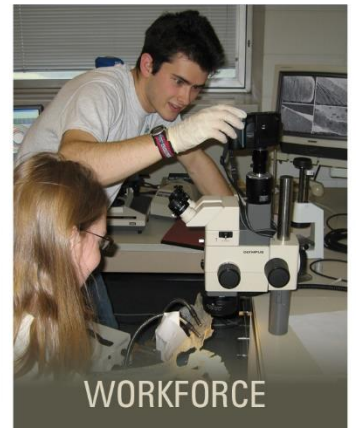
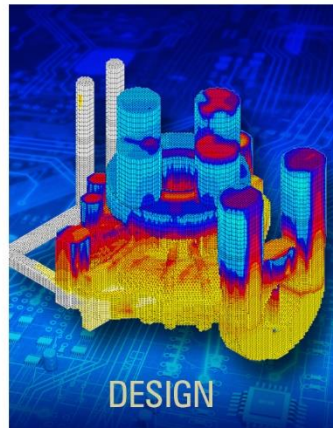
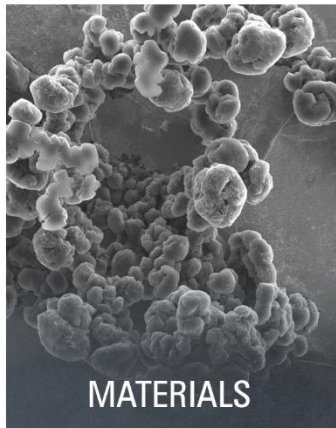
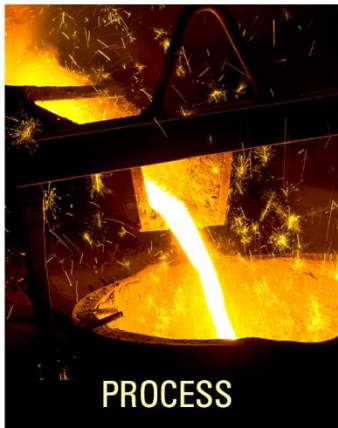




METALCASTING INDUSTRY ROADMAP



Identifying Future Research and Development
to Accelerate the Growth of
Advanced Manufacturing in the U.S.

Metalcasting Industry Roadmap

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Executive Summary

The American Metalcasting Consortium (AMC) managed the development of a Metalcasting Industry Roadmap to identify future research and development needs in order to accelerate the growth of advanced manufacturing in the U.S. Industry surveys and a focused workshop were conducted to develop and document metalcasting capability gaps, solutions, and recommendations for areas of investment that will strengthen and catalyze the U.S. metalcasting infrastructure in advanced casting production. The resulting roadmap is divided into four main topic areas: process, materials, design, and workforce, with readily executable key tasks mapped to timelines in each area. The following pages present a graphic summary of those high level topic areas, research focus areas, and actionable paths to advance the metalcasting industry. Each of the more detailed four main topic areas are identified by the icons below.



Process



Materials



Design



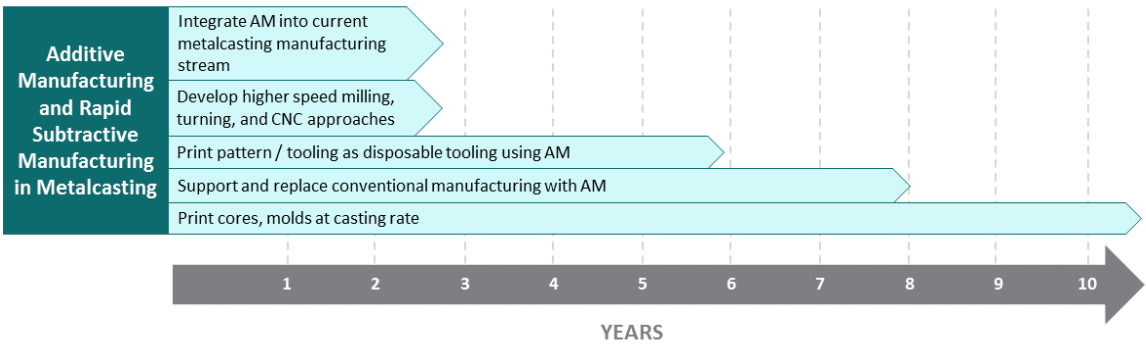
Workforce

American Metalcasting Consortium (AMC) would like to acknowledge the funding support received from the National Institute of Standards and Technology (NIST) advanced manufacturing technology planning AMTech grant for the project: “The Pathway to Improved Metalcasting Manufacturing Technology and Processes –Taking Metal Casting Beyond 2020.”

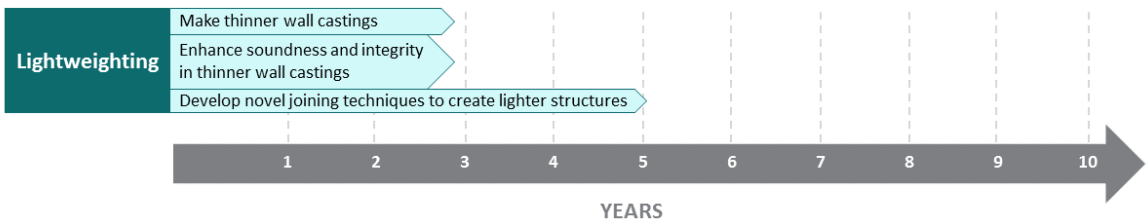


Process

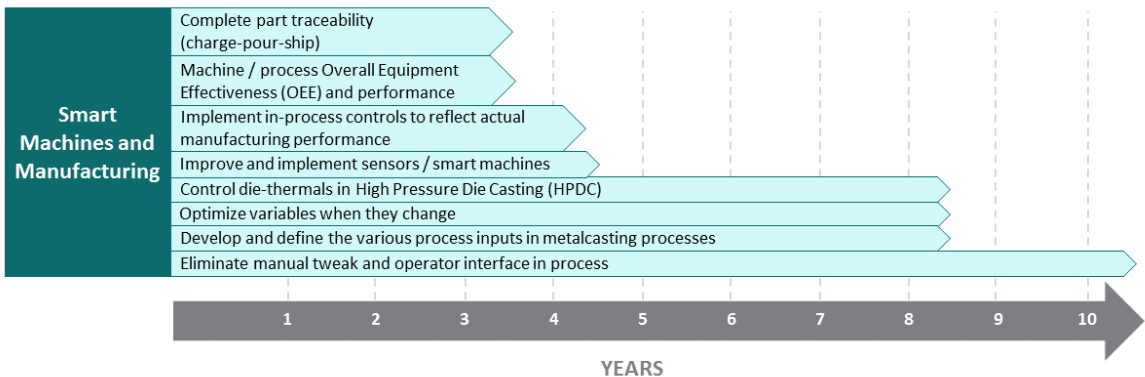
Additive Manufacturing and Rapid Subtractive Manufacturing in Metalcasting



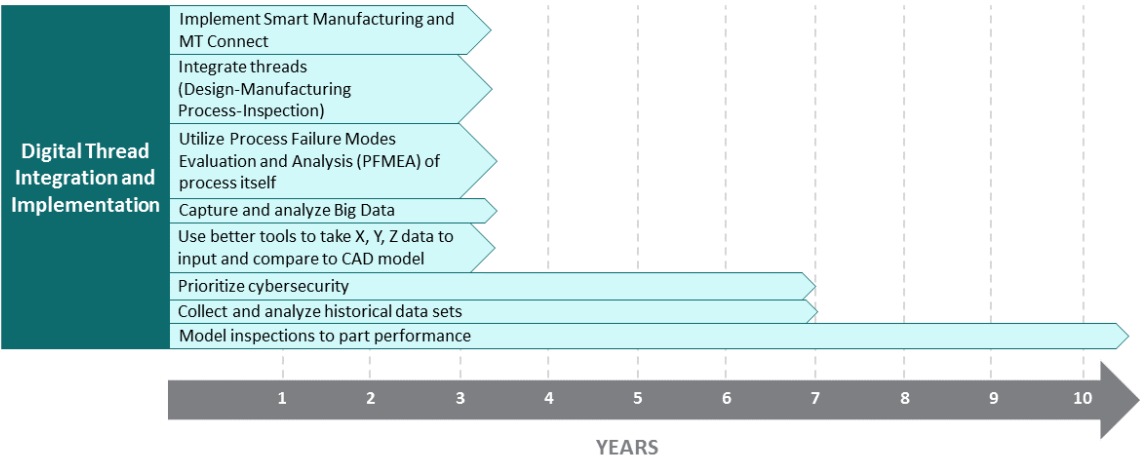
Lightweighting



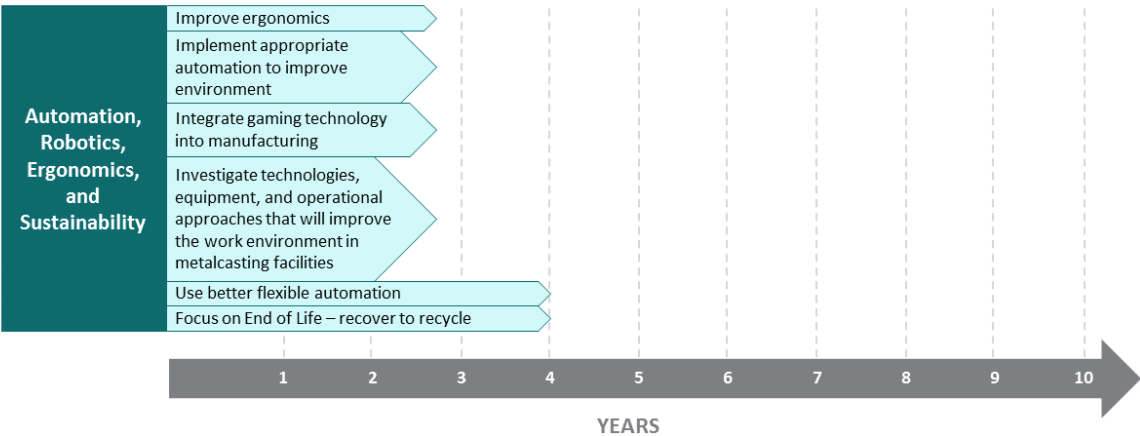
Smart Machines and Manufacturing



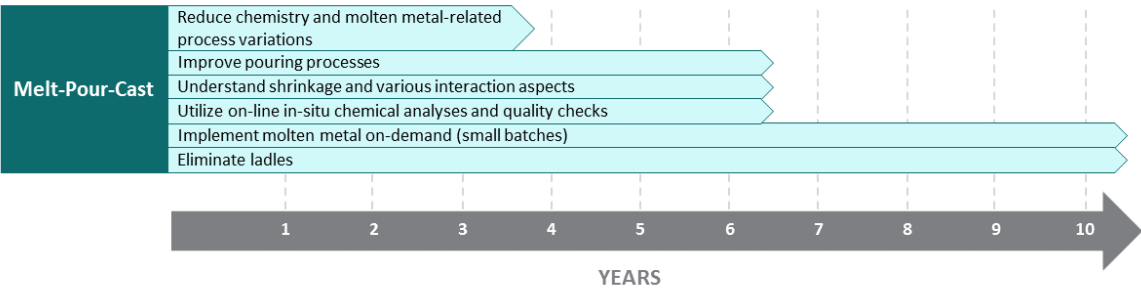
Digital Thread Integration and Implementation



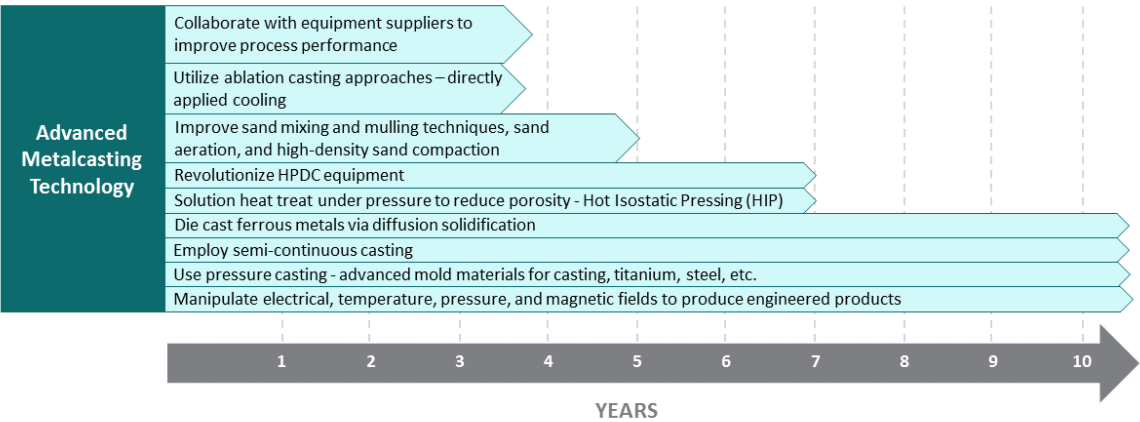
Automation, Robotics, Ergonomics, and Sustainability



