market and technical information and to ensure that the research priorities remain relevant to customer needs.

Exhibit 1-1. Selected High Priority Research Needs for the Metalcasting Industry

Products and Markets	Materials Technology	Manufacturing	Enviromental
Transform foundries to tier-one suppliers	Develop quantitative relationships between alloy chemistries, properties, and processing	Develop low-cost rapid tooling technology	Develop environmentally benign, dimensionally stable molding materials for sand casting
Develop computer design tools to move from design concept to a design for manufacturing	Establish standard methodologies for materials testing	Improve tooling design to reduce the time to get castings to market	Develop new uses for wastes streams and/or new ways to treat wastes to make them more usable
Develop methods to encourage/systematize concurrent engineering partnerships within the metalcasting industry	Develop a clean melting and remelting process	Develop cost-effective and dimensionally accurate patternmaking processes for use in sand casting	Develop emissions database for foundries to use to educate regulators
Develop ways to demonstrate the quality and value of castings	Develop methods for fast, accurate, and non-destructive evaluation of ingot and as-cast chemistries and properties (particularly for ferrous castings)	Improve the ability to produce size/dimension	
Develop tools and technologies to reduce lead times in the metalcasting industry	Develop improved techniques to measure the acceptability of liquid metal prior to casting	Develop smart controls and sensors for automation supervision	
	Develop a national initiative to foster interest in materials science and engineering	Develop a systems approach to scheduling and tracking	
		Figure out how die casting molds/dies actually fill	
		Understand folds for aluminum lost foam casting	
		Develop melting and pouring technologies that do not introduce gases to the process	
		Develop a mathematical model that describes process control and can control the machine	

CHAPTER 2

Products and Markets

The demand for metal components is expected to change as new markets and products emerge and others disappear. The metalcasting industry will need to anticipate emerging industry and consumer needs and provide innovative products that are superior in quality and competitively priced. New processes will be needed to cast metal components that meet the demanding material specifications and designs of new products. Learning how to meet the technical demands for new products and markets will be essential to the future viability of the metalcasting industry.

Current Situation

U.S. metalcasting industry shipments in 1996 totaled about 13.4 million tons with a value exceeding $23 billion. The major markets served by the metalcasting industry, shown in Exhibit 2-1, include motor vehicles (particularly passenger vehicles and light trucks but also medium and heavy trucks); industrial machinery; farm, construction, railroad, and transportation equipment; pipes and fittings; engines and turbines; pumps; compressors; and electric power equipment. Automobiles and other transportation equipment currently consume 50 to 60% of all castings produced in this country.

The U.S. foundry population has declined by about one-third over the last 20 years to about 3,000 foundries, largely as a result of foreign competition and increasing imports of goods containing castings. Another factor has been the cost of legislative compliance, which has become too burdensome for some marginally performing foundries to continue operations. Correspondingly, total industry production has decreased during this same time period -- although by a smaller percentage -- and the industry has lost about 9 million tons of capacity.

Exhibit 2-2 shows the forecasted casting capacity and demand/supply ratios predicted for 1997. Based on planned closings of facilities and planned expansions, the usable metalcasting capacity is estimated at 17,682,000 tons, the first increase of capacity since 1981 and a positive sign for the industry.

Approximately 13.8 million tons of castings with a value of about $25.2 billion are expected to be produced in 1997, a 2.7% increase over 1996. This upward swing is expected to continue at least through 1999. Although total shipment growth is modest, it indicates the metalcasting industry is beginning to follow the general trends in the overall economy.

Trends and Drivers

The metalcasting industry is in a state of change. Some segments of the industry are mature or declining, while others are emerging or transforming themselves as new industries. The mature ferrous sectors are

Exhibit 2-1. Major Markets Served by the Metalcasting Industry - 1994		
Market	**Ferrous (%)**	**Non-Ferrous (%)**
Motor Vehicles	28	43
Ingot Molds	20	0
Pipe	20	0
Industrial Machinery	14	15
Farm Equipment	9	0
Railroad	5	0
Construction	4	5
Transportation	0	13
Electric Power	0	24
TOTAL	**100**	**100**

Source: *A Technology Vision and Research Agenda for America's Metalcasting Industry*, American Metalcasting Consortium, February 1995.

Exhibit 2-2. Forecasted Casting Capacity and Demand Supply Ratios - 1997		
Metal	**Capacity (000 tons)**	**Demand/Supply (%)**
Iron	12,665	80
Steel	1,761	74
Aluminum	2,114	77
Copper-Base	400	75
Magnesium	40	78
Zinc	430	82
Other Nonferrous	62	65
Investment Casting	210	79
TOTAL	**17,682**	**79**

Source: *1997 Metalcasting Forecast & Trends*, The American Foundrymen's Society, 1996.

most susceptible to low-cost foreign producers because of the lower-value-added products they manufacture. These sectors are characterized by flagging demand for their products and little or no development of new markets. The emerging sectors, including the non-ferrous metalcasters, typically use newer processes in the manufacture of higher-value-added products, and are continuing to develop and exploit new markets. These casters in good position for the future, when castings are predicted to have more complex structural requirements, with higher performance castings replacing what once were assemblies. Some additional market trends are shown in Exhibit 2-3.

Several major factors affect the demand for specific castings. These include:

- shifts in the types of metals or metalcasting processes used for a given product
- the replacement of castings with non-cast components
- the shrinking materials requirements of lighter-weight automobiles and other transportation equipment
- continued loss of domestic castings markets to foreign metal casters

The majority of the loss in casting markets is attributed to a drop in the production of gray iron castings, which are **losing market share to other metals** (such as aluminum) as well as plastics. The continued loss of gray iron tonnage to aluminum in motor vehicles is expected to drop the average weight of gray iron per unit produced to 345 pounds in 1996 and 215 pounds in 2005. The market for ductile iron castings has increased significantly over the past 15 years, in part because of a shift toward the use of these castings instead of malleable iron, steel castings, and steel fabrications. Concurrently, U.S.-produced steel castings and malleable iron castings have lost portions of their markets. However, a new trend toward the conversion of suspension and brake parts from ductile iron to aluminum is expected to decrease ductile iron demand in the automotive market.

The loss in casting markets has also occurred with the **replacement of castings with non-cast components**. As mentioned above, plastics have replaced gray iron castings in many applications. For example, plastic pipe is now used in many iron-pipe applications. Plastics and wrought copper alloys are also substituting for brass and bronze castings in the plumbing market, decreasing the demand for these castings. Another example is the use of composite materials for structural components in special applications, which is cutting into the castings market.

The **downsizing of end products** has also reduced demand for castings in some markets. For example, the overall average weight of automobiles has decreased over 30% in the past 15 years. Die casters, half of whose business is generated by the automotive industry, are greatly influenced by weight reduction in vehicles. Vehicle downsizing has resulted in the substitution of magnesium for die-cast zinc trim, reducing production levels to about one-third of previous levels.

The market for many castings has also been penetrated by **foreign competition** from assembled components that contain castings, especially in the automobile, steel, and machine tool industries. Specific markets that have been lost to foreign competition include steel and iron valves (to China, Taiwan, and India), steel construction parts (to South Africa), municipal iron (to India), aluminum die castings (to Korea), gray iron engine/compressors (to Brazil), malleable iron fittings (to Thailand), and gray iron power transmissions (to India).

Exhibit 2-3. Metalcasting Market Trends

- **Production of aluminum, steel, and ductile iron castings is predicted to increase** over the next ten years; production of gray iron castings (currently the largest segment of the industry) is predicted to decrease because of competition from abroad and from other metals and materials.

- The **markets for aluminum and magnesium castings have been expanding** in part because of the substitution for ferrous castings in the automotive sector. Demand for aluminum components, especially driven by weight reduction needs in the automotive sector, is expected to increase substantially. Corporate Average Fuel Economy (CAFE) standards will require further weight reduction in cars.

- The **use of magnesium and titanium for castings continues to grow** in acceptance, particularly in the automotive and aerospace markets.

- The **use of aluminum-lithium alloys as investment casting materials holds promise** in opening new markets in the aircraft industry, where it could reduce the structural weight of aircraft by replacing wrought products.

- Rebuilding **the aging U.S. infrastructure provides a huge, continuing market** for iron and steel castings for decades to come.

Performance Targets

The metalcasting vision, *Beyond 2000: A Vision for the American Metalcasting Industry*, outlines three challenges for metalcasting market development:

- Recapture 25 to 50% of lost markets
- Improve market share in current markets by 10%
- Increase the rate of new market development

In terms of recapturing lost product areas with metalcasting products, many past markets have been lost to more competitive materials or to redesigned products that made cast products obsolete. While some lost markets may be regained, it will likely be with new applications and advanced products that may not resemble the old ones.

Technology Barriers

Metalcasters have an opportunity to build share in existing and emerging markets by considering the wide span of potential cast products and approaching them with new process and technology capability. However, to accomplish market expansion several types of barriers must be overcome, barriers that exist for both customers and producers. Many of these barriers address market structure, information, and knowledge issues between customers and producers that must be resolved before cast metal products can have a significant impact in emerging markets. As shown in Exhibit 2-4, areas that present the greatest barriers for expanding products and markets include:

- Design Tools and Processes

- Standards
- Customer Requirements
- Designer/Customer Knowledge
- Infrastructure
- Education

Lack of adequate **design tools and processes** is a key issue. Design tools exist for foundry designers but there are no adequate tools to help functional designers within the various customer industries such as automotive and aerospace. There is also no concurrent engineering process that is robustly applied across the industry today; product design and casting design are sequential processes that result in long lead times and suffer from a lack of interaction between the producer and the supplier. Another barrier is the lack of adequate design-for-manufacturing tools that are easy to use and access.

The lack of **standards** for castings that would aid both customers and producers limits opportunities for cast products. The available property and performance data on materials and castings vary widely, are not standardized, and are not contained in a single source. In addition, many new alloys do not appear in any national standard or construction code. This lack of standardized information on the characteristics of various alloy hurts castings ability to be considered for new applications. Many casting users cannot give quick approval to any casting alloy for safety reasons. Parts cannot be cast with new alloys for which detailed technical data and testing documentation are not available. The exclusion of many alloys from national standards and construction codes has created a barrier to wider use of these materials. In addition, the United States is not using international standards, putting it at a disadvantage vis a vis foreign producers.

Understanding **customer requirements** presents the biggest challenge to market development efforts. Both technical and marketing barriers prevent casters from fully communicating to customers the advantages that can be gained from using castings in products. For example, the customer often does not realize that a casting may be produced at a lower cost than alternatives.

Many foundries are small operations that do not have the staff or financial resources to spend sufficient time understanding customer needs, educating designers about process choices, and tracking future product trends. Castings are also seen as a manufacturing issue and not a primary design issue. This is unfortunate because proper consideration of casting in the design phase could help reduce the cost and increase the quality and integrity of the customer's product.

Several **knowledge barriers**, particularly among customers, prevent acceptance and expansion of castings' markets. Customers are very averse to risk; they understand how a wrought product will function in a design environment but they may not understand the capabilities and design issues associated with castings. Key individuals within the customer companies -- including the designers, purchasing agents, release engineers, and reliability engineers -- lack confidence in castings and are not accustomed to the time required for tooling and testing. With few exceptions, most end-users are completely unaware that castings are a part of the product they have purchased.

The current **supply and market infrastructure** also presents an organizational barrier to expansion of casting applications. Metalcasters are typically second- or third-tier suppliers and do not provide their products directly to the companies that will incorporate them into the end product. When an original equipment supplier (OEM) requires a casting, they typically turn to a machine shop or some other type of value-added supplier. The supplier, in turn, will go to a foundry for its casting requirements. The casters typically do not deliver their product directly to the OEM; they deliver their product to a value-added, first-tier supplier who then processes it further before delivering the required part, component, or subassembly to the OEM customer.

Exhibit 2-4. Major Technology Barriers in Market Development
(Most Critical Barriers Boldfaced)

AREA	BARRIERS
Design Tools and Processes	**Absence of concurrent engineering** - gap between what is expected and what is delivered Casting designs generally take longer than alternatives in concept development Lack of a common, easy access base of design information related to metalcasting No design-for-manufacturer tool that is easy to use and access The commonly used "design by analogy" method limits ability to consider major changes in basic design features Many castings not optimally designed for functionality and castability Difficult to convert a prototype design already approved as a machined-part fabrication to a casting Lack of intermediate shops between castings and finished product (e.g., machining, heat treating) Optimizing for internal productivity may not optimize for customer needs - mixing and unraveling is inefficient Production control systems are inadequate for casting - MRP systems do not work in reverse
Standards	U.S. is not using international standards Standards do not exist for information exchange (customer/producer) Performance database standards do not exist New component applications seldom considered as castings in part because of the lack of standardized design data Testing required to include alloys in U.S. standards and construction codes is extensive and costly Industry has not captured the logic inherent in metalcasting design choices

Exhibit 2-4. Major Technology Barriers in Market Development (Most Critical Barriers Boldfaced)	
AREA	**BARRIERS**
Customer Requirements	**Inability to adequately identify future customer needs and therefore predict technology** - company size makes this difficult **View that castings are a manufacturer issue, not a primary design issue** Inability to effectively market castings Customer drives demand, but casters do not understand the customer requirements Systems are not designed to make customer deliveries - casting traceability Delivery time is too long Customers are demanding higher quality and more value-added services - quality of castings is sometimes perceived as being insufficient
Designer/ Customer Knowledge	**Design engineers lack knowledge of existing methods** Lack of acceptance by users because of lack of knowledge about castings Final customer is completely unaware of castings in their product Customers are risk-adverse and lack confidence in castings - designers - release engineering - purchasing agent - reliability engineering Customers are not used to the time it will take for tooling, testing, etc. Customer underutilization of casting geometry to make better parts that are more castable
Infrastructure	**Foundries are not tier-one suppliers to original equipment suppliers (OEMs)** Transition from a sellers' market to a buyers' market Industry is often unable to respond quickly to emerging market opportunities Cost of start up, tool, pre-production, and testing are unique to themselves - not part of the metalcasting industry - metalcasting industry expects customer to pay for it Movement of existing tooling from foundry to foundry has been more prevalent than an emphasis on identifying and developing new applications
Education	Inability to educate/attract new employees at the high school level Inability to attract new engineers into metalcasting industry Different research capabilities will be required to solve emerging problems

Limited **education** appears to be one of the culprits behind the lack of understanding of metalcasting processes and properties. The industry has been unable to attract and educate new employees at both the college and high school level. Unlike some technical areas, instruction in metalcasting processes and properties is not incorporated into the general engineering curriculum, and students often are not exposed to this field of study.

Research Needs

Research required to overcome technical and market barriers should be characterized with sufficient detail to help focus the research community in solving technical problems but with a broad enough scope to encourage innovative approaches to complex problems. Research will be required in the near term (0 to 3 years) to improve many existing tools and processes, in the mid term (3 to 10 years) to meet more complex needs and pursue new markets, and in all time frames (0 to 10+ years) for ongoing research that will produce benefits in several time periods (see Exhibit 2-5).

