# Perspectives on Industry/University Partnerships to Support Innovations in the Steel Industry

## 2014 AIME Keynote and AIST J. Keith Brimacombe Memorial Lecture

*Presented by David K. Matlock*

This paper provided the basis for the 2014 AIME Keynote and J. Keith Brimacombe Memorial Lecture and was organized to present selected comments on industry/university partnerships that have evolved, or potentially will evolve, to enhance innovative opportunities for the steel industry. Prof. Brimacombe's career led to significant developments which moved from academic research at the university into industrial settings, where the fundamental principles he advanced in his research, particularly in process metallurgy, could be implemented, leading to world-recognized innovations in the production of steel with associated cost savings.[1] The information presented here was selected to illustrate a variety of approaches that have been implemented in the U.S. and abroad to foster interactions between industries and universities and is not meant to be an exhaustive review of all opportunities. An assessment of the role of government, its changing role in light of globalization, and the renewed emphasis on manufacturing in the U.S. is also included. While most would associate "innovation" with the implementation of new ideas, the importance of education at all levels to develop the necessary skills and thought processes in individuals to ensure that they are capable of being "innovators" cannot be overlooked.

## The "Innovation" Environment

Research and development environments that lead to innovative solutions are found in many different forms, and selected comments extracted from a recent publication[2] are reproduced here. While there is no unique format that guarantees that ideas will yield successful innovations, several common research structures currently in existence include large corporate or government research laboratories, individual university researchers with programs that are typically government-funded and which focus primarily on advancing fundamental research, loose collaborations among investigators on specific projects, individuals working alone and outside of formal research structures, etc. Due to economic pressures, in the recent past many corporate research facilities have experienced considerable organizational modifications. For example, in the United States, several historically important research facilities that have been seats of major innovations, e.g., Bell Laboratories in New Jersey and the U. S. Steel Research Laboratories in Monroeville, Pa., have been closed, restructured and/or significantly downsized. Technology was protected by patenting or maintaining "trade secrets" within the organizations, and the role of the university was mostly to provide talent and, on occasion, supplemental expertise. In parallel with the changes in research laboratories in the private sector, many of the government laboratories have refocused their missions and are continually increasing their involvement with industry.

All over the world, interest is rapidly increasing to organize research and development environments that emphasize "innovation" as a formally stated goal. This observation is clear via a simple Internet image search utilizing the keywords "innovation centers"

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Figure 1


An Internet image search identifies increased emphasis on innovation and technology transfer in both industry and government.

(Figure 1). This exercise, which identifies numerous corporate buildings, research parks, organizations, etc. throughout the world, is evidence that industries and governments are placing more emphasis on innovation and technology transfer. Companies and organizations develop formal "innovation centers" for a variety of reasons. The centers may be founded on fundamental principles of research management and designed to help facilitate cross-discipline interactions, leading to desirable results. The centers may evolve as a result of decisions to more efficiently utilize physical space.

Alternatively, as part of developing a marketing plan, it may be envisioned that an innovation center is necessary to remain competitive. While the term "innovation" may have different meanings to different people and organizations, this paper adopts that "…innovation is the process by which new ideas are successfully exploited to create economic, social and environmental value."[3]

It should be readily apparent that the act of associating the word "innovation" with a work unit, structure or organization does not ensure that successful outcomes will evolve. Critical to success is the ability to bring together individuals and organizations with different backgrounds and perspectives into a single environment with a focused, common goal. While there are several models of success, this paper focuses on the critical role of universities and industry/university partnerships. The importance of the university community in the overall innovation process was highlighted by Dr. Craig R. Barrett, retired CEO of Intel, in a recent article.[4] Parts are excerpted as follows:

> *"As individuals, companies and countries search for something magical to promote a competitive future, there is strong evidence that the ultimate wealth-creating machine is something created here in America and increasingly being noticed and copied by the rest of the world. That something is the American research university, where a unique blend of the best and brightest students from around the world, top-quality professors with aggressive research programs, and a close association with private industry has combined to spin off entrepreneurs with bright ideas for next-generation products, services and new companies. Have others noticed this phenomenon? Certainly the answer is yes.…*
>
> *"Western European countries…Chinese…oil-producing Middle East countries…Russians, with their Skolkovo Project…. All concerned see the 21st century as the innovation century where the top-tier research university is the key for spinning off smart people, smart ideas and wealth-creating innovation."*

As indicated by Barrett,[4] university programs that emphasize industry partnerships have been shown to create successful centers of innovative research. A university-based center can develop via a variety of paths. One can be identified as "top-down," where an individual or organization provides significant base funding to develop a center that then must be staffed by individuals selected to work toward common goals.[5] Top-down university centers may potentially fail if the participating faculty do not have a vested interest in the centers' successes and view the centers only as sources of funding for their own research. An alternate approach is referred to as "bottom-up," where individuals with a vision invest their energy to develop a program, identify sources of engagement and funding, and attract a critical group of participants, which usually involves students, faculty, professional staff and external partners. In this paper, selected different approaches to the development of industry/university cooperative programs are surveyed and contrasted. While emphasis is placed on research programs, both in the U.S. and globally, with the potential to lead to innovative solutions for society, the importance of partnerships to the overall educational program is also highlighted.

