Emerging Technology and Successful Partnerships: Lost Foam Casting

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ABSTRACT

In 1989, a consortium of foundries, suppliers, and academia joined the U.S. Department of Energy (DOE) in a research program to improve control over the lost foam casting process thereby reducing defects and producing high quality precision castings. Lost foam casting is a process that offers many energy and environmental advantages and enables the production of complex parts. The government side of this partnership is led by the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Office of Industrial Technologies (OIT), Metal Casting Industry of the Future. Research is conducted through the Lost Foam Technology Center at the University of Alabama - Birmingham. The Consortium has been credited as the driving force behind technical improvements in the lost foam casting process. It has improved knowledge and control in all stages of lost foam casting. The Lost Foam Casting research was recently profiled by the International Energy Agency, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). Lost foam casting is just one of many metal casting techniques. The Metal Casting Industry of the Future partnership is conducting research to improve productivity and energy efficiency in nearly all areas of casting.

Using the ongoing Metal Casting Industry of the Future lost foam research as an example, this paper discusses the benefits of industry-government consortia advancing R&D for critical U.S. industries such as metal casting. It describes how such partnerships can be pivotal in helping to move emerging technologies from concept to implementation.

Introduction

A vibrant, competitive and energy-efficient U.S. metalcasting industry is vital to the U.S. economy. Metalcasting enables the production of simple to complex parts to meet a variety of needs from engine blocks to plumbing fixtures. Cast metal products are found in virtually every sector of the economy. Almost 90 percent of all manufactured products contain one or more metal castings. (James P. LaRue, Ed.D. 1989. *Basic Metalcasting.* American Foundry Society).

The metalcasting process consists of pouring molten metal into a mold containing a cavity of the desired shape by the casting. Metalcasting processes can be classified either by the type of mold and pattern, or by the pressure or force used to fill the mold with molten metal. (Ezra L. Kotzin. 1981. *Metalcasting & Molding Processes*, American Foundry Society). The most widely used method for small to medium-sized castings is green sand molding. Other casting and molding processes include shell molding, permanent molding, investment casting, and diecasting. In addition, there are a number of innovative methods such as lost foam casting that are being pursued in the industry.

The Need for a Research Partnership

There are 2,950 metalcasting facilities across the U.S. Eighty percent are small businesses and employ less than 100 people. (*Facts and Figures about the U.S. Foundry Industry*. American Foundry Society). Because of the small business nature of industry, few individual companies in the foundry industry have the financial resources to conduct basic, high-risk research. Moreover, the U.S. metalcasting industry is diverse and utilizes many different molding and casting processes – each with its own unique characteristics and benefits. Major technical societies include the American Foundry Society (AFS), North American Die Casting Association (NADCA), and the Steel Founders' Society of America (SFSA). These technical societies are actively involved in research, training, and outreach to disseminate the latest in casting technology development to the industry.

With the large and diverse array of casting processes combined with limited resources for research and development (R&D) funding, advancing technology to the next level remains challenging. Consortia approach have proven to be a successful method for advancing metal casting processes such as lost foam to the next level. Using lost foam casting as an example, the remainder of this paper discusses how an innovative industry-government partnership, the Metal Casting Industry of the Future, is simultaneously addressing national energy efficiency goals and industry's productivity improvement goals.

Industry-Government Research Partnerships: Industries of the Future

A recent study by the National Research Council found that the "market will not support an optimal amount of research and development, possibly by a wide margin, without government support. The private sector tends to underfund research and development, and particularly high-risk projects and projects with long-term benefits." There are various models for performing for government research approaches. These include government-led research, consortia, and grants to industry, universities, and other organizations.

The Office of Industrial Technologies (OIT), Industries of the Future (IOF) strategy is a consortia approach fostering partnerships among industry as well as between government and industry. It targets nine economically vital, energy intensive U.S. industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. The Industries of the Future strategy discards fragmented approaches of the past and creates new alliances by emphasizing thoughtful planning and development of strategic roadmaps for research. Partnerships build trust, foster communication and create an avenue for the realization of new ideas. OIT acts as a facilitator, responsible for bringing together producers, suppliers, customers, stakeholders, and outside experts. These partnerships foster trust, communication, commitment, diligence, and innovation.