Research in **design tools** will focus on improving tools and deploying them rather than considering all the new tools that might be required. For example, a design-for-manufacture tool that is easy to use—possibly even web-based—would enable a design engineer to specify product attributes and have the design tool determine how metalcasting can be applied to the product in much the same way that the electronics industry uses design tools to meet circuit board specifications. A tool that would enable concurrent engineering throughout the production system and reduce lead times would be more responsive to customer needs. In the mid term, a more comprehensive design tool that would allow a designer to move from a part design to a casting design would streamline the design process and clarify design choices. There is also a need to develop a feature-based design tool that considers geometry and its relationship to physical and mechanical properties.

Research to improve **products and processes** must focus on developing ways to demonstrate the quality and value of cast products. Part of this will be accomplished by working with customers and end consumers to understand how they judge quality, and to demonstrate the cost and quality of metalcasting versus other metal forming processes. Processes must be developed to make products more consistent and their performance more predictable. For example, improved methods must be developed to predict the amount of contraction that occurs in patternmaking. In the mid term, tools must be developed to reduce lead times in the metalcasting industry. Rapid prototyping, for example, can greatly reduce the time needed to design a new casting. It will be important to coordinate the various research efforts underway to reduce lead times.

Perhaps the most critical need is in the area of **market transformation**. Both research and market push is needed to change the way metalcasters interact with their customers and the product and services they provide. The transformation of foundries to first-tier supply status to OEMs has the potential to substantially change the way customers perceive and use castings. By accepting a more prominent role with the customer, casters will ensure that the full value of castings in products and components is credited to the metalcasting industry rather than to a machine shop that might alter or change the cast product. There is also a near-term need to do a better job analyzing the demand for castings in future products. The ability to foresee changes or identify emerging material and part requirements is vitally important to the industry.

Casters must also work to help the customer to better assimilate metalcasting technology and design approaches. Most of the design community thinks in terms of wrought products, viewing standards, properties, and design processes from the perspective of a wrought producer. Metalcasters need to communicate cast metal properties in a way that a designer will understand.

Finally, in the **education and standards area**, metalcasting should become better integrated into the engineering curriculum at colleges and universities. In the electronics area, for example, all electrical engineers are taught advanced signal integrated circuits whether they plan a career in designing circuit boards or designing large utility power systems. One of the ways that metalcasting can become more accepted in engineering curriculums is to make tools (e.g., design-for-manufacturing software) more available to engineering programs. Component designers also need to be made more aware of the capability of castings. One way to help accomplish this is to develop product definition and quality standards.

Exhibit 2-5. R&D Needs in Products and Markets by Time Frame
(**k** = Top Priority; **M** = High Priority; **F** = Medium Priority)

Time Frame	Design Tools	Product and Process Improvements	Market Analysis and Transformation	Education and Standards
NEAR (0-3 Years)	**F** Develop tools to enable concurrent engineering throughout the production system - must be ready to act - increase responsiveness to customer need **F** Develop design-for-manufacture tool that is easy to use (possibly web-based) Develop robust, inter-operable analysis tools for the metalcasting industry Develop better solid model casting design tools Advance the integration of part/tool design and process variable specification	**M** Develop ways to demonstrate quality and value of metal casting products **M** Develop improved methods to predict patternmaking contraction	**k** Develop methods to encourage/systematize concurrent engineering partnerships within metalcasting industry - standardize specification for efficient transfer of information Conduct gap analysis among customers - who is going to help the small founders Determine how castings can be marketed effectively Analyze the demand for major cast products - change product design or change the casting process	
MID (3-10 Years)	**M** Develop computer design tool to move from a part design to a casting design **M** Develop a feature-based design that considers geometry and its relationship to	**F** Develop tools and technologies to reduce lead times in the metalcasting industry - coordinate existing work in this area - prototyping - production	Develop a system to determine and disseminate what the competition is doing - database of competitive properties, processes, and costs for competing	**F** Determine how to teach metalcasting across the engineering curriculum - determine how it happened with computers - make tools readily available

Exhibit 2-5. R&D Needs in Products and Markets by Time Frame (k = Top Priority; M = High Priority; F = Medium Priority)				
Time Frame	Design Tools	Product and Process Improvements	Market Analysis and Transformation	Education and Standards
	physical and mechanical properties - improve visualization of casting geometry in 3 dimensions Develop software to simulate casting processes and casting service under various conditions		materials - expert system to compare the best metalcasting processes against forging and weldment alternatives	Develop standards to change the expectations of castings Develop product definition and quality standards
ALL (0 - 10+ Years)	Develop tools required to turn casting design into production design - work castings into early stages of design - economics must be there	Develop castings for new applications in construction, large structures, transportation equipment, defense hardware, etc.	k Transform founders into tier-one suppliers Develop methods to facilitate and systematize metalcasting design and manufacture	

Potential Government Role

Government involvement in research for metalcasting products and markets has been identified for six areas. Developing design tools that enable concurrent engineering and design-for-manufacturing, while mostly seen as near-term priorities, would be appropriate for government participation. Developing advanced computer design tools that smoothly link part design and casting design is another area where the industry will require government resources and expertise. In product and process improvements, the government can play a key role in helping to coordinate existing research and technologies focused on decreasing metalcasting lead times.

Although specific activities still need to be identified, the government is seen as an important participant in helping to transform metalcasting markets. For example, the transformation of metalcasting companies to become first-tier suppliers to industrial customers will mostly be accomplished by industry. However, the government may have a role in participating in research in selected areas. The government can also help the metalcasting industry in conducting analysis of the demand for cast products.

Linking individual research needs to specific industry performance goals is difficult because there is no clear distinction between whether an activity will aid in expanding a market or in establishing a new one. The identified research needs are fairly generic and can apply to both existing and new market applications. As a general guide, however, activities associated with product and process improvements tend to contribute more to expanding existing product markets. Activities to develop and improve design tools tend to focus on facilitating the use of metalcasting in the development of new products and would contribute greatly to the goal of pursing emerging markets. Market transformation seeks to change the relationship of metalcasters with their customers to increase the application and use of cast products. If successful, it will contribute equally to existing and new market expansion.

CHAPTER 3

Materials Technology

The metalcasting industry of the future will be revolutionized by new materials as metallurgical breakthroughs lead to the development of new materials that are more manufacturable and environmentally friendly. The quality and availability of property and performance data about these materials, as well as the cost and availability of the materials themselves, will help determine how competitive metalcasters will be in the rapidly transforming international markets of the future.

Current Situation

More than 80% by weight of all castings produced in U.S. foundries are ferrous castings. Gray iron castings represented about 43% by weight of all U.S. casting shipments in 1995. Exhibit 3-1 shows the distribution according to metal of the total 14.4 million tons of casting shipments in 1995. The distribution of the total U.S. metalcasting industry value of shipments of $23 billion in 1994 is shown by metal in Exhibit 3-2.

Exhibit 3-1. Casting Shipments by Metal - 1995

Metal	Shipments (000 tons)	Percentage of Total
Gray Iron	6,251	43.4
Ductile Iron	4,027	27.9
Malleable Iron	249	1.7
Steel	1,470	10.2
Aluminum	1,652	11.4
Copper-Base	311	2.2
Zinc	394	2.7
Magnesium	31	0.2
Other Non-Ferrous	43	0.3
TOTAL	**14,428**	**100.0**

Source: *1997 Metalcasting Forecast & Trends*, The American Foundrymen's Society, 1996.

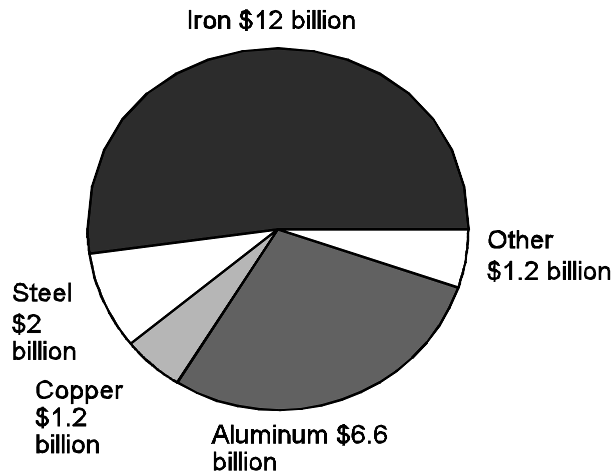
Cast metal components compete with polymer and ceramic materials in most product markets. These non-metallic materials (including composites) have challenged castings in established markets and shut them out of some emerging markets.

Trends and Drivers

The trends and driving issues related to the development, adoption, and use of new and improved materials for castings are centered on materials properties and material requirements.

Increased availability of data on **material and design properties** has increased the designer's ability to use castings. The development of a solid base of technical knowledge is helping U.S. metalcasters improve existing products and develop new applications in order to compete with alternative materials and metal-forming techniques as well as foreign castings. The enhancement of this knowledge base with additional performance data, together with its incorporation into design tools and the definition of materials standards, will increase user confidence and help castings penetrate new markets.

Exhibit 3-2. Value of U.S. Castings Shipped by Metal (1994)



In spite of the increases in available data on the mechanical, physical, performance, and design properties of materials and castings, many problems remain. For example, there is wide variation in the data and no single source of information exists. Gaps exist in the knowledge of the performance of standard steel, copper-based, and aluminum alloys; casting processes; and heat-treating processes.

An increase in the number of casting applications will lead to higher demands for **new materials** that are stronger, lighter, more reliable, and more manufacturable. Stronger and lighter-weight cast metal alloys will be needed to be able to compete better with composites in new engineered structural applications. The accelerating demands of technology will require metalcasters to place more emphasis on new materials processing techniques. New composites, ceramics, plastics, and other materials will be used in addition to metals.

Aluminum and magnesium castings with corrosion-inhibiting properties and high-quality ductile iron castings (with tighter tolerance and controlled microstructures/mechanical properties) are predicted to be increasingly in demand in the aerospace, electrical machinery, and automotive markets. There will also be increased demand for high-alloy steel castings that are heat-resistant for use in valve, pump, furnace, and turbine applications.

Environmental and health concerns have created a need to find an appropriate substitute for lead in the copper-based alloys, brass and bronze. Environmental and health concerns also have created a need to extend refractory life.

Consumable material suppliers are relied on by metalcasters to lead the way in developing materials that will produce higher quality castings with a minimum environmental impact. Improved materials for patterns and dies can reduce casting costs while increasing quality. Die life has a major impact on the production cost of die cast components, with the cost of the die contributing an estimated 10% or more of the cost of a die casting.

Performance Targets

The industry's vision, *Beyond 2000*, describes the metalcasting industry's goal in materials technology as follows:

> " improving the variety, integrity, and performance of cast metal products"

The industry has provided some insight into the factors influencing variety, integrity, and performance. The term "variety" as it applies to the performance target is assumed to refer to material flexibility. This includes both the availability of materials with specific properties and the standardization of materials to provide complete chemistry/property/performance data. Integrity includes factors such as porosity (and other melting and solidification discontinuities) and consistency, while performance is assumed to refer to product reliability and lifetime.

Desired improvements in variety, integrity, and performance are not able to be quantified because of the application-specific nature of these three attributes. Improvements would have to be based on baseline data, which differ for every alloy and every application.

Casting quality and consistency issues (which are related to integrity and performance of cast metal products) are discussed in Section 4, Manufacturing Technologies.

Technology Barriers

The barriers to realizing Materials Technology goals in the metalcasting industry are related to

- knowledge of material properties,
- availability of processing techniques,
- liquid metal and cast product quality,
- availability of new materials, and
- communication and institutional issues within the industry and between the industry and its customers.

As shown in Exhibit 3-3, the majority of technology barriers are related to material properties.

The single most critical barrier to improving the variety, integrity, and performance of castings is the lack of fundamental knowledge on **material properties**. Metalcasters agree that a major problem in their industry is the inability of designers to do an effective job because of:

- a lack of fundamental knowledge of material properties as a function of chemistries and casting route (i.e., how each casting process affects properties)
- a lack of knowledge of the interrelationships of various elements on casting performance (especially true for non-ferrous alloys)
- the lack of a common knowledge base on materials physical property data (especially for aluminum and magnesium but also for iron), casting design, and performance

For some alloys, the published property data are were developed 50 years ago or longer and may no longer be applicable to current metalcasting processes. On the other hand, the data may have gaps that force the designer to abandon a particular alloy or process. A related barrier is the inability to predict

Exhibit 3-3. Major Technology Barriers in Materials (Most Critical Barriers Boldfaced)	
AREA	**BARRIERS**
Material Properties	**Lack of fundamental knowledge of material properties as a function of chemistry and casting route** - lack of coordinated focus on doing this **Lack of actual operating data for use in simulation and modeling for properties** Designers do not really understand environment of product or properties they need Lack of property data Lack of guaranteed minimum properties for designers Inability to define maximum feature allowed (e.g., defect, morphology, porosity inclusion) and how it influences material properties - actual characteristic of morphology may not be entered in Databases of published test results do not include the specifics of what is being tested - strength-controlling mechanisms - technology transfer problems Variation among tests is an international problem - cannot afford to do all tests required - engineers do not know enough to determine which tests to specify - lack of agreement on standard tests Lack of non-destructive inspection techniques for castings Current radiography standards do not reveal enough to give casting designers appropriate guarantees for their designs Development of consistent properties in cast components has been difficult because of wide variation in chemistry requirements, effects of process parameters, and specific casting features
Processing	**Lack of methods to cast clean metals (alloy cleanliness is acceptable but then problems occur after melting and pouring)** **Inability to control the introduction of deleterious elements (Sb, P, S...) from recycled metals** - no method to control or analyze **Lack of knowledge on process-microstructure-chemistry-property interactions** **Lack of clean metals technology (undesired elements or inclusions)** Inability to melt/cast in-situ (like plastics molding) Lack of techniques for assessing liquid metal composition prior to casting Lack of convenient tools to measure stress level and die-surface hardness of casting dies Guidelines and techniques for removing the damaged surface layer produced during electric discharge machining (EDM) are insufficient

Exhibit 3-3. Major Technology Barriers in Materials (Most Critical Barriers Boldfaced)	
AREA	**BARRIERS**
Quality	**Lack of accurate, fast, reliable, and non-destructive methods to quantify casting defects** Quality problems with every kind of material
New Materials	**Lack of low-cost composite materials** Difficulty incorporating new materials into the industry (standards, industry mind-set) Lack of new stronger and lighter weight cast metal alloys hurts the ability of castings to compete with composite materials for certain structural components Many new alloys do not appear in any national standard or construction code Few alternatives to H-13 steel for making dies
Communication/ Institutional	Inability to get production intent for new materials from users Too much emphasis on cost-containment Casters do not understand what design engineer needs in terms of testing Lack of communication with designers - assessment of designers' needs

and describe how features such as level of inclusions, porosity, or morphology will influence material properties.

Several barriers in the material properties category are related to testing and the publication of test results. Current testing methods determine chemistries based on the metal before it is cast. Tensile properties are determined by separately cast test bars. However, alloy chemistries and properties can be slightly altered during casting, while cooling rates will alter tensile properties.

The variation among the different kinds of tests used in the industry is considered an international problem. Published test results typically do not include the specifics of what is being tested, limiting the usefulness of the data. The lack of agreement among metalcasters on standardization of testing is complicated by the inability of most metalcasters to afford all of the tests required to fully characterize a casting, and the lack of knowledge on the part of designers to determine which tests should be specified. Designers typically do not really understand the environment of the product or the product properties needed.