## Opportunities for Industry/University Partnerships

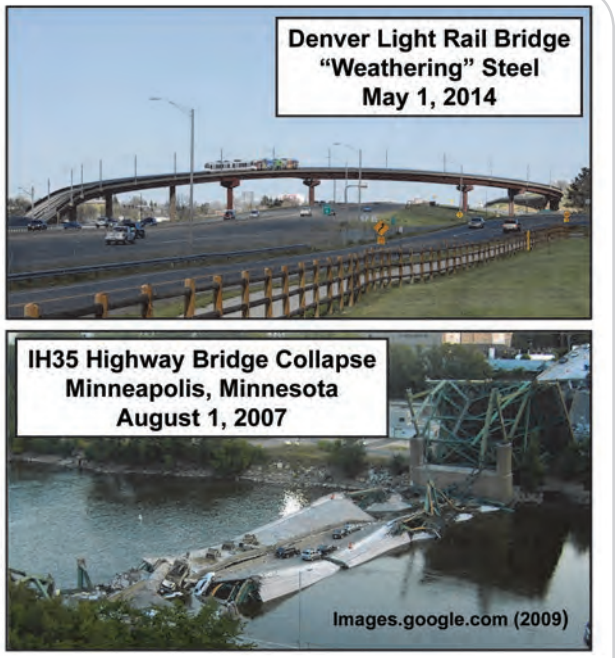
Drivers for Ferrous Metallurgy Research and Education — Over the past 30–40 years, several myths related to the steel industry in the United States and globally have been promulgated in various settings. These myths include the following:

1. The steel industry is a "mature industry," and all technological advancements of significance have been made.
2. The steel industry is a "dying industry."
3. Quality "university research" cannot be performed jointly with industry.
4. Quality "industrial research" cannot be performed jointly with a university.

Myths 1 and 2 are false, as multiple technological advances have led to increased productivity in the steel industry,[6] there has been a rapid growth in global steel production,[7] and new and enhanced products are continually being provided to market.[8,9] In this paper, myths 3 and 4 are also shown to be false, as there are numerous examples where successful research programs within industry/university partnerships have developed to the benefit of all parties involved.

There are many technical and economic drivers significant to the steel industry. Globally, there is an emphasis on the need for new energy production systems, both "conventional" and "renewable," and all require steel to enable economical and safe operation. The production of new oil and natural gas reserves requires new and/or improved steels capable of withstanding often harsh environments (e.g., deepwater drilling in the Gulf of Mexico or off the Brazilian coast, etc.) and higher-capacity pipelines for transportation of the products to market. Growth in the wind industry requires lightweight, high-strength, fatigue-resistant structures and high-performance gears and power transmission equipment for generation systems that continue to increase in size. The need to produce lighter-weight, more fuel-efficient automobiles simultaneously with the production of safer vehicles is driving significant developments in new advanced high-strength sheet steels and higher-performance bar and forging steels. New steels that can be economically incorporated in major infrastructure development and redevelopment projects are required, particularly as the world population migrates to urban areas (Figure 2). In addition to technical needs, highly educated employees with flexible skills to be true innovators are required for the steel industry to continue to advance. As with numerous manufacturing and engineering-dependent industries, many existing employees are nearing retirement, leading Dr. Charles Vest, president emeritus of the U.S. National Academy of Engineers, to state in 2011 that we now require "a new generation of brilliant engineers, researchers and entrepreneurs to create a vibrant future, just as preceding generations did…."[10] As no single entity (i.e., university, company, government, etc.) can provide the necessary new, innovative talent in addition to the technology advances required for the future, it is anticipated that the importance of industry/university partnerships will continue to grow.

Figure 2




Infrastructure development and redevelopment projects are among the drivers for research into ferrous metallurgy. Source of bottom photo: http://en.wikipedia.org/wiki/I-35W_Saint_Anthony_Falls_Bridge.

Assessment of the "Landscape" for Successful Partnerships — Industry/university partnerships can be established to enhance educational opportunities for undergraduate students, to foster industry-relevant graduate research, or a combination of both. Successful industry/university partnerships require that each participant clearly understands the needs and potential constraints associated with the different business and working environments experienced by each. Faculty must appreciate that companies are in business and require well-educated employees as well as innovative new technology with appropriate protection of intellectual property rights, leading to successful products in the marketplace. Companies need to appreciate that in any engineering university, faculty must be in work environments that foster their abilities to be successful in the three primary categories on which promotion and tenure decisions are based:

- Quality "teaching" at both the undergraduate and graduate levels.
- "Scholarship" as assessed by both quality and quantity of publications and by the success of graduates.

- "Service," which includes on-campus activities (such as university committees) and off-campus activities (including participation in professional societies).

Critical to a faculty member's success in the U.S. is the ability to develop a graduate research program which provides the necessary funds to attract and support graduate student research assistants and associated research expenses. All parties must truly view the interactions as "partnerships," where both parties work with a common goal to see that the partnership succeeds.

The ability of a faculty member to develop funded graduate programs in the U.S. depends on several factors, which usually include the availability of federal government support, typically from the National Science Foundation (NSF), Department of Energy (DOE), or one of the defense agencies. While there are excellent examples in which the NSF and other government agencies in the U.S. have continued to fund ferrous metallurgy-based research, the trend over the past few decades has been to de-emphasize the amount of funding for steel research programs in lieu of funding new programs such as nanomaterials, biomaterials, renewable energy, bioengineering, etc., all of which have merit in their own right. As a consequence, in North America and worldwide, higher education institutions that focus on metallurgical and materials engineering have modified offerings to move away from traditional metallurgical engineering programs and focus on materials science as a primary discipline. Correspondingly, many universities have de-emphasized or eliminated offerings related specifically to ferrous metallurgy (or in some cases to metals at all) or to manufacturing in general. Clearly the loss of metallurgical engineering programs which focus on ferrous metallurgy creates challenges for the steel industry and manufacturing industries that utilize steel, and thus the development of partnerships provides the opportunity to potentially overcome some of these challenges.