Through its IOF strategy, OIT encourages each of the most energy intensive industries to develop a vision for their future, and roadmaps (or technology pathways) that outline the R&D needed to attain that future. These guiding documents provide the framework for implementing a program of cost-shared, pre-competitive research. This research addresses both industry goals as outlined in the Visions and Roadmaps as well as national energy efficiency goals. Motivation for the IOF strategy includes the need for greater "technology pull" rather than "technology push" thus increasing the likelihood that energy efficient technologies will be implemented. In addition, the IOF strategy seeks to increase the industry share of R&D investment.

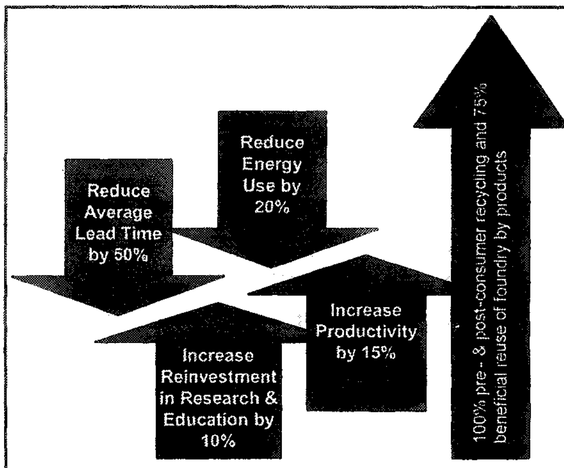
In 1999, the National Research Council, National Materials Advisory Board published the results of an evaluation that it performed of the IOF research program. This evaluation finds the strategy to be "carefully thought out and efficiently managed". The IOF program was found to be a "success" principally due to the involvement of industry consortia and the development of industry Visions and Roadmaps. It recommended the periodic revisiting of Visions and Roadmaps as well as regular portfolio analyses to keep the partnership dynamic. Another means to evaluate the value of R&D programs is the level at which industry is willing to provide cost share. In the case of the Metal Casting IOF, industry cost share as of 1998 was 54%. For every $1.00 of federal funding provided, industry put forward $1.08. (*Industrial Technology Assessments: An Evaluation of the Research Program of the Office of Industrial Technologies,* National Research Council).

Metal Casting Industry of the Future

In 1995, the Office of Industrial Technologies joined with the U.S. metal casting industry to form the Metal Casting Industry of the Future partnership for improving energy efficiency and productivity in the industry. This highly successful industry-government partnership is coordinated with industry through the Cast Metals Coalition (CMC). The CMC is comprised of the American Foundry Society, North American Die Casting Association, and the Steel Founders' Society of America. Collectively, this coalition represents the majority of the U.S. metalcasting industry.

Through industry visions and technology roadmaps, industry participants establish technology research priorities, assess the progress of R&D, and lead the way in applying research results. Leaders from the U.S. metalcasting industry established a vision for the future in *Beyond 2000: A Vision for the American Metalcasting Industry.* The Vision outlines specific goals for the industry over the next 20 years. These goals are shown in Figure 1. While Beyond 2000 identifies the broad needs of the industry, the *Metal Casting Industry Technology Roadmap* outlines the technology milestones needed to achieve the Vision goals.

The Metal Casting Industry of the Future maximizes limited federal resources. Each year, open and competitive solicitations are issued for proposals that address the research needs identified in the Roadmap. All research is cost-shared dollar for dollar between industry and the U.S. Department of Energy. The partnership emphasizes broad industry and academic participation. Metal Casting Industry



In 1995, the metal casting industry published *Beyond 2000: A Vision for the American Metalcasting Industry.* It outlines specific goals for the industry over the next 20 years. In 1998, the Metal Casting Industry Technology Roadmap was published. The Roadmap outlines research pathways needed to achieve Vision goals. It forms the basis for cost-shared research performed through the Metal Casting Industry of the Future.