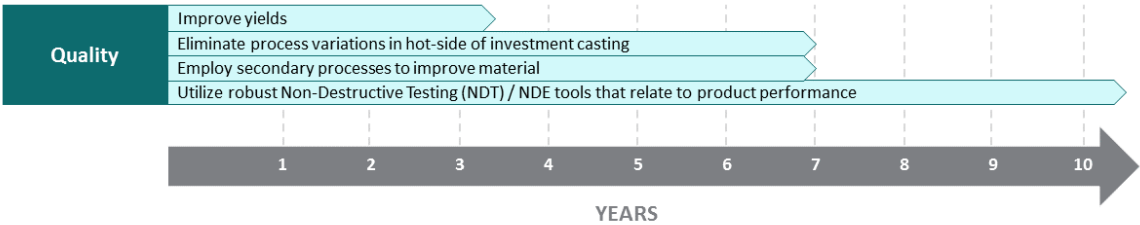
Melt-Pour-Cast



Advanced Metalcasting Technology



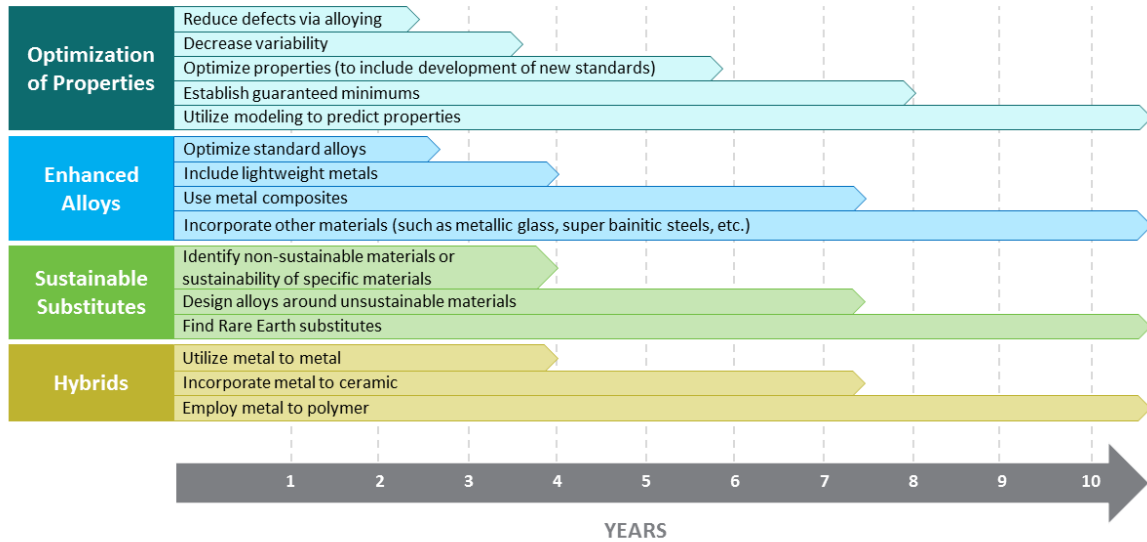
Quality



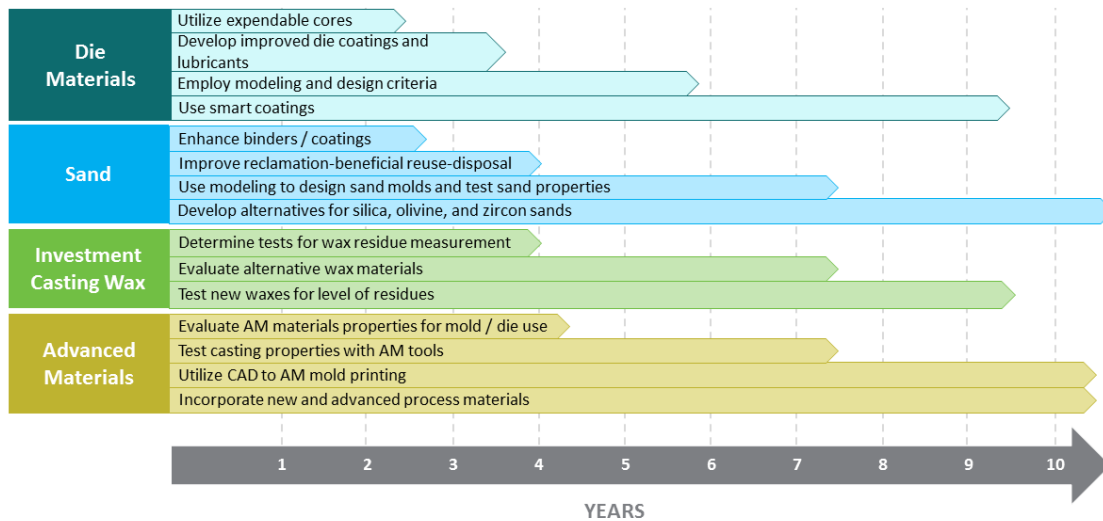


Materials

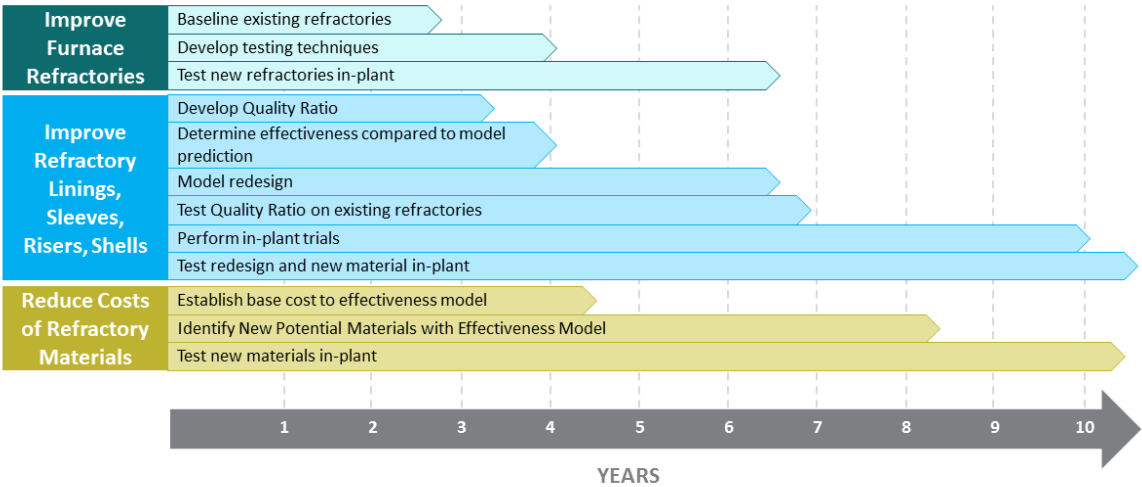
Cast Materials



Mold, Die, and Tooling Materials



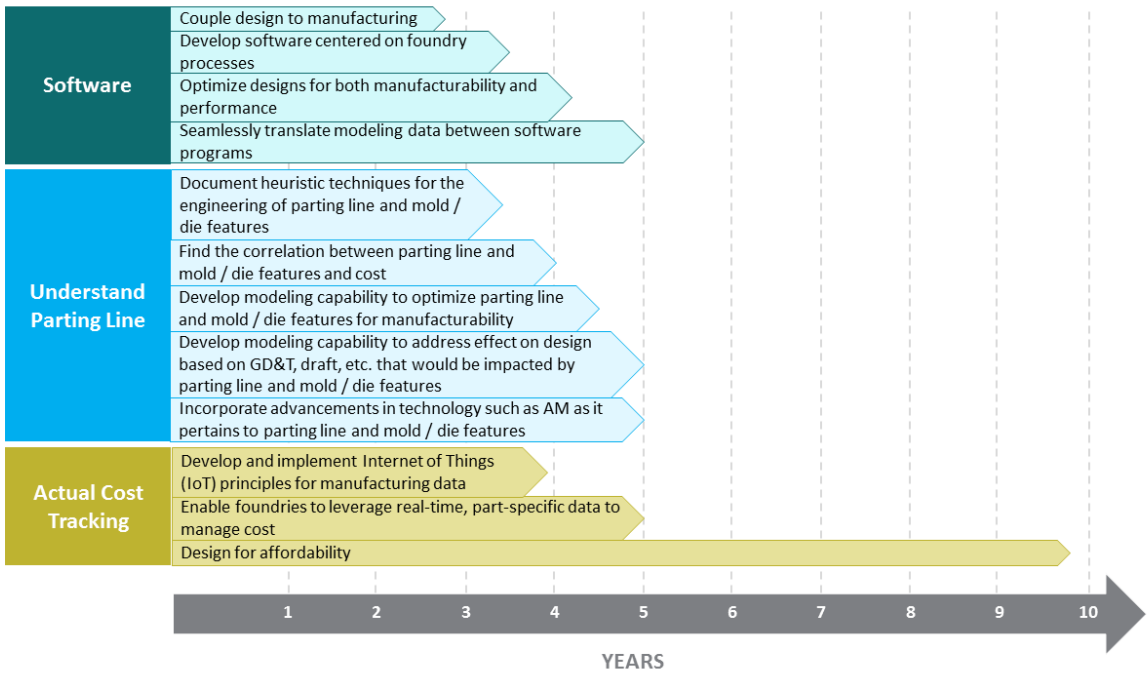
Furnace Refractories



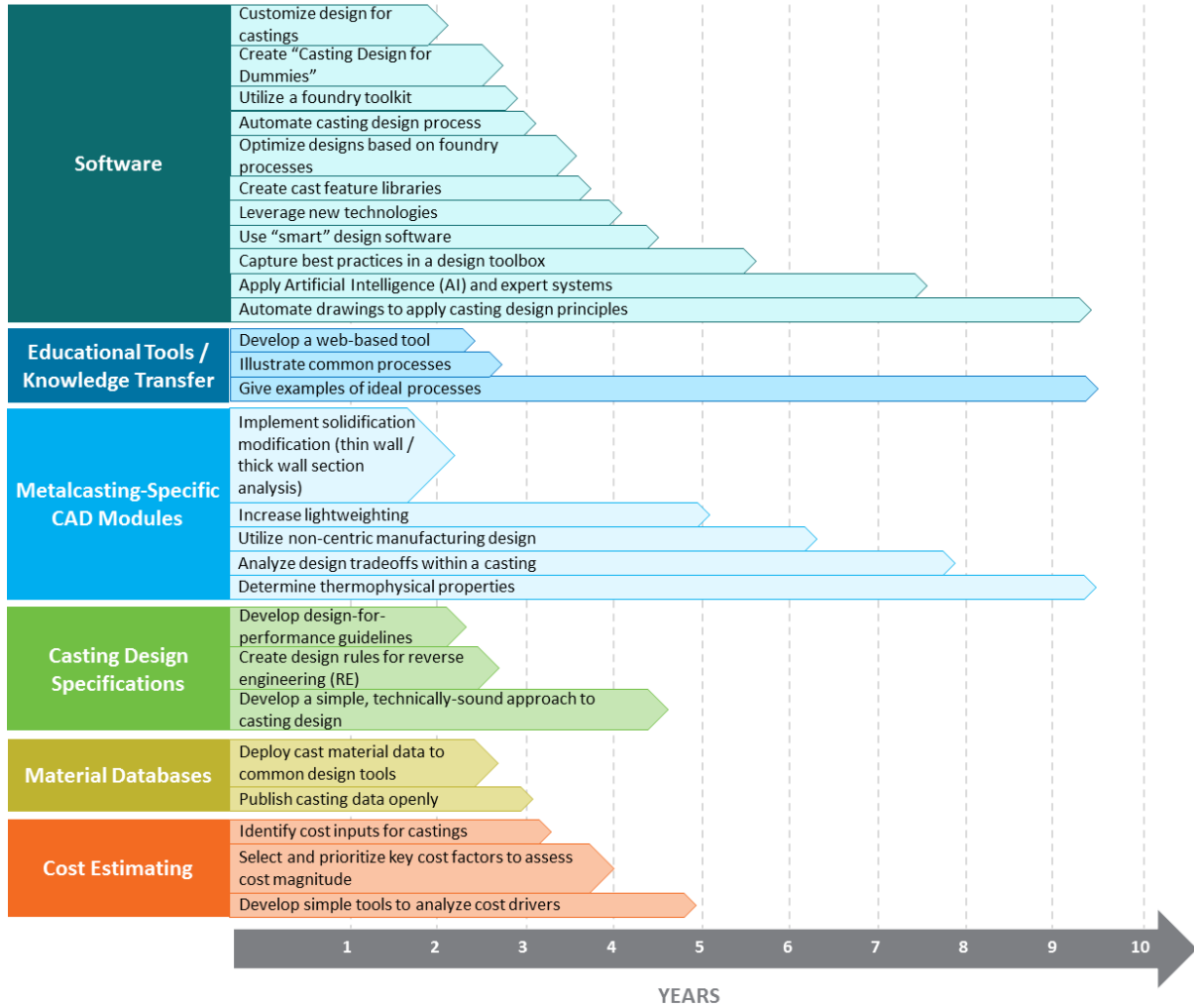


Design

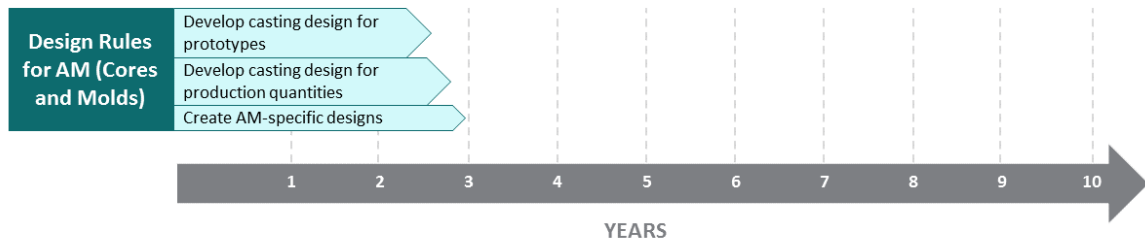
Design Tools for Manufacturing



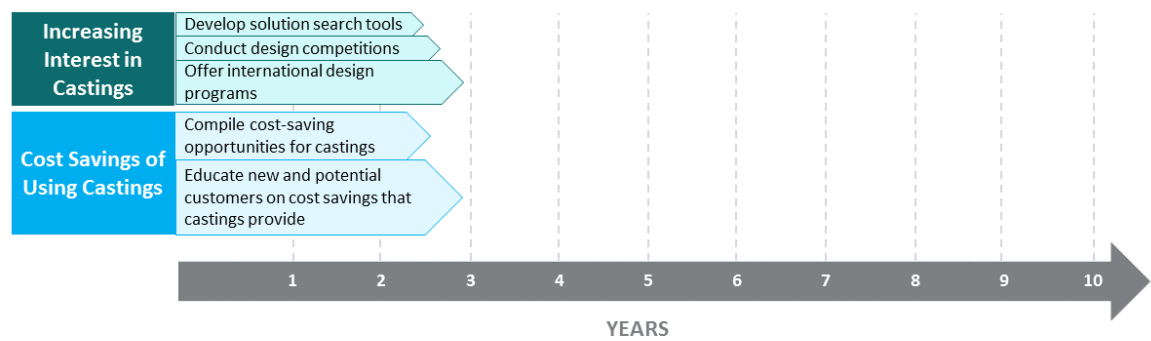
Design Tools for Casting



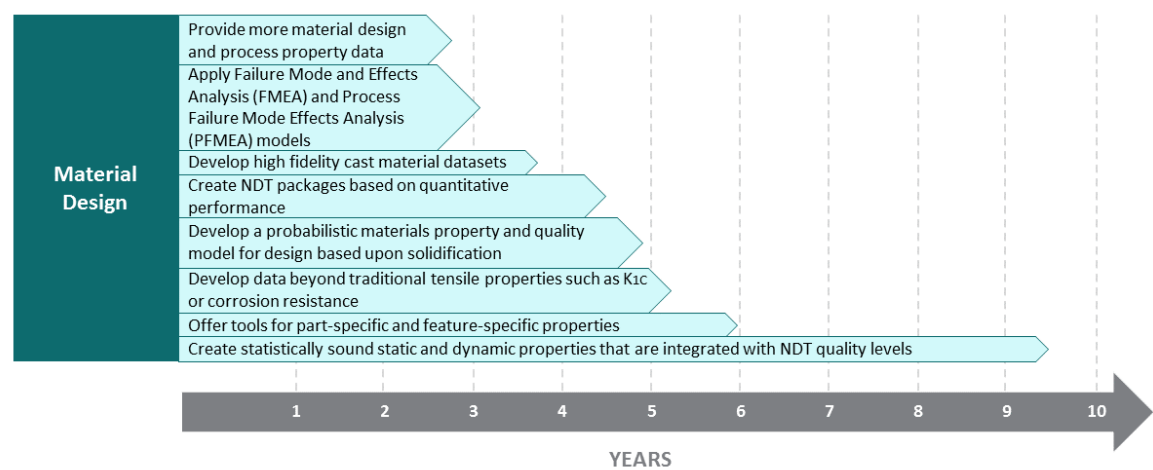
Additive Manufacturing (AM) Technology



Customer Resources



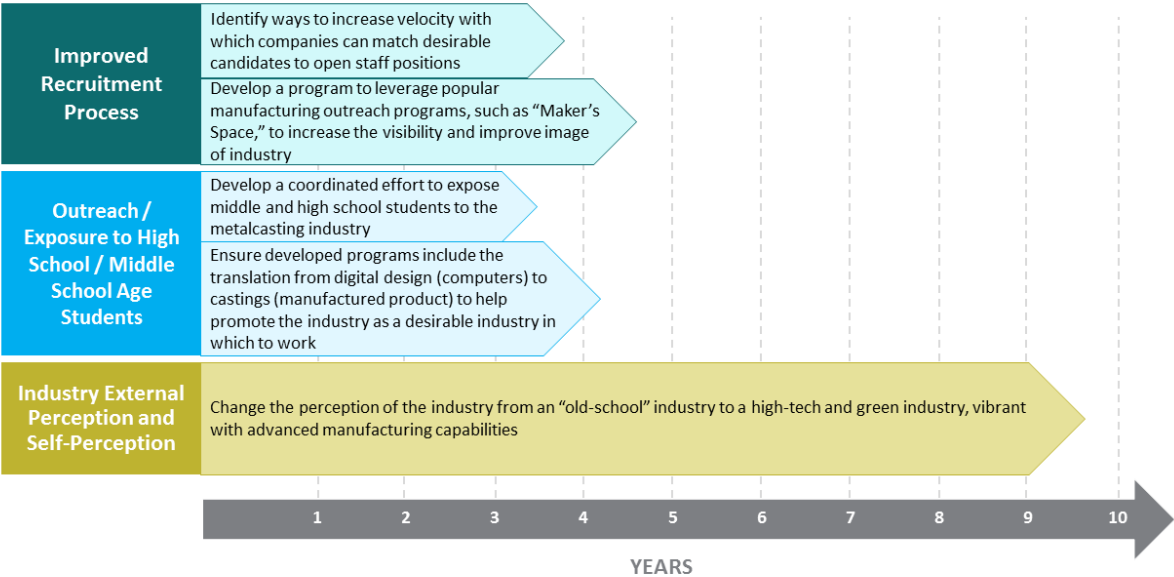
Performance-Based Reliability



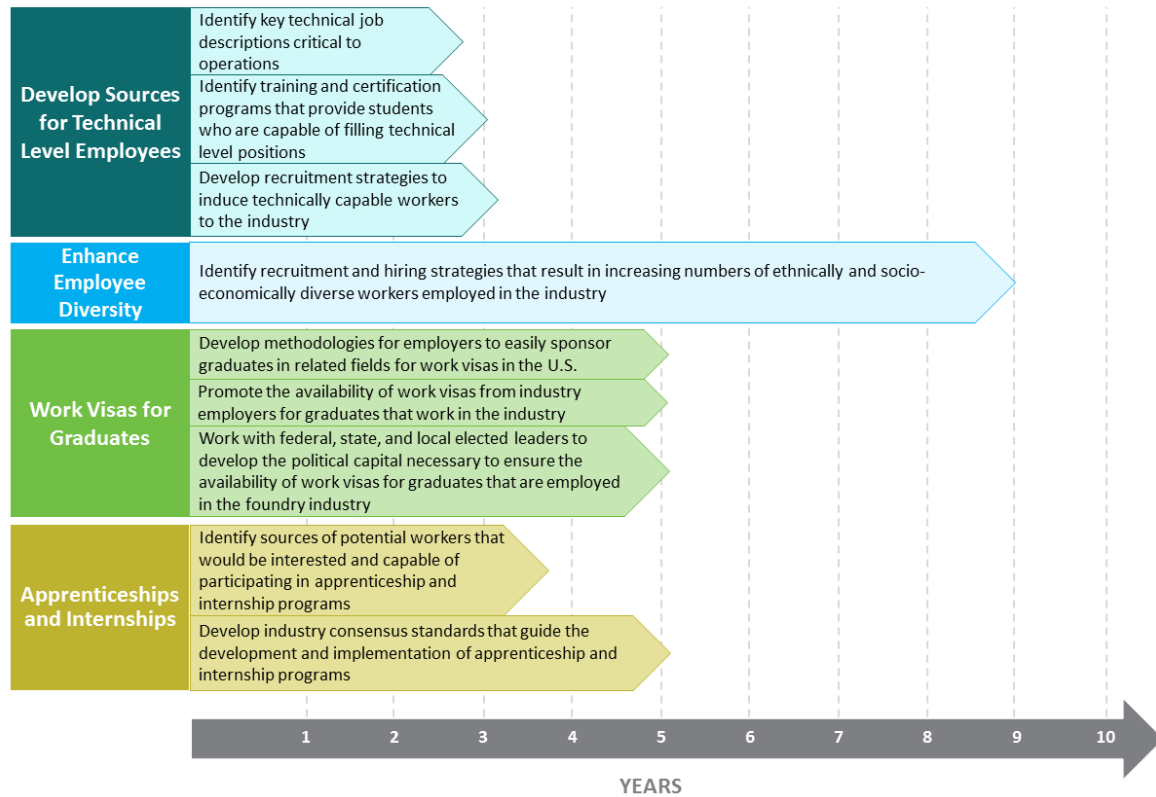


Workforce

Outreach

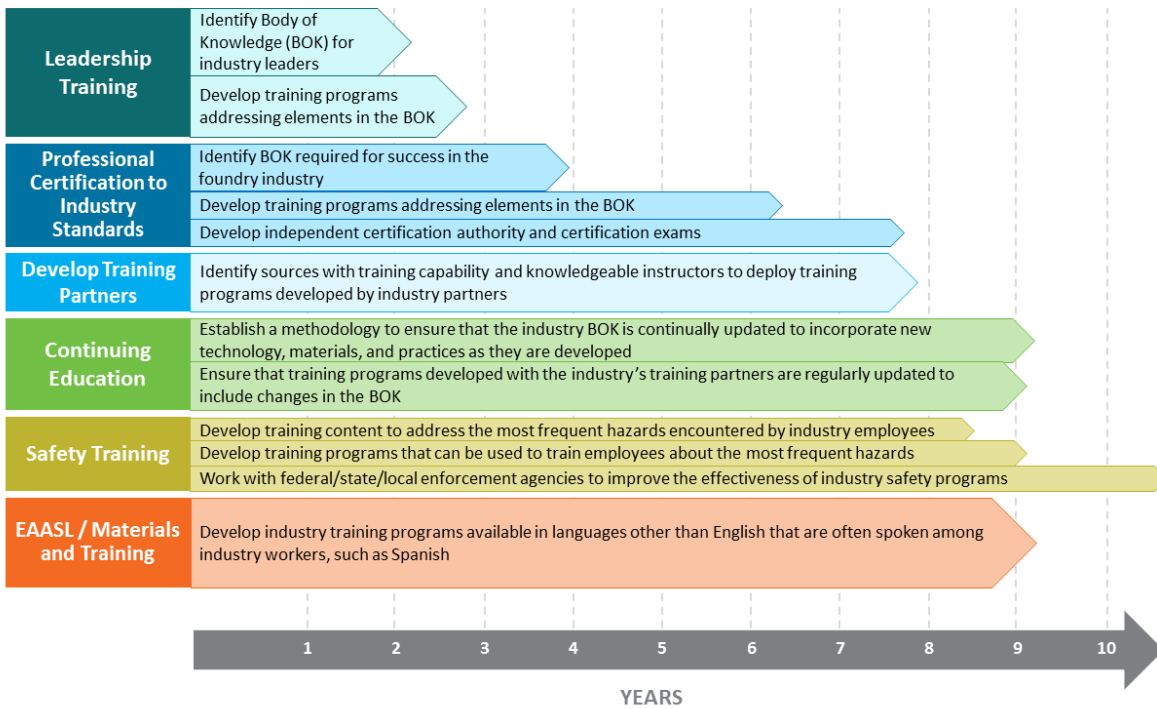


Attraction

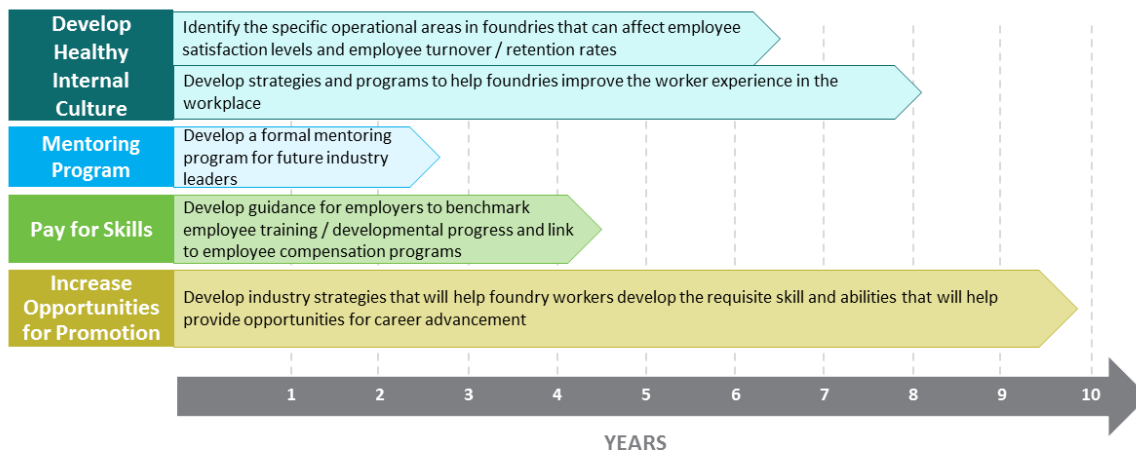


Metalcasting Industry Roadmap

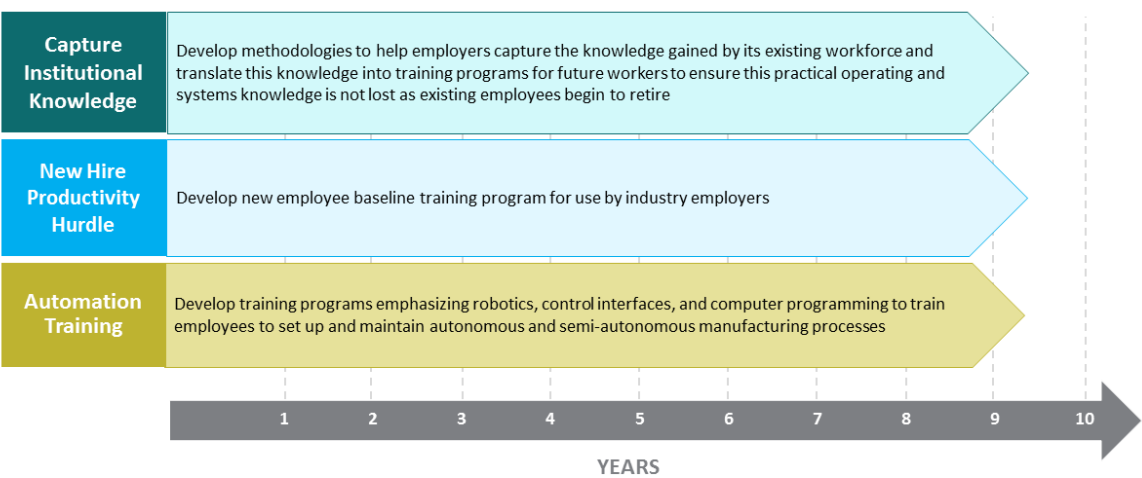
Training



Retention



Other Areas of Interest



Metalcasting Overview

Metalcasting is the most cost-effective method to manufacture a shaped metal component. The process consists of pouring molten metal into a mold containing a cavity of the desired shape. Metalcasting is one of America's oldest and most important industries, established in 1642. In 1776, seven foundry men signed the *Declaration of Independence*. Metalcasting is vital to the economy and security of the U.S. The industry helped the U.S. become the world leader in manufacturing, science, medicine, and aerospace and is helping it to sustain this position.

In addition to underpinning the transportation, aerospace, and defense industries, cast metal products are found in every sector of the economy including energy exploration and production, mining, construction, maritime, fluid power, instrumentation, computers, and a myriad of consumer products. Cast metal components include the following: engine blocks; suspension parts for railcars, trucks, and autos; fluid flow and power components, including valves, pumps, faucets, pipes, and fittings; mining, oil field, and energy producing equipment; surgical equipment and prosthetic devices; and components for many of the household and electronic devices used every day. Markets for products containing metalcastings are increasingly competitive and manufacturers are placing greater emphasis on the rapid production of high-quality, competitively priced castings delivered in small quantities. A major challenge for the industry is that the vast majority of metalcasters are small businesses that do not have the resources to perform the advanced research and development necessary to remain competitive. Figure 1 provides a snapshot of important facts about the metalcasting industry.

Facts about Metalcasting

- When you stand in the middle of the average U.S. city, you are never more than 10 ft from a metalcasting
- U.S. casting shipments totaled \$28.5 billion and 10.8 million tons in 2015
- The U.S. is the world's second leading casting producer
- There are 1,961 metalcasting facilities in the U.S.
- The industry employs more than 200,000 people
- Most metal casters are small businesses, and 80% employ less than 100 people
- Leading metalcasting states include Alabama, California, Indiana, Illinois, Michigan, Ohio, Pennsylvania, Texas, and Wisconsin

Figure 1: Metalcasting Facts¹

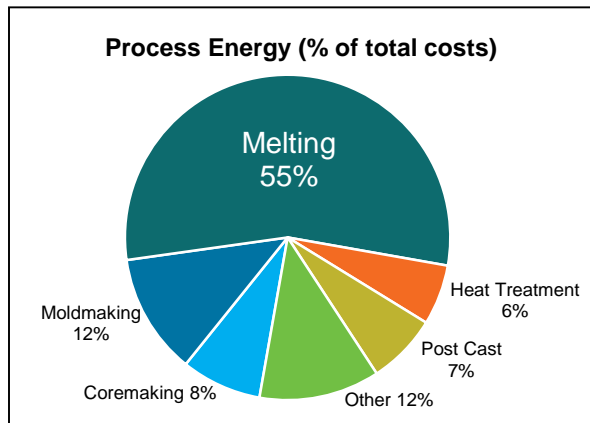


Figure 2: Process Energy²

Additionally, metalcasting is one of the most energy-intensive industries in the U.S. Approximately 55% of its energy costs are consumed in melting. Mold making, core making, heat treatment, and post-cast operations also use significant energy (see Figure 2). Research to improve these operations and reduce melting requirements will help the industry save energy, reduce the environmental impact globally, and improve competitiveness.

The future holds great promise for the metalcasting industry. New advances have

allowed the industry to employ materials such as aluminum, magnesium, titanium, zinc, advanced copper-based, and advanced iron and steel alloys to produce thin wall, high-strength castings with higher precision and more complex shapes. But to remain competitive and maintain a viable domestic industry, challenges must be overcome in casting design, processing efficiency, industry recognition, and employment attractiveness.

Increasingly, the U.S. metalcasting industry will need to reduce its cost of production to remain globally competitive. As long as non-U.S. manufacturers are able to benefit from low-cost labor and lax environmental constraints, U.S. manufacturers will continue to be at a disadvantage. Dramatic increases in U.S. metalcasting productivity and product and process technology are the economic answer to competition from commodity castings produced outside the U.S. Design, process, and material improvements to open new markets and applications, enhance metalcasting practices, advance alloy and component performance, and attract employees and students are all needed for the U.S. industry to realize its potential.

American Metalcasting Consortium (AMC)

AMC was established in 1992 to solve metalcasting procurement issues for the Department of Defense (DoD). AMC integrates the nation's top academic metalcasting researchers with the four leading metalcasting industry associations (American Foundry Society, Non-Ferrous Founders' Society, North American Die Casting Association, and the Steel Founders' Society of America) and their members. These four metalcasting industry associations represent members from over 95% of U.S. foundries. AMC is the nation's leading provider of technical and enterprise solutions for metalcasting supply chain challenges and the only existing metalcasting partnership providing access to the U.S. metalcasting industry. AMC has developed numerous successes for DoD, and DoE as the Cast Metals Coalition (CMC), through the development and enterprise-wide implementation of new technologies, best practices, and engineering expertise to facilitate and enhance capability, affordability, and sustainability of weapons system readiness (see Figures 3 and 4).

SCRA, a private, non-profit, proven world-leader in consortia management, is responsible for the day-to-day operations management of AMC.

THE NUMBERS

\$130M savings projected by DoD
\$2.6M saved using existing tooling
2,950 cast parts improved
2130 foundries accessible
2100 personnel trained in seminars
135 weapons systems enhanced
85 seminars conducted
82 DoD & AMC partners
27 leading research institutions
1 AMC metalcasting partnership

Figure 3: AMC Success Statistics³

SCRA, as consortium manager, provides consortium oversight, program management, and a direct conduit between the industry partners, academic institutions, and government clients. SCRA's strong and effective performance in managing AMC and CMC is marked by high levels of client satisfaction within industry, academia, and government. The AMC and CMC programs continue to outperform contract deliverables and cost share goals. All deliverables on all previous programs were submitted either before or on schedule and within budget. Consistently high scores received from the ManTech Joint Defense Manufacturing Technology Panel (JDMTP) validate the AMC program's outstanding record of technology relevance, project progress, technology transition, and resource leveraging.

AMC HIGHLIGHTS

- 2015 DMC Achievement Award
- 2011 DMC Achievement Award
- 2010 DLA Commander's Choice Award
- Numerous Defense Manufacturing Conference Award nominations
- 2002 MK-38 Handgrip Award
- 2003 DoD Value Engineering Award
- 1999 Hammer Award for Process Reinvention
- 1998 DoD Value Engineering Award
- Numerous papers published and presented at military and national conferences
- Articles in numerous publications, such as Modern Castings, Crucible, Die Casting Engineer, and Engineered Casting Solutions (see Section V)
- Participation in annual industry (Metalcasting Congress, CastExpo, T&O Conference) and military (DMSMS, DMC) conferences

Figure 4: AMC Highlights⁴

- AMC is the only metalcasting consortium consisting of the leading industry associations, their members, and the premier U.S. metalcasting researchers.
- AMC represents every aspect of the metalcasting industry.
- AMC's commitment is evidenced by industry and academia in-kind cost share.
- AMC has successfully implemented numerous solutions for DoD to enhance weapons system readiness and for DoE to save energy.

Roadmap Development

AMC managed the development of a Metalcasting Industry Roadmap to identify the research and development (R&D) technology, process, and workforce needs to ensure a competitive U.S. metalcasting industry and accelerate the growth of advanced manufacturing in the U.S. The roadmap effort was coordinated by the AMC Metalcasting Roadmap Executive Committee (REC) and AMC Roadmap Technical Advisory Committee (RTAC). The roadmap was developed by a select team of industry, government, and academic experts collaborating to identify metalcasting R&D technology, process, and workforce development investment needs. The AMC roadmap is an integrated and readily executable plan of action based on mapping capability gaps to solution paths with the greatest potential to meet the goals of the industry. AMC used previously proven roadmapping methods to bring together and facilitate the team of key enterprise stakeholders to deliver a thoroughly documented action plan.

Metalcasting Industry Roadmap

Based on results from two industry surveys conducted by AMC, the AMC REC and RTAC developed four main topic areas needed in the development of a metalcasting technology roadmap. The four main topic areas were:

- Process
- Materials
- Design
- Workforce

Thirty-six experts were then selected from industry, academia, and government to participate in the AMC Roadmapping Development Workshop to identify future metalcasting research / technology / workforce needs in the four topic areas.

Specifically, the major goals and objectives of the AMC roadmapping effort were to:

1. Improve the methods of designing castings for new markets and applications while maintaining current markets and move the industry towards integration of digital manufacturing and design.
2. Improve metalcasting processes through increased understanding of process variables, accurate simulation, more finite real-time controls, and improved operating efficiencies.
3. Attract students to the metalcasting industry and retain the brightest, most productive employees.
4. Increase the awareness of the importance of the metalcasting industry, and the components it produces, to the U.S. economy, national defense and everyday life.

