This is where we focus in regular intervals on the main institutions and organizations active in the field of thermoprocessing technology. This issue spotlights the Metal Processing Institute (MPI) at Worcester Polytechnic Institute.

**Metal Processing Institute** connects university and industry plus theory and practice

Worcester Polytechnic Institute’s Metal Processing Institute (MPI) is the largest industry-university alliance in North America. MPI conducts research in four research centers in the areas of metal casting (at the Advanced Casting Research Center, or ACRC), heat treating (at the Center for Heat Treating Excellence, or CHTE), resource recovery and recycling (at the Center for Resource Recovery and Recycling, or CR3), and most recently materials processing data (at the Center for Materials Processing Data, or CMPD). Each of the four centers has multiple industry members, which pay an annual membership fee to support pre-competitive research by MPI faculty members, students and research associates.

MPI is supported by more than 90 corporate partners as well as funding from private foundations and the federal government. MPI receives about $3–4 million annually in research funding and grants, 40% of which is from federal grants.

Additionally, MPI has strategic alliances with several key universities around the globe, including Colorado School of Mines, KU Leuven in Belgium, University of Tokyo in Japan, RWTH Aachen University in Germany, University of Padova and University of Bologna in Italy, Shanghai Jiao Tong, Tsinghua University, and Northwestern Polytechnic University in China.

In 2015, WPI celebrated 50 years of continuous industry-university alliance associated with MPI: 30 years with the ACRC, 15 years with CHTE, and five years with CR3.

Fig. 1 shows the team of the institute. Brajendra Mishra, who was recently named director of MPI, noted that MPI is making a significant impact on society: “Manufacturing is the backbone of any society’s growth and well-being. MPI supports the manufacturing industry in the United States through the development of new technology and materials,” he said.

In many ways, MPI reflects the foundation laid by WPI founders John Boynton and Ichabod Washburn more than 150 years ago. Boynton was a tinware maker while Washburn set up a machine shop on campus. Their business was in the metal processing world, and this institute continues to build upon that early vision. MPI also symbolizes WPI’s two towers of theory and practice that is at the cornerstone of a WPI education. In addition, MPI’s impact can be felt far and wide. In 2014, the White House select-
ed MPI as one of four core academic facilities aimed at revitalizing the nation’s manufacturing capabilities and competitiveness. WPI is now a member of eight far-reaching institutes that fall under a public-private partnership known as Manufacturing USA. Manufacturing USA brings together industry, academia and federal agencies to increase manufacturing competitiveness in the United States and promote a viable manufacturing infrastructure. Two of the eight institutes with which WPI is involved have a direct connection to MPI: WPI is a core member in Lightweight Innovations for Tomorrow (LIFT) through MPI, and its membership in Reducing Embodied-energy and Decreasing Emissions Institute (REDUCE) is through CR3. The founding director of MPI, Diran Apelian, is the technology pillar lead for metal casting in the LIFT manufacturing institute, while Mishra is the lead for the REDUCE institute.

Mishra said his initial goals for MPI include furthering CMPD, which will be focused on data that supports the aerospace and automotive industries, and expanding MPI’s membership base (notably in CR3, an NSF Industry/University Cooperative Research Center). In addition, MPI is expanding globally and, in 2017, will launch a new center at Shanghai Jiao Tong University in Shanghai, China, dedicated to non-destructive evaluation in metal processing. CR3 is in conversation with NTNU (Norway) and NTUA (Greece) in Europe for collaboration on research of mutual interest.

Ultimately, Mishra said, MPI will continue to focus on serving the metals and materials industrial base. “The primary purpose of MPI is to solve industry problems, to develop new methods or materials for the industry, and to share fundamental results that companies are seeking,” said Mishra. Today, each of the four centers that fall under MPI are making specific impacts.