Figure 1. Vision Goals for the U.S. Metalcasting Industry

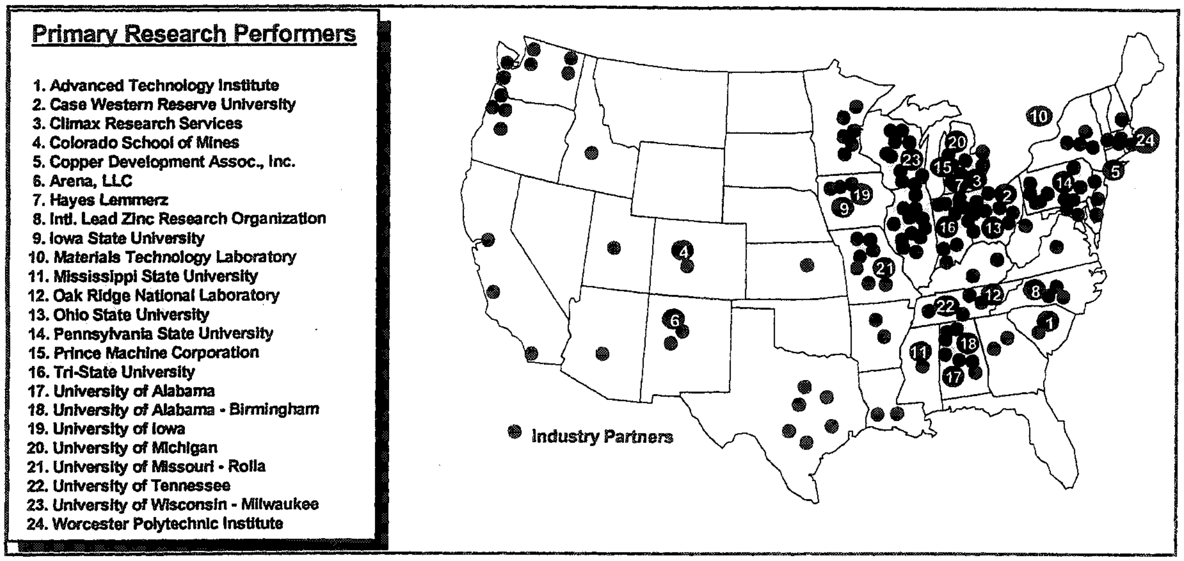


Figure 2. Metal Casting IOF Research Performers and Industry Partners

of the Future partnership currently involves 320 partners from industry and academia in 35 states (See Figure 2).

Energy efficiency and productivity. While Metal Casting Industry of the Future research is addressing the industry's process and technology needs for improving productivity, it is simultaneously addressing U.S. Department of Energy, Office of Industrial Technology goals for improved energy efficiency in industry. The Office of Industrial Technologies has established as one of its goals "a 25 percent improvement in energy efficiency and a 30 percent reduction in emissions for the vision industries by 2010".

The metal casting industry consumes a over 200 TBtu per year. In its Vision, the industry established a goal to improve energy consumption per unit of output by 20%. The research results coming from the Metal Casting Industry of the Future partnership help the U.S. metalcasting industry to improve productivity, increase energy efficiency and to become more competitive in world markets. For example, melting is the most energy intensive phase of the metalcasting process accounting for 55% of process energy costs. Through cost-shared research to develop simulation models as well as process and technology improvements, Metal Casting Industry of the Future research is helping to improve casting yield and reduce scrap, thereby reducing melting requirements. This improves both energy efficiency and productivity. In addition, research to improve material properties is reducing scrap by minimizing or eliminating defects. This materials research is opening new markets for high-strength, light-weight metal castings of aluminum, iron and steel. By reducing casting thickness, melting requirements are also reduced thereby saving energy.

Although there are many fine research accomplishments that have resulted from the positive partnership between the U.S. Department of Energy and the U.S. metalcasting industry, the remainder of this paper profiles one of those accomplishments – lost foam casting. It describes this innovative casting technique and its energy efficiency and productivity benefits. It also discusses the pivotal role that the consortia approach involving the Metal Casting Industry of the Future partnership is playing in moving this emerging technology from concept to implementation.

Lost Foam Casting: Achieving Energy Efficiency and Productivity through Partnership

There are several innovative and emerging metalcasting processes. One of these is lost foam casting. The lost foam casting process (also known as Expendable Pattern Casting) was first introduced in 1958. Yet, because of a need for improved understanding and control over the process, there was virtually no growth in the use of the process until the 1990s.

The lost foam process allows highly complex structures to be cast in one piece, reducing machining and assembly operations. In the lost foam casting process, expandable polystyrene patterns are surrounded by unbonded sand. Metal poured into the mold vaporizes and replaces the foam pattern, producing a casting identical to the original pattern. There are a number of benefits to lost foam casting. No binders or additives are required in the conditioning sand, the sand is reusable after cooling, and flasks are simpler and less expensive. Shakeout becomes "pour out", eliminating the need for capital intensive, heavy, shakeout equipment. In addition, yield is higher and the process is cleaner. Thin wall castings (as thin as 0.120 inch) are easier to produce, and complex, close-tolerance castings can be produced economically (James P. LaRue, Ed.D. 1989. *Basic Metalcasting*. American Foundry Society).