## Partnerships for Education

Universities and industries have always been "partners," as most university graduates eventually are hired into positions for which they are appropriately educated. The simple act of hiring a graduate transfers information the new employee gained while a student to the hiring company. However, prior to a former student joining a company for permanent employment, industries and universities have developed student-oriented "partnerships" in a variety of ways. Companies organize summer internships or formal co-op (cooperative education) programs which allow students to advance their education and professional preparation via work experiences. Other partnership activities include providing project ideas and materials for design classes or laboratory-based educational courses, providing corporate representatives as seminar speakers, particularly to Material Advantage Chapter meetings,[11] hosting student groups for tours, supporting scholarships, or providing direct funding for specific on-campus activities.

Development of endowed or direct-funded professorships that focus on ferrous metallurgy offers an important and unique opportunity for the steel industry to influence educational programs and provide a basis for partnerships, as often chaired professorships are viewed by academic administrations as enhancements outside of programmatic faculty decisions. The need for endowed professorships to support the steel industry is a point championed earlier by the late Prof. Kent Peaslee.[12] Several such professorships currently exist in U.S. universities, including:

- Nucor Corp. at Missouri University of Science & Technology and South Dakota School of Mines.
- United States Steel Corporation at Carnegie Mellon University and the University of Pittsburgh.
- The Finkl family at Illinois Institute of Technology.
- Armco Foundation at the Colorado School of Mines.
- POSCO at Carnegie Mellon University and Massachusetts Institute of Technology.
- Kobe Steel at North Carolina State University.

While many companies provide direct support for undergraduate students through scholarship programs, one specific program highlighted here is the unique program supported by ArcelorMittal initiated in 2010 at the Colorado School of Mines (CSM).[13] Through this program, funding is provided to support the undergraduate laboratory-based education important to CSM graduates and to provide opportunities to enhance ferrous metallurgy education across the metallurgical engineering curriculum. A unique feature of this program is that, at the end of August prior to entering their senior year, all incoming seniors are provided the opportunity to travel to ArcelorMittal facilities in Burns Harbor, Ind., where, over a two-day visit, they learn basics of steel production from practicing engineers and experience steelmaking operations firsthand. While this program introduces students to ArcelorMittal, the program is

also a benefit to all steel companies, as it illustrates to students the exciting opportunities the steel industry has to offer.

In ferrous metallurgy in the United States, industry/university partnerships have been enhanced by faculty members who joined academic programs after successful careers in the steel industry. Selected examples of prominent faculty members include Prof. John G. Speer at CSM (formerly with Bethlehem Steel Co.), Prof. Richard J. Fruehan at Carnegie Mellon University (formerly with U. S. Steel), Prof. Anthony J. DeArdo at the University of Pittsburgh (formerly with Jones and Laughlin Steel Corp.), Prof. Alan W. Cramb who is provost at Illinois Institute of Technology (formerly with Inland Steel and Bethlehem Steel), and very recently, Prof. Ronald J. O'Malley at the Missouri University of Science & Technology (MS&T) (formerly with Nucor). Prof. Peaslee also had experience with Bayou Steel, Border Steel Mills and CF&I before he joined MS&T. Similar successful paths to academic positions also have evolved internationally. For example, Prof. Wolfgang Bleck joined RWTH Aachen University from ThyssenKrupp Stahl, and Prof. Bruno De Cooman at the Pohang University of Science and Technology (POSTECH) was formerly with OCAS (now part of ArcelorMittal) in Belgium. As evidenced by the successes each of these individuals has had in their respective universities, the path from steel companies to academic institutions has globally benefited steel research and education, as all of these faculty members have successful academic research programs that are primarily industry-based.

## Partnerships for Research — North America

The Role of the U.S. Government — Faculty at many U.S. universities rely on the federal government for research funding with the NSF, often identified as a primary supporting agency. As summarized recently by NSF,[14] business-funded R&D expenditures at academic institutions amounted to about 4.9% of the total in 2011. This fraction contrasts sharply with the situation at selected universities, many of which have a long history of working with industry. For example, in FY2013 at the Colorado School of Mines, 37% of the total research budget was industry-funded.[15] Recently, many universities have awoken to the reality that significant positive benefits can be realized when their programs are aligned with industry and, due to both internal funding pressures and external opportunities initiated by the federal government (discussed further below), are now looking for ways to increase industry-based research funding. For example, in a recent *Denver Post* article (10 September 2013) on research funding at the University of Colorado (CU) in Boulder, the newspaper headline read, "CU Seeks Private Funds," with a byline indicating, "University officials are pursuing industry partnerships to replace federal money."[16]

The U.S. federal government has a variety of programs designed to establish industry/university partnerships at various levels, and some are considered here. Programs include those where the federal government provides significant funding for center operations,[17,18] and those for which only start-up funds are provided.[19]

The Engineering Research Centers (ERC) program was created in 1984 to bring technology-based industry and universities together in an effort to strengthen the competitive position of American industry in the global marketplace,[17] and it is indicated that NSF has continually refined the goals and purposes of the ERC program to meet the needs of industry in the global economy. Activity within the various centers is at the interface between the discovery-driven culture of science and the innovation-driven culture of engineering. Centers are typically funded for up to 10 years, and in FY2012, NSF's contribution to each center's program ranged from US$2.7 million to US$4.2 million annually.[17] In a similar manner, NSF supports centers focused on materials, and currently there are 30 NSF Materials Research Science and Engineering Centers (MRSECs) supported by the NSF, typically for five years at a time, with annual NSF funding on the order of US$2 million. Currently there are no MRSECs focused on steel.[18] As discussed further below, NSF also has had a successful program where initial seed funding is provided from the Directorate of Engineering through its Industry & University Cooperative Research Centers Program (I/UCRC).[19]

On 9 March 2012, President Obama announced a new initiative to establish a series of centers to form the National Network for Manufacturing Innovation (NNMI).[20] He discussed this initiative in both his 2013 and 2014 State of the Union messages, where in 2014 he indicated that two institutes had been formed and six more will be established in 2014.[21] As stated in the Broad Agency Announcement issued 9 July 2013,[22]