AMC is experienced in utilizing distributed technology management among industry, research, and government resources to develop, leverage, deliver, and apply innovative technology and processes in support of DLA's rapid procurement of cast parts in weapon systems. The CMC has done the same for DoE in the area of process energy savings. The organizational structure utilized by AMC ensures performance stability and reliability. AMC industry association partners represent approximately 2,000 casting manufacturers across the country in all casting processes. Their participation ensures that the roadmapping process is relevant and comprehensive, and that the results are significant to the sustainability of the metalcasting industry.

AMC Roadmap Technical Advisory Committee (RTAC)

Technical oversight of the roadmapping process was the responsibility of the AMC RTAC. This was made up of an experienced team of engineers from the casting industry. The abbreviated resumes of the AMC RTAC key personnel are highlighted in Table 1. These key personnel have over 100 years of leadership and management experience combined. The AMC RTAC guided the roadmapping process to identify critical technologies and potential gaps, ensure industry relevance, create a sustainable transition path, and achieve team consensus. The AMC RTAC made certain that the roadmapping team contained the right mix of metalcasting expertise so the correct R&D technology and processes were recognized.

AMC RTAC Key Personnel	Qualifications, Applicable Research, Engineering, Management Experience
David Poweleit , SFSA, B.S. Mechanical Engineering, 20 years' experience	SFSA, Vice President of Technology, AMC CAST-IT Application Engineer, member of AMC Technical Advisory Committee
Thomas Prucha , AFS, B.S. & M.S. Metallurgical Engineering, 40 years' experience	Vice President of AFS Technical Services; AMC Technical Advisory Committee member; 2003 AFS Award of Scientific Merit & 2007 Recipient of the Merton C. Flemings Award from the Advanced Casting Research Center (ACRC)
Jenny Swygert , SCRA, B.S. Mechanical and Aerospace Engineering, M.B.A., 23 years	CAST-IT Team Manager, SCRA Senior Project Manager, Recipient of 2014 SCRA Collaboration Award
Steve Udvardy , NADCA, M.S. Metallurgical Engineering and Material Science & Engineering, 30 years	NADCA Director of Research, Education, and Technology; Operational and R&D experience in metalforming design and production; AMC Technical Advisory Committee Member
Jerrod Weaver , NFFS, B.S. Manufacturing Engineering, 19 years' experience	NFFS Member Services Manager since 1996; Project Leader for AMC Defense Casting Resources for Supply Chain Integration program; Interface with DLA Supply Centers; AMC Technical Advisory Committee Member
Thornton White , SCRA, B.S. Chemistry, Chemical Engineering, M.B.A., P.M.P., 27 years	AMC Program Manager since 2002; AMC Technical Advisory Committee Member; Certified Project Management Professional

Table 1: Key Personnel - AMC Roadmap TAC (RTAC)

AMC Roadmap Executive Committee (REC)

The AMC REC was responsible for the overall strategic decisions and accountability of the AMC roadmapping process. The AMC REC consisted of recognized leaders from each area of the casting industry and also included the members of the AMC Executive Board and AMC RTAC (see Table 2). Government partners had reserved seats at all AMC REC meetings and the workshop.

Metalcasting Industry Roadmap

AMC REC Key Personnel	Qualifications, Applicable Research, Engineering, Management Experience
AMC RTAC	See Table 1 above
Jerry Call , AFS Executive Vice President	American Foundry Society (AFS) Executive Vice President serves on the board of directors for the American Metalcasting Consortium, the Cast Metals Coalition, the Industrial Advisory Trade Committee for ferrous materials for the Department of Commerce, and U.S. Delegate to the General Assembly of the World Foundry Organization; Prior experience includes Stahl Specialty Company (Human Resources/EHS Manager and, Plant Manager), Gardner Denver (Human Resources Manager)
James Mallory , NFFS Executive Director	Executive Director of the Non-Ferrous Founders' Society (NFFS), Board of Trustees of the Center for Leadership Development, an educational arm of the U.S. Chamber Foundation, and both as a Regent, Chairman, and Faculty member for the Institute for Organization Management at the University of Notre Dame; He chaired the <i>Small Manufacturers' Issues Group</i> for the NAM Council of Manufacturers' and served as a member of the <i>Future of U.S. Manufacturing</i> Task Force
Raymond Monroe , SFSA Executive Vice President	Executive Vice President of SFSA; AMC Board member since 1992; Past Chairman Cast Metal Coalition, serves on the Joint Defense Manufacturing Technology Metals subpanel (JDMTP) and the Industrial Advisory Trade Committee for ferrous materials for the Department of Commerce
Daniel Twarog , President of NADCA	President of NADCA since 1995. In the metal casting industry since 1978. AMC Board Member since 1992; Past experience includes materials R&D at Amsted Research Labs, quality and process control manager at an investment foundry, and AFS Director of Research
Jiten Shah , President, Product Development & Analysis LLC	Casting design and manufacturing consultant with over 25 years of experience in product development, reverse engineering, failure analysis, and redesign services
Buckley Brinkman , Executive Director, Wisconsin Manufacturing Extension Partnership	25 years of transformational manufacturing leadership to the WMEP, with a breadth of experience in helping companies drive growth, world-class competitiveness and performance excellence. Experienced in lean, Six Sigma, supply chain management and turnaround planning

Table 2: Key Personnel - AMC REC

Program Milestones

Task 1: Defining the Landscape

The AMC RTAC reviewed past metalcasting and related roadmaps and conducted surveys to determine baseline metalcasting industry needs. A designated “select” team of experts was developed to review the surveys, determine areas of metalcasting technology gaps, and outline general areas of R&D needs. The efforts were coordinated by the AMC RTAC and reviewed by the AMC REC.

Task 2: Preparing the Surface for the Road

The AMC REC helped set the topics, agenda, discussion leaders, and framework for the Roadmapping Development Workshop. A list of invitees was established, a date and location was set, and invitations were sent out. Prior to the meeting, results of Task 1 activities, including interviews, were compiled into workshop background materials and sent to the invitees, who were asked to identify focus areas such as advanced technology, new processes, education and training, industry needs, consortium and collaboration, transformative and disruptive technologies, etc. for participation in breakout sessions. The breakout sessions were facilitated by the selected members of the REC.

Task 3: Roadmapping Development Workshop

The AMC Roadmapping Development Workshop was conducted May 12-13, 2015 at the Hyatt Regency O’Hare, Rosemont, IL. Thirty-six experts were specially selected from industry, academia, and government to attend the workshop. The goal of the workshop was to identify future metalcasting research / technology / workforce needs. Participants presented and discussed the important metalcasting issues and the required R&D / technologies / resources needed in small breakout groups consisting of six to eight people per group. Each breakout group session lasted 45 minutes and had a facilitator and a record keeper. The four breakout group areas were: process, materials, design, and workforce. Participants are listed in Table 3 and their biographies, key issues, and results from this workshop are contained in the Appendix.

Task 4: Finishing the Road and Creating a Vision for the Future

The AMC REC reviewed, revised, and finalized the roadmap document. Before the final roadmap was issued, a draft document was sent out to those that participated in the roadmapping workshop for their suggestions and feedback.

Metalcasting Industry Roadmap

AMC Roadmapping Development Workshop Participants	Organization
Diran Apelian	Worcester Polytechnic Institute
Paul Armstrong	Armstrong RM Corporation
Robert Beard	Sloan Valve Company
Andy Behler	Blue Ridge Pressure Castings
Andy Bonczkowski	Wisconsin Manufacturing Extension Partnership
Buckley Brickman	Wisconsin Manufacturing Extension Partnership
Jerry Call	American Foundry Society
John Danko	Danko Arlington
Hal Davis	Sivyer Steel Corporation
David DeWyse	Stahl Specialty Company
Bruce Dienst	Simpson Technologies
Ray Donahue	Mercury Marine
Shelly Dutler	American Foundry Society / Institute
Kathy Hayrynen	Applied Process Inc.
Dean Hutchins	Defense Logistics Agency
Jack Lilley	MetalTek International
Jim Mallory	Non-Ferrous Founders' Society
Steve Midson	CSM / Midson Consulting
Paul Mikkola	(GM) Retired
Charlie Monroe	University of Alabama at Birmingham
Raymond Monroe	Steel Founders' Society of America
Kelly Morris	Defense Logistics Agency
Frank Peters	Iowa State University
David Poweleit	Steel Founders' Society of America
Thomas Prucha	American Foundry Society
Dave Schwam	Case Western Reserve University
Jiten Shah	Product Development & Analysis LLC
Al Spada	American Foundry Society / Modern Casting

Metalcasting Industry Roadmap

Jean-Louis Staudenmann	NIST (AMTech Project Manager)
Jenny Swygert	SCRA / AMC CAST-IT
Jerry Thiel	University of Northern Iowa
Doug Trinowski	HA International
Dan Twarog	North American Die Casting Association
Steve Udvardy	North American Die Casting Association
Jerrold Weaver	Non-Ferrous Founders' Society
David Weiss	Eck Industries
Thornton White	SCRA / AMC

Table 3: AMC Roadmapping Development Workshop Participants

The Metalcasting Industry Roadmap



Process

Many needs have been identified to more efficiently manufacture metalcastings. These include rapid tooling manufacturing, research, technology development, advancements and integration of digital data threads, as well as transformative and potentially disruptive approaches to how cast metal components are produced. Process R&D can improve quality, enhance performance, reduce weight, reduce lead times, and improve the cost-effectiveness of cast parts. In developing a metalcasting roadmap to address the area of manufacturing process, the roadmapping development workshop participants identified eight major categories in which to group the new technologies and processes needed for metalcasting. The eight major categories are:



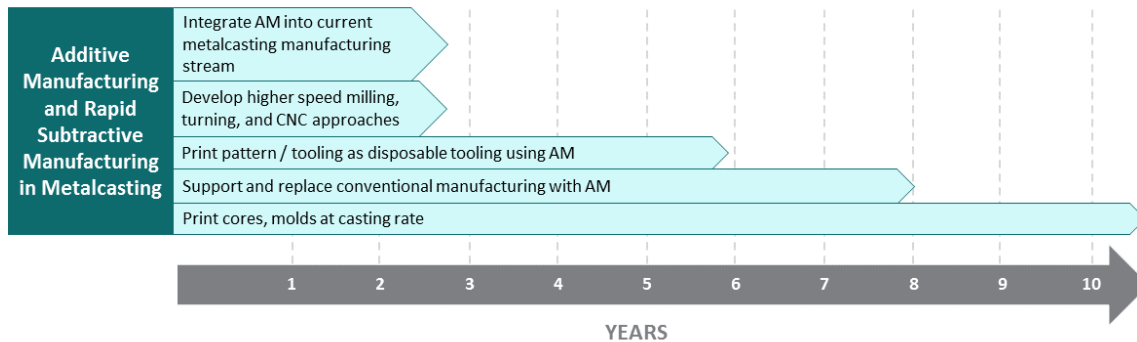
1. **Additive Manufacturing and Rapid Subtractive Manufacturing in Metalcasting** – Additive Manufacturing (AM), such as 3D printing, is a process of making a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using *additive processes*, where successive layers of material are laid down in different shapes. 3D printing is also considered distinct from traditional machining techniques, which mostly rely on the removal of material by methods such as cutting or drilling (*subtractive processes*). Rapid Subtractive Manufacturing (RSM) involves the advancement of computerized numerical control (CNC), chemical material removal, other removal techniques, and integration of digital technology to create tools, patterns, and even molds quickly.
2. **Lightweighting** – This refers to the need to reduce the weight and overall footprint of components in applications where castings are used. This is especially critical in the transportation sector (automotive, transport, aerospace) and defense / military products.
3. **Smart Machines and Manufacturing** – This involves the integration of network-based solutions to collect data, manage that information, make critical decisions, and adopt and control processes to improve quality and efficiency.
4. **Digital Thread Integration and Implementation** – This is the transformation of manufacturing by digital design, which replaces the draftsman's table with the capacity to work and create in a virtual environment. A common digital and sharable format is used to enable transfer of design, modeling, process simulation, and manufacturing data and inspection information management. This creates a digital thread that leads to improved designs and more efficient manufacturing processes to move beyond discrete manufacturing operations, integrate the information, and disseminate it across broad shared networks.
5. **Automation, Robotics, Ergonomics, and Sustainability** – These are used to improve the metalcasting work environment so it will not be as hot, dirty, or noisy and also won't

require strenuous and repetitive motions. The use of robotics and other dedicated equipment has helped alleviate some of these issues but its implementation is still not widespread, especially in lower volume applications and in the small-to-medium enterprises.

6. **Melt-Pour-Cast** – This relates to the improvement of metalcasting manufacturing processes via reductions in variation, reductions in handling, and creating more repetitive production approaches to transform the metalcasting industry.
7. **Advanced Metalcasting Technology** – To revolutionize the approaches used to manufacture castings, collaboration is needed among the various stakeholders which includes researchers at universities, the equipment manufacturers, material suppliers, the metalcasters, and the end customers. The future metalcasting operations will look more like mini-mills with the use of engineered cooling and thermal management or potentially on-demand melting and molding technologies.
8. **Quality** – To improve reliance on cast products as the most cost-effective solution, dramatic reductions in variability and improved yields are needed. Efforts should be directed to supplant qualitative Non-Destructive Evaluation (NDE) techniques (based upon international / national comparison standards that do not reflect the loads applied and performance expected from the product) with those that are quantitative.

Within each major category, the following areas were identified:

Additive Manufacturing and Rapid Subtractive Manufacturing in Metalcasting



AM holds the potential to be both a transformative and disruptive technology. The current approaches have been more on applications in new product development and specialty production. Efforts are needed to integrate the various methods of AM into a more manufacturing-based approach, which could include core and mold production via 3D Sand Printing (3DSP), printed investment cast patterns, and 3D printed die and tools. These efforts will move the technologies from Rapid Prototyping towards Rapid Production.

Key Tasks

- Integrate AM into current metalcasting manufacturing stream
- Develop higher speed milling, turning, and CNC approaches
- Print pattern / tooling as disposable tooling using AM

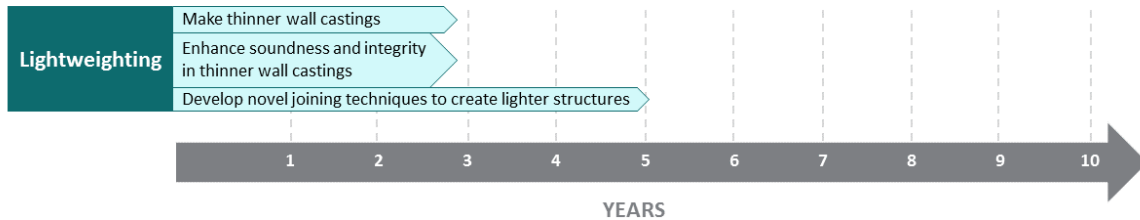
Metalcasting Industry Roadmap

- Support and replace conventional manufacturing with AM
- Print cores, molds at casting rate

Target Outcomes

- Broad adoption of AM in metalcasting operations
- Faster new product development times and reduced lead times
- More efficient designs
- Lower cost for complex parts and core / mold assemblies
- Rapidly produced patterns, tools, and molds via removal techniques

Lightweighting



Making efficiently-designed castings that use only the section thickness that is needed for the service loads, manufacturing variability and tolerance stack-ups, manufacturing capabilities of the casting process, and fluid life of the metal being cast will allow metalcasting to compete against other manufacturing technologies. The term “Thin Wall Casting” is a way of labeling this approach and the needs expressed by the community that uses castings. As wall thickness is reduced, the need increases to produce castings with enhanced soundness and integrity.

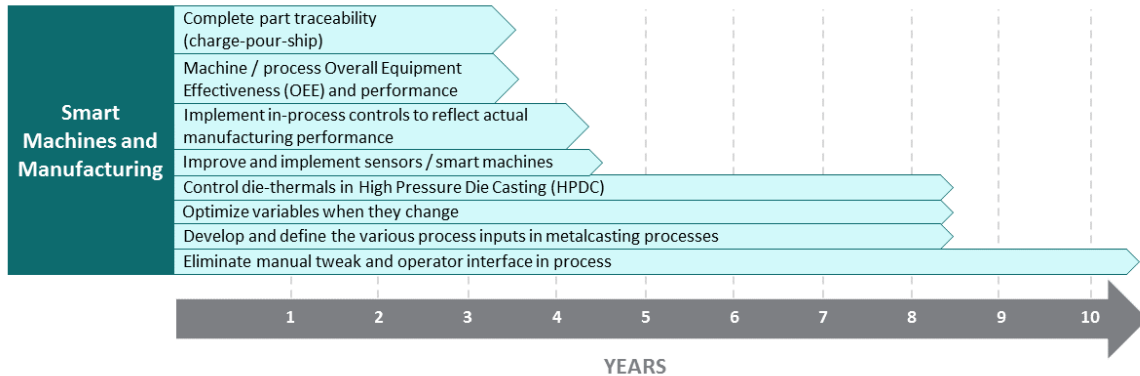
Key Tasks

- Make thinner wall castings
- Enhance soundness and integrity in thinner wall castings
- Develop novel joining techniques to create lighter structures

Target Outcomes

- Lower component weights, potential improved fuel efficiency in transportation sector
- Improved performance via higher integrity parts
- Enhanced products that incorporate multiple parts and materials

Smart Machines and Manufacturing



The integration of network-based solutions to collect data, manage that information, make critical decisions, and adopt and control processes to improve quality and efficiency will transform the metalcasting industry. Smart Manufacturing (SM) is integrating network-based data and information that comprises the real-time understanding, reasoning, planning and management of all aspects of a manufacturing and supply chain enterprise. SM is facilitated through the use of advanced sensor-based data analytics, modeling, and simulation in real-time. In SM, all information is available when it is needed, where it is needed, and in the form it is most useful -infusing manufacturing intelligence throughout the lifecycle of design, engineering, planning, and production.

Key Tasks

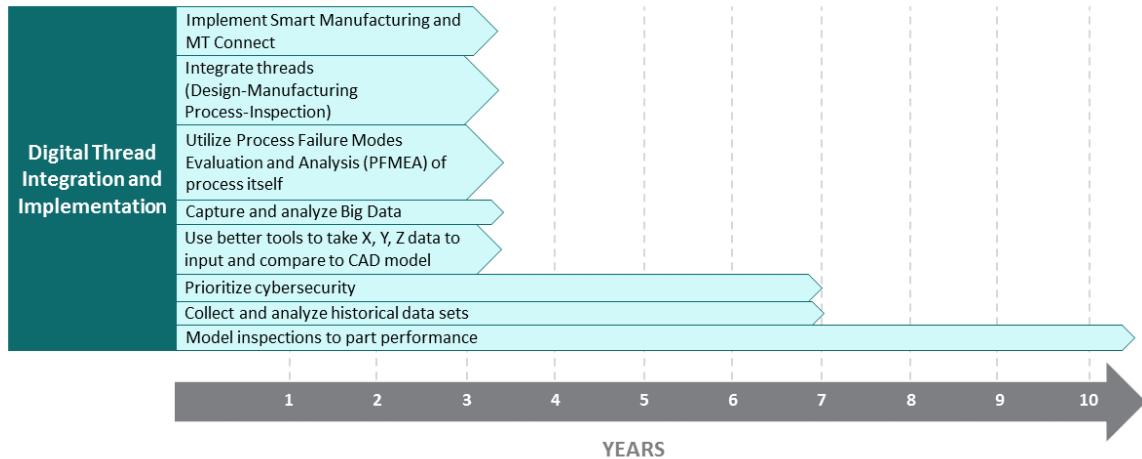
- Complete part traceability (charge-pour-ship)
- Machine / process Overall Equipment Effectiveness (OEE) and performance
- Implement in-process controls to reflect actual manufacturing performance
- Improve and implement sensors / smart machines
- Control die-thermals in High Pressure Die Casting (HPDC)
- Optimize variables when they change
- Develop and define the various process inputs in metalcasting processes
- Eliminate manual tweak and operator interface in process

Target Outcomes

- Manufacturing and inspection data tied to individual castings (born-on-date)
- Improved casting quality, process performance, efficiency, and cost
- Efficient manufacturing operations that can compete on the global stage
- In-process control tests and measurement approaches in real-time
- Enhanced products that incorporate multiple parts and materials
- Improved sensing and monitoring technology
- Effective and efficient die thermal management
- Movement from reactive to proactive and optimization of the process

- True control the metalcasting manufacturing process vs. anecdotal information or tests that are not direct measure of an output
- Reductions in or elimination of operator-based decisions

Digital Thread Integration and Implementation



Manufacturing is being transformed by digital design, which replaces the draftsman's table with the capacity to work and create in a virtual environment. A common digital and sharable format is used to enable transfer of design, modeling, process simulation, and manufacturing data and inspection information management. This creates a digital thread that leads to improved designs and more efficient manufacturing processes to move beyond discrete manufacturing operations and integrate the information and disseminate it across broad shared networks.

Key Tasks

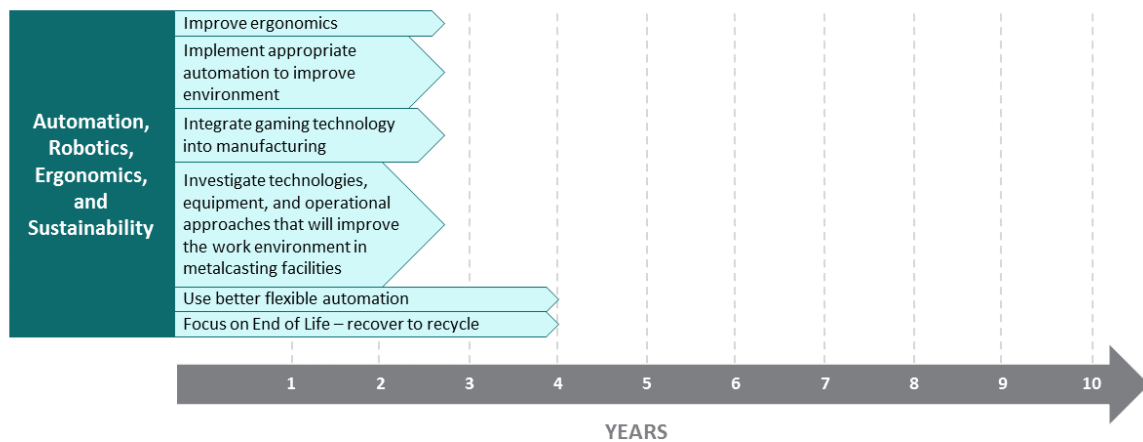
- Implement Smart Manufacturing and MTConnect
- Integrate threads (Design-Manufacturing Process-Inspection)
- Utilize Process Failure Modes Evaluation and Analysis (PFMEA) of process itself
- Capture and analyze Big Data
- Use better tools to take X,Y, Z data to input and compare to CAD model
- Prioritize cybersecurity
- Collect and analyze historical data sets
- Model inspections to part performance

Target Outcomes

- Broad shared data networks
- Incorporation of trend analysis, expert systems, past historical data, and probabilistic models in making process adjustments
- Improved designs and more efficient manufacturing processes via Digital Thread

- Understanding the manufacturing process and what contributes to variability, measurements, and controls
- Avoidance of errors due to manual layout process and integration of output via Digital Thread into process analyses like solidification modeling and Finite Element Analysis (FEA)
- More effective future work as a result of lessons learned from the past and from information already collected
- Movement beyond historical approaches that use comparative standards to performance-based criteria that are integrated into process and design / performance based modeling software tools

Automation, Robotics, Ergonomics, and Sustainability



The metalcasting work environment is often hot, dirty, and noisy and can require strenuous and repetitive motions. The use of robotics and other dedicated equipment has helped alleviate some of these issues but its implementation is still not widespread, especially in lower volume applications and in the small-medium enterprises. Automation will reduce long-term injuries, create a safer work environment, and improve the bottom line.