There are substantial energy and productivity benefits to the lost foam process. By allowing highly complex structures to be cast in one piece, machining and assembly operations are reduced or eliminated. This saves both energy and non-energy costs in the casting facility. In addition, because yield is higher and core-making is eliminated, less molten metal needs to be melted, resulting in substantial energy savings.

In spite of its benefits, the lost foam process has not been widely used in the U.S. metalcasting industry. There has been a lack of effective process control measures that are critical to the success of the lost foam process. These include the need to ensure dimensional accuracy of lost foam patterns, controlling the pour rate, methods to reduce or eliminate pattern distortion, and others. The lack of technical information and effective control measures over the lost foam process has hindered its acceptance by the industry.

One of the keys to recent successes in lost foam casting research is the successful industry-government partnership formed between the lost foam casting industry and the U.S. Department of Energy. In 1989, the American Foundry Society established the Lost Foam Casting Consortium to develop a better understanding of the lost foam casting process. The Department of Energy joined the Consortium that year.[1]

The consortium includes 29 members from industry including casting producers, foundry suppliers, end-users and the American Foundry Society. It brings together champions from industry and academia to help foster the partnership as it works towards its goal of advancing lost foam. Research is performed at the Lost Foam Technology Center at the University of Alabama at Birmingham with involvement by the University of Missouri - Rolla. This partnership is a

[1] DOE involvement in the Lost Foam Casting Consortium is through the Metal Casting Research Program. Since 1995, this program has lead DOE's involvement in the Metal Casting Industry of the Future.

natural for the Metal Casting Industry of the Future in that it is tackling pre-competitive, cost-shared research to improve both productivity and energy efficiency in industry.

The Lost Foam Casting Consortium with DOE involvement is credited as the driving force behind technical improvements in the process. "In large part, greater understanding about lost foam production has been obtained as a results of a consortium of...foundries, suppliers, and academia that have been working with the U.S. Department of Energy." (Michael J. Lessiter, ed. "Total Product Optimization via Lost Foam Casting". *Engineered Casting Solutions.* Winter 1999). Some of the major accomplishments include:

- Identifying a number of process control improvements
- Demonstrating energy efficiency improvements of as much as 27 percent over alternative casting methods
- Substantially increasing market opportunities for lost foam
- Training students through DOE/Industry-funded research are now entering the lost foam casting industry, and helping to address the industry's need for a new generation of skilled professionals.

The success of this ongoing research was recently profiled by the International Energy Agency, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). The partnership between the Department of Energy and industry, as represented by the Consortium, illustrates the many benefits possible through industry-government partnerships. The following briefly discusses some of the successes that have resulted from this partnership.

Process Control Improvements

This research partnership is improving the ability of industry to successfully implement the lost foam casting process. This lost foam research has removed a number of technical barriers, that were impeding commercialization. Examples of some of the barriers include a lack of control over pattern dimensions, pattern distortion, lack of control in achieving appropriate vibrational amplitude and direction of sand, a lack of understanding of the conditions surrounding sand flow and fill in the pattern cavity. Some specific technology and processes/improvements as a result of this research include:

- A single stage air gauging system was developed followed by a 30-channel commercial air gauge for rapid determination of pattern dimensions.
- Instruments and transducers were developed for measuring vibrational frequencies and amplitudes on compactor tables, on flasks, and in sand. Sand vibrational amplitude and direction is important in achieving efficient compaction.
- A distortion gauge was developed to determine when and under what conditions pattern distortion occurs during compaction.
- A fill gauge was developed that can be put in a pattern cavity to determine the conditions that cause sand to flow and fill.
- Two types of compaction gauges were developed to measure sand density in cavities during pattern compaction.

- A procedure was developed to measure the liquid absorption characteristics of liquid pattern pyrolysis into castings.

These developments have made it possible for many U.S. metalcasting companies to consider and adopt lost foam casting where before it was not feasible.

Market Growth for the Lost Foam Casting Process

The need for new foundry technology to combat foreign competition and produce quality castings and assembled components is evident in today's international economy. The lost foam casting process is capable of producing high value parts through improved energy efficiency, reduced materials consumption, and improved dimensional accuracy. A review of basic trends in the use of lost foam casting indicate that DOE's role has been quite important. As stated, there was virtually no growth in the use of lost foam from the time it was introduced to 1989. In 1989, the partnership between DOE and the Lost Foam Casting Consortium was formed and since that time the market potential for the lost foam casting process has improved dramatically.