> *"...these institutes will bring together industry, academia, and federal and state agencies to accelerate innovation by investing in industrially relevant manufacturing technologies with broad applications…and provide shared assets to help companies — particularly small manufacturers — access cutting-edge capabilities and equipment…and to educate…students…in advanced manufacturing skills."*

Five-year funding is at a level of approximately US$140 million, US$70 million of which will be provided by the federal government through either the Department of Defense or the DOE. Particularly relevant to the steel industry is the Office of Naval Research announcement to establish a Lightweight and Modern Metals Manufacturing Innovation (LM3I) Institute, where high-strength steels that facilitate lighter-weight designs will be a main focus area.[22] On 25 February 2014, President Obama announced funding for LM3I, and as a result, the American Lightweight Materials Manufacturing Innovation Institute (http://almmii.org) was formed.

Another mechanism for government funding of research at universities is through multi-agency collaborative programs,[23] usually structured to fund a single project or a group of projects for a fixed period of time. For example, in 2007 a program funded by the NSF (Civil, Mechanical and Manufacturing Innovation Division) jointly with the DOE (Lightweighting Materials Division) and managed by the Auto/Steel Partnership (A/SP) in Michigan was initiated. The program funded research on new advanced high-strength steels (AHSS) at nine universities. The program ended in 2012, and without continuation of funding, some of the research groups moved on to other pursuits.

**The Role of Professional Industry Associations —** Several professional industry associations are actively involved in fostering industry/university research programs, including those of the American Iron and Steel Institute (AISI). Over the past 50+ years, AISI has utilized a variety of formats to engage with industry/university/government research programs, and the approaches have changed over time. In the 1960s and 1970s, individual AISI committees directly funded focused programs at universities. In fact, in 1976, one of the primary programs that fostered the collaborative research on dual-phase steels at CSM between George Krauss and David Matlock[24] was funded by an AISI subcommittee on product metallurgy. Subsequently, in the early 1980s, AISI pooled all of its committee research funds to establish the Steel Resource Center at Northwestern University in 1986.[5] The center eventually ceased operations in the early 1990s due to unavailability of funds, although some individual faculty members have remained active in steel research.

In 1999, AISI partnered with the DOE to manage and fund Technology Roadmap Research for the Steel Industry (TRP),[25] a US$38 million cost-shared research and development program from July 1997 to December 2008 in which individual companies had the option to participate in particular projects within the broader program.[6] Specific benefits cited from this project were that "universities which must provide the next generation of steelmakers received 39% of the R&D funds," and that "TRP contributed to 56 advanced degrees and encouraged a large number of young engineers and science graduates to accept positions in the steel industry." Recently, AISI has managed follow-up joint industry/university/government programs on "transformational processes for making steel that will dramatically reduce or eliminate $CO_2$."[26] While not having an independent research budget, through its offices in Washington, D.C., Pennsylvania and Michigan, AISI continues to actively identify opportunities and organize collaborative research projects to leverage government funding with optional industry support to advance ferrous metallurgy R&D programs. In 2014, AISI's Committee on Manufacturing Technology is leading an effort to develop an updated technology roadmap for the steel industry.[27]

**Centers and Ferrous Metallurgy Programs at U.S. Universities —** AIST recently identified several remaining academic programs in North America which focus on metallurgical engineering with ferrous metallurgy still recognized in the curriculum.[28] Within some of these programs, successful graduate programs or research centers that emphasize ferrous metallurgy have also evolved, and each represents a different approach to industry/university cooperative research. Examples of cooperative research centers include:

- The Center for Iron and Steel Making Research (CISR) at Carnegie Mellon University.
- The Basic Metal Processing Research Institute at the University of Pittsburgh.
- The Steel Research Group at Northwestern University.
- The Continuous Casting Consortium at the University of Illinois at Urbana-Champaign.
- The recently established (2013) Kent D. Peaslee Steel Manufacturing Research Center at the Missouri University of Science & Technology.
- The Advanced Steel Processing and Products Research Center (ASPPRC) at the Colorado School of Mines.

While each program operates differently, the following section presents a case study of ASPPRC to illustrate one approach to the development of a long-standing industry/university partnership.

**Case Study: Advanced Steel Processing and Products Research Center —** ASPPRC, along with

several successful centers in a variety of engineering and scientific disciplines, has evolved with funding from the NSF I/UCRC[19] program, which is currently within the recently created Industrial Innovation and Partnerships Division (IIP) of NSF.[29] For these centers, seed funding is provided only for a maximum of five years, with the concept that if the center model is viable, then for subsequent years the center will become self-sufficient, funded completely by corporate partners. For a center to be able to achieve self-sufficiency, a dedicated staff must develop a critical number of corporate partners and a well-organized research model. Over the years, some centers that were unable to satisfy these criteria did not gain the minimum number of partners to achieve self-sufficiency, and as a result several centers have not survived.[30] Reasons for successes and failures in I/UCRCs were highlighted in a recent NSF review, which also included an assessment of the reasons for the success of ASPPRC.[30]

The ASPPRC in the George S. Ansell Department of Metallurgical and Materials Engineering at CSM was conceived in 1982 at a time when the climate for research on steels was in the process of dramatic change.[31] Through the 1960s and much of the 1970s, steel companies supported well-equipped and well-staffed research laboratories, and federal support of academic research on steels was significant. However, competitive pressures and a national emphasis on the development of other new materials changed those scenarios. Starting in the late 1970s, the American steel industry downsized its staff to become more competitive with less-expensive foreign imports. Financial support of steel research at universities nearly disappeared, scholarship and fellowship support was withdrawn, and hiring of new engineers into the American steel industry was limited for a time.