The lack of comprehensive, standardized data also limits the effectiveness of available simulation and modeling tools. The value of using process simulation tools to predict casting properties could be greatly enhanced if input data based on the actual operating environment were used.

The **melting and casting processes** currently used also present barriers to improving the performance and integrity of castings. Many of the barriers arise from the limitations current processes present in casting cleanliness. The industry as a whole has difficulty in preparing clean metals because of undesired elements and inclusions. Some of these undesired elements (e.g., antimony, phosphorus, sulfur) are introduced from recycled metal. Metalcasters are unable to control or even analyze such contaminants. Techniques for assessing and controlling the composition of liquid metal prior to casting are lacking in general. In addition to a lack of methods for cleanly casting metals, the inability to melt and cast metal in-situ (like plastics molding) is considered a barrier to metal integrity. Metal conveying and pouring operations can adversely affect cleanliness and quality.

A barrier that cuts across both the processing and material properties areas is the lack of information on the effect of casting processes and casting microstructure, chemistry, and properties. The interaction between these variables is key to controlling the quality and performance of cast products.

Quality issues are critical with every kind of metal currently cast, although the severity of the problem may vary with the size and resources of the foundry. Many quality issues are related to the ability to cast clean metals (described above). The lack of accurate, fast, reliable, in-line, and non-destructive methods for quantifying casting defects restricts metalcasters' ability to identify and correct operational problems in a timely manner.

The barriers associated with **new casting materials** encompass both technical and market/institutional issues that affect the availability and adoption of new materials by the metalcasting industry. For example, there is a lack of low-cost composite materials; unless such materials can be made cost-competitive, they cannot substantially penetrate the market. An industry-wide institutional problem is the difficulty that is typically encountered when incorporating new materials into existing applications.

Many of the barriers already discussed in other categories have **communication or institutional** components—the lack of agreement on test standardization, for example. Many barriers in this area are associated with the communications between the metalcaster and the designer. For example, some designers lack an understanding of what is required to make a reliable product and cannot convey what they really need to metalcasters. This lack of communication leads to inadequate assessment of designers' needs. One of the barriers mentioned in the material properties category—lack of understanding on the part of the designer about the properties needed for a product given its expected environment—is directly related to these communication barriers. Other barriers in this area include the industry's emphasis on cost-containment and the inability to get production intent for new materials from potential users.

Research Needs

A wide range of research and development is needed to overcome existing barriers to achieving the metalcasting industry's materials technology goals. Recommended R&D activities are depicted in Exhibit 3-4 by subject category and the expected time frame (near, mid, or long) for completion of the research. Exhibit 3-5 shows the relationships of some key research needs organized to show the relative timing of the R&D efforts by time period.

Research and development needs in the area of **material properties** are considered by industry to be the highest priority needs in materials technology. Specifically, the development of quantitative relationships between alloy chemistries and properties and the various casting processes used is deemed critical to advancing the integrity and performance of castings. Included in this activity would be the creation of a statistically significant property/process database. This R&D could be completed in the mid term (next 3 to 10 years).

A significant number of materials property R&D activities could be completed in the near term. This is particularly true of R&D needs that are more institutional than technical in nature. For example, standard methodologies for material testing should be established in order to reduce the variability of reported test results. In addition, because test specimens vary in size, the results of tests of cast properties should be

Exhibit 3-4. R&D Needs in Materials Technology by Time Frame
(k = Top Priority; M = High Priority; F = Medium Priority)

Time Frame	Material Properties	Processing	Quality	New Materials	Institutional
NEAR (0-3 Years)	k Establish standard methods for materials testing M Determine effect of inclusion and porosity content on alloy performance M Establish techniques for data as input to simulation models, especially heat transfer coefficient - prioritize properties most important to industry for modeling/ marketing verification F Determine alloy requirements (compositions) for thin-wall castings that have certain properties Correlate cast property results for various size test specimens Determine castability and cast properties of new wrought alloy chemistries Characterize existing non-metallic pattern materials in terms of wear/abrasion		M Assess current techniques available for melt quality and its relationship to part quality Develop improved processes for characterization of porosity defects	M Look at novel alloys (e.g., rare earth elements in aluminum alloys) and their effect on ductility and strength	M Develop a national initiative to foster interest in materials science and engineering F Create web-based material interaction databases; make other data readily available to interested parties Facilitate communication among industrial partners via teleconference, Internet, and other means Suggest to AFS to consider hiring an expert designer(s) Perform market study of designers' needs

Exhibit 3-4. R&D Needs in Materials Technology by Time Frame (k = Top Priority; M = High Priority; F = Medium Priority)					
Time Frame	**Material Properties**	**Processing**	**Quality**	**New Materials**	**Institutional**
MID (3-10 Years)	k Develop quantitative relationships between alloy chemistries, properties, and processing (data-driven) - testing at the limits rather than just the nominal (explore extremes of ranges) to get statistical distribution - property/process database M Develop models that allow modeling from a chemistry standpoint - identify gaps to piece together different types of modeling Determine the effects of casting defects and impurities on degradation of properties Quantify the effects of primary alloying elements and tramp elements on existing pattern shapes	k Develop a clean melting and remelting process M Develop melting/casting processes that minimize the processing steps and minimizes chemistry variations - continuous melting process M Examine emerging technologies (e.g., semi-solids) - assess material properties and how to control them M Develop methods to melt and cast in-situ	M Improve techniques to measure the acceptability of liquid metal prior to casting M Develop creative and innovative techniques for NDE/testing Desensitize alloys to secondary/ unwanted elements (stay in recycling stream)	Develop corrosion- and creep-resistant magnesium alloys Develop lighter weight casting alloys Develop alloys and composites that will facilitate producing stronger and thinner-wall castings Develop alloys and composites with better mechanical, chemical, or physical properties Develop lower-cost, process-insensitive alloys Develop new non-metallic pattern materials Develop improved dies - new die materials - better coatings Develop improved coatings, binders, refractories, and sand	

Exhibit 3-4. R&D Needs in Materials Technology by Time Frame
(**k** = Top Priority; **M** = High Priority; **F** = Medium Priority)

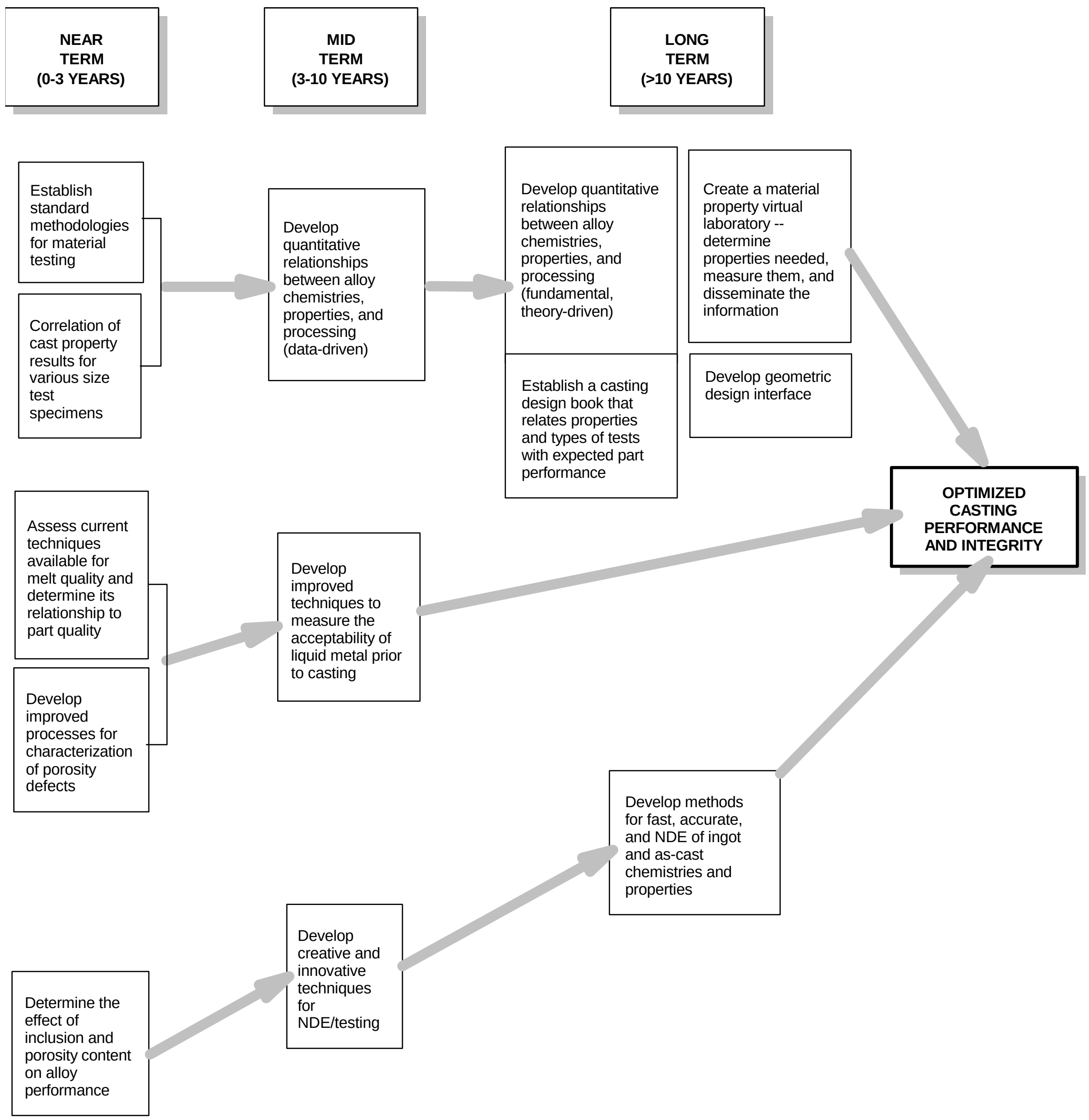
Time Frame	Material Properties	Processing	Quality	New Materials	Institutional
LONG (>10 Years)	**F** Establish a casting design book that relates properties and types of tests to expected part performance **F** Develop a material property virtual laboratory to determine the materials properties needed; measure these properties and disseminate the information Create a design interface for use in geometric design for selecting material (stresses, strains, fatigue, modulus) Develop quantitative relationships between alloy chemistries, properties and processing (fundamental, high risk, theory-driven)	**M** Develop property-driven, designer-oriented foundry processes	**M** Develop methods for fast, accurate, and non-destructive evaluation (NDE) of ingot and as-cast chemistries and properties - melt losses	Develop low-cost and castable composites - uniquely engineered for wear-resistance, stiffness, or other property - iron and aluminum composites Develop new materials that have properties comparable to composites	

correlated according to specimen size. Finally, techniques should be established for obtaining data for use as input to simulation models. The industry must set priorities on which properties and variables it considers most important for modeling and verification.

A more technical near-term need considered high priority by the industry is the determination of the effect of inclusion and porosity content on alloy performance. Other near-term technical needs include the determination of castability and cast properties of new wrought alloy chemistries, and the determination of alloy requirements for thin-wall castings (i.e., what alloy compositions will yield castings with the needed properties).

The most critical mid-term **material property** R&D need —the development of quantitative relationships between alloy chemistries, properties, and processing—is divided into two separate R&D needs. These needs are essentially the same except that the first is "data-driven," meaning that it is based on existing, available information. The second need is considered long-term because it is "theory-driven" and will include new data developed on virtually every element in the periodic table of elements.

Exhibit 3-5. Sequence of Key Materials R&D



A property/process data base will be developed based in part on the relationships developed in this R&D activity. The test data that will go into the data base should include results from testing conducted at the extremes of the ranges of operating conditions that a casting may encounter; current tests yield data from operation at nominal conditions This will yield a statistical distribution of results that will facilitate casting design, improve the performance of cast products, and encourage the selection of castings over products made with competing processes.

As shown in Exhibit 3-5, the development of "data-driven" relationships between chemistries, properties, and processes in the mid term will feed into the "theory-driven" data base in the long term. Associated with both of these R&D activities is the creation of a casting design book that relates materials properties and types of tests with expected cast part performance. In addition, the creation of a materials property “virtual laboratory” has been proposed as a long-term R&D activity. Based on a product and its intended application, the “laboratory” would determine the necessary materials properties, perform measurements, and disseminate the information.

The “utopic” system that would evolve from the proposed material property R&D would provide the designer with custom-made alloys for each specific application. This system would allow the designer to specify the expected conditions and desired properties for a given casting, and get a computer printout of the exact composition of the ideal alloys required for that casting.

All of the proposed R&D needs in the **materials processing** category are considered mid- or long-term needs. A very high priority in this area is the development of a clean melting and remelting process. Melting and casting processes that minimize the number of processing steps required (thereby minimizing chemistry variations) are another priority. One method of minimizing these processes would be the development of in-situ methods for melting and casting metals. There is also a need to examine emerging casting technologies, particularly semi-solid casting processes, and their effect on material properties. The goal of this effort would be to identify viable methods of controlling the material properties during processing. A long-term R&D need related to casting processes is the development of property-driven, designer-oriented foundry processes.

The **materials quality** R&D needs identified by the industry are distributed fairly evenly among the near, mid, and long term. In the near term, R&D should focus on assessing available techniques for measuring melt quality and determining its relationship to part quality. There is also a need for improved processes to characterize porosity defects.

The industry places a high priority on developing improved techniques to measure the acceptability of liquid metal prior to casting in the next 3 to 10 years. New, innovative techniques for non-destructive evaluation and testing of castings are also needed. In order to enhance the recyclability of castings without compromising the quality of products made from recycled metal, methods are needed to negate deleterious effects of unwanted secondary elements.

In the long term, additional methods for fast, accurate, non-destructive evaluation are needed to measure chemistries and material properties *after* melting and casting. These methods should expand on the mid-term R&D by extending their applicability to the input metal (ingot) and the actual cast product. Measurement of as-cast chemistries and properties will ultimately improve the integrity of cast products and allow them to meet tighter specifications, enhancing their attractiveness to designers.

The R&D needs identified in the area of **new materials** include a single near-term activity, an examination of novel alloys (for example, rare earth elements in aluminum alloys) to determine the effect that adding different components has on properties such as strength and ductility. In the mid term, corrosion- and creep-resistant magnesium alloys should be developed. These alloys would enhance the application of castings in the automobile and other markets.

Two related activities that would ensure that the metalcasting industry is not left out of the composite market are:

- the development of low-cost, castable composite materials uniquely engineered for wear-resistance, stiffness, or other properties

- the development of new materials that have properties comparable to composites

A high priority need in the **communications** area is the development of a national initiative to foster interest in materials science and engineering. Another idea is the development of web-based data bases (focusing on material interactions as well as other data) that would make critical data easily accessible by interested parties.

Other suggested near-term activities include a market study of designers' needs to help determine what types of information should be developed and made available; improved methods of facilitating communication among industrial partners, involving teleconferencing and use of the Internet, among others; and the possibility of having the American Foundrymen's Society hire an expert designer(s) who would be available to advise less experienced industry designers.

Potential Government Role

The R&D activity considered most appropriate for government co-funding is the long-term component of the development of quantitative relationships between alloys chemistries, properties, and processing (theory-driven). The mid-term component of this activity (develop relationships based on existing data) has also received significant attention in terms of appropriateness for government funding.