In 1997, the Consortium and the American Foundry Society conducted a survey of lost foam casting markets (*1997 Market Survey for Lost Foam Foundries*. 1997. Lost Foam Casting Consortium and the American Foundry Society). According to this study, an estimated 40,000 tons of lost foam aluminum castings were produced in 1994. This increased 25 percent to 50,000 tons in 1997. This is expected to increase another 64 percent to 82,000 tons by the year 2000 -- resulting in an estimated rate of increase of 105 percent over the six year period. Even faster growth is expected for lost foam iron castings, increasing 100 percent between 1994 and 1997 from 20,000 tons to 40,000 tons, and then more than doubling to an estimated 85,000 tons in the year 2000. This brings a total increase of 325 percent for lost foam iron castings over the six year period.

Energy Efficiency Improvements

The success of the lost foam research illustrates that improvements in productivity can go hand-in-hand with improvements in energy efficiency. Table 1 compares energy, productivity, and material costs of the Lost Foam Casting Process compared to conventional sand casting costs (Charles Bates. "Economic Evaluation, Energy Efficiency, and Environmental Impact of Lost Foam." 1999. University of Alabama - Birmingham). A comparison of energy usage for both lost foam casting and conventional green sand casting conducted by the University of Alabama - Birmingham, shows that lost foam casting results in energy savings of around 27 percent. Some 30 percent less metal has to be melted because scrap is reduced by that amount. Lost foam casting also eliminates the need for internal cores, which account for around 8 percent of the energy used in conventional casting. The energy needed for post-casting and machining is also greatly reduced.

- *Core Making.* Castings can be produced with no cores or having over 90% of the internal volume formed by cores. Approximately 50 percent of the labor hours involved in preparing a mold lies in core production. Also, approximately 8 percent of the energy consumed in a foundry is associated with making and drying cores. Lost Foam Casting

Process almost completely eliminates the need for cores, which can result in reduced production cost.

- *Melting.* Yields of 80-90 percent are common for castings made with the lost foam castings process compared to green sand foundry yields of 50-60 percent. (Yield is calculated as the ratio of the weight of the castings produced divided by the total weight of metal poured and expressed as a percentage.) Reduced riser sizes, which can be achieved with high mold density and stability, is the principal cause for the higher yield. Energy savings are realized if 30 percent less metal has to be melted and poured to produce the same number of castings.
- *Molding and Shakeout.* Molding requires approximately 2 percent less energy in lost foam casting because mulling is eliminated and the sand is free flowing and easier to handle. However, the differences are relatively small because the entire flask and its contents are vibrated to achieve compaction. Shakeout of lost foam casting molds is easier because the flasks can simply be dumped to remove the castings from the sand.
- *Heat Treatment.* Some castings require heat treatment to achieve the desired hardness and microstructure. The energy required to reheat a green sand casting for heat treatment is substantial because the castings are normally cooled and cleaned prior to heat treatment. Lost foam castings can be removed from the unbonded sand and placed in an insulated container. This container derives almost all the heat required for annealing from the castings themselves.
- *Post-Casting Cleaning.* Reducing the number and volume of risers, minimizes riser removal time. The sand in the Lost Foam Process is not bonded, shakeout is done by simply dumping the castings and sand from the flask. Grinding on parting lines and finned areas is eliminated.
- *Machining/Machinability.* The energy consumed in machining is reduced by achieving close casting tolerances, consistent casting harnesses, and improved surface finishes. Additionally, without parting line fins and burrs, lost foam castings avoid creating chilled edges and supercooled graphite in gray iron in thin sections. Fin elimination reduces cleaning room costs.

An analysis of the entire process indicates a total energy savings of about 27 percent coupled with a 46 percent improvement in labor productivity and the use of about 7 percent by weight fewer materials in lost foam casting compared to green sand or resin bonded sand molding. Production cost reductions of 20-25 percent are possible on reasonably simple cored items and 45-50 percent production cost reductions may be realized on complex castings.

Impact of Metal Casting IOF

A recent analysis performed for the National Academy of Sciences and using the results of a Lost Foam Market survey by the American Foundry Society indicate that the involvement of DOE has been significant. Over the period 1994 through 2005, the cumulative estimated tonnage of castings projected to be offset by lost foam is 9.4 million tons. This will displace an estimated 3 trillion Btu. Anecdotally, these projections are coming to fruition. Several large-scale casting facilities are being retrofitted for lost foam and new greenfield lost foam production facilities are planned. Companies developing these facilities include Teksid, General Motors, and Mercury Marine. Prior to DOE involvement, there was virtually no growth in lost foam castings. Without DOE involvement, market penetration of lost foam casting process would be expected to be delayed by five years. The result is that over the period 1994 to 2005, the cumulative estimated tonnage of castings offset by lost foam would be 1.9 million tons. The estimated cumulative energy displaced would be 0.6 trillion Btu.