Key Tasks

- Improve ergonomics
- Implement appropriate automation to improve environment
- Integrate of gaming technology into manufacturing
- Investigate technologies, equipment, and operational approaches that will improve the work environment in metalcasting facilities
- Use better flexible automation
- Focus on End of Life – recover to recycle

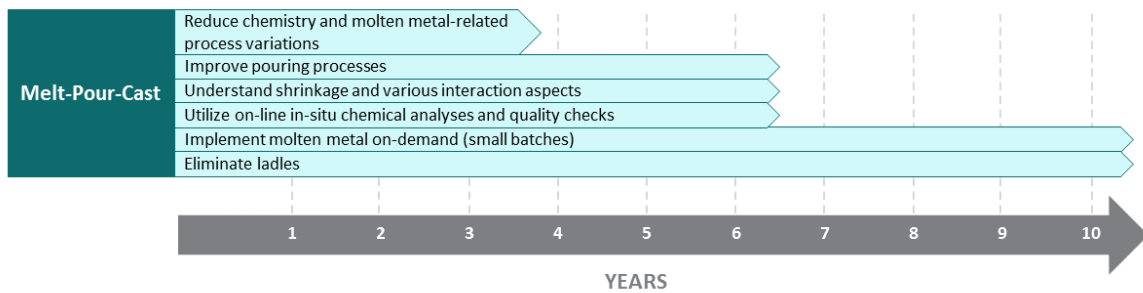
Target Outcomes

- Reduced repetitive injuries and safer workplaces

Metalcasting Industry Roadmap

- Workforce retention and creation of desirable workplaces
- Higher consistency of product quality
- Adoption of cross-cutting technologies from outside the metalcasting industry
- Implementation of automation into lower-volume manufacturing
- Autonomous communication between resources
- Integration of information from sensors as well as mechatronic data
- Reaching Zero Discharge
- Improved profitability

Melt-Pour-Cast



Improving metalcasting manufacturing processes via reductions in variation, reductions in handling, creating more repetitive production approaches, and movements away from the traditional approaches used to melt, transfer metal, pour, and cast components will transform the industry. This can lead to reduced chemistry and process variation, improved mechanical properties, reductions in scrap, improved yields, higher repeatability and predictability of casting performance, and higher efficiency. These are just some of the benefits from reducing variation in metal chemistries and other manufacturing process variables. Efforts should be made to identify the sources of variation and reduce them.

Key Tasks

- Reduce chemistry and molten metal-related process variations
- Improve pouring processes
- Understand shrinkage and various interaction aspects
- Utilize on-line in-situ chemical analyses and quality checks
- Implement molten metal on-demand (small batches)
- Eliminate ladles

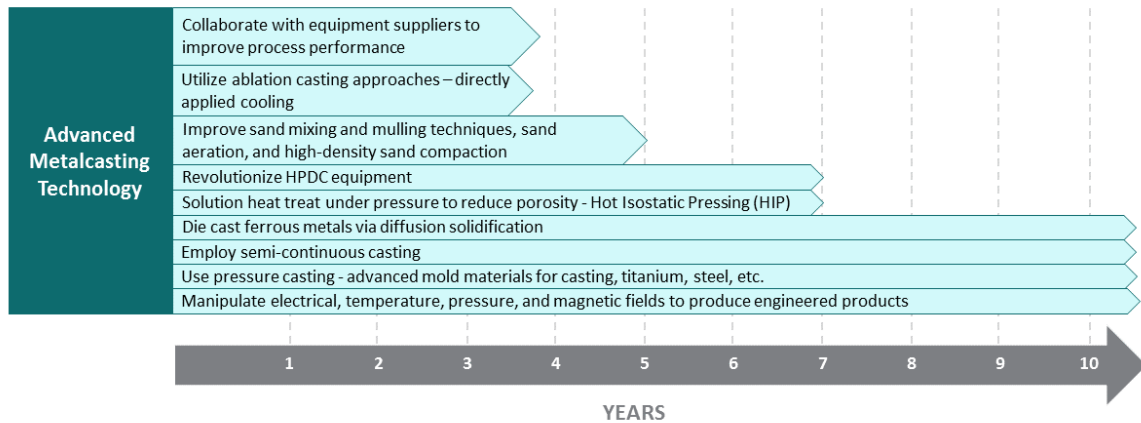
Target Outcomes

- Scrap reductions
- More accurate process and predictive models
- Improved mechanical properties
- Higher repeatability and predictability of casting performance

Metalcasting Industry Roadmap

- Energy reductions
- Improved profitability

Advanced Metalcasting Technology



To revolutionize the approaches used to manufacture castings, collaboration is needed among the various stakeholders, which include researchers at universities, equipment manufacturers, material suppliers, metalcasters, and the end customers to create advanced casting technologies. The future metalcasting operations will look more like mini-mills with use of engineered cooling and thermal management or potentially on-demand melting and molding technologies.

Key Tasks

- Collaborate with equipment suppliers to improve process performance
- Utilize ablation casting approaches – directly applied cooling
- Improve sand mixing and mulling techniques, sand aeration, and high-density sand compaction
- Revolutionize HPDC equipment
- Solution heat treat under pressure to reduce porosity - Hot Isostatic Pressing (HIP)
- Die cast ferrous metals via diffusion solidification
- Employ semi-continuous casting
- Use pressure casting - advanced mold materials for casting, titanium, steel, etc.
- Manipulate electrical, temperature, pressure, and magnetic fields to produce engineered products

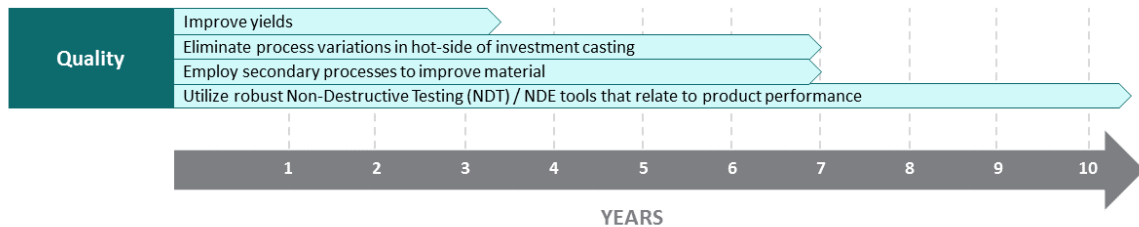
Target Outcomes

- Development, advancement, and refinement of manufacturing technology
- Rapidly-solidified structures and refinement of the metallurgical phases
- Higher integrity and potentially dramatic improvement in cast properties
- Rapidly produced near net shape castings with good surface finishes

Metalcasting Industry Roadmap

- Economical approaches to improve strength and casting integrity via application of pressure during solution heat treatments
- Casting ferrous components via infiltrating molten cast iron into a bed of iron powder, thus giving higher strengths and integrity
- Creating controlled thermal engineered processes that approximate what can be obtained in semi-continuous casting
- Porosity reduction via use of pressure to improve integrity and properties
- Use of energy / work fields (electrical, temperature, temporal, magnetic, pressure, chemical, and others) to change how cast products are made

Quality



To improve reliance on cast products as the most cost effective solution, dramatic reductions in variability and improved yields are needed. Efforts should be directed to supplant qualitative NDE techniques (based upon international / national comparison standards that do not reflect the loads applied and performance expected from the product) with those that are quantitative.

Key Tasks

- Improve yields
- Eliminate process variations in hot-side of investment casting
- Employ secondary processes to improve material
- Utilize robust Non-Destructive Testing (NDT) / NDE tools that relate to product performance

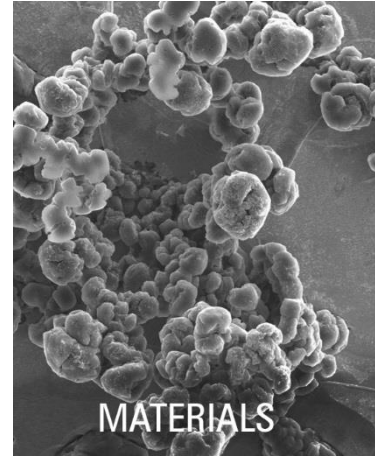
Target Outcomes

- Energy reduction
- Improved profitability
- Scrap reduction
- Expanded markets via the implementation of value-added activities
- No more operator interpretations and subjective evaluations
- Elimination of arbitrary standards
- Part evaluations that reflect actual performance



Materials

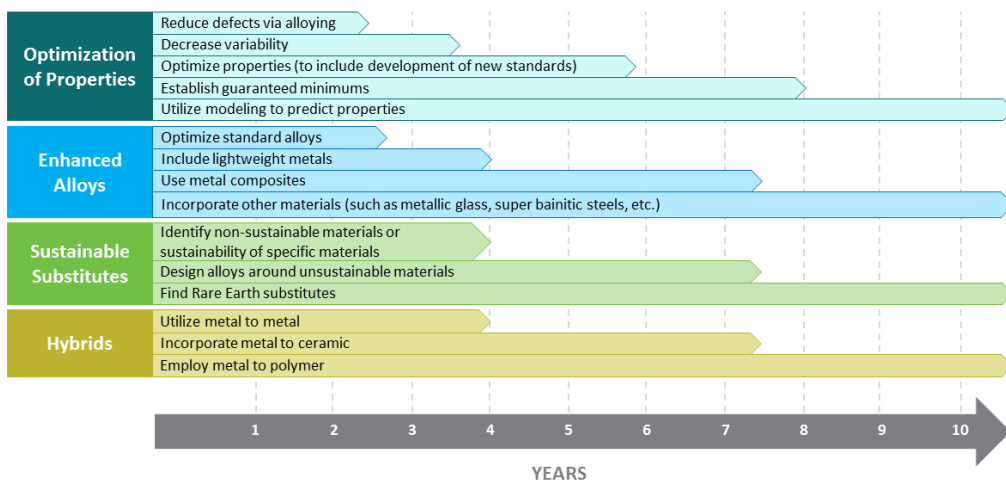
Research, data, and tools are needed to improve the materials used in the production of metalcastings. Material R&D can improve quality and performance, reduce weight, reduce lead times, and improve the cost-effectiveness of cast parts. In developing a metalcasting roadmap to address the area of materials, the roadmapping development workshop participants identified three major categories in which to group the new technologies and processes needed for metalcasting materials. The three major categories are:



1. **Cast Materials** – These are the liquid metals that are poured or injected into molds, then allowed to cool to produce solidified metal castings. This category includes enhancing properties / quality and sustainability of monolithic metals as well as hybrid materials, such as metal-matrix composites.
2. **Mold, Die, and Tooling Materials** – This refers to the materials that are used to contain the molten metals that are poured into them and form the shape of the casting once the metal is solidified. This category includes the materials used to make the molds / dies (sand, steel, ceramic, etc.) including the binder material, coatings, and the design / simulation of molds.
3. **Furnace Refractories** – These are the heat-resistant materials that constitute the linings for the furnaces and ladles used in metalcasting.

Within each major category, the following areas were identified:

Cast Materials



- a. **Optimization of Properties** – This area deals with optimizing the mechanical properties and quality of current casting materials to reduce variability and defects. Part of this

includes the development of the associated standards and specifications so the material can be specified in design packages. Modeling and simulation to predict cast material properties is also a part of this area.

Key Tasks

- Reduce defects via alloying
- Decrease variability
- Optimize properties (to include development of new standards)
- Establish guaranteed minimums
- Utilize modeling to predict properties

Target Outcomes

- Higher quality / performing parts
- Reduced scrap
- Cost savings from less metal usage

- b. **Enhanced Alloys** - This area deals with improving the quality of casting materials through the development of new alloys and the enhancement or modification of existing alloys. The topic area includes light-weighting, metal / nano-composites, metallic glass, and super Bainitic steels.

Key Tasks

- Optimize standard alloys
- Include lightweight metals
- Use metal composites
- Incorporate other materials (such as metallic glasses, super bainitic steels, etc.)

Target Outcomes

- Higher quality / lightweight parts
- Maximized potential of existing alloys
- Reduced scrap
- Conversion of fabricated parts to castings

- c. **Sustainable Substitutes** - Sustainability of cast materials is considered to be the ability to maintain the raw materials required to produce castings which is critical to the long-term viability of the industry. Topics in this area include improving the availability of raw cast materials and finding alternatives to critical rare earth elements.

Key Tasks

- Identify non-sustainable materials or sustainability of specific materials
- Design alloys around unsustainable materials

- Find Rare Earth substitutes

Target Outcomes

- Reduced production lead times
 - Supply chain reliability
- d. **Hybrids** - Hybrid materials as defined are considered to be a mixture of two or more materials, one of them being a cast metal. The major goal in creating a hybrid cast material is to improve strength and / or reduce weight. The combinations in this area include metal-to-metal, metal-to-ceramic, and metal-to-polymer.

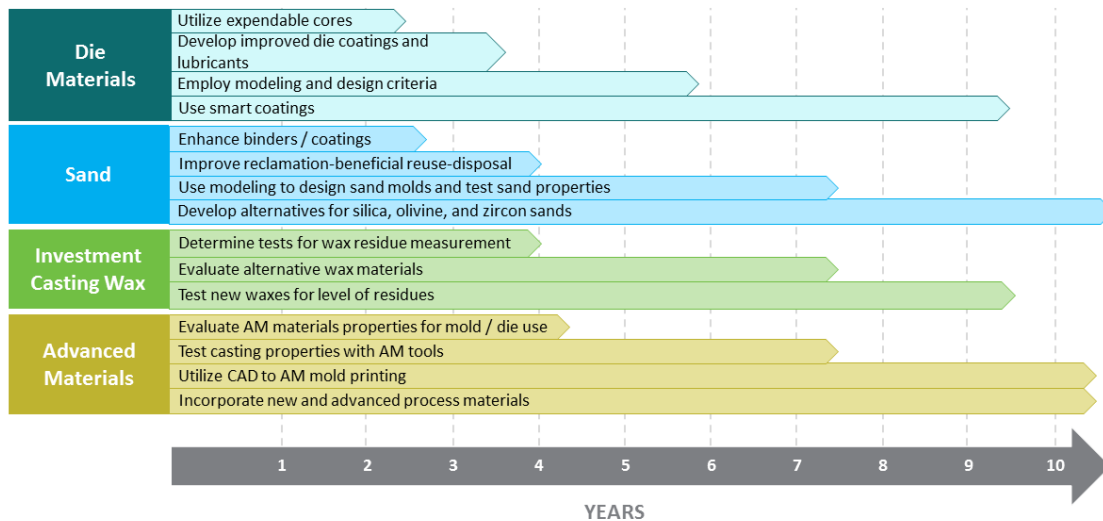
Key Tasks

- Utilize metal to metal
- Incorporate metal to ceramic
- Employ metal to polymer

Target Outcomes

- New higher performing / lightweight parts
- New and expanded markets for metalcastings

Mold, Die, and Tooling Materials



- a. **Die Materials** – Die materials refers to the mold cavities created using hardened tool steel (or other viable material) dies which have been machined into the shape of the part(s) being produced. R&D areas in this topic include improving the life of the die, developing better die coatings and lubricants, modeling and simulation of dies, and expendable cores.

Key Tasks

- Utilize expendable cores
- Develop improved die coatings and lubricants
- Employ modeling and design criteria
- Use smart coatings

Target Outcomes

- Reduced cycle / production lead times
 - Higher quality cast parts
 - Reduced porosity
 - Reduced gas related defects
 - Improved surface finish
 - Improved dimensional repeatability
 - Elimination of veining and erosion defects
 - Less scrap and re-work
 - Environmental improvements
- b. **Sand** – This refers to the material improvements involving sand molds. It includes the reclamation-beneficial reuse-disposal of sand, binders, and coatings used in the production of sand molds, developing alternatives for silica, olivine and zircon sands, and also modeling / simulation in the design of sand molds.

Key Tasks

- Enhance binders / coatings
- Improve reclamation-beneficial reuse-disposal
- Use modeling to design sand molds and test sand properties
- Develop alternatives for silica, olivine and zircon sands

Target Outcomes

- Reduced production lead times
 - Higher quality cast parts
 - Improved surface finish
 - Improved dimensional repeatability
 - Less scrap and re-work
 - Environmental improvements
 - Alternative resources if materials are unavailable or in short supply
- c. **Investment Cast Wax** - In the investment casting process, a ceramic slurry is applied or “invested” around a disposable wax pattern, and allowed to harden to form a disposable casting mold. The wax pattern is lost when it is melted out from the disposable ceramic mold which is later destroyed to recover the casting. This R&D area would involve

enhancements to the waxes to improve their strength / toughness, reduce shrinkage, as well as reduce the amount of wax residuals after melting.

Key Tasks

- Determine tests for wax residue measurement
- Evaluate alternate wax materials
- Test new waxes for level of residues

Target Outcomes

- Less scrap and re-work
- Environmental improvements

- d. **Advanced Materials** – This refers to the R&D needed to improve and enhance the materials used for molds, dies, and cores used in the production of castings. This area includes AM, which has the potential to transform the casting industry through the utilization of printed molds and cores.

Key Tasks

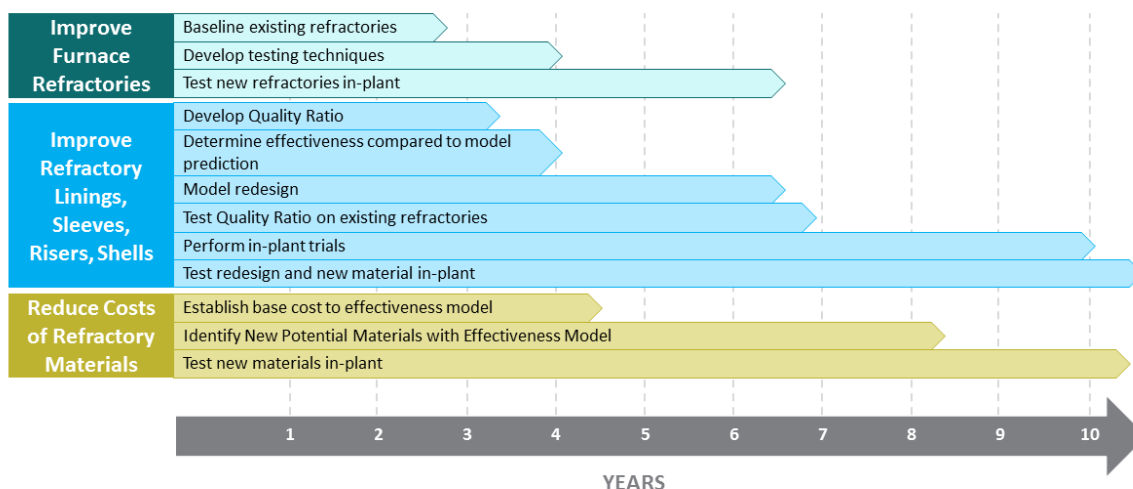
- Evaluate AM materials properties for mold / die use
- Test casting properties with AM tools
- Utilize CAD to AM mold printing
- Incorporate new and advanced process materials

Target Outcomes

- Reduced production lead times
- Cost-effective low quantity orders

Furnace Refractories

This refers to the heat-resistant materials that constitute the linings for the furnaces and ladles used in metalcasting. In addition to being resistant to thermal stress and other physical phenomena induced by heat, refractories must also withstand physical wear and corrosion. The R&D needed in this area includes improvements in new materials to improve quality / reliability, costs, and energy efficiency.



- a. **Improve Furnace Refractories** – Improved furnace refractories are needed to improve the performance of furnace refractories. This includes improved insulating effects / resistance to heat, better non-wetting properties, and longer performance life / reduction of refractory material deterioration over time and usage. Failure of refractory material may result in the loss of production time, equipment, and even the casting itself.

Key Tasks

- Baseline existing refractories
- Develop testing techniques
- Test new refractories in-plant

Target Outcomes

- Higher quality cast parts
- Reduced porosity
- Reduced gas related defects
- Improved surface finish
- Improved dimensional repeatability
- Elimination of veining and erosion defects
- Less scrap and re-work
- Energy reduction / improved energy efficiency

- b. **Improve Refractory Linings, Sleeves, Risers, Shells** – Refractory linings, sleeves, risers, and shells are very important in the performance, profitability and reliable operation of the casting operation. Non-performance of refractory linings, sleeves, risers, and shells will cause casting failure and may even result in unplanned emergency shutdowns. Effective and reliable modeling and simulation is needed to avoid / minimize unexpected and premature failures.

Key Tasks

- Develop Quality Ratio
- Determine effectiveness compared to model prediction
- Model redesign
- Test Quality Ratio on existing refractories
- Perform in-plant trials
- Test new redesign and new material in-plant

Target Outcomes

- Reduced production lead times
- Higher quality cast parts
- Less maintenance, tear-out, and relining
- Less scrap and re-work
- Environmental improvements

- c. **Reduce Costs of Refractory Materials** – Cost-efficient refractory materials can reduce the production expenses of foundries and improve profitability through longer service life and improved energy efficiencies.

Key Tasks

- Establish base cost to effectiveness model
- Identify new potential materials with effectiveness model
- Test new materials in-plant

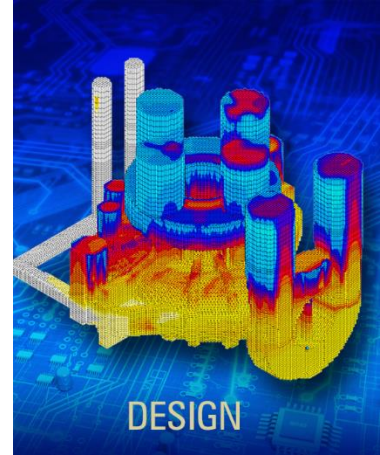
Target Outcomes

- Cost savings from reduced refractory costs



Design

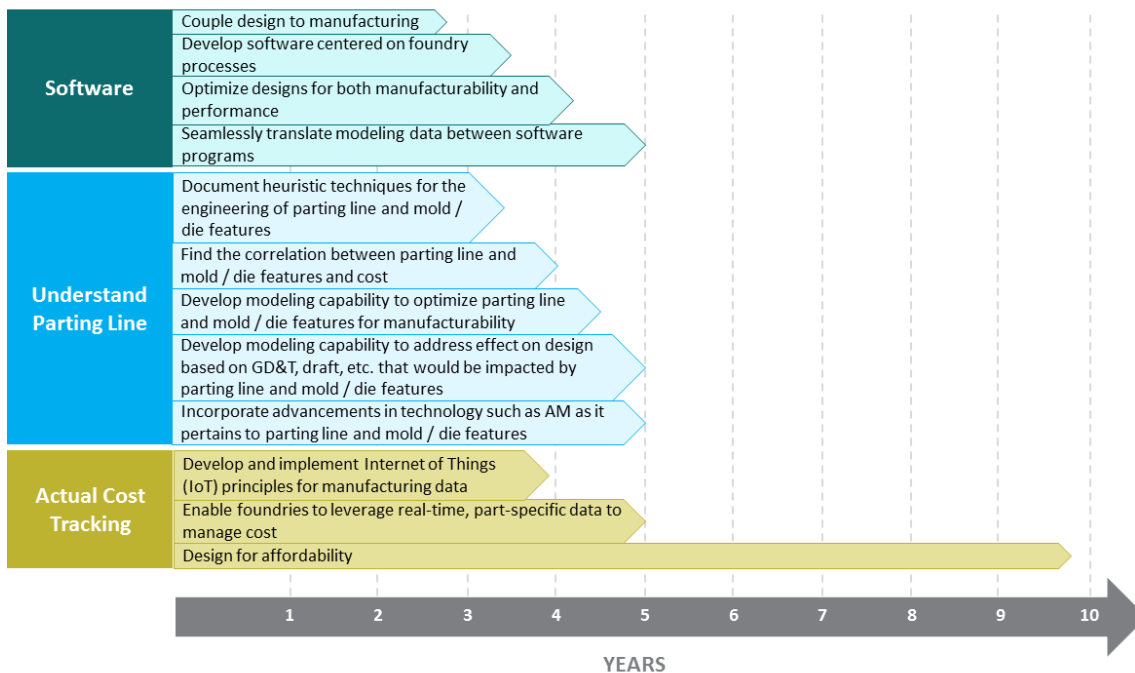
Tools, rules, education, and data are needed to improve the design and manufacture of metalcastings. In developing a metalcasting roadmap to address the area of design, the roadmapping development workshop participants identified five major categories in which to group the new technologies and processes needed for metalcasting design. The five major categories are:



1. **Design Tools for Manufacturing** – These are process design tools to help foundries determine the best way to make a part.
2. **Design Tools for Casting** – This refers to component design tools to help designers create a part that can be manufactured as a casting.
3. **AM Technology** – This includes design rules to leverage AM opportunities for castings.
4. **Customer Resources** – This relates to the benefits and cost savings of using castings.
5. **Performance-Based Reliability** – These are properties and quantitative NDT parameters to enable design for reliability.

Within each major category, the following areas were identified:

Design Tools for Manufacturing



- a. **Software** – This consists of applications to enable foundries to develop optimal casting processes. Stand-alone resources to integrate manufacturability into a part design to enable manufacturing a functional part will allow foundries to better meet the needs of

the end customer while optimizing the part for manufacturability. Artificial Intelligence offers the ability to learn from a decision tree. Developing processes and enabling the computer to design a casting would provide new technology to blend part design, function, and manufacturability; thus, enabling the foundry industry to showcase efficient cast part designs. To take advantage of modeling and simulation capabilities, solid model data needs to freely translate between different software programs. An example of this is creating the software to translate between CAD and MAGMA to identify riser locations. The ability to know how risers might be placed is critical when setting up datum targets for a part. The seamless integration of solid model data between software packages is important to make certain data is not lost and features do not have to be recreated.