Other R&D needs that have been singled out by industry for their appropriateness for government co-funding included the development of a "virtual laboratory" for material properties, the development of a national initiative to foster interest in materials science and engineering, and the development of web-based data bases related to castings.

CHAPTER 4

Manufacturing Technology

U.S. metalcasters have been striving to improve the timeliness, productivity, and efficiency of their operations while delivering consistent, high-quality castings at competitive prices. Continued progress in developing advanced design and manufacturing technologies is paramount to the financial success of the industry in increasingly competitive international markets for metal parts and components.

Current Situation

The manufacturing component of the metalcasting industry is extremely diverse and includes sand casting, investment casting, lost foam casting, die casting, permanent mold casting, and others. Various forms of sand casting dominate, accounting for about 60% of the volume (by weight) of castings. Permanent mold and diecasting combined account for another 20% of the total by weight, while investment casting has increased to 7% of the total. Exhibit 4-1 indicates the casting methods used in U.S. foundries, including the value of shipments by casting method.

Some key factors in evaluating the current state of casting manufacturing include:

- Lead time
- Productivity
- Quality and consistency
- Energy efficiency
- New or alternative processes

The **lead time** that it takes to bring a cast component from concept and design into production is critical to increasing castings' share of new markets. Typical casting lead times run into months for small parts with moderate complexity. For example, steel castings typically take 20 to 40 weeks to procure; "best practice" can bring this time down to about 4 weeks in some cases. The major contributors to lead time in cast components are tooling construction and process development.

Productivity is one of the most important factors affecting the competitiveness of the metalcasting industry, especially in light of the fact that there is an excess production capacity in the industry worldwide. Over the last 15 years many metalcasters have refocused their efforts to improve productivity. Most of the automotive industry's producers of metal castings and finished cast parts are large foundries who have computerized every phase of their production operations. The productivity of these foundries and other large U.S. foundries is estimated to be comparable to that of major foreign competitors. The average metal yield in the casting industry, also an indicator of productivity, is approximately 50%.

Exhibit 4-1. Casting Methods Used and Value of Castings Shipped by U.S. Metalcasting Facilities (1994)

Method	Use (%)	Value of Shipments ($ billion)
Sand	60.0	10.4
Permanent Mold	11.0	1.8
Die	9.0	7.6
Investment	7.0	2.3
Other (Subtotal)	13.0	0.9
Shell Mold	7.0	--
Centrifugal, plaster, and evaporative pattern	6.0	--
TOTAL	**100.0**	**23.0**

Sources: *A Technology Vision and Research Agenda for America's Metalcasting Industry*, American Metalcasting Consortium, February 1995.
A Vision of the Future of the U.S. Metalcasting Industry, Idaho National Engineering Laboratory, September 1994.

The U.S. metalcasting industry has also made great strides in improving the **quality and consistency** of its products over the past 15 years in order to survive in the face of reduced demand. Typical scrap rates are currently only a few percent compared with rates in the 10 to 20% range during the 1970s and early 1980s. This improvement has occurred in spite of the fact that today's higher quality requirements necessitate scrapping many castings considered acceptable 15 years ago. However, even a few percent of castings scrapped translates into more than $50 million annually in wasted manufacturing costs.

In general, the quality of U.S. iron castings is considered to be higher than Pacific Rim and South American castings but lower than German and Japanese castings. U.S. steel castings are considered to be essentially equal in terms of quality as their major competitors. Non-ferrous castings made in the U.S. are considered to be of higher quality than Japanese castings and only slightly lower in quality than German castings.

The U.S. metalcasting industry's annual **energy use** is estimated to be about 250 trillion Btus. Most of the energy is used for major operations such as melting, molding, and heat treating. The major fuels used are electricity and natural gas. Energy costs account for an estimated nearly 25% of the cost of diecasting products; for other industry segments, energy is estimated to account for 15% of total product cost.

The energy efficiency of equipment used in U.S. foundries has been estimated at less than 45%. Cupola furnaces, still used by some iron casters, are less than 35% efficient. These furnaces are slowly being replaced with coreless induction furnaces that are 75 to 80% efficient.

A number of **new casting processes** have recently been developed and others are emerging. Investment casting and lost foam (expendable pattern) casting technologies have proven to be adept at new designs that displace complex machined or fabricated parts, and may provide new product and application opportunities. Thin-wall casting techniques can be used to produce castings with superior mechanical and physical properties at lower weights, leading to growth of cast metals in the automotive, aircraft, and other markets. Two relatively new thin-wall casting processes -- the Cosworth process for non-ferrous castings and the FM process for ferrous castings -- have been developed for producing clean, thin-wall castings. However, further understanding of all of these processes needs to be obtained to realize their full potential.

Trends and Drivers

Each of the key manufacturing factors described above is an integral part of the overall process of producing a casting. The combination of increased competitiveness and more demanding customers has put more pressure on metalcasters to improve their performance as measured by these factors.

The **lead time** required to get the first article delivered to the customer is a critical factor in the competitiveness of metalcasting versus other fabrication techniques. Traditionally, metalcasters are not always able to respond quickly to changes in the customer's design (and vice versa). The U.S. metalcasting industry is continuing its efforts to cost-effectively develop and produce castings faster (or just-in-time) while improving casting quality and consistency.

The lead time to produce a casting depends on a number of factors, especially the availability of and reliance on computer-based tools. New computer-based technologies are improving capabilities in casting design, prototyping, process development, control, and production. Emerging technologies in computer hardware, CAD/CAM software, computer modeling (including solidification modeling), rapid prototyping and rapid tooling make design and development of cast metal prototype components easier, faster, and more accurate. Those casters who use rapid prototyping techniques have significantly reduced the time required to produce a casting from a concept or CAD design.

Casting lead time is affected by the availability of standardized data on specific properties, data that are limited even though cast components have been used for over a century. Designers often use "case histories" of comparative components as their guidelines for new designs. This design method limits the ability to make changes, as illustrated by the months required to design a radically new component. The variation in data on casting properties also hurts the more advanced casting designers who use finite element modeling interfaced with CAD/CAM programs to develop cast metal components. Predictive software used to design parts and molds can eliminate the high cost of trial-and-error runs or expensive tooling modifications if rules for dimensional control are known.

The **productivity** of the casting process is crucial to the survival of the U.S. metalcasting industry. Improvements in the industry's productivity have been steady. New automation and computer-based technologies are improving casting control and production. Modern computational hardware and software tools can greatly streamline and modernize casting production. Robust, reliable sensors can be linked to computers to control a process and its critical parameters in real time. Process control computers can in turn be linked to production flow computers to form a network that controls an entire foundry. However, few foundries can afford these technologies and systems. Continuing technological advances in achieving greater precision in patterns and tooling, and also tighter tolerances in production machinery and molding media, can yield parts that meet design and performance specifications with minimal seconds operations. Casting **quality and consistency** are important factors in determining the successful application of castings in both current and new markets. The quality (specifically metal cleanliness, mechanical properties, and dimensional accuracy) of castings affects the manufacturing costs of products containing castings. Many high-alloy and other high-value-added castings that were sourced off-shore during the 1980s are now returning to domestic foundries because of improved exchanged rates and the inability of foreign foundries to meet, on a continuing basis, the quality and delivery requirements of domestic customers.

Casting customers are increasingly demanding higher quality castings; more and more casting suppliers and customers consider zero-defect castings as a production objective. The pressure of the customer on the metalcaster to deliver a higher quality product faster will be exceeded by the metalcaster's own needs to optimize his manufacturing process for lower overall costs and quicker response. Through improved process and quality controls, mold and casting scrap can be minimized, thus significantly improving both casting quality and productivity.

The **energy efficiency** of casting processes directly impacts the cost of the casting, providing casters with an incentive to reduce their energy use. Melting processes have the largest energy requirements in the foundry; in some cases, inefficient cupola furnaces are being replaced with more energy-efficient electric furnaces.

New manufacturing processes are needed to produce the light-weight, high-strength, and thin-wall components essential to competing in new and emerging markets. For example, the development of lost foam casting has created new opportunities to expand casting applications with new products. Components cast to near net shape (which reduces machining) will be increasingly common in the future.

Performance Targets

In *Beyond 2000: A Vision for the American Metalcasting Industry*, the industry identified a number of performance targets related to manufacturing and environmental issues. While the original indication was that these goals were to be achieved over the next 20 years, they have been modified by the industry for achievement within five years:

- Increase productivity 15%
- Reduce average lead time 50%
- Reduce energy consumption 3 to 5%

While the original goals represented a good starting point, there was general agreement that they were too conservative for the 20-year time horizon. The manufacturing goals to increase productivity and reduce energy consumption are thought to be relatively easy to achieve in the next several years with existing technologies. A more aggressive, but achievable, goal for productivity by 2020 is to produce *twice* as much with the same amount of people. On an interim basis, the industry should strive to achieve a 15% increase in productivity (measured as tons produced per production worker) every five years.

Likewise, the goal to reduce by 50% the average lead time required to manufacture a casting is thought to be achievable over a 5-year time horizon rather than 20 years. Many customers would probably like to see lead times reduced by even more (75 to 80%). Energy efficiency can also be improved at a faster pace; by 2020, the industry should endeavor to reduce the amount of energy consumed per unit value of shipments by 20%, with interim reduction targets of 3 to 5% every five years.

Technology Barriers

A number of challenges lie ahead for improving manufacturing technologies in the metalcasting industry. These challenges, or technology barriers, are shown in Exhibit 4-2. They are categorized as follows:

- Manufacturing
- Sensors and controls
- Modeling
- Lead time
- Productivity
- Quality and consistency
- Energy
- Cross-cutting

Customers are pressing for quicker turnaround times and have needs for products with increasingly higher levels of dimensional accuracy. Other **manufacturing** barriers include a lack of rapid die casting technologies, metal handling capability limitations of much of the existing metalcasting equipment used in the industry, and a fundamental lack of knowledge concerning scrap generation. In addition, not enough is known about some of the newer casting processes, including lost foam, FM, and Cosworth. The small size of the average foundry limits the ability of the industry to allocate major capital outlays for unproven technology. As a result, it is easier to make progress on incremental improvements than to introduce technologies that require major redesigns of manufacturing processes and casting techniques.

The lack of low-cost and accurate **sensors and controls** hurts metalcasting productivity and quality. The sensor and control equipment that is currently being used in die and sand casting is often not very effective. For example, there is a lack of continuous monitoring capability in sand molds, and existing sensors are unable to detect subtle changes in conditions in molds, gates, runners, and risers. While more automation of casting processes could be beneficial, particularly in improving dimensional accuracy, increasing productivity, and reducing lead times, the automated control systems currently in use are neither sophisticated enough to learn from past mistakes nor an adequate substitute for manual controls.

Linking advanced sensors and controls with new **computer models and analysis tools** holds great promise for the industry. Model developers face several technical challenges. The casting process is extremely complex, which makes the integrated modeling of the various process steps particularly difficult. Modeling runners and gates is particularly difficult. Modeling enhancements could help with defect reduction, but adequate models of turbulence in the casting process have not yet been developed. Also interfering with advancements in modeling is the lack of consistent data for mold filling and an inability to predict the micro-structure as a function of composition and processing.

Chief among the barriers to reducing **lead times** is the amount of trial and error that is currently needed to develop and set up tooling equipment. Other key barriers are the lack of effective scheduling software and the need for rapid tooling technologies that can be used to manufacture customized products in smaller lots. The lack of three-dimensional part descriptions and the typical absence of calculations of expected results during the design phase also present problems.

Exhibit 4-2. Major Technology Barriers in Manufacturing
(Most Critical Barriers Boldfaced)

AREA	BARRIERS
Manufacturing	**Difficult and expensive to achieve higher levels of dimensional accuracy** **Using new technologies is costly and funds for capital outlays are scarce** **Many of the causes of scrap generation are not known** Lack of rapid die-casting technologies Lack of materials other than steel for die casting dies Limited capabilities of existing equipment for metal handling Soldering problems in die tools Present understanding of the lost foam process is considered deficient in several key areas Lack of full understanding of the FM process and the Cosworth process; specific issues include increasing dimensions, cleanliness, and soundness
Sensors and Controls	**Lack of continuous monitoring of sand in molds** Automated controls are incapable of learning Current sensors cannot detect subtle changes Don't know when control algorithms are optimized
Modeling	**Modeling runners and gates is hard due to complexities** **Inability to model turbulence for defect reductions** No consistent data for mold filling Lack of fundamental understanding of the microstructure of materials Mold designs are not fast or intuitive Problems with system compatibilities between processes (computer and other)
Lead Time	**Customization for smaller lots requiring rapid tooling** **Too much trial and error in tooling development** **Lack of effective scheduling software** Lack of 3-D description of parts Lack of understanding of process flow Lack of engineering discipline - design expertise Lack of software that puts on the gates and risers

Exhibit 4-2. Major Technology Barriers in Manufacturing **(Most Critical Barriers Boldfaced)**	
AREA	**BARRIERS**
Lead Time (cont)	No calculations of expected results during design phase Failure to communicate changes in product requirements Lack of process versatility commensurate with materials versatility Businesses require back-logs Industry is vertically disintegrated Typically it takes longer for concept development, tooling production, and prototype delivery of castings than alternative product forms Long lead times limit the use of castings in new component designs
Productivity	**Too much labor in the cleaning room (post-casting processing)** **Lack of robust productivity sensors** **Lack of process models that adequately describe metalcasting processes** Casting yields that are less than optimal increase the costs of castings, making them less economical compared with more expensive fabricated components such as welded assemblies or forgings The rules currently used in designing gating and pouring systems are at best empirical, contributing to low casting yield and quality Too much downtime
Quality and Consistency	**Too many inclusions** Gaps in knowledge about the conditions that cause the different types of casting defects inhibit the ability of casters to modify and control casting processes to eliminate defects Perceived soundness issues have prevented castings from being considered for many critical applications Inability to test molten metal quality "in real time" Lack of consistency in the soundness of castings has prevented them from being treated as forgings or weldments. Lack of directional solidification during casting Molding processes that have typical tolerance recognition are extremely conservative in their capabilities prediction, giving a poor perception of the dimensional accuracies attainable with common casting processes Problems with dimensional control hurt the ability of some producers to assure potential customers that their tolerances can be met The complex injection profiles used by die casters are less than optimal because of a lack of

Exhibit 4-2. Major Technology Barriers in Manufacturing (Most Critical Barriers Boldfaced)	
AREA	**BARRIERS**
	knowledge about the transition between the different portions
Energy	**Lack of robust sensors and controls suitable for hostile environments** Lack of understanding of process flow Long heat treating times Energy wasted in metal melting High temperatures for handling metals may not be needed The melting processes used in metalcasting are not controlled as well as those in wrought steel production, leading to higher energy intensity in metalcasting Inadequate understanding of material/process interactions and process fundamentals related to induction hardening Relatively low cost of energy
Cross-Cutting	**Lack of educated workforce** Existing knowledge base is not being applied Metalcasting is not a time-efficient, low-cost manufacturing process Lack of systems to identify scrap at early stages of process where value added components is low Poor equipment choices

Some lead-time barriers also relate to the structure and practices of the industry—for example, absence of vertical integration fragments a single job. In addition, the desire for order backlogs inhibits just-in-time scheduling in small job shops. Some cross-cutting barriers that have a significant impact on lead time include the scarcity of employees with strong engineering backgrounds as well as gaps in understanding process flow relationships. Both of these factors serve to limit the technical knowledge that can be applied to solve manufacturing problems. Poor communication between customers and casters about product requirements also inhibit improvements in lead times.