The need to counteract the decline in steel research overall, coupled with the strong culture of ferrous metallurgy research and teaching at CSM and encouragement from industry, led Profs. George Krauss and David Matlock in 1983 to submit a proposal titled "Planning for a University-Industry Steel Research Center" to the NSF Division of Industrial Science and Technological Innovation. After a year of planning that included visits to multiple corporate laboratories, a successful proposal to establish ASPPRC was funded, and with six corporate partners, center operations initiated on 1 October 1984. The consortium research program is unique, as it brings together CSM faculty and students with companies that are competitors, suppliers and/or customers into an environment where all research results are shared between participants. To accommodate companies with diverse research interests, programs in three primary sub-groups evolved: Bar and Forging Steels, Sheet and Coated Steels, and Plate and Hot Rolled Steels, with additional focus on specialty alloys within the appropriate sub-groups. At the same time ASPPRC was formed, a second NSF I/UCRC, the Center for Iron and Steelmaking Research at Carnegie Mellon University, was also being established.[32] As with ASPPRC, this second center continues to be active today, with a research focus on upstream process metallurgy that complements the product-oriented research at ASPPRC.

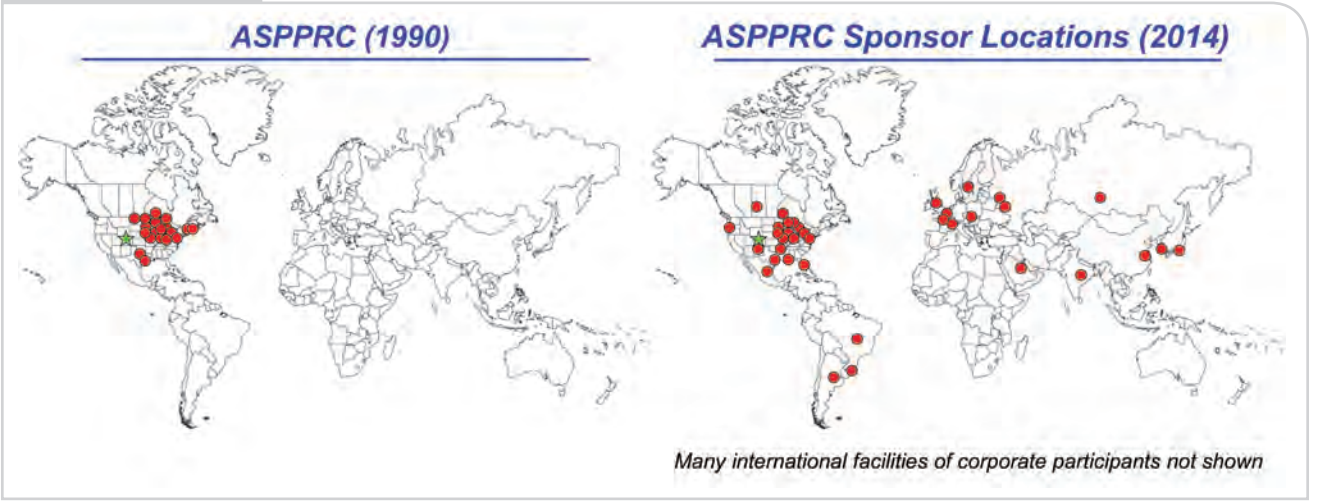
One primary objective of ASPPRC was, and continues to be, to perform research of direct benefit to both suppliers and users of steel. As a direct consequence of performing industrially based research in a university environment, steel research topics evolve that provide exciting opportunities for new graduate students to select careers focused on steel, in lieu of alternate career paths in other materials-related disciplines (e.g., ceramics, electronic materials, nanomaterials, biomaterials, etc.). The industry/university partnership is a very powerful recruiting tool, as after learning about ASPPRC, many students find that the opportunity to work on industry-supported research is very attractive. Also at CSM, a very important and often overlooked benefit of ASPPRC is that, by the center's existence, the overall undergraduate educational program is enhanced by maintaining faculty involved in teaching with interest in ferrous metallurgy and by offering undergraduate research opportunities.

ASPPRC has responded to significant changes in the worldwide steel industry that have evolved along with the industrial globalization that has occurred since the early 1990s. The unique ASPPRC partnership with industry has successfully transformed from a program focused on the North American steel industry to one that is currently recognized internationally. While consolidation in the steel industry applied financial pressures to the operation of ASPPRC as the number of North American sponsors decreased (e.g., currently 17 companies that were once independent corporate partners are all now part of five current ASPPRC sponsors), international exposure of the ASPPRC programs has expanded until today there are 30 corporate sponsors with headquarters in 13 countries (Figure 3).

Examples of innovations that have evolved from ASPPRC research include:

- Improvements to experimental test methodologies, including development of test procedures for dent testing,[33] and sheet metal friction and shear fracture testing methods.[34]
- Identification of alloy modifications for high-temperature carburizing steels.[35]

Figure 3




The Advanced Steel Processing and Products Research Center (ASPPRC) at the Colorado School of Mines has expanded to include 30 corporate sponsors with headquarters in 13 countries.

- Advancing new approaches and process methodologies for the production of new third-generation advanced high-strength steels (3GAHSS).[8,36–40]

Within the latter example is the latest in a series of innovations, the identification and development led by Prof. John Speer of the "quenching and partitioning" process (Q&P), a unique approach to the production of high-strength steels with the significant amounts of retained austenite predicted to be required for 3GAHSS (Figure 4).[38–40] The term "Q&P steel" is now a steel designation accepted worldwide. Significant fundamental research and production developments on Q&P steels are currently ongoing globally,[41,42] and one company is in the early stages of commercializing products.[9] Recently, the importance of Prof. Speer's innovative concept was recognized as he received the 2014 AIST Tadeusz Sendzimir Memorial Medal.