Key Tasks

- Couple design to manufacturing
- Develop software centered on foundry processes
- Optimize designs for both manufacturability and performance
- Seamlessly translate modeling data between software programs

Target Outcomes

- Higher quality / performing cast parts
 - Advances in modeling technology to allow a foundry to interact with customers to optimize designs
 - Software for foundries to optimize processes
 - Reduced production lead times
 - Efficient and error-proof transition of modeling data between software packages
- b. **Understand Parting Line** - Casting design for conventional casting processes require determining how to best create a split line as it relates to part performance, draft (ability to remove mold from pattern and part from die), secondary operations like machining (locating points, etc.) and assembly, and the need for additional manufacturing operations for cores, pulls, and loose pieces. Current approaches require significant manual design input and past experience expertise. Using expert-based rules to automate the process would result in more efficient casting design, lighter weight castings, and reduced costs.

Key Tasks

- Document heuristic techniques for the engineering of parting line and mold / die features
- Find the correlation between parting line and mold / die features and cost
- Develop modeling capability to optimize parting line and mold / die features for manufacturability
- Develop modeling capability to address effect on design based on GD&T, draft, etc. that would be impacted by parting line and mold / die features
- Incorporate advancements in technology such as AM as it pertains to parting line and mold / die features

Target Outcomes

- More cost effective designs
 - Ability to manufacture parts to the better match an initial design
 - Foundry tools to guide and enhance parting line and mold / die feature design and analysis
- c. **Actual Cost Tracking** – Activity Based Costing is important for all of manufacturing as companies benefit from the knowledge of what jobs are truly profitable. Knowing true cost allows companies to make improvements in manufacturing to make products that substantiate their business and future investment. One challenge for foundries is the extensive variability in means of manufacturing a casting. Therefore, standard cost estimating for the manufacturing operations required is difficult and not very valuable. Enabling a foundry to track part-specific costs through real-time automated data acquisition, empowers the foundry to know costs, including those of rework. Plus, it does not add the burden and inaccuracy of acquiring the cost data and does not require time studies which are inefficient and often biased. Furthermore, the ability to modify a design upfront or throughout its life cycle for manufacturing efficiencies will promote affordability. Smart Manufacturing is defined as the ability to solve current and future problems at the speed of business. New smart technologies will allow systemic rather than point solutions to be provided to the metalcasting manufacturing enterprise. This includes low cost sensors and the integration of programmable controllers and systems into a digital space, Big Data to provide real time control to optimize products and efficiency, and modeling to design and improve products. As laid out in the Internet of Things (IoT), much of the information needed is already available; thus, it is just a matter of bringing it all together and using it. Therefore, leveraging actual data from Smart Manufacturing will provide the key for actual cost.

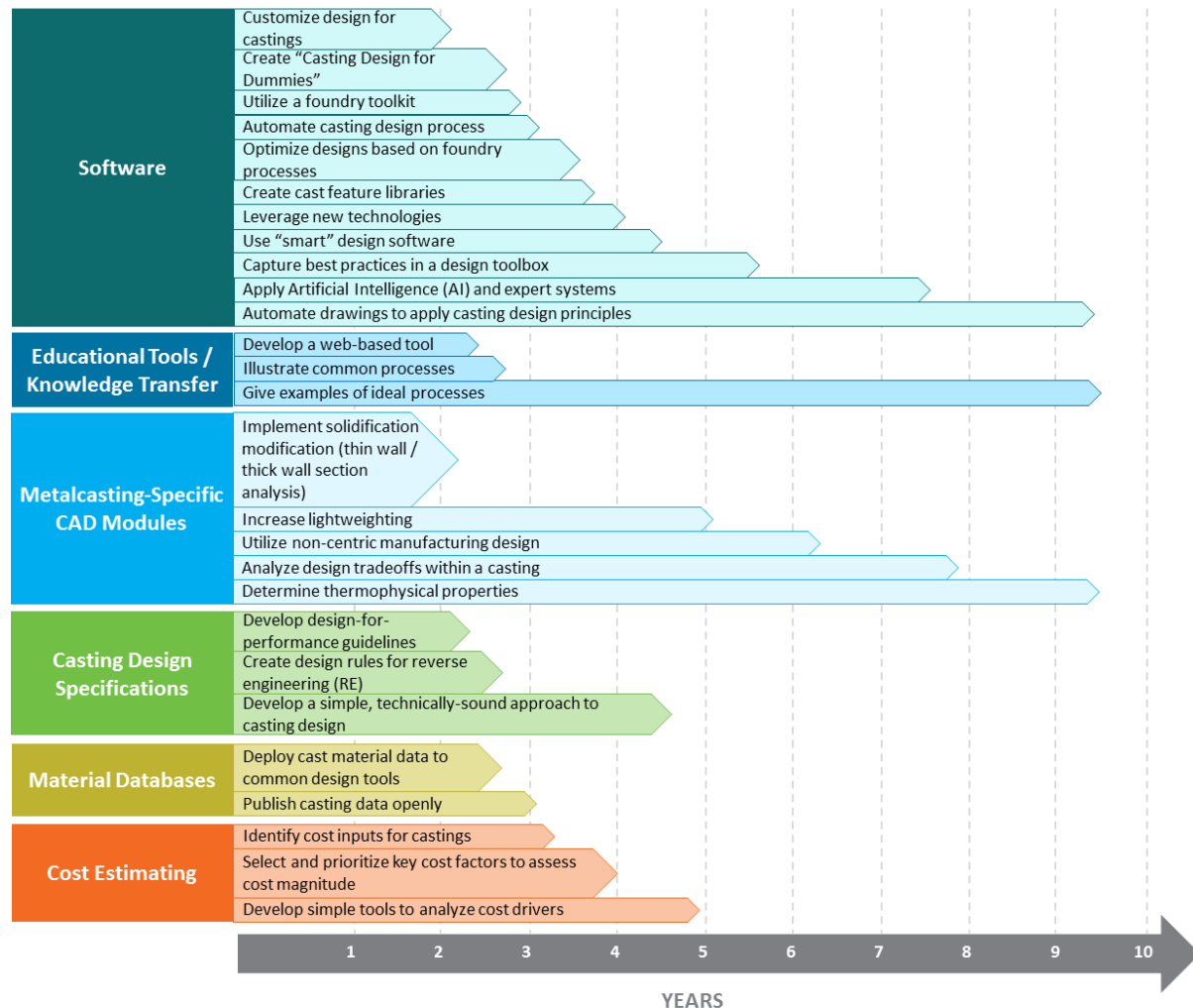
Key Tasks

- Develop and implement Internet of Things (IoT) principles for manufacturing data
- Enable foundries to leverage real-time, part-specific data to manage cost
- Design for affordability

Target Outcomes

- Manufacturing efficiencies
- A more responsive casting supply chain
- Cost reduction to enable reinvestment which will insure long-term industry capability

Design Tools for Casting



- a. **Software** – This consists of applications to guide the designer in developing optimal cast parts. Design For Manufacturability (DFM) casting-specific tools should include design optimization capability and references to historical examples and cost (including life cycle cost). The goal is stand-alone resources to integrate manufacturability into a part design to enable manufacturing of a functional part and software for designers that is process-centered with computer-based technology that will optimize a design based on any of the casting processes. Many design tools are available, but do not consider designing to part performance versus to specific features that may limit the ability to produce a given part by a variety of manufacturing processes. Designing a part for performance versus a manufacturing process allows the supply chain to vet the most capable and cost-effective technique for production. Software can assist with communication of these opportunities and should apply Artificial Intelligence and expert systems to learn from a decision tree. Developing processes and enabling the computer to design a casting would provide new technology to blend part design, function, and manufacturability. Algorithms should be used to apply casting design principles

automatically to drawings. Computer-driven technology should be used to automatically pick a starting place to leverage the ability to compare and modify solid model geometries to a set of standard and proven designs of select parts that are easy to cast. Smart software should be used to create casting designs that would be of high value to both foundries and part designers. Public domain, not profit-centered, shareware software or open source software will allow all designers to take advantage of casting technology. Whether designers have a new part that they are making in their basement or a new part at a multi-million dollar company, they need widely available tools to create cast parts. Creating cast feature libraries will enhance software capabilities through datasets that will enable designers to better leverage their native CAD software to create cast designs. Creating an internet tool such as “Casting Design for Dummies” will provide a simple overview of casting design to offer the basic resources for designing a cast part. Software will be critical to reach the next generation of customers. Educating customers on new designs and redesigns of parts as castings through a foundry toolkit will help foundries teach customers what works for casting and what does not. Foundries could continuously evolve the toolkit based upon their capabilities and customer base. Capturing best practice knowledge in a software design toolbox is critical as an aging manufacturing workforce is replaced with the next generation. The loss of tribal knowledge is a great threat to the U.S. manufacturing base. With decades of experience ready to walk out the door and a disconnect due to the gap of generations in the workforce, a great challenge exists for America to be able to make the parts it has historically made. This also means that knowing what has historically worked is lost also on the OEM side. Developing a system to capture this knowledge and enable the next generation to use it will reap dividends in both expanded capabilities and development of future enhancements.

Key Tasks

- Customize design for castings
- Create “Casting Design for Dummies”
- Utilize a foundry toolkit
- Automate casting design process
- Optimize designs based on foundry processes
- Create cast feature libraries
- Leverage new technologies
- Use “smart” design software
- Capture best practices in a design toolbox
- Apply Artificial Intelligence (AI) and expert systems
- Automate drawings to apply casting design principles

Target Outcomes

- Useful tools for casting design
- Effective use of cast part designs
- Advanced state of technology for the casting design process

- b. **Educational Tools / Knowledge Transfer** – This relates to information on common manufacturing processes and access to casting expertise. Educational tools for common manufacturing processes should use iconic products to illustrate the processes. A simple way to promote understanding of the capabilities of major casting manufacturing methods is to tag them to commonly made products. This will show neophytes where these processes have historically worked best. With the support of industry and academia, examples of optimal casting processes should be provided along with the rationale to explain the unique capabilities of the different casting methods. This can be set up in an open-source format such as a wiki where the community can be involved and add to the details; thus, constantly evolving the knowledge base.

Key Tasks

- Develop a web-based tool
- Illustrate common processes
- Give examples of ideal processes

Target Outcomes

- Easily accessible resources for self-guided and directed casting education
- An enabled next generation of designers and manufacturers for cast parts

- c. **Metalcasting-Specific CAD Modules** – These are tools to increase the manufacturability of cast designs. For example, a simple thin wall and thick sections analysis tool to look at transitions would provide important information to a foundry for feeding a casting as it solidifies. Simple design tweaks based upon section size analysis could increase the manufacturability of cast designs. Lightweighting technology is inherent in cast geometry as metal can be placed only where it is needed, which is a specific advantage of cast parts. Further enhancing this through high performance alloys and designing for weight reduction can increase lightweighting opportunities, which are critical in many industries. Modeling technology that can convert an optimized FEA into cast geometry would enhance this opportunity. A tool that makes design tradeoffs within a casting such as knowing how design decisions impact the manufacturability of a casting will facilitate the design of complex parts, and assist foundries in working with new designers who are inexperienced. Non-centric manufacturing design tools allowing a part to meet the performance requirements of a system versus being artifacts of CAD systems are important to ensure the optimization of the manufacturing process. Incorporating thermophysical properties of alloys, molds, and cores, as well as heat transfer coefficients will improve the modeling capability of existing software. Room temperature properties are commonly known for most materials; however, castings are made above the liquidus point of metals. Thus, knowing properties at temperatures for the metal and mold during the manufacturing process are needed to develop accurate simulation software.

Key Tasks

- Implement solidification modification (thin wall / thick wall section analysis)

- Increase lightweighting
- Utilize non-centric manufacturing design
- Analyze design tradeoffs within a casting
- Determine thermophysical properties

Target Outcomes

- Advanced modeling technology for the casting process
 - Cast designs for weight reduction and high performance
 - Enhanced casting specific software utilities for design and manufacturing
- d. **Casting Design Specifications** – This relates to the development of a simple, technically sound approach to casting design like the American Welding Society Structural Welding Code, AWS D1.1. Simple designs do not require the use of expensive AI design technologies that many companies cannot afford (at least initially). Having simple guidelines will prove a benefit in these cases. Castings do not currently have robust design-for-performance guidelines. Providing such will give designers a path for using castings through design specifications and will grow additional opportunities. Understanding how castings are different from other metal manufacturing processes will promote reverse engineering techniques that take into account casting features such as draft, riser contacts, parting lines, etc.

Key Tasks

- Develop design-for-performance guidelines
- Create design rules for reverse engineering (RE)
- Develop a simple, technically-sound approach to casting design

Target Outcomes

- Robust capability to readily use castings for engineered parts
 - Ability to reverse engineer legacy cast parts
- e. **Material Databases** – The goal here is to make sure casting materials are included in commonly available material databases. Cast alloys are different than wrought alloys with typical variances in chemistry and grade names. If casting materials are not available to designers in instruments they are already using, they will not be used for part designs.

Key Tasks

- Deploy cast material data to common design tools
- Publish casting data openly

Target Outcomes

- Better data for engineers to leverage in casting design to insure part performance

- Ability to utilize a casting design from the onset of the part development
- f. **Cost Estimating** – The ability of both the foundry and the customer to estimate cost is necessary to identify good casting candidates and then optimize them. Cost estimating provides the foundry with a basic rough order of magnitude cost to see if a part will be a good fit. Cost estimating provides the customer with a means to assess the supply chain to vet procurement. Simple cost estimating can be based on characteristics of a casting design such as number of cores and isolated heavy sections. It should be noted that even advanced costing packages such as aPriori struggle with the variables associated with castings such as order quantity, type of tooling, method of manufacturing, and supply and demand. Therefore, an estimate would likely better serve as an identification of cost drivers in a given design.

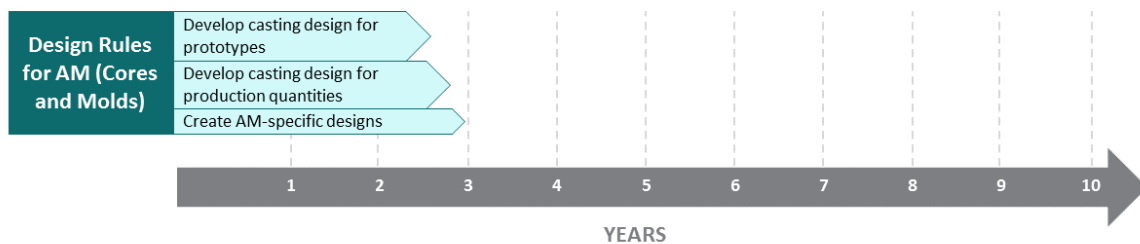
Key Tasks

- Identify cost inputs for castings
- Select and prioritize key cost factors to assess cost magnitude
- Develop simple tools to analyze cost drivers

Target Outcomes

- Technology to assess casting designs for cost
- Mechanism to educate both the foundry and customer on cost drivers

Additive Manufacturing (AM) Technology



- a. **Design Rules for AM (Cores and Molds)** – AM offers new capabilities for producing cores and molds. Understanding when these can be leveraged, and that printing technology for casting does not result in a printed casting are important for setting the right expectations and not exceeding capabilities. AM offers the ability to print reverse draft or internal features that would be difficult or impossible to do otherwise; thus, offers unique flexibility and applications. AM tooling can be used to prove out manufacturability of a design as traditional casting tooling cost and lead-time can preclude cast parts from consideration for low volume runs such as prototype development. Unfortunately, if casting is not identified in this initial design phase it is often never again considered as the additional cost to design and test the part cannot be overcome. Finally, expanding what industry has already leveraged in applying AM to casting will advance additional capabilities for casting designers.

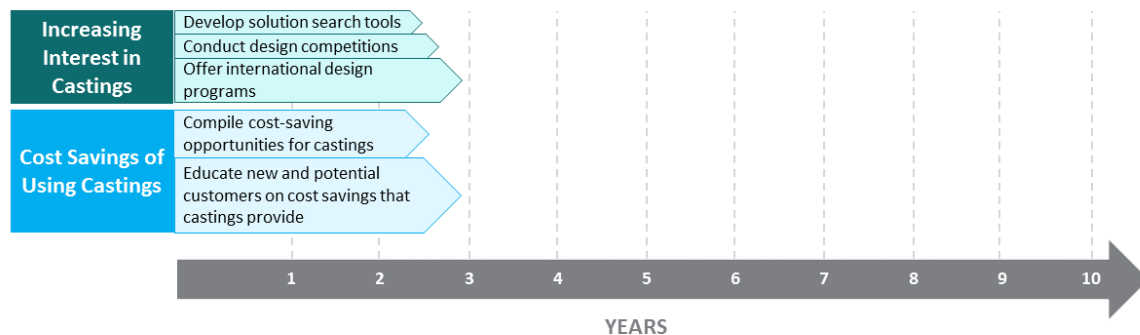
Key Tasks

- Develop casting design for prototypes
- Develop casting design for production quantities
- Create AM-specific designs

Target Outcomes

- Continue to grow and enhance the use of AM in the casting industry
- New opportunities for cost-effective or innovative tooling for castings
- Shorter lead times, faster production, and less expensive castings
- New enhanced and more efficient casting designs that take advantage of design freedom offered by AM technologies

Customer Resources



- a. **Increasing Interest in Castings** – There are many ways to promote interest in castings. A directory of casting experts could be provided, search tools could be created that allow someone to find casting solutions, competitions for casting design with scholarships could be sponsored, and an international metalcasting design summer school at European universities could be offered. Communication and education of casting options could also be provided through videos, TV exposure, and social media. Other possibilities to increase awareness include providing opportunities to work with engineers with casting expertise, developing an industry marketing plan, leveraging PR people, and offering contests and casting apps.

Key Tasks

- Develop solution search tools
- Conduct design competitions
- Offer international design programs

Target Outcomes

- Increased interest and comfort in the capabilities of castings so they become part of a designer's toolbox
 - Educational materials that enable leading-edge manufacturing of castings
- b. **Cost Savings of Using Castings** – Cast geometry inherently provides cost effective parts as it creates complex geometry of any size and shape from the liquid metal that fills a mold. It is the best process for creating internal geometry and for providing net-shape geometry for alloys that are expensive. Castings offer the flexibility of tailored alloys and mechanical properties based both on material and the design. Castings can reduce part counts and eliminate issues with tolerance stacks in assemblies. These opportunities along with looking at total cost when it comes to sourcing to a U.S. domestic foundry, all need to be communicated to the end user of the casting. Because of the variations in means of manufacturing a casting and the unique capabilities of different foundries, it is very challenging to develop a good cost-estimating tool. The development of a formula to estimate casting cost will help OEMs identify the right opportunities for castings. Providing a feel for the cost at the conceptual stage by building the capability for designers to quickly evaluate the cost in the initial design phase will best enable long-term decisions and allow upfront change to reap savings over the life of a system. Design parameters should be defined to deliver desired characteristics at an affordable cost and encourage life cycle responsibility (life cycle cost). Characterizing design parameter cost impacts will allow designers to consider the most cost-effective methods for manufacturing an item as well as the total cost over the life of a system.

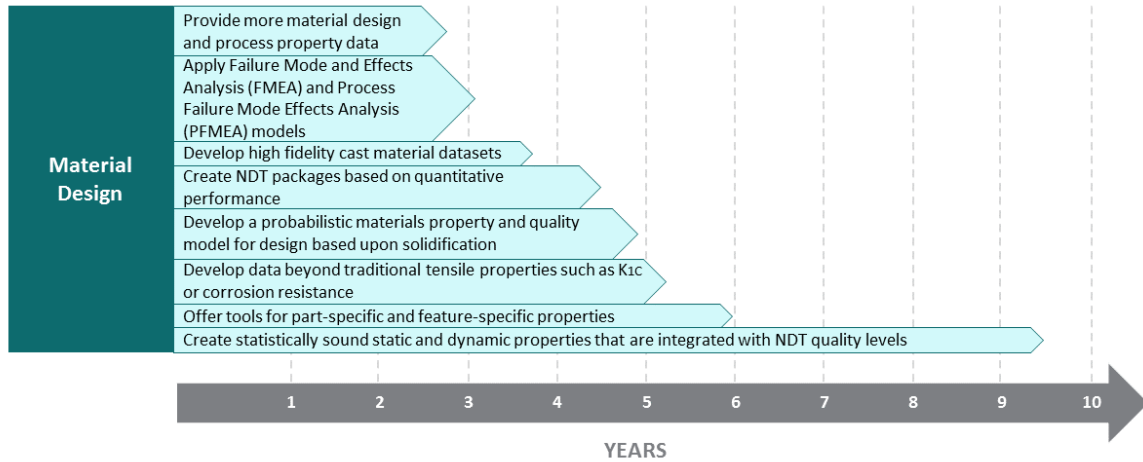
Key Tasks

- Compile cost-saving opportunities for castings
- Educate new and potential customers on cost savings that castings provide

Target Outcomes

- Beneficial relationship between purchaser and supplier
- Identification of additional cast parts

Performance-Based Reliability



- a. **Material Design** – This relates to the development of properties and quantitative non-destructive testing (NDT) parameters to enable design for reliability. Moving from liquid to solid is key for any casting and being able to model and predict properties is required if designers are to leverage castings and integrate them into simulation software for analysis of system functionality. A probabilistic materials property and quality model for design based upon solidification should be developed to advance casting use. Current NDT is based on workmanship and is only qualitative. This has worked largely due to the performance history of components, or by testing parts to failure. The latter is costly and time consuming. Parts can be designed using FEA, but the actual parts still need to be inspected to ensure they meet a quality threshold for performance. Providing an NDT package based on performance that is quantitative will enable advanced casting designs. Statistically sound material design static and dynamic properties that are integrated with NDT quality levels should be created. Having known properties that can be utilized during design is critical to assuring designers that a casting will achieve an expected level of performance. Unfortunately, casting property data is not readily available. Specifications often call out minimums and the material data is based on a heat sample versus actual properties within a part. Ensuring high part performance will require a much more detailed material database.

Key Tasks

- Provide more material design and process property data
- Apply Failure Mode and Effects Analysis (FMEA) and Process Failure Mode Effects Analysis (PFMEA) models
- Develop high fidelity cast material datasets
- Create NDT packages based on quantitative performance
- Develop a probabilistic materials property and quality model for design based upon solidification
- Develop data beyond traditional tensile properties such as K_{1c} or corrosion resistance

Metalcasting Industry Roadmap

- Offer tools for part specific and feature specific properties
- Create statistically sound static and dynamic properties that are integrated with NDT quality levels

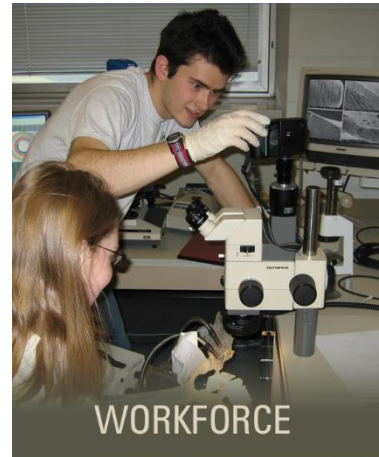
Target Outcomes

- Quantitative NDT
- High fidelity modeling
- Performance based reliability in cast parts



Workforce

Significant investment in workforce development will be required in order for the cast metals industry to remain vibrant and competitive in the future. A significant portion of the industry workforce, including a large population of “baby-boomer” generation workers, is approaching retirement age. As these workers transition from the active workforce, new workers will be needed to replace them. Input gathered from industry participants during the roadmapping workshop indicated a concern regarding the availability of workers that have the requisite skills, knowledge, and aptitude to be successful in the foundry industry. Accordingly, workshop participants identified broad areas of focus that will help develop the workforce necessary to carry the foundry industry into the next decade.