One of the most significant barriers to increased **productivity** is the lack of process models that accurately and completely describe metalcasting processes. In addition, available sensors and controls are not robust or sophisticated enough to measure and control all the process parameters. Another key problem is that far too much time and labor is spent to clean and process the products for final shipment after they have been cast. Less-than-optimal yields and equipment downtimes also hurt foundry productivity.

Casters feel that the level of inclusions in cast components is still too high. Barriers related to improved casting **quality and consistency** include lack of complete understanding of defects, which impedes casters ability to control or eliminate them. The lack of real-time techniques to test molten metal quality increases the occurrence of defects. Other problems are related to dimensional control and directional solidification during casting.

The lack of advanced sensors and process controls that can withstand the hostile environments inside and around the melting and holding furnaces is a key barrier to achieving **energy efficiency** goals. Relatively inefficient uses of energy in melting metal and long processing times associated with heat treating are recognized problems in all segments of the industry. Other barriers include the relatively low cost of energy, the relative inefficiency of the melting process, long heat treating times, and a lack of complete understanding of induction hardening, which leads to some casters to use the more energy-inefficient carburizing process.

An important **crosscutting** barrier to achieving the industry's long-term goals is the lack of a technically educated work force. As equipment becomes more sophisticated and computer-based, and as the industry shifts from the image of making "commodity parts" to making high-quality "engineered components," more technical skill will be needed from the labor force. Other barriers arise from the inherent nature of the metalcasting process, which is not a time-efficient, low-cost process. Poor equipment choices contribute to poor performance; as in many other facets of foundry operation, the knowledge that exists is not necessarily being applied.

Research Needs

The research that the industry believes is needed to overcome the technology barriers in manufacturing (shown in Exhibit 4-3) fall into the following areas:

- Fundamental understanding
- Design aids
- Processing technologies
- Mold technologies
- Sensors and controls

A critical area of research that will rely heavily on government funding is the development of a better **fundamental understanding** of metalcasting processes. A top research need is to improve the ability of metalcasters to produce to size or dimension. Examples include the use of low-expansion sand in lost foam or the use of "three-dimensional shrink factors" in die casting. Successful research in this area would help the industry make progress towards three goals: improved productivity, reduced lead time, and reduced energy consumption. It is possible that this research, if supported by the government, could yield commercially applicable results in the near-term (within three years).

An investigation of the die casting process to determine the mechanisms by which die casting dies actually fill would help the die casting industry improve its productivity. This is a long-term research effort that would require government funding to complete. Developing an understanding of folds for aluminum lost foam casting and methods to improve yields are two high-priority research needs in the area of fundamental process understanding thought to be achievable within ten years.

Exhibit 4-3. R&D Needs in Manufacturing By Time Frame
(k = Top Priority; M = High Priority; F = Medium Priority)

Time Frame	Fundamental Understand-ing	Design Aids	Processing Technologies	Mold Technologies	Sensors and Controls
NEAR (0-3 Years)	k Improve the ability to produce size/dimension - the use of low-expansion sand in lost foam casting - the use of "3-d shrink" factors in die casting Correlate thermal and physical properties to flowability in sand systems Database of the thermal and physical properties of sand molding systems	k Improve speed and accuracy of tool design simulation software Develop systems to support distributed design - to improve collaboration among physically separated participants Improve existing rapid prototyping processes for cast components	ž Transfer understanding of current scrap analysis methods and remedies S includes an atlas of root causes, defects, and preventative measures	k For die casting (permanent molds), need capability to cast to shape - use of cavities	k Develop a systems approach to scheduling and tracking M Develop robust sensors and controls suitable for hostile environment
MID (3-10 Years)	k Understand folds for aluminum lost foam casting M Develop understanding of what causes inclusions - reducing defects will reduce waste M Develop methods to improve yield M Improve the correlation between separately cast test bars versus the material in casting - help improve design of castings	k Develop low-cost rapid tooling technology - for both making and changing the tooling M Develop design-for-casting methods and supporting systems - e.g., CAD environments that help design/ engineer castings Develop better solid model casting design tools	k Cost-effective and dimensionally accurate patternmaking processes for use in sand casting M Improve lost foam casting process for steel casting segment - energy improvement - dimensional improvement - yield improvement - lead-time reduction M Develop the advantages of semi-solid metal casting (SSM) process - for higher-performance (aluminum)	k Improve tooling design to reduce the time to market - low-cost rapid tooling technology - both making and changing the tooling ž New molding processes for as-cast dimensional accuracy in sand systems ž Dimensionally stable molding materials for sand casting that are environmentally benign S sand molding or core systems with low or no emissions	ž Affordable, robust software for gating and risering F Methods to rapidly determine quality and dimensions - e.g., tomography, real-time x-rays - develop data to verify gate-flow models M Develop mathematical model that describes process and can control machine

Exhibit 4-3. R&D Needs in Manufacturing By Time Frame
(k = Top Priority; M = High Priority; F = Medium Priority)

Time Frame	Fundamental Understand-ing	Design Aids	Processing Technologies	Mold Technologies	Sensors and Controls
MID (3-10 Years)			- more alloys - environmentally benign M Demonstrate effective joining techniques for new and dissimilar cast materials - to join new alloys (especially for automotive applications) F Develop methods to produce thinner wall castings - expand metal casting into new markets - improve energy efficiency - will depend on better dimensional control Miniaturization of systems to reduce cost and increase utilization Integration of pattern core and sand mold systems to improve dimensional accuracy	ž Die materials and coatings to eliminate solder and heat checks in permanent cast applications S search for die materials other than steel Develop better understanding of the mechanisms of dimensional change of mold materials during the processes of pouring and solidification	
LONG (>10 Years)	k Figure out how die casting dies actually fill ž Model of micro-structure to determine residual stress and mechanical properties F Tie modeling to casting	M Develop better methods for describing parts - describe shape, functionality design intent, materials, etc. - digital description	ž Melting and pouring technologies that do not introduce gases to the process F Processing techniques with alloys that don't need heat treatment F Faster heat treating processes for both ferrous and	Smart molds for continuous monitoring Develop low-cost production mold technologies (vs. prototype) - cheaper ways to make mold quickly that is dimensionally correct	k Smart controls and sensors for automation supervision M Develop automated system for gating location - fully automated

Exhibit 4-3. R&D Needs in Manufacturing By Time Frame (k = Top Priority; M = High Priority; F = Medium Priority)					
Time Frame	Fundamental Understanding	Design Aids	Processing Technologies	Mold Technologies	Sensors and Controls
LONG (>10 Years)	processes to determine defects in the microstructure F Develop modeling technology for all casting processes - include optimization of energy use F Develop relationships between process conditions, material attributes, and part attributes		non-ferrous materials Develop lost foam capability for iron and steel in addition to aluminum F Develop material that adheres to dies and does not have to be replaced each cycle	- recyclable - disposable	F Develop fast-response, closed-loop diecast shot cylinder controls

Another of industry's most critical tasks is to improve the correlation between separately cast test bars and the material that is actually in the casting. In the mid term, this will help improve the design of castings and make the overall process more energy-efficient and productive. Again, it is unlikely that industry will be able to pursue this research without funding support from the government.

Advances in modeling can lead to better fundamental understanding of various phenomena that can particularly benefit the industry's goals to increase productivity and reduce energy consumption. However, better data will have to be developed to support advanced models and automation systems for foundries and casting processes. Some high-priority R&D needs that fill this need include developing modeling technology for all casting processes (including optimization of energy use), relationships between process conditions and material and part attributes, a model of microstructure to determine the effect of residual stress on mechanical properties, and the capability to tie modeling to casting processes in order to determine defects in the microstructure.

In the area of **design aids**, the industry has determined the most critical need to be improving the speed and accuracy of tool design simulation software, which it feels could be accomplished in the near term. In the mid-term time frame, a high-priority need is the development of design-for-casting methods and supporting systems such as computer-aided-design (CAD) environments. A longer term need is the development of better methods for completely describing individual cast components, possibly digitally. As shown in Exhibit 4-3, several other design aids are needed to help design engineers communicate information about casting designs and create better original casting designs. This research contributes principally towards the goal of reducing manufacturing lead time.

New **processing technologies** can contribute to the industry's productivity, energy efficiency, lead time reduction, and environmental goals. Cost-effective and dimensionally accurate patternmaking processes are considered a top priority. Better documentation and transfer of current scrap analysis methods and remedies could provide benefits in the near term.

New manufacturing processes that enable production of thinner wall castings will provide new markets and contribute towards two of the industry's manufacturing performance goals -- improved productivity and reduced energy consumption. A pressing need in this area is to improve the lost foam casting process for manufacturing steel castings. This would greatly expand the industry's ability to cast dimensionally correct steel components with a higher yield, lower energy consumption, and shorter lead time. Likewise, developing the advantages of the semi-solid metalcasting (SSM) process for use with more high-performance alloys would expand metalcasting markets while improving the productivity and energy efficiency of the overall manufacturing process. These are both mid-term research efforts that will require government funding to fully pursue. Long-term processing needs include the development of cleaner melting/pouring technologies and minimization of heat treating processes for all alloys.

Technology advances would be particularly valuable for **mold technologies** and tooling designs to make them faster, cheaper, more precise, and accurate. A top priority research need identified by the industry is the development of low-cost, rapid tooling technology for both making and changing metalcasting tooling. Research achievements here would greatly reduce the lead time required to manufacture cast components.

A more near-term solution is research aimed at eliminating steps in the casting process and developing technologies capable of "casting to shape" by making better use of cavities. Additional mid-term research in mold technologies for sand casting could be the development of new technologies that can achieve as-cast dimensional accuracy; environmentally benign, dimensionally stable materials for sand molds; and die materials and coatings that eliminate the need for solder and heat checks.

Greater accuracy in the casting process, including the ability to predict and relate the properties of materials, would allow better process control and would reduce defects. To make further progress in this area in the long term, new **sensors and controls** are needed for automation supervision, and "smart" molds need to be developed that have continuous monitoring capabilities. A high-priority research need overall is the development of a systems approach to scheduling and tracking. This research is likely to be undertaken by individual companies in order to reduce lead times and improve productivity. Companies undertaking this research could expect to see commercial results in the near- to mid-term time frame.

Another pressing need is to develop methods for rapidly determining the quality and dimensions of cast components, which would improve productivity and reduce lead times. For example, tomography and real-time x-rays can be used to measure these characteristics during the manufacturing process. Both die and sand casting processes would benefit in the near term from new x-ray imaging systems that could gather real-time data to verify gate-flow models. This research could produce commercial results in the mid term, but is not likely to be undertaken in the absence of government funding support. Another priority is the development of fast-response, closed-loop controls for die-cast shot cylinders. In the mid term, the development of cost-effective software for gating and risering could help improve productivity, while new mathematical models that describe the process could be developed to control the machine.

Potential Government Role

The majority of the research needs identified as being most appropriate for government support are in the long-term research category, including needs for modeling and advanced processing technologies.

Government support is considered critical for virtually all of the R&D needs listed under "Fundamental Understanding."

The overwhelming majority of the manufacturing technology research needs are unlikely to be pursued by industry in the absence of government funding support. Because the majority of the metalcasting industry is composed of small companies with very limited R&D budgets and in-house research facilities, all but the "business-critical" R&D will probably not be funded or performed by individual companies. Furthermore, to maintain the metalcasting industry's international competitiveness, much of the identified R&D is required more quickly than industry can support on its own. Therefore it is essential that industry leverage its R&D activities by partnering with outside agencies to remain competitive.

CHAPTER 5

Environmental Technology

Improving environmental performance while keeping regulatory compliance costs at a minimum is one of the key challenges affecting the future competitiveness of metalcasters. How well the industry copes with increasingly stringent controls on emissions to the environment will have dramatic impacts on production costs as well as industry growth. The issues of environmental compliance will be further complicated as manufacturing practices change to meet market demand for new casting products and to reflect changes in customer needs.

Current Situation

Metalcasting produces a number of gaseous, liquid and solid waste streams (shown in Exhibit 5-1 for ferrous casting processes), many of which could have an adverse effect on the environment. Waste products from casting operations include waste gases from molding and core making, melting, molding, and shakeout; contaminated and unusable spent sand from sand casting shakeout; slag from melting; and particulate from melting, shakeout, and cleaning. Air-borne pollutants and contaminants also present a major environmental issue for all metalcasters. These include dust, particulate, off-gases, fumes, and gases (such as carbon monoxide) from furnaces, and other byproduct gases and fugitive emissions.

Metalcasting also produces some very positive impacts on the environment by preventing the landfilling of large amounts of scrap metal. The foundry industry is one of the largest recyclers in North America, saving 13.3 million tons of scrap metal from disposal every year. Scrap iron and steel are currently used to produce at least 85% of all ferrous castings in the United States.

The waste streams produced by metalcasting are subject to compliance with a number of environmental regulations governing air, water, and solid waste effluents. Major environmental statutes and regulations affecting the metalcasting industry include the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act (RCRA), and the Superfund Amendments and Reauthorization Act (see Exhibit 5-2). Of these, the Clean Air Act Amendments of 1990 pose the most difficult and costly near-term challenge.

The foundry industry spends over $1.25 billion per year to comply with Federal, state, and local government regulations. The Department of Commerce reports spending of nearly $330 million in 1994 in operating costs for pollution abatement and control, although this does not include some smaller foundries, certain categories of environmental compliance costs, and pollution control costs from captive foundries reported under different industry classifications.

Exhibit 5-1. Foundry Solid Waste Stream Estimates (Ferrous)				
Waste	**Generation Process**	**Average Waste Generation in 1989 (tons)**	**Production Rate (ton waste/ ton casting)**	**Percent of Solid Waste Stream (%)**
Spent sand (non-hazardous)	Shakeout	8,093	0.384	57
Spent sand (hazardous)	Shakeout	165	0.008	1
Slag	Melting	3,695	0.175	26
Particulate	Melting, Shakeout, and Blast Cleaning	2,272	0.107	16
TOTAL		**15,073**	**0.674**	**100**

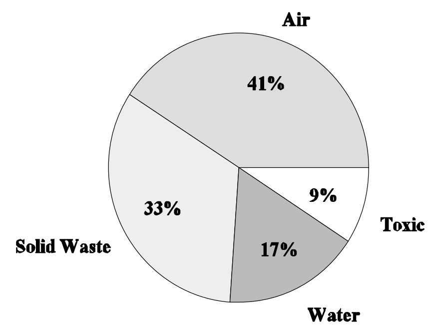
Source: *Environmental Compliance in the Foundry Industry*, Energetics, Inc., June 1995.