ADVANCED CASTING RESEARCH CENTER
The flagship Advanced Casting Research Center, founded in 1985, has the distinction of being the longest-running center of MPI. ACRC – originally known as the Aluminum Casting Research Laboratory – was formed by Apelian, the Alcoa-Howmet Professor of Mechanical Engineering at WPI. Apelian ultimately launched MPI at WPI in 1996. As founding director of MPI, he continues to direct the activities of ACRC.

Members of ACRC collaborate on research addressing the global foundry industry. The center brings fundamental understanding to existing processes, and develop new methods and address management-technology interface issues with its industrial partners.

Members of ACRC include primary producers such as Rio Tinto Aluminum, suppliers such as Foseco, end users like Boeing and Mercury Marine, and casters including Eck Industries and NEMAK. Additionally, ACRC includes system and component suppliers, services groups, and trade associations and national laboratories.

Apelian noted that ACRC has engaged in several key projects over the years. Many impactful projects have been completed that have helped the industry advance their methods and materials. A notable example of impactful work that has advanced the industry is a recent project on development of a method to quantitatively measure the cleanliness of molten aluminum. Inclusions and oxides in the molten metal can have deleterious effects in the end product. However, assessing molten metal quality has been a difficult task, even though numerous methods have been developed over the years, none of which are in situ and none of them give the complete picture. ACRC researchers developed a LIBS (Laser Induced Breakdown Spectroscopy) technique that operates in situ, and in less than 60 s provides data on: (i) composition of inclusions; (ii) the volume fraction of inclusions present; and (iii) size distribution of inclusions. This is a major patent-pending innovation, and agreements are in place for Melt Cognition LLC to sell, distribute, and service the technology. It represents a prime example of a laboratory concept commercialized in the real world. Fig. 2 represents a scheme of a LIBS inclusion detector, while Fig. 3 shows the technology in practice.
In addition, a noteworthy product development project focused on production of aluminum nano-composites for elevated temperature applications. Particulate-reinforced metal matrix composites have been used in many industries for many years and, with the advent of nanotechnology, the size of the reinforcing particles has progressively been scaled down to the nano-level. Aluminum matrix nano-particle composite materials have shown promising mechanical and thermal properties; e.g. high strength, hardness, stiffness, as well as resistance to thermal degradation and creep. Unfortunately, manufacturing aluminum matrix nano-composites is not easy and numerous attempts have been made to overcome the manufacturing issues such as mechanical alloying, powder metallurgy, infiltration techniques, and spray deposition. However, these processes are expensive and have their own limitations. In-situ fabrication of the particles within the metal matrix could be the answer to the manufacturing challenges. In this case, the nano-sized particles were formed directly in the melt by reacting with a gas. The reaction of a nitrogen-containing gas with a molten aluminum alloy led to formation of AlN particles that were well dispersed in the matrix alloy and were characterized by a clean particle/matrix interface. An optimized and scalable economical process for manufacturing AI-alloy AlN nano-particle composite material was developed with full characterization and microstructural and properties measurements of the resulting material.

ACRC members see significant value in the projects. Russ Cochran, who works in research and development for Boeing, said the collaboration among companies is critical. "The best part of ACRC membership is networking with other members who are peers in metal casting. Next is working with the staff and student project leaders at WPI. It is all about working with knowledgeable and outstanding people in the industry and future leaders graduating from WPI," he said.

Raymond Donahue of Mercury Marine also lauded ACRC. "Being a member of ACRC provides us with an ‘insurance policy’ patent strategy," he said. "As members, we are entitled to use – royalty free – any patents obtained on research work conducted during membership, such as ‘Slurry-On-Demand,’ the ACRC patent for CRP."

**CENTER FOR HEAT TREATING EXCELLENCE**

CHTE was founded in 2000 as part of ASM’s R&D committee’s road mapping efforts. A home for R&D in heat treating was needed to implement the roadmap and conduct pre-competitive R&D for the thermal processing industry. The member companies of CHTE are a diverse group representing the aerospace, automotive, energy and heavy equipment industries, industrial gas companies, industrial furnace manufacturers and heat treating service providers. The member companies propose and select the projects to be conducted by CHTE.