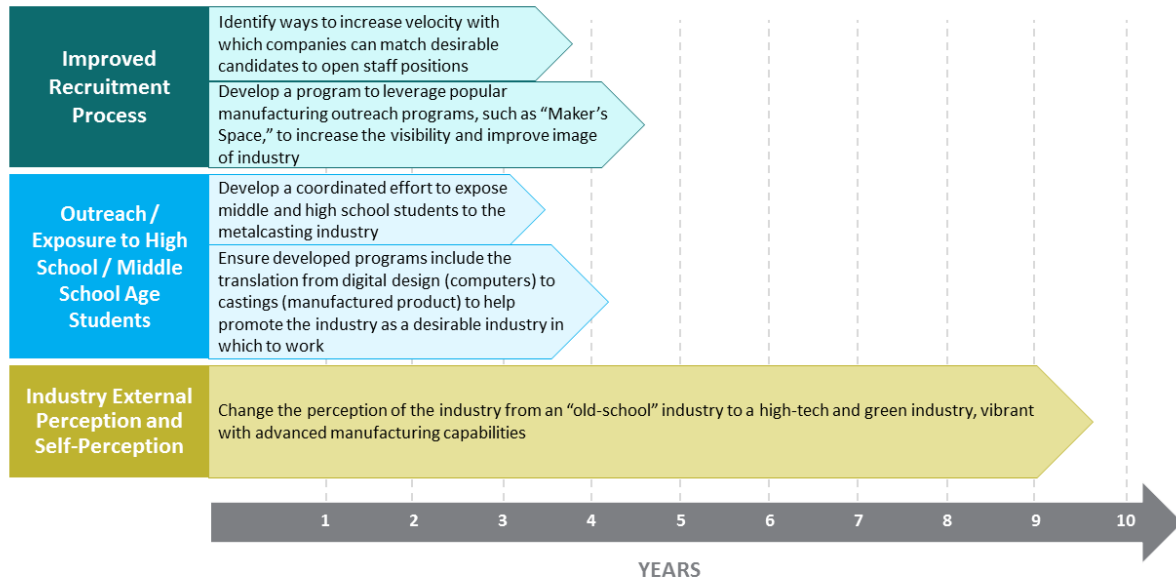
These topics include:

1. **Outreach** – Improved outreach strategies are needed to help promote the industry to younger students and to recruit college students who are looking for career paths upon graduation.
2. **Attraction** – New methods of employee attraction will be needed to supply highly trained and competent technical and managerial level employees to meet the industry’s needs.
3. **Training** – The following training aspects will be critical to developing the industry’s workforce skills to satisfy future industry requirements: developing specific training programs for production and management level employees; establishing / improving distribution channels to provide training; developing reliable sources of funding to ensure training materials remain relevant, updated, and available; and providing a framework for the development of industry professional certifications for specific industry job classifications.
4. **Retention** – Developing methods to help retain high-quality workers in the foundry industry will be a vital part of the industry’s workforce development efforts in the future.
5. **Other Areas of Interest** – Strategies must be developed to assist the industry with capturing existing employee knowledge from the shop floor and translating this information into training programs that can accelerate the pace at which new hires become productive foundry employees.

Within each major category, the following areas were identified:



Outreach



- a. **Improved Recruitment Processes** – Foundries typically are too late in the recruitment cycle, take too long to make a decision to hire desirable students / employees, and often do not provide sufficient starting salaries to draw the most desirable candidates to the industry. In addition, the foundry industry is often perceived as an “old-school” industry that is dirty and filled with old technologies. Changing the narrative so that potential employees perceive the industry as modern and “high-tech” is important. When coupled with popular manufacturing outreach programs such as “Maker’s Space” type programs and improved industry hiring practices, the most desirable candidates are more likely to consider the foundry industry as a high-value destination for their career path.

Key Tasks

- Identify ways to increase the velocity with which companies can match desirable candidates to open staff positions
- Develop a program to leverage popular manufacturing outreach programs, such as “Maker’s Space” to increase the visibility and improve the image of the industry

Target Outcomes

- Improved outreach capabilities to prospective and desirable industry workers
- b. **Outreach / Exposure to High School / Middle School Age Students** – Development of a program to help introduce young students to metalcasting can help raise visibility of the industry to young potential workers and help teach them of the careers that are available to them in the industry. Programs such as a “\$20 dollars and 24 hours” campaign aimed at middle school and high school students could help promote the foundry industry and its capabilities to younger students. This type of outreach program will provide access to

students in grades 7-12, when some students begin thinking of future career paths, and provide a compelling argument in favor of a career in the casting industry. Exposure to the digital design and its integration into the metalcasting process can help reinforce the idea that metalcasting is a high tech and “cool” industry to want to work in during their career.

Key Tasks

- Develop a coordinated industry effort to expose middle and high school students to the metal casting industry
- Ensure developed programs include the translation from digital design (computers) to castings (manufactured product) to help promote the industry as a desirable industry in which to work

Target Outcomes

- Increased awareness among young students about the availability of career paths in the foundry industry
 - Improved industry perception by the next generation of workers
 - Increased numbers of young workers seeking employment in the foundry industry as a career path
- c. **Industry External Perception and Self-Perception** – Some workshop attendees felt that the external perception as well as their own self-perception of the foundry industry as a dirty, dusty, and “old-school” industry was resulting in potential employees looking for work in other industries. Changing the external perception of this industry (i.e. defining the industry as a “green” industry because of the recycling aspect of the industry or defining it as high-tech because of the use of computer design and solidification software) may help persuade new types and sources of employees to pursue careers in metalcasting.

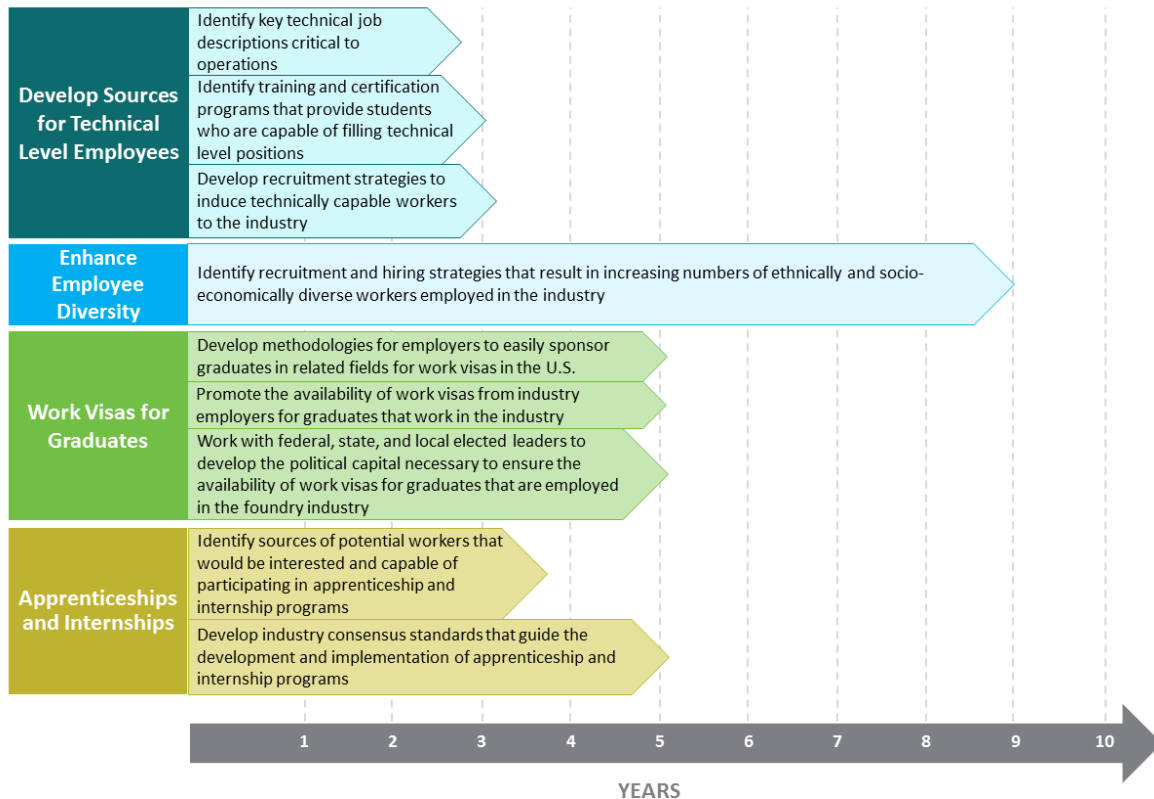
Key Tasks

- Change the perception of the industry from an “old-school” industry to a high-tech and green industry, vibrant with advanced manufacturing capabilities

Target Outcomes

- Improved levels of industry perception among potential industry workers, leading to more workers desiring employment within the foundry industry

Attraction



- a. **Develop Sources for Technical Level Employees** – Technical level employees were defined as being the employee class that sits between foundry management and foundry laborers on most organizational charts. These include welders, patternmakers, machinists, and other job classifications that typically require technical level training and / or certification. These were identified as the types of staff positions that are the most difficult to fill from the foundry viewpoint. Developing additional sources for these “technical” level employees would increase the pool of eligible workers who can fill these roles, increase the visibility of the foundry industry to these sources, and ultimately lead to increasing numbers of technical employees who come to work in the foundry industry.

Key Tasks

- Identify key technical job descriptions critical to operations
- Identify training and certification programs that supply students who are capable of filling technical level positions
- Develop recruitment strategies to induce technically capable workers to the industry

Target Outcomes

- Increased pool of technically capable employees working in, and desiring employment in, the foundry industry
- b. **Enhance Employee Diversity** – Concerns were raised regarding the lack of diversity in foundry employee demographics, as well as at industry leadership events such as CastExpo and other industry / association events. It was discussed that increasing diversity in all layers of the industry, from trade associations to universities to foundries themselves, can help attract new employees with a “millennial” viewpoint.

Key Tasks

- Identify recruitment and hiring strategies that result in increasing numbers of ethnically and socio-economically diverse workers employed in the industry

Target Outcomes

- Increased numbers of non-traditional workers employed within the foundry industry
- c. **Work Visas for Graduates** – Concern was expressed by several workshop participants that once students are educated in related disciplines, such as material science and mechanical engineering, they are sent “back home” rather than staying in the U.S. to benefit domestic industries. A program that actively helped provide work visas to graduates within specific technical fields could help the industry fill the technical positions that are typically difficult to staff and in particular help foreign national graduating seniors identify the foundry industry as a potential career path.

Key Tasks

- Develop methodologies for employers to easily sponsor graduates in related fields for work visas in the U.S.
- Promote the availability of work visas from industry employers for graduates that work in the industry
- Work with federal, state, and local elected leaders to develop the political capital necessary to ensure the availability of work visas for graduates that are employed in the foundry industry

Target Outcomes

- Increased numbers of foreign nationals with advanced degrees actively working in the cast metals industry
 - Increased pool of available prospective employees to staff hard-to-fill technical positions
- d. **Apprenticeships and Internships** – Multiple different comments were consolidated into this broad category. Ultimately, the consensus was that identifying potential employees

Metalcasting Industry Roadmap

early in their career and providing a path to competency, such as an apprenticeship / internship program, is the key to successfully managing the long-term labor needs for this industry. Many alluded to the apprenticeship type training programs that used to exist for this (and other) industries and to the fact that these types of programs really do not exist anymore. It was felt that these programs could be part of an effective long term strategy for attracting talented students to the foundry industry.

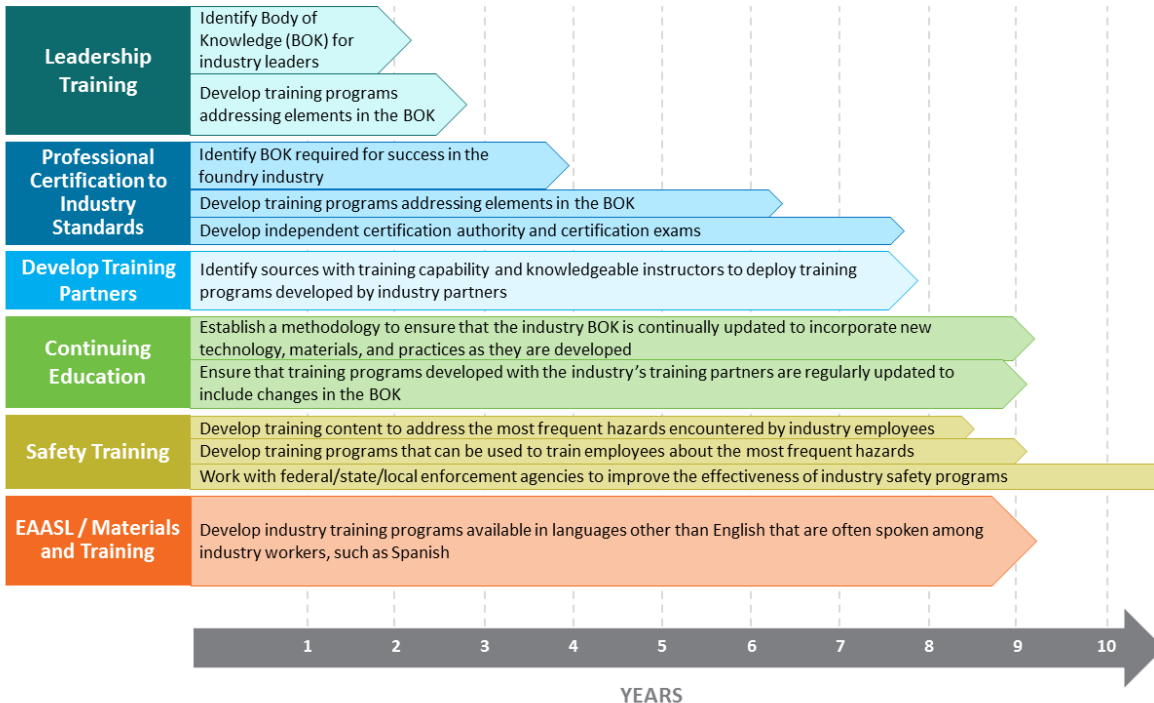
Key Tasks

- Identify sources of potential workers that would be interested and capable of participating in apprenticeship and internship programs
- Develop industry consensus standards that guide the development and implementation of apprenticeship and internship programs

Target Outcomes

- Increased numbers of potential workers available to fill labor openings in the industry
- Improved effectiveness of new hires in foundry operations

Training



- a. **Leadership Training** – The next generation of industry leaders will require training to effectively lead the industry. “Leaders cannot be led, they can only be trained” was repeated by participants on more than one occasion.

Key Tasks

- Identify Body of Knowledge (BOK) for industry leaders
- Develop training programs addressing elements in the BOK

Target Outcomes

- Industry executive level leadership training programs available

- b. **Professional Certification to Industry Standards** (e.g. certified foundry technician) – The intent was to develop a knowledge base and benchmark for the education, skills, and abilities that would be required for success in the foundry industry. Training materials should be developed to address the content of the knowledge base, and an independent certification would allow employers to see an impartial certification of a potential new hire’s capabilities and competencies.

Key Tasks

- Identify BOK required for success in the foundry industry
- Develop training programs addressing elements in the BOK
- Develop independent certification authority and certification exams

Target Outcomes

- Well-qualified industry workforce with independent verification of skills / abilities
 - A clear directory of industry skills and education necessary for workers to be successful
 - A prescribed course of study that will provide an efficient methodology to quickly develop skills and abilities in new industry hires
 - An industry professional certification that is viewed by employers as a desirable credential and by industry workers as a path to industry employment
- c. **Develop Training Partners** – Develop training partners such as associations, education foundations, universities, and community colleges to provide training to the industry and its employees by knowledgeable instructors. This is partially a result of the desire of companies to offload the requirements for employee training, especially for remedial skills.

Key Tasks

- Identify sources with training capability and knowledgeable instructors to deploy training programs developed by industry partners

Target Outcomes

- A robust network of training providers able to reach industry employers and employees in all geographic areas of the United States
- d. **Continuing Education** – Technology continues to develop at an increasing rate, and it was deemed important to develop continuing education content to help industry employees stay abreast of new technologies, materials, and practices that will impact the foundry industry.

Key Tasks

- Establish a methodology to ensure that the industry BOK is continually updated to incorporate new technology, materials, and practices as they are developed
- Ensure that training programs developed with the industry's training partners are regularly updated to include changes in the BOK

Target Outcomes

- Robust training programs that are relevant and up-to-date with developments in product design, casting materials, and industry processes
- e. **Safety Training** – Improved safety training materials can benefit the industry in many ways, including: 1) promotion of a safer work environment, leading to more employees wanting to work in the industry; 2) increased retention of existing industry workers; 3) reduced numbers of injuries / illnesses resulting in improved industry productivity / profitability; and 4) reduced numbers of recordable incidents lower the industry visibility to enforcement agencies such as federal / state OSHA.

Key Tasks

- Develop training content to address the most frequent hazards encountered by industry employees
- Develop training programs that can be used to train employees about the most frequent hazards
- Work with federal / state / local enforcement agencies to improve the effectiveness of industry safety programs

Target Outcomes

- Comprehensive library of industry specific safety training programs and materials, provided in a variety of languages and designed to make employee safety training easy and effective
- f. **EAASL Materials and Training** – With an increasing portion of the industry workforce speaking English As A Second Language (EAASL), the need for industry training materials available in the language most commonly spoken by plant employees is

increasing as well. It is felt that adoption of the worker's native language in plant operating documents will help recruit and retain key employees who speak EAASL.

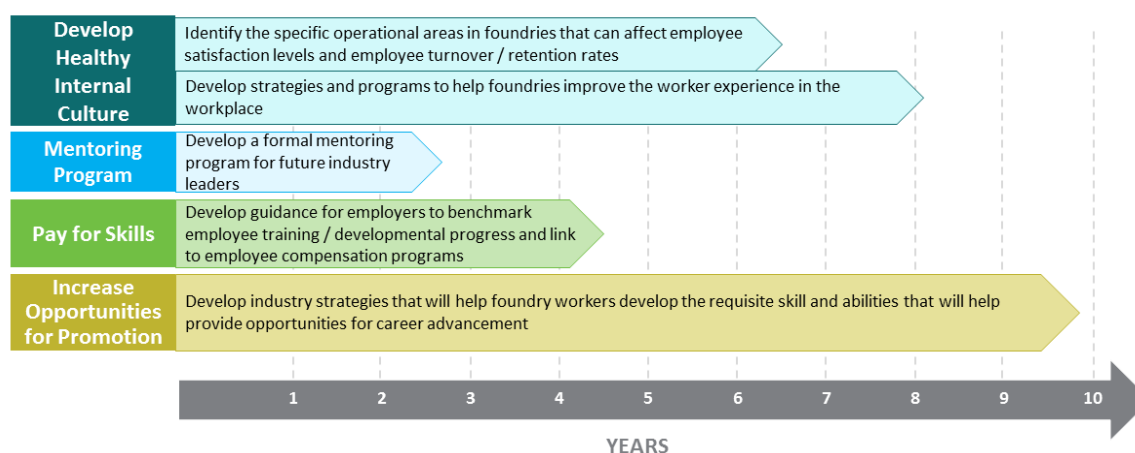
Key Tasks

- Develop industry training programs available in languages other than English that are often spoken among industry workers, such as Spanish

Target Outcomes

- Training programs available in a wide variety of languages other than English

Retention



- Develop Healthy Internal Culture** – Developing a “healthy” internal culture is a critical component of retaining industry workers. Better working environments will help to reduce employee turnover rates and improve employee retention levels.

Key Tasks

- Identify the specific operational areas in foundries that can affect employee satisfaction levels and employee turnover / retention rates
- Develop strategies and programs to help foundries improve the worker experience in the workplace

Target Outcomes

- Improved employee retention rates and workplace satisfaction levels
- Mentoring Program** – Development of a foundry mentoring program was identified as a positive step in retaining / recruiting key foundry employees who may form part of the next generation of foundry leadership. Mentors are much more likely to be able to

proactively train potential new leaders and to help them develop the skills required to lead in the coming years / decades.

Key Tasks

- Develop a formal mentoring program for future industry leaders

Target Outcomes

- Improved numbers of next-generation foundry leaders with requisite skills and abilities available to lead foundry operations
 - Improved industry retention levels of qualified executives
- c. **Pay for Skills** – Paying increased wages to workers who successfully complete employee training and development programs is critical to retaining these employees in the industry.

Key Tasks

- Develop guidance for employers to benchmark employee training / developmental progress and link to employee compensation programs

Target Outcomes

- Improved foundry employee retention rates
- d. **Increase Opportunities for Promotion** – Increasing opportunities for promotion is important to retain quality industry workers who often do not see a path from foundry worker to foundry management.

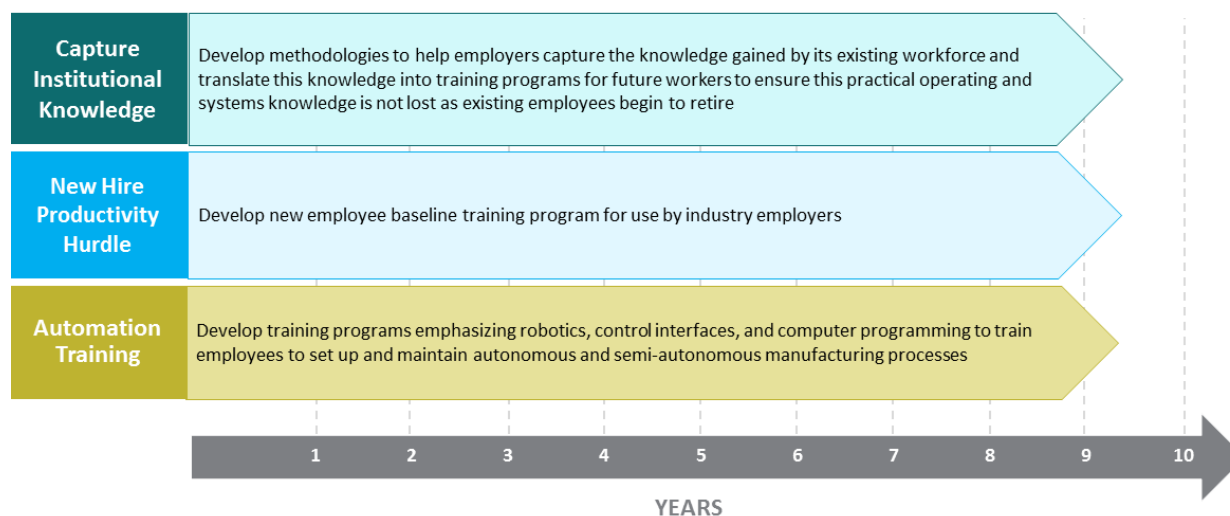
Key Tasks

- Develop industry strategies that will help foundry workers develop the requisite skill and abilities that will help provide opportunities for career advancement

Target Outcomes

- Increased industry retention levels of high quality workers

Other Areas of Interest



- a. **Capture Institutional Knowledge** (Processing Techniques, Organizational History, Past Experiences, etc.) – This item was placed into the other category, but it should not be perceived as a minor issue. With the rapidly aging workforce within the foundry industry, there is concern about how to capture and retain the knowledge gained by employees over the past years / decades and to translate that information and experience into training for the next generation of employee.

Key Tasks

- Develop methodologies to help employers capture the knowledge gained by its existing workforce and translate this knowledge into training programs for future workers to ensure this practical operating and systems knowledge is not lost as existing employees begin to retire

Target Outcomes

- Practical systems that can be used by industry employers to document existing workforce knowledge and provide this knowledge base to future hires
- b. **New Hire Productivity Hurdle** – Concerns were raised about the “lag” time between a new employee’s hire date and the date at which that employee can be productive. Typically there is a learning curve that employees must navigate before they can be productive. Development of a new employee “onboarding” or baseline training program that new employees must successfully pass would shorten the time between hire and productivity.

Key Tasks

- Develop new employee baseline training program for use by industry employers

Target Outcomes

- Reduced time between an employee hire date and their date of “productivity”
- c. **Automation Training** – Automation was identified as an ongoing cause for reductions in employee counts across the industry. Development of potential employees who can help manage plant automation would be especially beneficial as foundries strive to reduce variation and improve worker safety levels by implementing automation into their production methodologies.

Key Tasks

- Develop training programs emphasizing robotics, control interfaces, and computer programming to train employees to set up and maintain autonomous and semi-autonomous manufacturing processes

Target Outcomes

- Increased numbers of workers available to manage automated foundry manufacturing processes

Appendix

Acronym List

3D	Three Dimensional
3DSP	Three Dimensional Sand Printing
ACRC	Advanced Casting Research Center
AFS	American Foundry Society
AI	Artificial Intelligence
AM	Additive Manufacturing
AMC	American Metalcasting Consortium
AWS	American Welding Society
BOK	Body of Knowledge
BS	Bachelor of Science
CAD	Computer Aided Design
CAST-II	Casting Advanced Systems Technology - Integration Team
CMC	Cast Metals Coalition
CNC	Computerized Numerical Control
DFM	Design For Manufacturability
DLA	Defense Logistics Agency
DMC	Defense Manufacturing Conference
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoD	Department of Defense
DoE	Department of Energy
EAASL	English As A Second Language
EHS	Environmental Health and Safety
FEA	Finite Element Analysis
FMEA	Failure Mode and Effects Analysis
GD&T	Geometric Dimensioning and Tolerancing
HIP	Hot Isostatic Pressing
HPDC	High Pressure Die Casting
IoT	Internet of Things
JDMTP	Joint Defense Manufacturing Technology Panel
K _{1c}	Critical fracture toughness
MS	Master of Science
NADCA	North American Die Casting Association
NAM	National Association of Manufacturers
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Testing
NFFS	Non-Ferrous Founders' Society

Metalcasting Industry Roadmap

OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OSHA	Occupational and Safety and Health Administration
PFMEA	Process Failure Modes Evaluation and Analysis
PMP	Project Management Professional
PR	Public Relations
R&D	Research and Development
RE	Reverse Engineering
REC	Roadmap Executive Committee
RSM	Rapid Subtractive Manufacturing
RTAC	Roadmap Technical Advisory Committee
SFSA	Steel Founders' Society of America
SM	Smart Manufacturing
T&O	Technical and Operating
US	United States

May 2015 Roadmapping Workshop – Key Issues Identified by Participants

The AMC Roadmapping Development Workshop was conducted on May 12-13, 2015. Participants presented and discussed the important metalcasting issues and the required R&D / technologies / resources needed in small breakout groups consisting of six to eight people per group. The information below lists the key issues identified by participants prior to the breakout group sessions.