Exhibit 5-2. Major Environmental Statutes Affecting U.S. Foundries		
Statute	**Target Waste Stream**	**General Requirements**
Clean Air Act	Particulate, hazardous air pollutants	Emission control equipment, monitoring, reporting, and permits
Clean Water Act	Wastewater from scrubbers for emission control and storm run-off	Pre-treatment of waste- and storm water prior to discharge, discharge limits, and permitting program for discharges
Resource Conservation & Recovery Act (RCRA), Subtitles C&D	Spent sand and slag with RCRA-characteristic waste	Restrictions on transport, storage, and disposal (e.g., land disposal); RCRA permit
Superfund Amendments & Reauthorization Act (SARA) Title III	All waste streams of releases (spent sand, slag, particulate, sludge, wastewater, etc.) containing a Section 313 (toxic) chemical	Record keeping on the types and amounts of emissions and reporting on an annual basis

Source: *Environmental Compliance in the Foundry Industry*, Energetics, Inc., June 1995.

About 40% of compliance costs are used for control, treatment, and disposal of air pollutants and related sludges. Solid and hazardous waste disposal -- mostly sands and slags -- account for about 33% of compliance costs (Exhibit 5-3). It is estimated that environmental compliance costs represent 2% of the cost of a casting. New environmental regulations are expected to increase this portion to 5% of casting costs in the near future. In terms of new capital expenditures, it has been estimated that environmental expenditures consume as much as 30 to 60% of total annual spending for the foundry industry.

Ex 5-3. Environmental Cost by Media



Trends and Drivers

The metalcasting industry has been struggling with environmental regulation and compliance issues for decades. Surveys of U.S. foundries indicate that environment, health, and safety issues -- and the regulations that govern these areas -- are the top concerns facing the future of their businesses. It has been estimated that the cost of compliance to metalcasters has been at least partly responsible for the demise of about 2,000 metalcasting firms over the last twenty years. Smaller foundries (which comprise more than 80% of the industry) can least afford to deal with environmental costs and are usually the hardest hit by new regulations. Increased compliance costs fall disproportionally on smaller foundries, continuing the shutdown of marginal small foundries and the trend toward larger facilities.

Environmental regulations are expected to become increasingly strict over the next two decades and will have significant impacts on metalcasters in terms of cost and economic viability. EPA is currently involved in rulemaking under the Clean Air Act Amendment (CAAA) of 1990 that will directly affect U.S. foundries. The new regulations, which are scheduled for enactment in the year 2000, will enforce new environmental standards for iron and steel foundries. Implementing these new regulations is expected to increase environmental compliance costs by $750 million over the next five years.

Sand casters face major environmental issues related to treatment and disposal of spent sands that may be contaminated with toxic or hazardous wastes. RCRA Subtitle D restrictions on non-hazardous wastes is expected to cause a large percentage of existing landfills to close, increasing the cost of treatment and disposal by $13 per ton, or about 20% of the current life-cycle cost of sand.

Technologies that reduce or eliminate waste and improve performance will greatly enhance the future success and world-wide competitiveness of the industry. In the international market, domestic metal castings must sometimes compete with castings produced in countries with less demanding environmental standards and where the cost of environmental control is far less. To stay competitive and cope with the rising cost of environmental compliance, metalcasters have begun to examine ways to reduce waste generation at the source as well as increase utilization of waste and byproducts. In many cases, capital funds are diverted to compliance with regulations (end-of-the-pipe command and control) rather than development of technologies or strategies to reduce, eliminate, or utilize waste products. However, some new technologies and materials are being investigated, including non-toxic binders, sand reclamation systems, and air and water purification systems, all of which have made important contributions to cleaning up metalcasting processes. In addition, metalcasters have been working with some success to develop new alloys that have less environmental impacts (e.g., alternates to lead-bearing copper alloys).

Performance Targets

In *Beyond 2000: A Vision for the American Metalcasting Industry*, the industry identified long-term targets to improve its overall environmental performance and to become publicly recognized for responsible environmental management practices:

- Achieve 100% pre- and post-consumer recycling
- Achieve 75% re-use of foundry byproducts
- Eliminate waste streams completely

Some industry representatives have indicated that a target of 100% pre- and post-consumer recycling is probably unrealistic. The reasoning here is that the *theoretical* maximum is closer to 95%, and achieving the theoretical maximum recycling rate would be difficult and costly. In addition, to reduce confusion about "eliminating" waste streams (e.g., determining what is characterized as a "waste" and handling products that are process "wastes" but can be beneficially reused), an alternative goal of achieving "zero discharge" levels has been proposed.

The chief drivers of environmental performance goals are regulation and economics. Significant further advances in environmental technologies will thus be motivated by government regulations or clear cost savings potential.

Technology Barriers

Metalcasters have been facing serious environmental challenges for the last two decades, and have made some headway in learning how to comply with the growing profusion of regulations. However, there are still many impediments to the environmental progress of this industry, many of which are associated with the fractionated, small-business nature of metalcasting. For example, to create long-term solutions, metalcasters must invest in R&D and information gathering that will meet long-term goals (e.g., eliminating waste streams entirely, or increasing recycling of foundry products) along with compliance. This has been difficult for many foundries, most of which are small businesses with limited funds for capital expenditures or research of any kind. When faced with large fines or plant closures due to non-compliance, many are forced to invest in compliance and control rather than reduction or elimination strategies.

Exhibit 5-4 shows other environmental technology barriers that currently prevent the industry from achieving its environmental goals. These barriers are categorized as waste characterization, waste utilization, technological, and institutional.

The ability to develop effective approaches to environmental problems must be based on a comprehensive **characterization** of foundry waste streams, an analysis which has not yet been performed. A full characterization could identify missed opportunities for beneficial reuse of waste and help overcome the concern of potential users of the waste byproducts.

There is a severe lack of data on foundry emissions and currently used and best available control technology. For example, if data were available to adequately assess the environmental impact of mold/core binders or other sand additives, the environmental impact of the casting process could be optimized while at the same time maintaining world-class quality for castings. Data to properly select the technology to produce or deliver molten metal to molds would minimize the environmental impact of the casting process while at the same time maintaining world-class quality for castings.

Exhibit 5-4. Major Environmental Technology Barriers
(Most Critical Barriers Boldfaced)

AREA	BARRIERS
Waste Characterization	**Lack of waste stream characterization**
	Lack of data to adequately assess the environmental impact of mold/core binders or other sand additives
	Lack of data to properly select the technology to produce or deliver molten metal to molds
	Lack of information on the redesign and reconfiguration of common foundry processes, tools, equipment, and materials to reduce cumulative trauma
	Lack of systems to identify scrap at early stages of process where value-added component is low
	Lack of understanding of the public health effects of trace elements
Waste Utilization	Opportunities for the use of foundry residuals as substitutes for other raw materials used in processes in other industries are not well known or understood
	Presence of long-lived materials in waste streams
	Lack of methods for removing zinc and waste oil from water in a usable way
	Lack of identification system for materials recycling
	Large number of alloys used makes post-consumer recycling tougher
	Concerns of potential users about using waste stream by products
	Lack of viable uses for waste streams
	Provisions that pull inert materials into a hazardous waste regulatory framework
	Identification and application of environmental solutions is a moving target
Technological	Aluminum sticks to steel in die casting - requires use of die lubricants
	Lack of technologies for recovery of low-temperature waste heat
Institutional	**Lack of educated workforce**
	Enviromental requirements often based on social rather than technical considerations
	Capital costs of sand recycling for small founders

Waste utilization barriers include a lack of knowledge of the potential uses of foundry residuals as substitutes for other raw materials and the lack of viable uses of waste streams. The large number of alloys used makes post-consumer recycling more difficult, compounded by the lack of a comprehensive materials identification system. In addition, no economical technologies currently exist to recover usable waste oil and zinc from water.

Foundries are adversely impacted by provisions that pull inert materials into a hazardous waste regulatory framework. Certain RCRA provisions (e.g., restrictions on scrap metal consumers, new requirements for industrial non-hazardous waste, mandated toxics use reduction) could discourage the beneficial re-use of non-hazardous materials.

Long-term changes in the composition and manufacturing practices of the metalcasting industry make the identification and application of environmental solutions a moving target. The industry should consider developing effective and resilient strategies for the application of pollution prevention technologies to respond to both long-term environmental and market needs.

Many of the barriers listed under waste utilization are also **technological** barriers, such as the separation of zinc and waste oil from water. Some additional technological barriers include the lack of technologies for recovering low-temperature waste heat from metalcasting processes and the inability to die cast aluminum without using lubricants because of problems with sticking.

The **institutional** side of environmental management also presents barriers to environmental technology improvements. For example, regulatory requirements are often shaped by social, not technical, considerations. An important crosscutting barrier to achieving the industry's long-term goals in environment as well as other areas is the lack of a technically educated work force.

Research Needs

A wide range of research and development is needed to overcome existing barriers to achieving the metalcasting industry's manufacturing and environmental technology goals. These needs are depicted in Exhibit 5-5, which shows the R&D needs by subject category and distributed by the expected time frame (near, mid, or long) for completion of the research. To produce castings in a more environmentally sound manner, the industry needs to understand the nature of its waste streams, develop viable uses for byproducts, and investigate ways to reduce and eliminate waste streams.

A near-term effort to compile a database of environmental emissions for foundry and die casting processes would provide environmental regulators with better baseline information that could be used in setting more effective standards. **Characterization** of all material flows and waste streams in the production process would allow the industry to better understand the sources and magnitudes of wastes and pollution. Foundry processes could be **modeled** to identify and minimize environmental problems in both the design phase as well as during operation.

Waste utilization R&D activities could include investigation of potential beneficial uses of spent foundry sand and other products such as spent baghouse dust, iron oxide, sludges, slags, and waste oils. Over the longer term, research is needed to identify new uses for known waste streams and/or new ways to treat waste streams to make them more usable. New energy-efficient sand reclamation technologies could be developed, as well as low-cost production mold technologies that facilitate recycling.

In general, the development of both new processes and new materials that could minimize or eliminate the generation of certain foundry wastes is considered a priority area for research. **New processes** could include in-process recycling, closed-loop water systems, and low-cost waste treatment technologies. In addition to developing new technologies, the industry could attempt to optimize existing technologies through improved control or other methods to reduce waste generation.

Exhibit 5-5. R&D Needs in Environmental Technologies (k = Top Priority; M = High Priority; F = Medium Priority)					
Time Frame	**Waste Characterization**	**Modeling**	**Waste Utilization**	**Waste Reduction - Processes**	**Waste Reduction - Materials**
NEAR (0-3 Years)	**M** Develop emissions database for foundries to use in educating regulators Characterize all material flows and waste streams in the production process		Investigate beneficial uses of spent foundry sand and other waste products for applications in other industries - baghouse materials - iron oxide - wet collector sludge - slag - machining oils	Improve or optimize existing processes to reduce or prevent the production of wastes - improved process control	
MID (3-10 Years)			**M** Develop new markets for foundry byproducts Develop new energy-efficient concepts in sand reclamation	**M** Develop new processes to reduce or prevent the production of wastes - in-process recycling - closed-loop water systems - low-cost treatment technologies	**k** Develop environmentally benign, dimensionally stable molding materials for sand casting - sand molding or core systems with low or no emissions Develop/exploit new materials to reduce or prevent the production of wastes - charge materials
LONG (>10 Years)		**F** Model foundry processes to identify and minimize environmental problems in both the design and operation stage	Develop low-cost production mold technologies (vs. prototype) - cheaper ways to make and/or recycle molds - disposable?		**F** Develop material that adheres to dies and does not have to be replaced each cycle

New materials could include environmentally benign sand binders as well as additives and charge materials. The development of these types of materials (achievable in the mid term) and the development of low-cost materials that adhere to dies and don't have to replaced each cycle (achievable in the long term) are expected to be undertaken by vendors in response either to government regulation or to the market demand for the products by the metalcasting industry. However, there is some concern as to whether research on environmentally benign binders can be adequately addressed by the private sector alone.

Potential Government Role

The overwhelming majority of the research needs are unlikely to be pursued by industry in the absence of government funding support. Because the majority of the metalcasting industry is composed of small companies with very limited R&D budgets and in-house research facilities, all but the "business-critical" R&D will probably not be funded or performed by individual companies. Furthermore, to maintain the metalcasting industry's international competitiveness, much of the identified R&D is required more quickly than industry can support on its own. Therefore it is essential that industry leverage its R&D activities by partnering with outside agencies to remain competitive.

CHAPTER 6

Human Resources

The metalcasting industry realizes that, in addition to its customers, its chief asset is its employees. The industry cannot hope to achieve its vision without trained people in sufficient numbers. Metalcasting workers must not only be willing to perform demanding tasks, but they must also have a relatively high level of educational and work skills. The skills of tomorrow's foundry workers will require more than a simple understanding of metalcasting. The demands of future product needs will require employees to maintain a constant awareness of technological developments over a wide range of disciplines. This will allow the industry to remain competitive with foreign metalcasters as well as alternatives to castings.

Current Situation

There is presently a shortage of skilled labor in the U.S. metalcasting industry. Early retirements and staff reductions in response to depressed market conditions, as well as low levels of hiring, have resulted in a shortage of experienced technical, management, and supervisory people. The average age of diemakers, patternmakers, and other craftsmen in the United States is over 50 years. The attrition rate of experienced engineers far exceeds the number of new engineers entering the metalcasting industry.

Foundry programs have been dropped or de-emphasized by all but a handful of engineering schools. The number of undergraduate engineering students choosing foundry technology as a major course of study has decreased dramatically, while the lack of industry support for graduate research work in metalcasting has created a low turnout of graduate engineers interested in entering the metalcasting industry. There is also a concern that the vocational (high school) side of the industry has been neglected. Few high schools have vocational arts programs that teach metalcasting skills or any other programs that match the needs of the industry.

In terms of continuing education of the existing workforce, U.S. foundry workers on the average receive less technical training each year than their counterparts in Germany, Japan, and Korea. Compared to major foreign competitors, U.S. foundry workers have lower participation rates in apprentice programs that teach skills such as patternmaking and diemaking, which require significant hands-on training and practice.

Numerous educational activities aimed at the metalcasting industry workforce are sponsored by the industry trade associations as well as others. A number of state programs are in place that are designed to offer training and introduce new technologies to small and medium-sized companies. The metalcasting industry trade associations sponsor conferences, workshops, continuing education courses and in-plant training, and publish newsletters, resource books, brochures and other documents to keep members informed. Some specific outreach efforts include:

- The American Foundrymen's Association's abstract search and retrieval system for answering technical questions

- The Casting Industry Suppliers Association's on-line electronic program to assist metalcasters in the rapid selection of advanced equipment and products

- The North American Diecasting Association's die-casting database for die casters and customers, a fax-on-demand system to transfer information to industry, and a simulation program for use in training

- The Steel Founders' Society of America's series of videotapes for educating design engineers on steel castings

In addition, the University of Northern Iowa, through the Metalcasting Manufacturing Technology Center project, has been training design engineers from the U.S. Department of Defense and commercial companies on designing with metalcastings.

Trends and Drivers

Metalcasters believe that the quality of foundry employees will play a major role in controlling the rate of change in the industry. Other industries that are more attractive will capture the best available employees. With the demographics of an aging workforce, the metalcasting industry will have to scramble to attract skilled and qualified people. Tomorrow's workers won't possess the hands-on skill of earlier generations of workers.