Steve Ferdon, director of engineering services for Indiana-based Cummins Inc., a global power leader, says there are significant benefits to CHTE. "We joined because of the dynamic resources available. No other consortium provides hands-on assistance with the challenges the heat treating industry is facing," said Ferdon, who currently serves as chairman of CHTE.

Also, Alexander Brune of Sikorsky Aircraft said being a member of CHTE "...has made it easy to tap into a pipeline of invaluable knowledge and a far-reaching network of excellent people with countless years of heat treating experience."

Richard Sisson, the George F. Fuller Professor of Mechanical Engineering at WPI and CHTE technical director, pointed to a few key projects.

Recently several significant and successful projects have been completed. A standard to quantify the hardenability of high hardenability steels during gas quenching has been developed. As part of that project a methodology to map the quenching effectiveness in terms of HTCs in an industrial gas quenching vacuum furnace has been developed and tested. Another project has focused on the development of a coating system to extend the life of fixtures and alloys used in gas carburizing furnaces. Based on the results of two-year tests in an industrial gas carburizing furnace, a patent has been applied for an alumina forming coating for this carburizing and oxidizing environment. The new projects will address the post processing of additively manufactured parts and heat treatment processes to form Bainite.

**CENTER FOR RESOURCE RECOVERY AND RECYCLING**

The Center for Resource Recovery and Recycling (CR³), led by WPI’s Mishra, is committed to being the premier cooperative research center focused on sustainable stewardship of the earth’s resources. The center’s focus is on helping industry address a pivotal societal need — the need to create a sustainable future. CR³ advances technologies that recover, recycle and reuse materials throughout the manufacturing process. These advancements help businesses reduce energy costs and increase profitability, while protecting our natural resources. There are nearly two dozen center members, including Global Mineral Recovery, General Motors, Olympus, and the U.S. Army Research Laboratory.

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**Fig. 3:** The LIBS technology in the ladle at Palmer Industries, in Palmer, MA
Marleen Esprit, director of Pre-Competitive Research at Umicore, a global materials technology and recycling company, said being a member has had many benefits. “Being a member of CR has proven to leverage pre-competitive research in such a way that companies can use it in their own competitive field,” she said. “This unique collaboration combined with its industrially driven research portfolio stimulates innovation throughout institutions.”

Esprit added that Umicore wanted to broaden its traditional university network with international universities with complementary expertises. She said that companies collaborate to define topics for research where there are common knowledge gaps, still at the research and thus non-competitive level. “They jointly direct the projects towards what is really to the interest of the industry,” she added.

Robert DeSaro, president of Energy Research Co (ERCo) based in Plainfield, NJ, also finds advantages with CR. “As a CR member, I reap the benefits of other members’ knowledge and experience since we cross-fertilize and provide guidance on each other’s projects, and CR successes are part of my legacy,” he said.

One of the major projects completed in CR focused on processing spent Lithium ion batteries. The work has led to the establishment of a company, Battery Resources. The developed technology recovers Li, Co, Ni and Mn metal values from cathode material of spent lithium ion batteries and synthesizes new cathode material LiNi1/3Mn1/3Co1/3O2 with recovered materials. This work has looked at how the impurities (Fe, Cu and Al) affect the crystal structure and electrochemical properties of synthesized cathode materials. Lithium ion battery (LIB) is being widely used in portable electronics, hybrid/electric vehicles and large scaled grid storage. However, because of capacity fading, the lifetime of LIB is only a couple of years. After that, they start to perform at significant lower capacity and need to be disposed. The rapidly growing product amount of LIB worldwide motivated CR to consider the importance of recycling them, from both the viewpoints of economic attraction and the environment protection.