- Higher integrity, higher performance cast products
- Porosity reduction
- Higher strength, thin wall, porosity free, aluminum die casting
- Structural aluminum die cast alloy technology
 - Alloys
 - Fluidity
 - Refractory metal shot sleeves
 - Pressurized solution heat treat for T6 heat treating
- How to integrate advancing next generation of metalcasting employees via relevant real-world activities
- Increased performance
- How to speed up casting parts by a factor of 10 by 2025
- To develop disruptive technologies to ensure US metal casting industry's competitiveness via knowledge creation and knowledge workers
- Thin wall castings and lightweighting
- Knowledge transfer, growing technology through education
- Sustainability (as the) key driver of molding materials innovation
- Workforce succession plan
- Design approach technically sound / accessible to next generation
- Transfer of knowledge, experiment – model, teaching, identify gaps
- Effective workforce recruitment and development
- Implementation of new technology additive manufacturing
- Improved alloys
- Key industry technical concerns for DoD
- Improve industrial base, promote competition, and reduce costs (faster, better, cheaper)
- Technology transfer to non-believers
- Transfer new technologies to practical application in industry
- Get best / brightest to foundry floor
- Manufacturing system whose primary metric isn't tons produced
- Integrated digital casting design and production
- Design for performance-based reliability in a digital world
- Process control systems
- Environmentally benign casting processes (mid-term)

Metalcasting Industry Roadmap

- Attract, retain, and develop talent in industry
- Incorporating / attracting the next generation
- Digital design and manufacturing for communication and capture knowledge
- Eliminate the properties gap between cast and forged / wrought products
- Learn the needs of the metalcasting industry
- Interaction of technologies and how they relate to SMFG
- Casting and design software app or CAD
- Use new technologies to grow casting market share versus losing market share to new technologies (process evolution)

Workshop Results by Breakout Group

AMC Technology Roadmap: Process-Related Technology

Short Term

- **Advancement & Integration of Additive Manufacturing (AM) in Metalcasting**
 - Integration of AM into current metalcasting manufacturing stream
 - AM Print pattern / tooling as disposable tooling
 - AM to support / replace conventional manufacturing
- **Lightweighting**
 - Thin wall casting
- **Smart Machines, Manufacturing, Testing and Controls**
 - Complete Part Traceability
 - Machine/Process OEE & Performance
 - In-process control to reflect actual manufacturing performance
 - Improve and implement sensors/smart machines
- **Digital Thread Integration & Implementation**
 - Smart Mfg.- MT Connect
 - Digital Thread Integration
 - Process Failure Modes Evaluation and Analysis
 - Capture and analyze Big Data
 - Better tools to take X,Y, Z data to input and compare to CAD model
- **Automation, Ergonomics & Sustainability**
 - Improve Ergonomics
 - Appropriate automation to improve environment
 - Integration of gaming technology to manufacturing
- **Melt-Pour-Cast**
 - Reduce chemistry and process variation
- **Advanced Metalcasting Technology**
 - Collaboration with equipment suppliers to improve process performance
 - Ablation casting—directly applied cooling
 - Revolutionize Die Cast Equipment
 - Solution Heat Treat under pressure to reduce porosity
- **Quality**
 - Improve Yield

Mid Term

- **Smart Machines, Manufacturing, Testing and Controls**
 - Controlled die-thermals in HPDC
 - Optimization of variables when they change
 - Develop and define the various process input in metalcasting processes
- **Digital Thread Integration & Implementation**
 - Collect and analyze historical data sets
- **Automation, Ergonomics & Sustainability**
 - Better flexible automation
 - End of Life – recover to recycle
- **Melt-Pour-Cast**
 - Improve pouring process
 - Understand shrinkage and various interaction aspects
- **Quality**
 - Eliminate process variation in hot-side of investment casting
 - Secondary processes that improve material

Long Term

- **Advancement & Integration of Additive Manufacturing in Metalcasting**
 - Print cores, molds at casting rate
- **Smart Machines, Manufacturing, Testing and Controls**
 - Eliminate manual tweak and operator interface in process
- **Digital Thread Integration & Implementation**
 - Modeling inspections to part performance
- **Melt-Pour-Cast**
 - Molten Metal On-Demand
 - Eliminate ladles
- **Advanced Metalcasting Technology**
 - Die casting of ferrous metals via diffusion solidification
 - Semi-continuous casting
 - Pressure casting-advanced mold materials for casting, Ti, steel, etc.
 - Manipulate fields to produce engineered product (elect, temp, pressure, and magnetic)
- **Quality**
 - Robust NDT/NDE tools that relate to product performance

AMC Technology Roadmap: Design-Related Technology

Short Term

- **Design for Manufacturing**
 - Software Tools
 - Customized for Castings
 - Couple Design to Manufacturing
 - Understand parting line
 - Cost Estimating
 - Educational Tools
 - Incorporating Material Databases
- **Design Tools**
 - Automation of Casting Design Process
 - “Smart” Design Software
 - Metalcasting-Specific CAD Modules
 - Thin Wall / Thick Section Analysis
 - Lightweighting
 - Casting Design Specifications
 - Create group of design specs for castings
 - Design rules for reverse engineering
 - Accessible Software
- **Additive Manufacturing (AM) Technology**
 - Design
 - Design rules for AM (cores and molds)
 - Creating AM specific designs using advantage of process flexibility
 - Prototyping/Production
 - Use of AM to prove out manufacturability of the design
 - Direct printing of functional parts
 - Design for AM as a prototyping tool
- **Performance-Based Reliability**
 - Create statistically sound material design static and dynamic properties that are integrated with NDT quality levels
 - More material property data

Mid Term

- **Design for Manufacturing**
 - Software Tools
 - Process-Centered
 - Design Optimization Tools
 - Understand parting line
 - Cost Estimating
- **Design Tools**
 - Metalcasting-Specific CAD Modules
 - Non-centric manufacturing design
 - Casting Design Specifications
 - Simple technically sound approach to casting design
 - Accessible Software
- **Seamless CAD / CAM Between Different Software Programs**
- **Performance-Based Reliability**
 - Create statistically sound material design static and dynamic properties that are integrated with NDT quality levels

Long Term

- **Design for Manufacturing**
 - Cost Estimating
 - Design for Affordability
- **Design Tools**
 - Automation of Casting Design Process
 - Apply artificial intelligence and expert systems
 - Automate drawings to apply casting design principles
 - Metalcasting-Specific CAD Modules
 - Design tradeoffs within a casting
 - Thermophysical properties for alloy, molds, heat transfer coefficients
 - Accessible Software

AMC Technology Roadmap: Material-Related Technology

Short Term

- **Cast Materials**
 - Optimization of Properties
 - Reduction of Defects via Alloying
 - Enhanced Alloys
 - Optimization of Standard Alloys
 - Sustainability
 - Hybrids
- **Mold Materials**
 - Die Materials
 - Improved Dies / Die Life
 - Die Coatings and Lubricants
 - Expendable Cores
 - Sand
 - Disposal/ Reclamation
 - Binders / Coatings
 - Wax
 - Wax Without Ash
- **Consumables**
 - Improved Furnace Refractories
 - Improved Refractory Lining, Sleeves, Risers, Shells
 - Cost reduction
 - Improved quality

Mid Term

- **Cast Materials**
 - Optimization of Properties
 - Optimization of Properties (to include development of new standards)
 - Reduce Variability
 - Enhanced Alloys
 - Metal Composites MT
 - Lightweight Metals (includes xvi) MT
 - Other (such as metallic glasses, super bainitic steels) MT
 - Sustainability
 - Hybrids
- **Mold Materials**
 - Die Materials
 - Modeling and Design Criteria
 - Sand
 - Modeling
- **Consumables**
 - Improved Furnace Refractories

Long Term

- **Cast Materials**
 - Optimization of Properties
 - Modeling to Predict Properties
 - Establish Guaranteed Minimums
 - Sustainability
 - Hybrids
- **Mold Materials**
 - Sand
 - Silica replacement
- **Consumables**
 - Improved Furnace Refractories

AMC Technology Roadmap: Workforce-Related Technology

Short Term

- **Training**
 - Leadership
 - Professional Certification to Industry Standards
 - Develop Training Partners
 - Continuing Education
 - Safety
 - English as a Second Language
- **Retention**
 - Develop Healthy Internal Culture
 - Mentoring Program
 - Pay for Skills Development
- **Attraction**
 - Resources to Develop and Promote Technical Level Employees
 - Enhance Employee Diversity
 - Work Visas for Graduates
 - Apprenticeships/Internships
- **Outreach Programs**
 - Recruitment Process
 - Industry external perception and self-perception
 - Outreach/Exposure to High School/Middle School students
 - Utilize Maker's Space popularity to promote opportunities in foundry industry
- **Other**
 - Capturing Institutional Knowledge
 - New Hire Productivity Hurdle
 - Automation Training

Mid Term

- **Training**
 - Leadership
 - Professional Certification to Industry Standards
 - Develop Training
 - Continuing Education
 - Safety
 - English as a Second Language
- **Retention**
 - Develop Healthy Internal Culture
 - Mentoring Program
 - Pay for Skills Development
- **Attraction**
 - Resources to Develop and Promote Technical Level Employees
 - Enhance Employee Diversity
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 - Recruitment Process
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 - Outreach/Exposure to High School/Middle School students
 - Utilize Maker's Space popularity to promote opportunities in foundry industry
- **Other**
 - Capturing Institutional Knowledge
 - New Hire Productivity Hurdle
 - Automation Training

Long Term

- **Training**
 - Leadership
 - Professional Certification to Industry Standards
 - Develop Training
 - Continuing Education
 - Safety
 - English as a Second Language
- **Retention**
 - Develop Healthy Internal Culture
 - Mentoring Program
 - Pay for Skills Development
- **Attraction**
 - Resources to Develop and Promote Technical Level Employees
 - Enhance Employee Diversity
 - Work Visas for Graduates
 - Apprenticeships/Internships
- **Outreach Programs**
 - Recruitment Process
 - Industry external perception and self-perception
 - Outreach/Exposure to High School/Middle School students
 - Utilize Maker's Space popularity to promote opportunities in foundry industry
- **Other**
 - Capturing Institutional Knowledge
 - New Hire Productivity Hurdle
 - Automation Training

Workshop Participant Biographies (May 2015)

Diran Apelian

Alcoa-Howmet Professor of Mechanical Engineering, Director, Metal Processing Institute, Worcester Polytechnic Institute (WPI), Worcester, MA (508) 831-5992

Dr. Apelian received his BS degree in Metallurgical Engineering from Drexel University (1968) and his Doctorate in Materials Science and Engineering from MIT (1972). After graduating from MIT, he joined Bethlehem Steel's Homer Research Laboratories where he co-developed the Ultra-Form series of high strength low alloy steels. He joined Drexel University in 1976 and held various positions at Drexel, including professor, Head of the Department of Materials Engineering, Associate Dean of the College of Engineering, and subsequently Vice-Provost of the University.

He joined WPI in July 1990 as the Institute's Provost and led the mission of broadening WPI's academic programs and research agenda. After a six-year tenure as Provost, he headed the Metal Processing Institute (MPI) at WPI, which is an industry-university alliance with Centers in Metal Casting, Heat Treating, and Resource Recovery and Recycling. MPI is supported by over 80 corporate partners, as well as funding from private foundations and the federal government.

Dr. Apelian is widely recognized for his innovative work in metal processing and for his leadership as a researcher and educator. His work in the fields of molten metal processing, plasma processing, spray casting, and shape casting of aluminum alloys can be described as pioneering work. More recently, his work in the development of technologies to recover and recycle materials is critically important for a sustainable future. He has over 600 publications to his credit and twelve books, which he has written or co-edited. For his achievements, Professor Apelian has been honored with numerous awards.

He is a member of the NAE (National Academy of Engineering), European Academy of Science, and the Armenian Academy of Sciences. Professor Apelian is a member of various professional societies including TMS, ASM, AFS, NADCA, and MPIF. He serves on several corporate boards, as well as on the strategic / science councils of several global corporations.

Paul Armstrong

Director of Sales and Marketing for Armstrong Rapid Manufacturing, East Syracuse, NY

rangefinder@earthlink.net (781) 255-1080 (office); (617) 697-5307 (cell)

Metalcasting Industry Roadmap

Paul Armstrong is a second generation partner and Director of Sales and Marketing for Armstrong Rapid Manufacturing (ARM) in East Syracuse, NY. Paul has worked at ARM since 1989 as well as serving many associations within manufacturing, including two terms as Chairman for the American Metal Consortium (AMC), NFFS Board member and founder of RIM Molders Association (RMA).

Paul attended Rochester Institute of Technology School of Engineering from 1973-1978 and has become known within industry as an innovative and free thinker on issues of new technology and promoting manufacturing to the new generation of engineers and buyers.

Armstrong RM is an industry leader providing prototype and short run production of complex machined aluminum castings using several different processes dependent on the application including, Rubber Plaster Mold, Air Set Sand, and Graphite Die Casting. ARM is ISO 9001 and AS 9100 certified.

Robert L. Beard

Advanced Development Director, Sloan Valve Company, Augusta, AR

Robert.Beard@sloanvalve.com (870) 347-8133

Robert Beard has been the Advanced Development Director at Sloan Valve Company in Augusta, Arkansas since August 2014. He was the Plant Manager / Director of Operations at Sloan Valve from December 1987 to August 2014. He has been employed in the foundry industry since 1973, first with ITT Grinnell, then NIBCO, and finally at Sloan Valve.

Robert served on the NFFS Board from 1997 thru 2009 as Board Member, Executive Board Member, Treasurer, Vice President, President and finally Immediate Past President. He continues to serve on the NFFS Finance Committee. He has served on the AFS Division 3 Copper Alloy Committee from 1988 to present, and has served as Secretary Elect, Secretary, Vice Chair, Chair, and Past Chair. He received the Division's Dave Kunkle Award in 2012 along with an AFS Special Merit Award for Service.

Robert is a Graduate of Arkansas State University. He is married to Janice, has a son, Rob, daughter-in-law, Casey, and granddaughter Emma.

Andrew D. Behler

Vice President, Blue Ridge Pressure Castings, Lehighton, PA

abehler@brpc.net (610) 377-2510

Andrew D. Behler is a third generation die caster, literally having grown up in the die casting industry. His extensive die casting experience is a result of the opportunity to work in every phase of the die cast business and a lifetime of participation in die cast association activities. He is trained as an engineer, holding B.S. degrees in Engineering Science and Mechanical Engineering from Lafayette College. In addition, he is a licensed Professional Engineer in the state of Pennsylvania.

Behler spent his career in attempting to apply engineering principles to the solution of die cast problems. In the area of zinc die casting his work includes conducting the field work for the NJZ in their “Thin Wall Zinc Die Casting Demonstration Project”. This very early work included development of machine instrumentation and characterization, thermal analysis and temperature control, application of Ilzro-Battelle gating techniques, and process optimization through statistical methods. Result of this work was shared with the industry through publication and demonstration. Efforts in brass die casting include; die material analysis of both refractory base materials and conventional hot work steels, alloy development in minimizing the effects of hot shortness through element control in manganese bronze. The work he did on closed form analysis of machine and die deflection provided the basis for almost twenty years of NADCA research by Dr. Al Miller and his team at OSU. Working with tier one OEM’s on aluminum die cast designs, Behler provides guidance and training in the integration of finite element analysis and fatigue analysis utilizing safe load methods for fatigue avoidance. Understanding the inherent die cast defects and their impact on fatigue, toughness and pressure tightness, he provides a design guideline where none exists.

Inspired by his dad to participate in industry association activities he quickly learned the benefit of being an active member at both the local and national level. Participating as both a student and a leader he has had the opportunity to both learn and lead. His tenure dates to 1973 and the NADCA predecessor organizations, where he served as chairman of the R&D committee, and culminated with a position on the NADCA Board of Governors. During his time on the board he served as secretary / treasurer, vice president and chairman of the board. Committee activities have included R&D committee, Finance committee, and Government Affairs. As chairman of the Finance Committee his conservative fiscal policy helped steer the Association back to a position of financial strength. In addition, he has served on many sub committees helping evolve the technology roadmaps, strategic plans and industry liaisons which have guided our industry through an ever changing landscape. Behler remains a most ardent fan of NADCA and its role in the die cast industry.

Andy Bonczkowski

Manufacturing Specialist, Wisconsin Manufacturing Extension Partnership, Madison, WI

Bonczkowski@wmep.org (414) 403-4716

Andy comes to WMEP with over 15 years of operations experience in manufacturing. He has successfully led Lean transformations and Six Sigma project teams throughout his career,

Metalcasting Industry Roadmap

bringing positive results in Safety, Quality, Delivery and Cost. Andy brings experience from multiple industries and has worked for companies such as Black and Decker(Assembly), Plymouth Tube Company (Steel), Guardian Industries (Glass), Graham Packaging (Plastics) and Trulite Glass.

Skill Set:

- Total Productive Maintenance
- Quick Changeover (SMED)
- Value Stream Mapping
- Facilitating Kaizen Events
- Standard Work
- 5S
- Kanban
- Lean Daily Management System
- Talent Development
- Six Sigma (DMAIC)
- Statistical Process Controls
- ISO 9001:2008 Lead Auditor

Education & Certification:

- Certified Lean Six Sigma Black Belt, The George Group
- Mid-Level Management Training, Cox School of Business, SMU
- B.A. in History from Augusta State University
- US Army Signal School for Electronics, Ft. Gordon, GA

Buckley Brinkman

Executive Director, Wisconsin Manufacturing Extension Partnership, Madison, WI

brinkman@wmep.org (608) 240-1740

Mr. Brinkman brings more than 25 years of transformational manufacturing leadership to the WMEP, with a breadth of experience in helping companies drive growth, world-class competitiveness and performance excellence. Experienced in lean, Six Sigma, supply chain

management and turnaround planning, he has led efforts to save dozens of operations in the U.S. by finding new ways to compete.

Throughout his career, Brinkman has provided executive leadership to companies ranging from \$5 million to more than \$4 billion in sales. He is credited with reviving the North American operations of the world's largest playing card company, leading the turnaround of a prominent trade bindery and catalyzing the profit turnaround of a recycled paperboard mill.

Mr. Brinkman has served as president and chief operating officer of U.S. Music Corp., an Illinois-based musical instrument manufacturer, and as chief operating officer of Minneapolis-based Manchester Companies, where he received the Turnaround of the Year award for his work with a medical device manufacturer. Most recently, he served as president of Vallon, LLC, a Minneapolis-based interim executive placement firm. Brinkman is an industry thought leader who has authored several white papers on innovation, corporate culture, business strategy and other topics.

A Wisconsin native, Mr. Brinkman holds a bachelor's degree from the University of Wisconsin and a master's degree in business administration from Harvard Business School. He is the founder of the Forge Alliance, a networking and educational group for manufacturing executives. He also served on the board of directors of Safe Passage for Children, a nonprofit corporation that trains volunteers and business leaders to be advocates for children in foster care, child protection and public adoption programs.

Jerry Call

Executive Vice President, American Foundry Society, Schaumburg, IL

jcall@afsinc.org (847) 824-0181 ext. 255

Mr. Call joined the American Foundry Society (AFS) in his current position of Executive Vice President in 2004. Prior experience includes Stahl Specialty Company (Human Resources / EHS Manager and, later, Plant Manager), Gardner Denver (Human Resources Manager).

Mr. Call's 28-year service to the metalcasting industry includes serving on the AFS 10-Q Safety & Health Committee, which developed a series of three ANSI safety standards for the metalcasting industry, as well as the Metalcasting Ergonomic Handbook 1st Edition. He also served as a member of the AFS Government Affairs Committee that developed the industry's legislative and regulatory priorities.

During his tenure at Stahl Specialty Company, Mr. Call was a member of the board of directors for the Associated Industries of Missouri and a member of the Education Committee for the Missouri Chamber of Commerce. In 1991 he was awarded the AFS Environmental Health & Safety Service Award, and in 1997 he was awarded the AFS Service Citation.

Metalcasting Industry Roadmap

Currently he serves on the board of directors for the American Metalcasting Consortium, the Cast Metals Coalition, the Industrial Advisory Trade Committee for ferrous materials for the Department of Commerce, and he is the United States Delegate to the General Assembly of the World Foundry Organization.

Jerry earned Bachelor of Science degrees in Education and Industrial Safety, respectively, from Central Missouri State University, now University of Central Missouri

John D. Danko

President, Danko Arlington, Inc., Baltimore, MD

jdanko@dankoarlington.com (410) 664-8930 ext. 13

John is the President of Danko Arlington, Inc., specializing in aluminum and bronze sand castings, industrial patterns and molds, CNC machining, and additive manufacturing. Danko Arlington, Inc. is a pioneer in the use of additive manufacturing (3-D printing) in the foundry industry. John is a member of the American Foundry Society and the Non-Ferrous Founders' Society. A native of Baltimore, MD, he is an active member in the Baltimore Workforce Investment Board and the Education and Workforce Training Board for Maryland Correctional Institutions. John received a B.S. in Mechanical Engineering from Lafayette College and pursued graduate studies in Business Administration at Loyola University in Baltimore and Theology and Philosophy at Mount Saint Mary's University in Emmitsburg, MD.

Hal Davis

Director of Technology / Technical Services, Sivyer Steel Corp., Bettendorf, IA

hdavis@sivyersteel.com (563) 355-1810 ext. 235

Mr. Davis is the Director of Technology / Technical Services for Sivyer Steel in Bettendorf, IA, a position he has held since 2001. Prior to that Mr. Davis was Director, Military & Locomotive Products, ABC-Naco Inc. He received his B.S. in Metallurgical Engineering from the Missouri University of Science & Technology.

David DeWyse

Technical Director, Stahl Specialty Company, Kingsville, MO

dewysed@stahlspecialty.com (816) 282-4454

David graduated from Michigan Technological University in 1987 with B.S. in Metallurgical Engineering. His first job after college was with Zollner Piston in Ft. Wayne, Indiana as Assistant Foundry Metallurgist.

In 1988, he moved his family to Bristol, Indiana to join the growing enterprise that Ray Witt was building at the relatively new CMI location. This plant grew from 89k sq ft to 440k sq ft over the course of the next 13 years. Products were mainly high volume automotive permanent mold and squeeze castings. He worked at the same location under four ownerships until July 2014.

In August of 2014 he had the opportunity to join Stahl Specialty Company as Technical Director and is excited about the future growth of the permanent molding iconic group.

Bruce Dienst

President & Chief Operating Officer, Simpson Technologies Corporation, Aurora, IL

bdienst@simpsongroup.com (630) 417-9001

Mr. Dienst is currently the President and Chief Operating Officer for Simpson Technologies Corporation in Aurora, IL, where he has over 30 years of experience, including positions as Sales Engineer, Sales Manager, General Manager, and Executive Vice President. He is also a member of the Board of Directors for Simpson Technologies Corporation, Aurora, IL, Simpson Technologies GmbH in Baar, Switzerland, Wesman Simpson Technologies Pvt. Ltd. in Kolkata, India and Bremen Castings, Inc., in Bremen, IN. He is the President-Elect of the American Foundry Society and a Past President of the Casting Industry Suppliers Association, the CISA Export Trade Group, Inc. and the Foundry Educational Foundation. He has been a member of the Metalcasting Industry Advisory Board at Pennsylvania State University and Bradley University and has received numerous awards and citations in the metalcasting industry.

Mr. Dienst received a Masters of Management from the J.L. Kellogg Graduate School of Management, Northwestern University, Evanston, IL and a B.S. in Finance from Miami University Oxford, OH.

Ray Donahue

Fellow - Mercury Marine, Fond du Lac, WI

Ray.Donahue@mercmarine.com (920) 929-5421

Ray has been working at Mercury Marine in Fond du Lac, WI for over 40 years. His positions there have included Manager, Director, Sr. Director, and Fellow. He is currently on the Board of Directors of the WPI Metal Processing Institute, Chairman of the ASF Division 11 - Lost Foam Research Committee, Chairman of the NADCA R&D Committee, and a Reviewer for the Natural Science and Engineering Council (NSERC)'s Strategic Project Grants (SPG) program.

Ray's previous experience includes Instructor at Illinois Institute of Technology and Professor of Metallurgy - University of Connecticut. He has served as on the Board of Directors for the Steel Founders' Society of America, Chairman for Selection Committee for the ASM Engineering Materials Achievement Awards, and Chairman of the Milwaukee Chapter of ASM International.

Ray has over 60 patents. He received his B.S. and Ph.D. in Metallurgical Engineering from Illinois Institute of Technology, Chicago, Illinois.