The nature of the jobs available to future employees will also be different. This will be the case by design -- through process reengineering, for example -- and also as technology continues to create or recreate jobs.

Performance Targets

Renewed emphasis on human resources, education, and training will enable the U.S. metalcasting industry to:

- Attract sufficient talent to the industry
- Keep present employees current with latest technologies and techniques

Barriers

The barriers to improving the caliber of the metalcasting industry workforce are shown in Exhibit 6-1. A smaller pool of employees at all levels will make **attracting skilled employees** a key issue. The metalcasting industry is considered relatively "low-tech" and unglamourous, hurting its ability to attract young people. The work and educational skills of entry-level personnel are considered inadequate by most metalcasters. In general, many high school graduates and potential entry-level employees are felt to lack the basic education needed to function in a manufacturing environment.

Exhibit 6-1. Major Human Resources Barriers

AREA	BARRIERS

Availability of Skilled Employees	"Low-tech" image of the industry High school graduates lack the basic education and skills needed to function in a manufacturing environment Lack of experienced personnel Shortage of engineers skilled in computer science who wish to work in the metalcasting industry Difficulty finding and hiring willing and qualified employees to work in the metalcasting industry
Technical Training/ Information Transfer	Insufficient knowledge of metal castings as viable design components Lack the resources to send employees to training programs Public training programs not geared to needs of small metalcasting companies Reductions in technical staff by vendors has reduced the flow of information to metalcasters Poor connection between academia and manufacturing View that information transfer and education are not cost-reducing or productivity-enhancing measures

At a higher level, there is an acute shortage of engineers who wish to work in the metalcasting industry and are trained in the interdisciplinary fields of computer science and engineering. Few people with critical technical and production experience are available.

The combination of fast changing technology, economic pressure, and the poor connection between academia and manufacturing diminish the **information transfer** process. For example, there is insufficient knowledge of castings as viable design components throughout the design community and in engineering schools.

Metalcasting companies, particularly smaller ones, view information transfer and education from a problem-solving perspective and not as cost-reducing or productivity-enhancing measures. Small individual metalcasting companies often lack the resources to send employees to training programs, placing them at a serious competitive disadvantage. Past industry downsizing, coupled with an increase in business activity, has intensified the problem of staff being off the job for training. Smaller companies tend not to participate in public training programs, largely because such programs are generally not geared to their needs. In addition, reductions in technical staff by vendors has reduced the flow of information to metalcasters, especially smaller companies.

Integration with the Technology Roadmap

The operating philosophy of the metalcasting industry will continue to be "change"as dictated by the technology, environmental, and competitive pressures of the industry. This operating philosophy will demand higher levels of problem solving abilities, technology, knowledge, skills, and even new attitudes. Engineers, chemists, metallurgists, technicians, and craftsmen of all types are needed throughout the industry to meet the challenges presented by advanced equipment, new processes, and the production of complex cast parts. Increased education of the industry's workforce will help the industry achieve and maintain a competitive advantage. For example, a more skilled and knowledgeable workforce will be able to envision more new product applications and will be quicker to adapt to process changes and new manufacturing technologies.

The industry believes that education is the most effective way to address its future human resource challenges. Continued educational programs of various types are needed for the industry to prosper; the industry sees these programs as among the wisest investments it can make.

In addition to worker education and training, new mechanisms of technology transfer must be developed and employed to keep foundries up to date with information on new manufacturing technologies and processes, new alloys and other casting materials, and casting design and material property data. This is especially critical for small and medium-sized foundries who typically lack the resources to take advantage of traditional technology transfer methods. The metalcasting industry will also have to take advantage of the education, training, and information transfer capabilities of the metalcasting associations, vendors, universities, national laboratories, consultants, and government agencies.

Current information transfer approaches need to be restructured to account for the industry's diversity. Diversity among metalcasting organizations is key when assessing information transfer, education, and training objectives. This diversity includes industry variables such as company size, types of technology utilized, number and sophistication of staff, and geographical distribution. Implicit in these variables is the ability to devote time and money to implementing the technology needed to successfully cope with problems.

Some specific education, training, and technology transfer needs for current members of the metalcasting workforce, as well as metalcasting customers and university and high school students, are shown in Exhibit 6-2.

The metalcasting industry has identified a number of training methods that could be used to effectively educate its **existing workforce**. These include increased in-house education and training programs, self-directed programs using video/audio tapes and computer-assisted instruction, in-plant programs, and other "close to the site" alternatives such as Optic Link Tutorials. The industry associations have already begun to test some of these methods, and initial assessments suggest that many of them will soon be an integral part of the education process in the metalcasting industry.

The technology transfer process can also be enhanced through the use of electronic bulletin boards, on-line data bases, and communication networks. The coordination of these efforts with small foundries would allow these foundries to access information on technology currently being utilized. The ability to access technology at the foundry in "real time" will help foundries to immediately solve problems. For example, a foundry could conduct a literature search using a computerized abstract service that is modemed to the computer at the foundry. Though highly effective in concept, there are many problems in perception and skill among the users that will need to be addressed to assure that these mechanisms are utilized optimally.

In addition to developing new methods, current information transfer methods must be studied to improve their ability to deliver the needed information to the industry. Trade journals, continuing education programs, and conferences are all established methods that need to be reviewed and improved for added effectiveness. Refocusing and updating these information sources is critical to all metalcasters. Smaller companies could build a consortium that can share costs and staff for common areas of information transfer (see Section 8, Partnerships and Collaborations).

Exhibit 6-2. Human Resources Needs			
Existing Industry Workforce	**Casting Designers and Customers**	**University Students**	**High School Students**
Continue testing new training methods - in-house education - self-directed programs using video/audio tapes and computer-assisted instruction - optic link tutorials Develop electronic bulletin boards, on-line databases, and communication networks Develop ability to access technology at the foundry in real time Improve the ability of current information transfer methods Build a technology transfer consortium of smaller companies	Improve the perception of the quality, lead time, and applications of castings by designers and purchasers Increase marketing and promotional programs to existing and potential customers Develop technical and performance standards Educate customers about the true costs of cast components Familiarize customers with the advantages of using castings	Make more research funds available to conduct industry research Support cooperative education programs for undergraduate students	Create apprenticeship programs Work with local schools to inform them of industry's basic requirements Become a resource to local schools

The perception of the quality, lead time, and applications of castings by **designers and purchasers** must be improved (see Sections 2, 3, and 4). Much of the information and design data that designers have on castings are incomplete or inaccurate. To remedy these problems, the metalcasting industry will need to increase its marketing and promotional programs to its current customers as well as potential customers. Technical and performance standards (discussed in Section 3) will need to be written and distributed to designers of castings. A national communication system could possibly be developed to link component designers throughout manufacturing with design information on castings.

Since today's customer is looking for higher quality products with better service at lower costs, it is imperative that customers be educated about the true costs of cast components. Such costs include the customer's internal costs (i.e., machining, painting, etc.) as well as the initial cost of the component. Customers must also be familiarized with the advantages of using metal castings versus other processes, advantages such as weight reduction, cost reductions through better castings designs, and reproducibility with reliability.

If more research funds were available to conduct industry research, then more **college students** would be graduating with a better appreciation and understanding of the metalcasting industry (see Section 7, Profitability and Industry Health). Additionally, industry needs to support cooperative education programs for undergraduate students. This would expose the individual to the industry and the company to the abilities of the individual.

The metalcasting industry needs to create apprenticeship programs to gain interest in the industry on the part of **high school or vocational school students** The industry will need to accept that remedial education and training will be its responsibility to provide to many new employees. Metalcasting companies will need to work with local schools to inform them of industry's basic requirements for graduating students. In some areas, metalcasters will need to become a resource to the schools. This will require increased partnering with state and local government agencies for assistance and support (see Section 8).

CHAPTER 7

Profitability and Industry Health

Casting suppliers must cope with volatile and cyclical demands that are driven by the demand for durable goods. High interest rates and under-utilized capacity plagued metalcasters through most of the 1980s. The low level of business and the stagnant prices during this decade reduced the profits available for investing in new equipment and hiring new, skilled workers. As companies focused on survival, new casting applications and process improvements were given low priority. In the early 1990s, falling interest rates, increased casting demand, and the closing of some foundry capacity led to a significant improvement in metalcasting business. Those companies that survived and continued to grow in sales and profits through the late 1980s and early 1990s are more knowledgeable about the importance of education, marketing, and customer relations.

Current Situation

The total volume of castings produced in the United States exceeds $20 billion annually. Although the value and tonnage of castings shipped is decreasing relative to economic growth as measured by GDP and FRB's durable goods production index, real growth in the value of castings shipments is expected to increase over 2% annually through the year 2000.

The U.S. is the third-largest producer of metal castings in the world after China and the EC countries collectively; historical data indicate a slow decline in the U.S. share of total world output. For both ferrous and non-ferrous castings, international trade accounts for a very small but growing percentage of the U.S. casting market. The domestic balance of trade in ferrous and non-ferrous castings for major trading partners is shown in Exhibit 7-1.

The U.S. ferrous metal casting industry has seen a considerable decline in aggregate production, overwhelmingly due to a drop in gray iron production. Production of non-ferrous castings (dominated by aluminum castings) is at about the same level it was 30 years ago, having recovered from a steep drop in the late 1970s and early 1980s. Total industry employment decreased by about 20,000 between the late 1980s and early 1990s, although employment levels were up somewhat in 1995. Capacity is currently close to full utilization.

The typical U.S. foundry is a small business; about 80% of operating foundries employ fewer than 100 workers. Small foundries spend a higher proportion of their funds available for capital improvements on pollution control equipment. The industry as a whole, however, invests significantly in new capital. Compared to other manufacturing industries, and with the exception of the steel casting sector, the ferrous sectors of the industry had above-average capital stock (investment in new capital of all types)

Exhibit 7-1. United States Trade Balance for Ferrous and Non-Ferrous Castings - First Two Quarters of 1993 Exports Minus Imports ($ millions)		
Continent	**Ferrous Castings**	**Non-Ferrous Castings**
Other North America (Canada and Mexico)	+51.7	+2.0
European Community	+12.8	-3.3
Asia	-32.3	+2.0
Japan	+1.75	-3.3
Brazil	-7.5	+0.2
WORLD TOTAL	**+97.0**	**+16.5**

Source: *Workshop on U.S. Metal Casting Technical Priorities and Strategies*, Rand Critical Technologies Institute, March 1994.

from 1972 to 1987 when measured by the value of assets per employee. New investments in the non-ferrous sectors of the industry were about average compared to other industries.

In the late 1980s, total funding for metalcasting research in the United States amounted to less than $500,000 per year, and that was supplied entirely by technical societies and trade associations. As of 1992, the U.S. metalcasting industry was receiving approximately $5 million in funding from various sources, including the Federal government and technical and trade associations. Today, the U.S. metalcasting industry and its technical societies, often working in partnership with government, academia, and its supplier base, have significant research programs in place.

Despite the recent growth in funds for metalcasting-related R&D in this country, the United States lags behind major competing nations in total research dollars spent on metalcasting. In Germany, there are three major foundry research institutes to which the German government provided matching funds to industry for their R&D investments. Metalcasting research institutes in Japan, Brazil, and many European countries receive substantial funding from their governments.

Trends and Drivers

Specific factors that affect the industry's health include interest rates, currency exchange rates, inflation, industry capacity, and tax laws, among others. Total cost will continue to put major pressure on metalcasters. Costs may also result in continued globalization, as casters expand into regions of the world where labor is inexpensive and plentiful. The majority of U.S. metalcasters are small businesses that lack the resources to upgrade their operations, much less fund any technical research and development. Lenders are often reluctant to commit financial resources to basic industries such as metalcasting, which are considered risky investments because of environmental compliance issues and the associated financial liabilities. This creates a "Catch-22" situation -- metalcasters cannot easily obtain financing for new foundries or equipment because the industry is considered insufficiently profitable, yet these capital investments could substantially increase the industry's profitability, reducing the risk to lending institutions.

Another trend has been the downsizing of many domestic equipment suppliers as a result of the dual forces of increased foreign competition and a contraction of the U.S. metalcasting industry. The research and development budgets of these companies were frequently reduced or eliminated.

New technology spawned by the computer revolution has required a shift from a "cottage industry" to larger capitalization to finance improved efficiencies. This leads to a requirement for new skills for operators, maintenance personnel, engineers, and management. The industry has historically concentrated on volume rather than value; this is gradually changing as casters increase the value added to their products.

Other key challenges to industry profitability facing metalcasters in the near future include the changing demands and needs in the marketplace; tougher domestic and foreign competition; more aggressive marketing efforts by competitive processes and materials; and the growing numbers of environmental, safety, and health regulations and laws. In addition, quality systems like ISO 9000 are becoming critical for successful competition in the world-wide market.

Performance Targets

Based on its expected health and profitability in the future, the industry would like to increase the financial resources available to fund research and educational and marketing programs by 10%.

Barriers

As shown in Exhibit 7-2, barriers to increased industry profitability and health are categorized in terms of costs and profits, capital expenditures, R&D expenditures, and markets and marketing. The industry operates in a very price-competitive environment, largely due to its fragmented nature. Low **profits** are a deterrent to recapitalizing the industry. The rate of change in the industry is likely limited by the ability to invest in getting new technologies into use, not the funding to discover new processes or products. A significant challenge will be to recognize the extent to which improved operating efficiency can be leveraged into lower prices for customers without reducing or eliminating profits.

Small foundries seldom have the financial resources or access to credit that is necessary for **capital expenditures** in extensive modernization or even equipment. These foundries cannot achieve economies of scale in some manufacturing functions such as purchasing and marketing. In addition, many cannot afford state-of-the-art technologies (e.g., CAD/CAM/CAE) that would help them compete in the international market. retooling. Many metalcasters, particularly smaller ones, are under-capitalized and do not have sufficient capital for investing in new equipment or exploring new applications of metal castings.

A competitive disadvantage is created by purchasing equipment (particularly molding machinery and technology) from foreign suppliers. The same weak dollar that helps U.S. metalcasters export castings makes the capital cost of expansion incrementally more expensive when the equipment and technology are imported. Molding technology that comes with the machinery is developed offshore. The tie to technology is necessary for companies that do not have their own in-house resources to overcome molding and coremaking problems.

Exhibit 7-2. Major Profitability and Industry Health Barriers	
AREA	**BARRIERS**
Costs and Profits	Price-competitiveness of the environment Low profits are a deterrent to recapitalizing the industry Incorporating improved operating efficiency into lower prices without reducing or eliminating profits Expansion of casting into regions of the world where labor is inexpensive and plentiful
Capital Expenditures	Inability of small foundries to invest in extensive modernization or even equipment retooling Lack of capital for investing in new equipment or exploring new applications of metal castings Purchase of equipment (particularly molding machinery and technology) from foreign suppliers Molding technology that comes with the machinery is developed offshore Many domestic equipment suppliers have reduced or eliminated R&D budgets Compliance with government regulations (particularly environmental) has reduced the earnings available to purchase new technologies, modernize plants, or train workers Product liability costs are much higher in the U.S. than in competing countries
R&D Expenditures	Small financial and human resources of small foundries Lower overhead costs of foreign competitors Low R&D budgets of domestic equipment suppliers A lack of sufficient funding for metalcasting research
Markets/ Marketing	Transition from a sellers' market to a buyers' market Metalcasting operations are becoming more product-driven rather than process-driven Industry's lack of proficiency in generating new markets Competition from other processes and materials Unwillingness or inability of many U.S. companies to pursue international customers

Increased foreign competition and a contraction of the U.S. metalcasting industry has forced many domestic equipment suppliers to reduce or eliminate R&D budgets. This has led to slow technology growth in the domestic equipment supplier industry. The industry contraction has also created a large market of used equipment, which is re-sold in lieu of equipment incorporating the latest technological innovations.