Another development deals with a rapid process that allows the selective recovery of Scandium (Sc) from Jamaican bauxite residue (red mud), a waste product from aluminum production. The process design focused on minimizing reagents used and on establishing highly selective process steps (sulfation, leaching, precipitation) in order to minimize costs and waste produced. Furthermore, this approach allowed the recovery of a mixture of rare earth oxide side product. A comprehensive and systematic economic performance assessment provided support that the employed process development strategy is highly promising for red mud remediation.

Despite the desire of RE consumers to deviate from risk in materials manufacture, the Scandium (Sc) market in particular is predicted to grow substantially over the next decades, due to the projected use of Sc in lightweight, high-strength aluminum alloys in aerospace and fuel-efficient vehicle applications. As current Sc production rates will not allow an expansion of Sc use, there is an urgent need for new Sc sources to be explored.

Bauxite residue is a production waste from aluminum ore refining and is one potential alternative source of Sc. RM is being produced on scales as large as 120 million t/a, while significant amounts are already stockpiled, as no commercial use or commercially feasible remediation strategies have been devised. The Sc content of RM varies between 15 and 170 ppm, depending on the source of bauxite; furthermore, other REs are also present (~850–1200 ppm of mostly Y, La, Ce, Pr, and Nd). If all Sc from RM could be recovered, 6,600–20,400 t/a Sc could be made available just from the yearly production of RM.

With this in mind, our work focused on optimizing separation selectivity and minimizing reagent use in each step of the herein described approach. Both of these design principles have previously been formulated in the Green Chemistry Principles and been used by us for efficient and cost-effective process design. 75% of the Sc content can be recovered employing the devised process steps. Commercial feasibility analysis of the devised flowsheet in the presence of uncertainties shows very favourable prospects for its commercialization.
tion, even at current low Sc prices. Additionally, a missed RE oxide (Y, La, Ce, Pr, and Nd) is obtained as side product of the process, which may provide further value generation opportunities.

CENTER FOR MATERIALS PROCESSING DATA
The Center for Materials Processing Data (CMPD), the newest of the four centers, generates and collects materials property data for use in manufacturing process models. This data, often transient – time and/or temperature dependent – is difficult to find, yet imperative to produce accurate models. CMPD members have exclusive access to this data, and play a large role in deciding what data are generated and when. Fig. 4 shows researchers at CMPD analysing data from aluminum alloys.

Members will also have access to some of the best laboratory equipment in the world at the three partner universities: WPI, University of Connecticut, and University of Buffalo. A fourth partner, ASM International, offers access to the world’s largest metals-focused materials engineering community as well as additional data resources, and the latest information from the field of materials design and manufacturing.

BENEFITS OF MPI TO INDUSTRY MEMBERS
As a member of MPI, member companies submit and vote on research projects undertaken annually by the institute, network with global industry leaders, and have royalty-free IP rights to pre-competitive research. Companies may opt to sponsor company-proprietary research that remains exclusive and at the same time have access to findings from large-scale projects funded by the U.S. government or foundation grants. Members recruit top students from various engineering disciplines, and have access to all (past and current) MPI technical reports and process data. Companies have access to characterization facilities at all member institutions and can consult MPI faculty, which helps members get timely solutions to factory floor problems without additional cost. Members can sponsor student projects (senior thesis) and industrial internships, additionally.

PROVIDING UNMATCHED VALUE
Clearly, WPI’s Metal Processing Institute continues to provide unmatched value to its members while making an impact in an array of critical areas. The centers are also busy collaborating on a range of projects throughout the year. The ACRC/CHTE joint spring meeting takes place June 13–14 at WPI and will feature a variety of industry presentations, funded project updates, and focus group meetings. Similarly, the CR³ spring meeting takes place May 23 and 24 at the University of Tokyo for corporate members and invited guests.

“MPI has made incredible strides over three decades, and we are excited to bring together the top minds across the manufacturing industry to address some of the most pressing issues of the day,” said Mishra.

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