## Partnerships for Research — International Universities

Industry/university partnerships are not unique to North America, and several notable programs have evolved globally. However, there are many fundamental differences between academic programs and funding opportunities between the U.S. and other countries. These differences have often led to diverse perceptions and expectations by both industrial and academic partners. As one example, staff and graduate student funding models vary widely between countries. In the U.S., faculty members are typically hired on nine-month contracts, while in most foreign countries the faculty members are on 12-month contracts. Thus, in the U.S., faculty are responsible for raising funding to cover, at a minimum, the additional three months of their annual contracts, as well as the tuitions, fees, research expenses and stipends for graduate students not funded by their employers or fellowships. In contrast, in many other countries, once students are admitted to graduate school, their tuition may be covered by their government, and often they and/or their families are responsible for their living expenses, leaving funds raised by faculty available for support of the direct costs of research. As a result, the direct costs to a company for participation in industry/university collaborative research may differ significantly between countries, leading to different perceptions in benefits received. In the following paragraphs, specific industry/university partnerships in countries other than the U.S. are briefly summarized to contrast the different types of programs that exist globally.

Canada — In 2000, strong support from Dofasco (now ArcelorMittal Dofasco Inc.) and Stelco (now U. S. Steel Canada) led to the founding of the Steel Research Center,[43] a partnership that evolved from long-established industrial collaboration at McMaster University. To support ferrous metallurgy research, Dofasco endowed the Dofasco Professor of Ferrous Metallurgy, held by Prof. Gordon Irons, co-director of the center, and the Dofasco Chair in Process Control and Information Technology, now held by

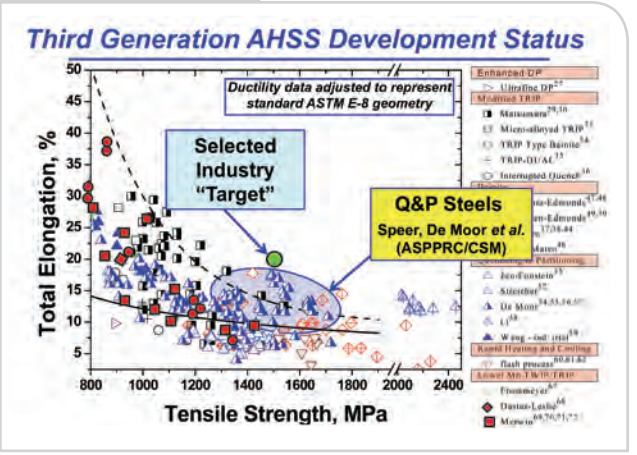
Prof. Christopher Swartz in the Chemical Engineering Department. Stelco supported an industrial research chair (IRC), co-funded by the Natural Sciences and Engineering Research Council of Canada (NSERC)[44] in the steel product area; the chair is now named the NSERC/U. S. Steel Canada Industrial Research Chair in Advanced Coated Steels and is held by Prof. Joseph McDermid in the Mechanical Engineering Department. Following the inception of the center, U. S. Steel Canada established another endowed chair in sustainable steel production, held by Prof. Neslihan Dogan. Thus, there are four chairs associated with the center, funded through the steel industry and the Canadian government in the departments of Materials Science and Engineering, Chemical Engineering and Mechanical Engineering. The center has also attracted support from other steel companies and suppliers to the industry, and there are now 13 member companies.

In Canada, industry/university partnerships, such as the Steel Research Center, are significantly facilitated by the government funding polices of the NSERC, which establishes partnership chairs with partial funding from industry.[44] The presence of NSERC chairs in universities provides a strong foundation for industry-relevant research, as opportunities exist for early-stage researchers via an "associate industrial research chair" that is available for five years and for distinguished senior researchers via a renewable "senior industrial research chair." Currently, there are 47 associate chairs and 118 senior chairs active in Canada, of which seven focus on metallurgy and materials.[45] University/industry-based research is also enabled via major equipment and facility funding from the Canada Foundation for Innovation, as evidenced by a grant to McMaster University for process metallurgy equipment to simulate industrial galvanizing operations.

Europe — In Europe, there are several internationally recognized research institutes and universities that foster industry/university collaborations with a focus on ferrous metallurgy. For example, the Max-Planck-Institut für Eisenforschung GmbH,[46] which receives 50% government and 50% institutional co-sponsoring by industry, is a unique example of a public-private partnership to support European industry. The institute also offers opportunities for doctoral programs. The Department of Ferrous Metallurgy at the RWTH Aachen University is another example of an educational program where student research projects are based on fundamentals and also lead to relevant results to solve real-life problems.[47]

In contrast to consortium programs, where results are shared between companies, in Europe often the industry/university partnerships revolve around specific support for a single student, usually pursuing a Ph.D., at a university to work on a research project exclusively for a single company. Once the project is completed, continuity of the program depends on the availability of follow-up funding. In addition to projects supported by individual companies, the European Commission, Directorate General for Research and Innovation, through the Research Fund for Coal and Steel (Figure 5), is a primary supporter of ferrous metallurgy-based research at universities

Figure 4




The identification and development of Q&P steels came about through the research of the ASPPRC. Source: "Strategies for Third-Generation Advanced High-Strength Steel Development," AIST Transactions, *Iron & Steel Technology,* November 2010.

Figure 5


The Research Fund for Coal and Steel is a primary supporter of ferrous metallurgy-based research at universities in Europe.

Figure 6

The Graduate Institute of Ferrous Technology, part of POSTECH in Korea. Source: http://en.wikipedia.org/wiki/Graduate_Institute_of_Ferrous_Technology.

and has a 2014 budget of approximately €48.4 million,[48] with a similar budget anticipated to be available well into the future. Each project involves multiple participants, bringing together researchers from universities, industries and government laboratories, and is funded partially by industry matching funds.