Compliance with government regulations (particularly environmental) has reduced the earnings available to purchase new technologies, modernize plants, or train workers. An estimated $750 million annually (in addition to the current $1.25 billion annually) is predicted to be required to bring foundries into compliance with the additional regulations that government is proposing.

A lack of sufficient **funding for metalcasting research** is the largest barrier to getting quality engineers to enter the industry. Small foundries seldom have the financial or human resources to support any research and development programs. Since many foreign competitors obtain more R&D assistance from their governments than U.S. foundries, they enjoy lower overhead costs and can thus offer lower prices for finished products.

Major barriers in **markets and marketing** include the industry's transition from a sellers' market to a buyers' market, its relative lack of proficiency in generating new markets, stiff competition from aggressive competitors (both other processing techniques and other materials), and the unwillingness or inability of many U.S. companies to pursue international customers.

Integration with the Technology Roadmap

The health of the U.S. metalcasting industry continues to be affected by the loss of end-use markets and the substitution of non-cast components, issues addressed in Section 2. Any R&D efforts that result in the development of new markets and products or the recapture of lost markets will therefore have a positive effect on the industry's health and profitability. Similarly, improvements in casting quality, consistency, performance, lead time, and productivity (see Sections 3 and 4) will help maintain and improve the industry's status.

Increases in industry profits will enable the industry to further invest in its future by sponsoring more technical research and development, investing in new technologies and processes, and increasing its educational investments. By reinvesting a portion of its financial gains in these areas, the industry can enhance its competitive position, becoming the preferred supplier of net shape metal components.

Metalcasters of the future will need to be amenable to change to survive. Willingness to change ways of doing business, management techniques, and products and services offered will be important to long-term industry viability. Effective sales and marketing programs, as well as sponsorship of relevant research and development efforts in all aspects of metalcasting, will help the industry secure profitable long-term growth. A more skilled and educated industry workforce (see Section 6) will improve the industry's performance in existing markets while facilitating its entry into new ones. Other changes and developments that would contribute to a healthy industry are shown in Exhibit 7-3.

Exhibit 7-3. Profitability and Industry Health Needs		
Processes/ Technologies	**Markets/Marketing**	**Customers**
Lead time reduction from concept to commercial castings through the use of computer-aided design, finite element analysis, casting process simulation, or rapid prototyping techniques Availability of a wider variety of metals, alloys, and metal matrix composites Effective integration and application of new technologies Expanded variety of casting process capabilities	Modern management and marketing techniques Business plan driven by customer product needs, not foundry capabilities. Identification of new geographical markets, new applications, and markets in industries not presently served	More value-added services offered to customers, such as casting design, machining services, chemical impregnation services, etc. Streamlining of all customer-contact procedures to simplify and speed up the process of making casting design changes and purchase order changes Improved communication with casting customers, which can increase a metalcaster's chances for repeat business Recognition by everyone in the foundry, from the chief executive officer to the lowest rated worker, of the importance of customer service and customer satisfaction

CHAPTER 8

Partnerships and Collaborations

The U.S. metalcasting industry is emerging from two decades of consolidation and attrition in its ranks. The companies that survived are smarter and more competitive, yet they still face significant competitive and technological challenges to their position as a leading player in the world market. Collaborative relationships with partners from both the public and private sectors, including government agencies, supplier companies, non-profit professional societies, and academia, are necessary for the industry to overcome these challenges.

Current Situation

The industry's largest collaborative partner (in financial terms) is the U.S. government. In the past several years, the Federal government has invested approximately $50 million, much of which was matched by the industry, in metalcasting research. The U.S. Department of Energy (DOE) has been the largest government participant but the National Institute of Science and Technology, the National Air and Space Administration, the National Science Foundation, and the former Bureau of Mines have also contributed. DOE works cooperatively with the Cast Metal Coalition, an industry consortia that has developed legislation adopted by Congress to sponsor cost-sharing, energy-related research.

The industry's closest collaborative partner, however, is its equipment and materials supplier base. In many instances metalcasters, casting customers, and equipment and material suppliers are collaborating in government and industry-sponsored research projects.

Metalcasting trade associations, through technical meetings, trade shows, and published materials, provide a focal point around which metalcasters can gather to solve common problems. The American Foundrymen's Society (AFS) works with various government offices and agencies to make them aware of the need for metalcasting research. AFS also manages separately formed research consortiums to fund activities in areas of common interest.

Other trade associations are also involved in collaborative efforts. For example, the North American Die Caster's Association is a partner with other companies and trade associations in Ohio State University's Engineering Research Center for Net Shape Manufacturing, a research consortium funded jointly by the member companies and the National Science Foundation. The Ferroalloy Association is attempting to enhance internal market opportunities through cooperative agreements on shared technology with foreign partners.

Recently, the six major metalcasting trade associations have collaborated to form the American Metalcasting Consortium (AMC), allying the thousands of small and medium-sized metalcasters within the market with the goal of re-establishing the viability of the U.S. metalcasting industry. The AMC's primary focus is on technology transfer. The Defense Logistics Agency (DLA) is providing program management to the AMC, giving the consortium access to DOD design engineers and facilities. Currently the DLA, the AMC, and the University of Northern Iowa are jointly developing a linkage between all of the national Manufacturing Technology Centers and the U.S. metalcasting industry.

The industry also works with state governments in addition to Federal agencies. Several U.S. states have begun to establish regional manufacturing networks to help small and medium-sized businesses adopt new technologies. The programs work through the local community college or school system to provide centers in the immediate area of the foundries. Some states have adopted the concept of the cluster, a group of foundries that are within a relatively small geographic area and are supported by a common outreach program. The use of clusters facilitates technology transfer between the participating foundries and also provides opportunities for those foundries to draw on the resources of national networks and various professional societies.

Trends and Drivers

Emerging metalcasting markets in the future will lead to further industry competition, accelerating the recent partnering trend and ushering in a new era of connectivity between metalcasters, their suppliers, and their customers. Equipment suppliers already play an important role in the development and deployment of new foundry technology and the training of foundry personnel to use this technology. Because of this role, equipment suppliers are considered to be the primary technology transfer mechanism throughout the metalcasting industry. Similarly, metal and materials suppliers are often relied on by metalcasters to lead the way in developing future materials. The development of new materials by material suppliers must be in partnership with the industry because the collective resources must be used to understand the production, quality, and environmental needs.

The government has recently begun mobilizing its national laboratories for closer collaboration with U.S. industry. One benefit of government partnerships is that it allows industry to take advantage of the relationship government agencies already have with many research organizations, which makes the process of qualifying for support simpler. There is also the benefit of using existing contacts to find more matches between needs and expertise. Industry trade associations are also powerful instruments for collective action. With delivery systems and relationships already in place, they can be an efficient tool when expanded resources are available.

Another trend has been the increasing development of sponsorship consortiums for a research program rather than for an individual research project. A multi-task program allows the researcher to satisfy many more individual sponsor theories and allows the results of simultaneous tasks to build upon one another. Sponsorship involvement enhances the program through the shared experiences of the companies represented.

Performance Targets

The industry will continue to encourage partnerships and collaborations to combine the experience, resources, and knowledge available in public- and private-sector organizations.

Barriers

The industry realizes that it cannot, on its own, perform all of the R&D and information transfer activities needed to increase or even maintain its competitiveness in the fast-changing world market. For example, although some sectors of the industry have sponsored updating of design standards and materials properties for traditional materials and products, they have not been able to extend this analysis to newer processes and materials. The industry also has trouble keeping pace in its technology transfer efforts because of rapidly changing technology, lack of resources, and poor communications between academia and industry. These barriers and others are summarized in Exhibit 8-1.

Although a few metalcasting companies are highly active in developing advanced technology, the **industry** as a whole is disaggregated, with few technological advances coming out of the numerous small foundries. The industry relies on its **suppliers** to keep it on the leading edge of technology. However, the industry is increasingly using equipment suppliers who are not based in the United States. This has been compounded by the downsizing of some equipment and consumable material suppliers, which has affected the resources available for technology transfer to the industry.

Recent signs indicate a resurgence in the amount of research related to process metallurgy and manufacturing being conducted by **academia**. However, the focus of such research is typically the analysis of existing processes, not the development of radically new processes. The academic research community is key to bringing current scientific discipline to industry problems, but as importantly to form connections between students in training and actual industrial situations. More such connections are needed to elevate the status of manufacturing among engineering students.

Integration with the Technology Roadmap

The metalcasting industry and its technical societies, often working in partnership with government, academia, and its supplier base, have strong research programs in place covering many of the areas discussed in Sections 2, 3, and 4 (a partial listing of ongoing projects is given in Appendix A). The enhancement of these programs will pave the road to increased competitiveness for foundries of the future. In the coming years, foundries will achieve success by engaging in joint research with technical societies, forming partnerships with foundry and non-foundry companies and securing governmental cooperation. Some general types of collaborations that the industry believes could help it achieve its vision of the future are shown in Exhibit 8-2.

Exhibit 8-1. Barriers to Increased Collaboration

AREA	BARRIERS
Industry and Suppliers	Rapidly changing technology Industry disaggregation Reliance on foreign equipment suppliers Lack of resources for R&D Decreasing supplier resources for technology transfer efforts
Academia	Focus of academic research is typically existing processes rather than new processes Poor communication between academia and industry

	Lack of emphasis on forming connection between students and industry

Exhibit 8-2. Suggested Collaborations		
Education	**R&D**	**Other**
Create partnerships with state and local government agencies to increase interest in metalcasting at the high-school level Develop casting technology and engineering centers at major universities, providing engineering services to casting organizations and training educators and casters alike	Develop joint technology or process development ventures with multi-sector participants Actively involve at least five and preferably more metalcasters in each R&D projects sponsored by trade societies	Develop purchasing cooperatives for buying fuel, electricity, and possibly for handling and treating waste streams Develop small regional consortia to share people, training, equipment, and information

Trade associations, and more recently association consortia, will continue to oversee the industry's overall research efforts. These associations are also leading the effort to seek financial or in-kind contributions from the industry, as many federally funded projects require matching funds. The use of growing information technology will accelerate the sharing of technical knowledge and contribute to the industry's success. The industry and its societies will help secure the future through more effective communication with designers, specifiers, and buyers of structural parts about the advantages offered by cast metal components. The industry will also need to continue its strong relationship with its supplier base, whose previous contributions to increased industry productivity and quality have been invaluable.

The relationship between the metalcaster and the customer (and possibly the casting end user) will need to become more interconnected. Successful foundries of the future will be a natural extension of the customer. Direct access to ordering, scheduling, and inventory status will exist that is cross-linked to the customer floor, with shipments tied to just-in-time needs. Cost and profit goals will be jointly established so that both customers and suppliers will be satisfied.

Metalcasters will need to become parts designers, collaborating with a customer's engineers to create the most economical castings possible. Metalcasters must become proactive in assisting their customers in a continuous product improvement mode where the casting producer will be working ahead of the customer to enhance the designs. In this mode, both will become the beneficiaries of forward-looking engineering concepts for product improvements and cost reductions.

Academic institutions will continue to play a major role in the metalcasting industry of the future, not only to educate scientists and engineers for careers in metalcasting, but increasingly to be involved in applied research programs.

APPENDIX A

Relevant Industry R&D Projects

A number of projects related to issues in the *Roadmap* are ongoing or have recently been completed. Many of these projects are collaborations between industry, the metalcasting technical societies, government agencies, academia, and other stakeholders. A partial listing of these projects is provided below.

Products and Markets

- *Casting Conversions*

Materials Technology

- *Development of Material Data Bases for HPNb and HPNb+ Microalloy Steels*
- *Thermophysical Properties for Modeling*
- *Anisotropic Porous Castings*
- *Approval of Cast Metals for the Energy Industries*
- *Bismuth-Selenium Modified Red Brass Phases I and II*
- *Die Casting Die Life Extension*
- *High Speed Milling and Pulsed ECM: New Machining Technologies to Increase Die Life*
- *Determination of Residual Stress and Softening Effects on the Life of Die Casting Dies*
- *Extending the Life of H-13 Die Casting Dies*
- *Shot Sleeve Failure Analysis*
- *Coatings for Improved Wear Resistance of Die Casting Dies*
- *Evaluation of Coatings for Die Surfaces*
- *Permanent Coatings for Die Casting Dies*

- *Wear of Foundry Tooling*
- *Impurity Limits in Aluminum Bronzes*
- *A Study of Alloy-Microstructure-Performance Interactions*
- *Technology Development for Iron Casting Production*
- *High Alloy Steel Welding Practices*
- *Late Stream Inoculation*

Manufacturing Technology

- *Rapid Prototyping Applied to Tooling*
- *Wear Analysis of Foundry Tooling Materials*
- *Development of Process Improvements and Inspection Methods for High Alloy Stainless Steel Castings (standards, material data bases)*
- *Casting Design Software Evaluation*
- *Assessment of Fast Shot Transition Point on Filling Patterns and Casting Quality for Pressure Die Casting*
- *Design and Process Parameters for Permanent Mold Casting*
- *Yield Improvement (Using Solidification Software)*
- *Benchmarking*
- *Die Casting Quality Improvement Through Enhanced Die Casting Flow Performance*
- *Preventing Die Soldering During Zinc Die Casting*
- *Die Casting: Slow Shot Profiles*
- *Castability of Aluminum Foundry Alloys*
- *Heat Transfer and Casting Distortion*
- *Characterization of and Procedures to Eliminate Macro-Inclusions During Foundry Processing*
- *Sensor Systems for Die Casting Cavities*

- *On-Line Quality Assessment of Aluminum*
- *Investigation into the Formation of Casting Penetration Defects*
- *Machining Reject Reduction*
- *Development of Process Improvements and Inspection Methods for High Alloy Stainless Steel Castings (testing techniques to replace radiography)*
- *Thin Wall Iron Castings for Light Weight Components*
- *Clean Metal*
- *Lost Foam Process Development: Phases III and IV*
- *Die Casting: Dimensional Reproducibility*
- *Die Casting: Skin Thickness in 390 Alloy Casting*
- *Dimensional Capabilities*
- *Sensing and Control Systems for Die Casting*
- *Improved Process Control (Controlling Pouring Temperature)*
- *Cupola Modeling and Neural Networks*
- *Energy Assessment Procedure Manual*
- *Intelligent Induction Hardening*
- *Reduction in Energy Costs Due to Process Yield Improvements (Innovative Riser Techniques)*
- *Energy Manual for Die Casters*
- *Lost Foam Process Development: Phase III and IV*
- *Permanent Mold for Copper Alloys*
- *Semi-Solid Metalcasting and Squeeze Casting*

Environmental Technology.

- *Ferrous Foundry Emission Quantification*
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