Shelly Dutler

Curriculum Development Manager, Institute at the American Foundry Society, Schaumburg, IL

SDutler@afsinc.org (847) 803-4300

Shelly Dutler is the curriculum development manager for the Institute at the American Foundry Society, AFS whose career spans seventeen years of involvement in the metalcasting industry. While Shelly was earning her Bachelors of Science in Manufacturing Technology at the University of Northern Iowa, UNI, she entered the metal casting program and met her first and current mentor, attended her first AFS Casting Congress in 1998 as a student "red coat" for the technical sessions, and served as vice chair of the student AFS chapter. After receiving her degree with honors, she accepted a full time position in the Product Engineering Center at John Deere & Company where she was employed for over five years in both the agricultural and engine divisions. She held positions of increasing responsibility as drafter, designer, and senior designer. As senior designer her primary responsibilities included working with supplying foundries to produce new casting designs, reduce scrap and improve existing casting quality through design changes.

In 2002 Shelly accepted a position as a Project Engineer, which expanded into Client Manager at MAGMA Foundry Technologies where she was employed for twelve years supporting casting designers and foundry process engineers in the use of simulation and also where she gained valuable experience in metal casting knowledge from her clients during the many foundry visits.

She realized that to further optimize casting designs, simulations required available and accurate high temperature thermo-physical property data.

As Shelly was earning her Masters in Material Science and Engineering at the Illinois Institute of Technology, she researched and developed high temperature creep curves for a martensitic grade of stainless steel. These creep properties now make it possible to simulate the casting distortion and stresses during the steel heat treatment process and to provide more accurate prediction of the occurrence of hot tears during solidification. For accurate prediction in simulation, the properties of the mold materials are just as important. Shelly worked with her original mentor at UNI on the research published in the AFS transactions, "High Temperature Physical Properties of chemically Bonded Sands Provide Insight in to Core Distortion and Provides New Data for Casting Process Simulation" which was given the Howard Taylor Award for Scientific Merit at the 115th AFS Metalcasting Congress.

Shelly is currently serving on the Foundry Education Foundation Academic Advisory Board for UNI's metal casting program, and she is a member of the Society of Women Engineers, SWE. She has volunteered for GEMS (Girls in Engineering Math and Science), Expand Your Horizons (SWE), and Girl Scout STEMPalooza events to support young women's introduction to the metalcasting industry in make molds and pouring metal castings. Shelly will continue to believe that supporting the education of and encouraging the next generation is a high priority of the future of metal casters.

Kathy L. Hayrynen

Director of Research & Development, Applied Process Inc. - Technologies Division, Livonia, MI

khayrynen@appliedprocess.com (734) 464 8000 ext. 232

Kathy has a BS, MS and PhD in Metallurgical Engineering from Michigan Technological University. Her graduate studies were focused on production of ductile iron and austempered ductile iron (ADI). Following her graduate work, she completed a post-doctoral research program for the US Army Tank Automotive Command on combining mechanical deformation steps with ADI for use on track systems for armored vehicles in conjunction with the Keweenaw Research Center and Michigan Tech.

Kathy joined the Applied Process Companies in 1995 as the Technical Director and now serves as the Director of Research & Development. The Applied Process Companies are a group of commercial heat treat facilities that focus on helping customers develop innovative austempering solutions to engineering challenges. During her tenure at AP, she has worked on commercializing Carbodic ADI, Carbo-AustemperedTM steel and LADITM (localized ADI).

Kathy has had a broad breadth of experience with AFS on multiple fronts. Her MS program was AFS sponsored research so she understands how that relationship functions. She is a past-Chair of the 5I Committee (Ductile Iron Research Committee) as well as a past-Chair of Division 5

(Cast Iron Division). Kathy is currently in the officers' rotation for the Division Council. She has also served on a number of monitoring committees for research programs within Division 5.

Kathy has been honored with several AFS awards including: a Ray H Witt Management Award, an Award of Scientific Merit and five Best Paper Awards within the Cast Iron Division.

Dean Hutchins

DLA Casting R&D Program Manager, Defense Logistics Agency

Richmond, VA

Dean.Hutchins@dla.mil 804-279-5033

Dean Hutchins currently manages the Castings & Forgings Manufacturing Technology (ManTech) programs. Dean also represents DLA on the Metals Processing & Fabrication sub panel of the Joint Defense Manufacturing Technology Panel (JDMTP). In his 12 years with the DLA, he has also worked at DLA Aviation in their Engineering Directorate working in their sustainment engineering branch on reliability improvement projects.

Before working at the DLA, Dean spent 17 years working for the U.S. Army in a variety of functions. He worked for the Army Environmental Center (AEC) as the leader of the acquisition team, which reviewed the environmental quality documents of the major Army weapon systems in preparation for their Milestone A, B & C reviews. Before heading up the acquisition team, he managed three Army Installation Restoration Programs (IRP) programs; two of which were National Priorities List (NPL) sites. Yearly budgets for each IRP program ranging from \$1M to \$4M. Work at each site included Site Investigations, Remedial Investigations, Feasibility Studies, Proposed Plans, and / or Records of Decision; all of which were negotiated with and approved by the State environmental and / or EPA representatives.

He began his federal career at the U.S. Army Chemical RD& E Center as a mechanical engineer building Army weapon systems in the acquisition development phase (6.3b). He would design and built prototypes for testing and fielding. He also managed and worked closely with the many members of the Weapon System Management Team; including the testing, reliability, packaging, human factors, producibility engineers.

Mr. Hutchins has also been a small business owner / partner; helping to take an LLC from startup, through construction and into operation. He was the business manager from 1999-2008 with approximately a \$120K / year operating budget.

Mr. Hutchins has a Bachelor of Science in Mechanical Engineering from North Carolina State University.

Jack Lilley

Corporate Technical Director, MetalTek International, Waukesha, WI

Jack.Lilley@MetalTek.com (262) 544-7985

Jack Lilley is the Corporate Technical Director for MetalTek International. MetalTek operates seven casting facilities in the United States and United Kingdom producing sand, investment, and centrifugal castings from a broad range of iron, nickel, cobalt, and copper based alloys. Jack has been active in the Steel Founders' Society of America for over twenty years, and is currently serving as Immediate Past President.

James L. Mallory

Executive Director, Non-Ferrous Founders' Society, Park Ridge, IL

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Jim Mallory is the Executive Director of the Non-Ferrous Founders' Society, a seventy year old trade association headquartered in Park Ridge, Illinois representing the U.S. non-ferrous foundry industry. NFFS members produce castings of aluminum, brass & bronze, and other nonferrous metals. Members are mostly small, privately-held companies with fewer than 50 employees. Many are family-run businesses as well, frequently to the third and fourth generation.

Jim has more than thirty-five years of professional experience in all aspects of Association Management and has guided NFFS and its members since 1985. Throughout his career, he has been active in many national associations and has served on several advisory committees for the federal government. Jim served on the Board of Trustees of the Center for Leadership Development, an educational arm of the U.S. Chamber Foundation, and both as a Regent, Chairman, and Faculty member for the Institute for Organization Management at the University of Notre Dame. He chaired the Small Manufacturers' Issues Group for the NAM Council of Manufacturers' and served as a member of the Future of U.S. Manufacturing Task Force. He is a past member of the Council's Board and also chaired its Knowledge Exchange Committee.

Jim holds a Bachelor of Arts degree in Sociology with a minor in Marketing from Loyola University of Chicago. He earned the Certified Association Executive (CAE) designation from the American Society of Association Executives in 1985. In recognition of his dedication to the field of Association Management, Mr. Mallory received the John C. Thiel Distinguished Service Award from the Association Forum in 1992. He also received the Forum's Management Excellence in Association Programming Award in 1996, and was selected as the recipient of the NAM Council's Leadership Award in 2002.

Steve Midson

Part Time Research Professor, Colorado School of Mines, Golden, CO

steve@themidsongroup.com 303-778-0271

Dr. Steve Midson is a part time Research Professor at the Colorado School of Mines, where he is Managing Director of the Center for Advanced Non-Ferrous Structural Alloys (CANFSA). He is also President of The Midson Group, a Denver-based consulting company specializing in castings and materials. Midson has a Ph.D. in metallurgy from the University of Sheffield (UK) and 30 years casting and metallurgical experience. He has served as Chief Operating Officer of two commercial casting companies, Director of a development and prototyping company, as well as working in the R&D labs for two Fortune 500 companies. Midson is currently chair of the NADCA Die Materials Committee, a member of the NADCA R&D Committee, and serves on the Semi-Solid International Scientific Committee. He has authored more than 50 technical papers, and has received awards from the North American Die Casting Association, the Society of Automotive Engineers, the American Foundry Society and Sheffield University.

Paul Mikkola, General Motors (Retired), Manchester, NH

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Paul Mikkola FASM, was awarded a Bachelor's Degree in Metallurgical Engineering from Michigan Technological University in 1966, and a Master of Science, Metallurgical Engineering Degree in 1968 by the University of Wisconsin, Madison. He received an Honorary Doctorate of Engineering from Michigan Tech in May 1989. He work at varied positions at General Motors primarily in the Foundry area for 32 years. After his GM career he worked for investment caster, Hitchiner Manufacturing Company, in 2001 he was named the President of Metal Casting Technology Inc. a Hitchiner Manufacturing-General Motors joint venture company from which he retired the end of 2008. He is a Past President of both FEF and AFS and continues to be active in the casting industry.

Charles Monroe

Assistant Professor, Department of Material Science and Engineering, University of Alabama at Birmingham

camonroe@uab.edu (205) 975-4128

Charles Monroe is an Assistant Professor at the University of Alabama Birmingham in the Department of Material Science and Engineering. He is also the Assistant Director of the MPAD Center which is a multiple material manufacturing center focused on metal casting and composite manufacturing at production size parts (meter size). The metal casting capability include aluminum, iron, steel, magnesium pouring with chemically bonded sand or lost foam technologies to name a few. Charles received his B.S. in Mechanical Engineering from Penn State University, and his M.S. and Ph.D. in Mechanical Engineering from the University of Iowa.

Raymond Monroe

Executive Vice President, Steel Founders' Society of America, Crystal Lake, IL

monroe@sfsa.org

(815) 455-8240

Mr. Monroe is the Executive Vice President of the Steel founders Society of America. Prior to this, for a year he worked for Saturn Corporation, a General Motors subsidiary, in the lost foam casting area. Mr. Monroe also was the Research Director of SFSA for five years before leaving to join Saturn Corporation. Other past experience includes contract research in metallurgy, failure analysis and casting processes at the Southern Research Institute in Birmingham, Alabama for six years; and, while a student, working for NASA at Marshall Space Flight Center.

He holds a B.S. in Chemical Engineering from Auburn University and received his M.S. in Engineering Science from the University of Alabama -Birmingham in 1980. He is active in the American Society for Testing and Materials and the American Foundry Society.

Ms. Kelly Morris

Chief, Defense Logistics Agency R&D, Ft. Belvoir, VA

kelly.morris@dla.mil

(703) 767-3285

Kelly Morris leads the Logistics Research and Development (R&D) program at the Defense Logistics Agency (DLA), valued at \$42M / year. Innovative R&D programs under her purview include R&D in Castings, Forgings, Batteries, Additive Manufacturing, Military Uniforms, Combat Rations, Energy, Storage and Distribution and many other areas.

Prior to this position she was the DLA Chairperson at the Eisenhower School (formerly Industrial College of the Armed Forces) from 2008-2014, teaching Acquisition and Supply Chain Management. She also led the Transportation Industry Study. Her research and writing includes a case study on the “F-22 Raptor Sustainment Strategy” and a booklet entitled “Federal Procurement Survival Guide: Contracting Basics for Joe the Warfighter”. Prior to coming to ICAF, she was responsible for leading DLA’s partnership efforts and liaison support to Unified Combatant Commanders in order to influence and improve collaborative, integrated adaptive planning capabilities and logistics sustainment.

Ms. Morris served as the Deputy Executive Director for the DLA HQ’s Logistics Analysis and Business Integration Office in DLA Headquarters, responsible for matters related to logistics analysis, readiness, and performance assessment, as well as logistics operational resource requirements management, business planning and administration.

Ms. Morris was the Associate Center Procurement Official at the Defense Energy Support Center (1998-2001) and Director, Direct Delivery Fuels at the Defense Energy Support Center, where she led a \$544.5 million direct vendor delivery contracting program for ground fuel, into-plane and ship bunkers products. She held an unlimited Contracting Officer’s Warrant and helped to lead the dynamic, award winning DoD Natural Gas Program (1991-1998). The DoD Natural Gas Program was recognized by winning the DoD Productivity Award (1994), the DoD Superior Management Award (1995), the David Packard Excellence Award (1996) and the DLA Scissors Award (1997).

Ms. Morris earned a Master’s Degree in National Resource Strategies from the Industrial College of the Armed Forces, as well as a Bachelor’s Degree in Biological Sciences and German from the University of Northern Colorado. Ms. Morris is Level III certified in Contracting and Level I certified in Life Cycle Logistics under the Defense Acquisition Workforce Improvement Act (DAWIA). She is a member of the Defense Acquisition Corp.

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Manufacturing system and process improvements is the common theme of Dr. Frank Peters' research work. He has worked with a variety of industries to develop solutions to improve quality and deliverability. Specific examples in the metalcasting field include heat treatment control and optimization, rapid patternmaking, decreasing product variability, and reducing the measurement error associated with visual inspection. Other areas of interest include dimensional variability of products, metrology and fixturing. Most recent work is on manufacturing system improvements and automated solutions for the manufacture of large composite wind blades. Dr. Peters received his BS, MS, and PhD degrees in Industrial and Manufacturing Engineering from Penn State University.

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David obtained his BS in Mechanical Engineering from Milwaukee School of Engineering. He has several years of manufacturing experience with custom-engineered castings that were used for heated part applications. David currently works for Steel Founders' Society of America as the Vice President of Technology, where he provides technical resources for SFSA members, oversees SFSA's Research portfolio, supports SFSA Technical and Operating committees and groups, provides technical support to DOD programs such as AMC, and represents the steel casting industry in specifications including ASTM and ISO. Mr. Poweleit is a member of AMC's CAST-IT Team of Application Engineers and serves on the AMC Technical Advisory Committee (TAC). David assists the AMC in its efforts to cut cost, reduce lead-time, and build supply chains for DLA.

Thomas E. Prucha

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Thomas E. Prucha is Vice President of Technical Services for the American Foundry Society where he oversees the technical department, including committee activities and research projects. Mr. Prucha spent over 30 years working in and with the metalcasting industry, most recently at Internet Corp., Troy, MI, where he last served as vice president of technical services. Mr. Prucha is the 2007 recipient of the Merton C. Flemings award from the Advanced Casting Research Center (ACRA), Worcester, MA, recognizing significant contributions to solidification processing fundamentals which have been applied commercially in the metalcasting industry. He was also past recipient of the ACRC Ray Witt award and the AFS Award of Scientific Merit.

Mr. Prucha graduated from the University of Wisconsin at Madison with a B.S. in Metallurgical Engineering. He went on to acquire his Masters of Science from University of Wisconsin at Madison.

David Schwam

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Dr. Schwam is a Research Associate Professor in the Department of Materials Science and Engineering at Case Western Reserve University and Director of the Case Metal Casting Laboratory. He also serves as the Forging Industry Magnet Professor for Case. His research interests include die casting and squeeze casting of aluminum and magnesium alloys, additive manufacturing, evaluation of die materials, rapid prototyping and tooling, recycling, computer simulation of flow and solidification, energy efficiency and thermal technology. He is a member of NADCA, AFS, ASM, MRS and Laser Institute of America.

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Mr. Shah has over 25 years of experience with casting digital design, performance validation, rigging design and manufacturing simulation for various alloys and processes, reverse engineering and rapid prototyping; additionally worked on several contract research projects towards new alloys, processes, virtual simulation, and agile manufacturing development of castings in the last 20 years for various agencies, including DARPA, NASA, AMC, USCAR / USAMP and ONR.

Alfred Spada

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Alfred Spada is Editor / Publisher of Modern Casting and Metal Casting Design & Purchasing magazines and AFS Vice President Business Development. Spada is a graduate of Northwestern Univ. and has an MBA from the Univ. of Colorado.

Spada entered the metalcasting industry in 1997 as an editor for Modern Casting. His previous experience was in journalism and communications as an editor for Pro Football Weekly magazine. Spada has spent his 17 plus years in metalcasting visiting metalcasting facilities across the globe and writing about the industry from both a technical and management perspective.

In addition to his role with AFS and its magazines, Spada serves as Publisher for the International Journal of Metalcasting and has edited two books on metalcasting—the Iron Casting Engineering Handbook and Metal Casting Design & Purchasing.

Spada regularly speaks to both metalcasters and casting buyers about the present and future of the global metalcasting industry, casting applications and casting design. Spada has a wife, Beth, and three daughters, Alyssa, Abigail and Audrey.

Jean-Louis Staudenmann

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Dr. Jean-Louis Staudenmann has been a Project Manager in the Project Management Office (PMO) at TIP since its inception in January 2008, where he manages projects on sensors and energy harvesting devices, materials advances, metallurgical processes, and recycling technologies, as applied to civil infrastructure and advanced manufacturing. Prior to those activities at TIP, Dr. Staudenmann was a member of the Chemistry and Materials Group with the Advanced Technology Program (ATP) at NIST since 2000, managing materials advances, metallurgical processes, and recycling technologies.

From 1993 to 2000, Dr. Staudenmann was a scientist in the Quantum Metrology Division of the Physics Laboratory at NIST, working mainly on x-ray optics and designing wide energy range multi-crystal monochromators for testing the Chandra x-ray telescope, now in orbit around the earth. He also worked on several standards for x-ray powder diffractometry.

Dr. Staudenmann is a member of the Materials Information Society (ASM International), the Materials Research Society (MRS), and The Minerals, Metals & Materials Society (TMS). Dr. Staudenmann obtained his Ph.D. and M.S. in Experimental Solid State Physics from the University of Geneva (Switzerland) and an Engineering Diploma in Mechanical Engineering from the Geneva School of Engineers.

Jenny Swygert

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Jenny Swygert is a Senior Project Manager in the Advanced Materials Division of SCRA Applied R&D supporting the Defense Logistics Agency (DLA). She currently serves as the Casting Advanced Systems Technology - Integration Team (CAST-IT) Manager of five metalcasting application engineers. CAST-IT collaborates to solve part procurement problems for legacy weapons systems, helping DLA obtain high-quality, cost-effective metal castings with reduced lead times. Jenny also supports the National Shipbuilding Research Program (NSRP) by managing projects associated with the Planning, Production Processes and Facilities panel. Jenny has a bachelor's degree in Mechanical and Aerospace Engineering from Princeton University and an MBA from the University of South Carolina.

Jerry Thiel

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Jerry Thiel is the Director of the Metal Casting Center at the University of Northern Iowa. He has a diverse industrial background and has held management positions in the metal casting and related industries for over 35 years. His background includes metal casting experience in steel, iron and non-ferrous alloys. Jerry holds degrees in materials science, manufacturing and manufacturing process development and has published numerous research papers pertaining to molding and core materials for the foundry industry. He is a past chairman of the Hawkeye chapter of the American Foundry Society as well as the chairman of the AFS division IV executive committee. Jerry also served as the chairman for the Cast Metals Institute. Jerry received the AFS Scientific Merit Award in 2011, the division IV best paper award in 2012, 2015 and is a three time recipient of the AFS Howard Taylor award. Jerry will receive the AFS service citation award in 2015.

Douglas M. Trinowski

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Since January 1, Doug is now the Vice President for Special Projects at Hüttenes-Albertus. Previously as Vice President for Global R&D at Hüttenes-Albertus, Doug lead all global research and product development for foundry resins, refractory coatings, resin coated sands and auxiliary materials. Doug brings over thirty-five (35) years of foundry and phenolic resin technical expertise. Hüttenes-Albertus is one of the leading suppliers of these consumable materials for the global metalcasting industry.

Doug came to Hüttenes-Albertus in January 2013 from HA International, where he was Vice President – Technical. Doug joined HA International at the inception of the company in April 2001. He has held positions in R&D, Sales, Marketing and Technical Service for Delta Resins & Refractories and the Chemicals Division of The Quaker Oaks Company.

Doug is active in the American Foundry Society (AFS), and is currently a member of the Research Board. He holds a Bachelor of Science degree in chemistry from MacMurray College (1972) in Jacksonville, Illinois.

Daniel L. Twarog

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Mr. Twarog is a graduate of the Illinois Institute of Technology with a degree in materials and metallurgical engineering. Following graduation, he worked in materials research and development with Amsted Research Laboratories. He then spent five years as quality and process control manager for an investment casting foundry. In 1985, he joined the Cast Metals Institute staff as associate director of education and laboratory manager. Promoted to the position of Director of Research in 1988 for the American Foundrymen's Society, his many responsibilities included overseeing the foundry industry research programs, which totaled more than \$4.5 million. Mr. Twarog has provided testimony to the Department of Energy and the U.S. congress on the need for research in the metalcasting industry.

In August 1995, Mr. Twarog became the Executive Vice President of NADCA. His primary mission is to implement the Association's Strategic Plan and provide products to the membership that will help them run their companies more effectively. In his short time at NADCA, Mr. Twarog has worked with his staff to develop and improve many NADCA products and services. Mr. Twarog was promoted to President of NADCA in June, 1999.

Mr. Twarog has authored several papers and articles on process capabilities, investment casting technology, tramp element effects in aluminum and copper alloys, alternate reuse technology of foundry waste sand, and development of replacement alloy for lead in copper castings. He has also spoken to numerous private groups and government agencies on the methodology of association and industry research.

Stephen P. Udvardy

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Stephen (Steve) P. Udvardy is the Director of Research, Education & Technology for the North American Die Casting Association where he has held this position for the past eighteen years. His responsibilities include: coordinating research & development efforts between member companies, government agencies, government laboratories and universities; enhancing and

implementing the NADCA educational program and; further developing the level and quality of technology transfer between NADCA and its members. Steve joined NADCA after serving two years as Vice President of Engineering & Technology for Teledyne Casting Service in La Porte, IN. This foundry is a producer of large gray and ductile iron castings. Prior to his position at Teledyne, Steve managed the Materials Engineering Group and Materials Laboratory at Honeywell's (formerly, AlliedSignal Aerospace Company) Aircraft Landing Systems in South Bend, IN where he spent 15 years. Aircraft Landing Systems is a manufacturer of aircraft wheels and brakes. Steve holds both a B.S. and M.S. degree in Metallurgical Engineering & Materials Science from the University of Notre Dame.

Jerrod Weaver

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Jerrod Weaver is the Director of Education and Training for the Non-Ferrous Founders' Society. Mr. Weaver has worked with NFFS since 1996 to develop a whole host of innovative educational content, including quality management systems and safety and health programs for the foundry industry. Mr. Weaver also manages several grant and contract programs, including the AMC phase I project (NQS9000) and the recent Metal Matrix Composites program. Mr. Weaver holds a certified association executive credential, as well as certified quality auditor, quality manager and lead auditor credentials issued by the American Society for Quality. Mr. Weaver received a BS in Manufacturing Engineering (with a cast metals emphasis) from Western Michigan University in 1996.

David Weiss

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Mr. David Weiss, vice president of engineering and R&D for Eck Industries, Inc., is responsible for development and application of high performance alloys and casting concepts for the foundry and their customers. He participated in the development of the lost foam casting process for magnesium alloys for which he shared the Howard Taylor award from the American Foundry Society (AFS), has worked on modified low pressure casting techniques for sand molds and has patented a hybrid high-pressure shell casting process. He received a second Howard Taylor Award for his work on low pressure casting of magnesium. He is past chairman of the AFS aluminum and magnesium divisions and is currently on the Board of Directors for AFS. Weiss

has authored over 40 papers on the processing and application of aluminum, metal matrix composite and magnesium castings and in 2005 received the Hall/Heroult Scientific Merit Award for his development work on aluminum alloys. In 2008 Weiss shared a third Howard Taylor award for work on aluminum nanocomposites and was a recipient of the William Frishmuth award from the aluminum division of AFS. Weiss presented the Hoyt Memorial Lecture during the 2009 AFS Casting Congress and was awarded the Ray H. Witt Award from the Metal Processing Institute of Worcester Polytechnic Institute. A fourth Howard Taylor award was received in 2014 for work on high temperature aluminum alloys.

Thornton C. White

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Mr. White is a Senior Program Manager with the SCRA Applied R&D for the American Metalcasting Consortium. He has over twenty years' experience leading and working with government and commercial clients in a number of areas, including project planning and control, financial analyses, material acquisition and management, activity-based cost (ABC) accounting and management, predictive and preventive maintenance programs, and engineering and chemical analyses. Prior to joining SCRA, Mr. White was a Senior Manager and the Charleston SC Office Director for Arthur D. Little, Inc.

Mr. White has a M.B.A. from The Citadel, a B.S. in Chemical Engineering from the University of Florida, and a B.S. in Chemistry from Jacksonville University. He is a certified Project Management Professional.

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