Table 1. Energy, Productivity & Materials Usage Comparisons		
Process Energy Costs		
	Sand Casting	Lost Foam Casting
Core Making	8%	
Mold Making	12%	10%
Melting	55%	50%
Heat Treat	6%	3%
Post Cast	7%	3%
Others	12%	7%
Productivity		
Productivity	Sand Casting	Lost Foam Casting
Core Making	20%	
Mold Making	15%	30%
Melting	12%	12%
Heat Treat	6%	6%
Post Cast	30%	6%
Others	17%	
Materials Cost		
	Sand Casting	Lost Foam Casting
Molding	21%	15%
Melting	67%	65%
Others	12%	13%

Summary of Savings	
Energy Savings	27%
Productivity Increase	46%
Material Reduction	7%

Training Future Scientists and Engineers

One of the top concerns voiced by the leaders in the U.S. metalcasting industry and other base industries in the U.S. is the lack of students pursuing careers in those industries. The future of the U.S. metalcasting industry depends upon a sufficient and well-trained work force. A fundamental aspect of the DOE/OIT Metal Casting Industry of the Future is its emphasis on University-based research. The Metal Casting IOF partnership is introducing literally hundreds of students to the U.S. metalcasting industry. In an small business industry such as metalcasting, this is a vital contribution.

Research and development funding at the undergraduate and graduate level help ensure that a supply of well trained scientists and engineers will be available in the future. Metal Casting Industry of the Future research is providing hands-on training and experience to the future scientists and engineers of U.S. industry. It is enabling students to develop first-hand experience in the latest processes and technologies available to the U.S. metalcasting industry. In addition, it is instilling in them the fundamental relationship between process and technology improvements, energy efficiency, industrial productivity, and competitiveness. This is critical to the future success of the U.S. metalcasting industry.

Over the program's history, nearly nine out of ten research projects have involved universities as the lead performing organizations. Although no complete survey of student involvement has ever been performed, data collected from several of the program's current university partners shows that 200 students have participated in recent Metal Casting Industry of the Future research. They have gone on to receive B.S. and M.S. degrees as well as Ph.D.'s. The vast majority have entered careers in the U.S. metalcasting industry. Although complete data are not available, approximately 85 percent are currently working for U.S. metal casters, suppliers, or end-users. Several others have gone on to careers in education, teaching future engineers and scientists in metalcasting. In recent years, nearly 20 students have participated in lost foam casting research and gone on to graduate with B.S. and M.S. degrees as well as Ph.D.'s. Moreover, a new crop of students is currently involved in lost foam casting research. These students are entering the U.S. metalcasting industry and applying the results of the lost foam process control and technology improvements that they have learned while participating in Metal Casting Industry of the Future research. They are one of the best methods for technology transfer and are vital to the future of the U.S. metalcasting industry.

These students are one of the best vehicles for technology transfer. Using the training that they have received, these students are applying the latest in technology and process improvements directly in the U.S. metalcasting industry. Educated in measures that both save energy and improve productivity, they are contributing to the future competitiveness of the U.S. metalcasting industry. The program has recently begun an effort to form a network of Metal Casting Industry of the Future alumni. This will be a network of students from universities across the country who have participated in Metal Casting Industry of the Future research.

Summary

With the threat of eroding research budgets in today's intensely competitive business environment, consortia models of industry-government research , such as the Industries of the Future strategy, are demonstrating that they can have a significant impact. They facilitate much-needed intra-industry coordination and focus of research. They leverage public and private investment to improve industry processes that result in both improved productivity and improved energy efficiency in industry. The Industries of the Future strategy enables industry to consider long-term research perspectives. The success of lost foam casting exemplifies the positive role that public/private consortia can play in advancing both technology and national energy efficiency goals. Analysis has shown that in the absence of government involvement in this research effort, market penetration and subsequent energy savings would have been delayed by several years. Government, working in partnership with industry, can achieve important National goals – such as energy efficiency, preserving the environment, enhancing global competitiveness, and improving job growth in industry.

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