Korea — In Korea, the Pohang University of Science and Technology (POSTECH) was founded in 1986 with support from POSCO. The university is now recognized as a top technical university in Asia. In 2005, the commitment of POSCO to support graduate education and research was strengthened through initiation of the Graduate Institute of Ferrous Technology (GIFT), a stand-alone facility and educational program at POSTECH with a mission to grow into a world leader in education and research specializing in advanced iron and steel technology.[49] A 25,000 $m^2$ facility (Figure 6) was constructed and opened in 2009 to house nine focused laboratories, each headed by an internationally known director (e.g., Prof. Bruno De Cooman for the Materials Design Lab and Prof. Harry Bhadeshia for the Computational Metallurgy Lab).

United Kingdom — In the United Kingdom, in 2011 Tata Steel RD&T and the Royal Academy of Engineering jointly funded a new Chair for Research into Low-Carbon Materials Technology in the Warwick Manufacturing Group (WMG) at the University of Warwick.[50] The two partners each provided £600,000 to support the new chair, and in March 2013, Prof. Sridhar Seetharaman assumed the chair. While this chair was established to work closely with Tata Steel Europe, it is noteworthy that it was established at WMG, an organization currently having 450 participants and four buildings within the university. The WMG was established in 1980 to help reinvigorate U.K. manufacturing with a stated mission: "…to improve the competitiveness of organisations through the application of value-adding innovation…."[51]

Japan — The Japanese government recognized "…the important role that research universities…should play…and enacted in 1999 the Law on the Special Measures for Revitalizing Industrial Activities to encourage the transfer of technology from universities to industry…."[52] As an example of the response to this directive, in 2010, the Steel Research Center was established at Kyushu University in Japan under the direction of Prof. Setsuo Takaki. Research there is focused on the production of steel and the evaluation of its properties.[53] While the center does have financial support primarily from two steel companies, as well as the government, unlike the ASPPRC consortium research program, proprietary corporate-funded steel research is segmented (rather than shared) based on the supporting company.[54]

In December 2013, the Japanese government inaugurated a new 10-year program, with an initial annual funding of 4.09 billion yen (≈ US$40 million), with the goal of reviving the international competitiveness of Japan's manufacturing industry.[55,56] The program's focus is to develop high-performance materials, including steels, to facilitate weight reduction in transportation equipment. A new organization, the Innovative Structural Materials Association,[56] will manage collaboration between manufacturers (including three major Japanese steel companies) and academia. Unlike multiple-company programs elsewhere in the world, individual companies will have the responsibility of interacting with universities, and research results will not be shared with other companies.

China — In China, where the rate of increase in governmental support for education[57] has mirrored the rate of increase in steel production,[7] many universities have been structured to provide direct benefits to industry. Of particular importance to the steel industry is the University of Science and Technology Beijing (USTB), where metallurgical engineering is indicated as a "national key discipline." USTB's School of Metallurgical and Ecological Engineering website indicates that "…the discipline of metallurgical engineering in the school enjoys high reputation both at home and abroad."[58] The ferrous metallurgy emphasis of UTSB commenced on its founding in 1952, when it was known as the Beijing Industrial Institute of Steel and Iron, to be renamed in 1960 as the Beijing Steel and Iron Institute, and subsequently adopting its current name in 1988. Key government-funded programs, e.g., the National Engineering Research Center for Advanced Rolling Technology, have been established to develop innovative technologies and provide pilot plant operations to facilitate advancements in support of the steel industry in China.[59]

Recognizing the need to be able to attract, recruit and retain a new generation of highly qualified employees for the future, several of these international programs have a significant focus on education. For example, Tenaris, a major supplier of seamless and welded pipe to the oil and gas industry, particularly in Latin America, has developed programs to encourage students to pursue careers in the steel industry, as well as programs to enhance employees' careers once they join the company.[60]

## AIST Initiatives and Opportunities

The Association for Iron & Steel Technology (AIST), through the AIST Foundation, has established several significant programs designed to simultaneously enhance ferrous metallurgy education, primarily in North American universities, as well as foster industry/university partnerships. The Foundation provides awards totaling more than US$600,000 each year.[61,62] There are several specific programs of note:

- Undergraduate scholarships including the FeMET Scholarship, StEEL Scholarship, AIST Foundation Premier Scholarship, Lewis & Elizabeth Young Scholarship, and others.
- The "Steel to Students" program (Figure 7), which includes student plant tours, methods to connect with Member Chapters, and reimbursement of expenses for student chapter meetings.
- Faculty grants, including the FeMET Design Grant, FeMET Curriculum Development Program, and the Kent D. Peaslee Junior Faculty Award.
- Support of Material Advantage chapters at individual universities.
- Hosting of student receptions to facilitate networking at AISTech.
- Various contests for students, including the AIST Foundation "Real Steel" Video Contest and student project and poster presentation contests.

Figure 7


The Steel to Students program is part of the AIST Foundation's efforts to get students more involved and interested in the steel industry.

AIST's support of these scholarships, awards and programs provides additional opportunities to enhance industry/university partnerships at all participating universities.

## Discussion and Summary

The examples surveyed above illustrate that industry/university collaborations are structured in a variety of ways, and as such, the subject of this paper, industry/university partnerships, has different meanings depending on the perspective of the observer. It is clear that in order to maintain the breadth of collaborations considered in the illustrations discussed here, absolutely essential elements are: (a) a group of faculty dedicated to research and education on ferrous metallurgy, (b) a graduate research program sustained by university administrative support and (c) a funding plan to ensure continuity for the "long haul." The existence of a formal graduate program is necessary to provide an environment where, in the modern-day university, faculty can be successful in their careers. Primary features of successful industry/university partnerships also include the ability to (a) maintain continuity in funding and staff and (b) be in a position to manage economic and societal changes that have occurred and will assuredly occur in the future.

Stability in funding and structure of programs in support of the steel industry has been achieved in a number of ways. Governmental funding policies in some countries enable the continuity of successful industry/university collaborations, and as a result, the government policy is in place to ensure those programs continue. For example, the Chinese government support's for USTB ensures that the university maintains its stated focus to provide research and educated talent to support industry. In Europe, institutes and research universities benefit from funding from the Research Fund for Coal and Steel and government tax incentives that encourage companies to invest in research partnered with universities. In Canada, the NSERC-supported professorships provide a framework to encourage faculty to participate in industry-based research and expand industry/university partnerships. Support of professors early in their careers provides a mechanism to encourage young faculty to partner with more senior faculty and develop stable industry/university collaborative research programs. In partnerships where a single company provides the base funding, as is the case of the Graduate Institute of Ferrous Technology in Korea supported by POSCO, continuity is assured, as the student-oriented research is aligned with the company's own internal research programs.

A company's approach to and involvement in a formal industry/university partnership depends on several criteria. Often the decision is based on different perceptions of how to protect corporate intellectual property. Alternately, the decisions may be driven by broader interests to advance fundamental knowledge in ferrous metallurgy and to develop a pool of technical personnel who can implement fundamental information to achieve innovative solutions for the steel industry. It appears that it is often easier for companies to perceive potential benefit from participation in a one-on-one project directly related to ongoing corporate needs. However, as evidenced by the discussion above, there are several examples, particularly in North America, where industry/university centers based on consortium funding and shared research have been, and continue to be, successful.[30,31,63]

There are multiple benefits of consortium-based research programs. The benefits that have been realized over the past 30 years since ASPPRC at CSM was established are extensive.[30] For instance, a significant number of students who were interested in metals upon completion of their undergraduate programs, but were unsure of the specific focus for their careers, were attracted to the industry-based research program. As a result, over 210 M.S. and Ph.D. theses have been completed, with many of these students currently working in the steel and related manufacturing industries. To date, more than 570 technical papers have been published, many of which have been cited for national and international publication awards.

ASPPRC staff recognized early the need to develop faculty to support the center's research and educational opportunities. For example, as steels are very important to the forging industry, a successful proposal was submitted to the Forging Industry Educational and Research Foundation (FIERF) to establish, in 1989, the FIERF Professorship at CSM, with a designated responsibility to interact with ASPPRC. Another extremely important contribution to faculty development at the university and to the steel industry is that the center provides an environment to attract and mentor young faculty members so that they can establish successful careers with teaching and research emphasis on ferrous metallurgy. The existence of ASPPRC at CSM has also helped to maintain a strong undergraduate program that continues to emphasize ferrous metallurgy in its curriculum.

The center has also supported professional societies, as staff members have helped to organize many topical conferences jointly with professional societies. These have included AIST, The Minerals, Metals & Materials Society (TMS), the International Deep Drawing Research Group (IDDRG), as well as sessions at society conferences, including the Society of Automotive Engineers (SAE) annual meeting, the annual joint Materials Science & Technology meeting, and others. Of particular note is the series of conferences on advances in sheet, bar and plate steels organized jointly since 2004 with AIST. For example, in 2013 the AIST International Symposium on New Developments in Advanced High-Strength Sheet Steels was held in Vail, Colo., and an AIST conference on bar and forging steels is being planned for 2015 to follow up on a bar steel conference held in 2006.

ASPPRC staff members have been asked to be advocates for the steel industry and have been called on to participate in workshops designed to develop broader-based research agendas for U.S. funding agencies, national laboratories and corporate organizations. In addition, faculty members have provided interviews for international publications, including the *Wall Street Journal* and the *New York Times*.[64] In 2004, ASPPRC staff participated, along with AISI and industry representatives, in a special U.S. Senate Science and Technology Caucus meeting entitled, "American Steel: Forging Strong Links Between Materials Science & Technology to Invigorate the Industry," and presented a lecture on the importance of industry/university partnerships.[65]

In summary, industry/university partnerships have been shown to be extremely successful and provide an environment leading to innovations. Participation

in these types of partnerships should be viewed as important, and as a key component in future programs for the steel industry in general and individual companies in particular. There are two important observations relative to all of the partnerships that have been successful. First, each possesses a method of funding and support that ensures program continuity, even during changing economic environments and with staff changes which occur over time. Second, industry participants and university faculty and staff all view the relationship as a true partnership, where all participants work toward the same common goals to reach program success. It is apparent that many organizations, including AIST, and corporations have and will continue to support ongoing programs and to identify new opportunities to advance industry/university partnerships that benefit the steel industry. Without their support, programs like ASPPRC and others cited above would not have been successful.

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## Did You Know?

### AIME Leadership Visits AIST/TMS Headquarters

Michele Lawrie-Munro, executive director, AIME, and Dale E. Heinz, AIME president, recently met with staff from AIST and TMS at their headquarters in Warrendale, Pa., USA, on 9–11 June 2014. During this time, the AIME Investment Committee also met with key AIST and TMS personnel, as well as SME representative Mike Hedges and SPE representative Steve Byrne, to discuss data and best practices. A brief overview was presented to all staff by Michele and Dale, emphasizing AIME's mission to support its member societies. Details included the history of AIME, current membership, ongoing collaborations, initiatives and future work within the organization. A commemorative plaque was presented by AIST to Dale Heinz in appreciation for his service as the 2014 AIME president.

AIME visited AIST and TMS on 9–11 June 2014 (left to right): Adrianne Carolla, Michele Lawrie-Munro, Mike Hedges, Dale E. Heinz, Ron Ashburn, Steve Byrne and Mark Didiano.