DIRECT FROM MIDREX
4TH QUARTER 2015

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COMMENTARY

MIDREX R&D – LAB COATS AND STEEL-TOED BOOTS

By Vincent F. Chevrier
Director, Research and Technology Development

This summer Midrex dedicated the latest renovation of its research and development center. Like the company it represents, the Midrex Research and Development Technology Center is a blend of experience, expertise and enthusiasm. It is where ideas are conceived, tested, evaluated and refined.

Midrex and its parent and technology partner, Kobe Steel Ltd., have expanded and equipped the facility to function as their center of excellence for direct reduction and associated technologies. Over the last 40 years, Midrex labs have tested more than 7,000 iron-bearing materials, and some of the testing protocols developed by Midrex have become ISO standards. The state-of-the-art laboratories and testing equipment allow Midrex to thoroughly evaluate various iron ores and alternative iron-bearing materials, as well as non-ferrous materials. The facilities, equipment and personnel also are valuable resources for supporting MIDREX® Process Licensees, partners and potential clients.

When asked what is the role of research and development at Midrex, my answer is, “it revolves around 3 missions: expertise, support and innovation.” The R&D Technology Center may be called upon to investigate the fundamental science of areas of potential commercial interest, to discover new ways to adapt existing processes and best utilize existing products, to provide hands-on training for young engineers or to assist customers to optimize their materials and equipment.

R&D always has been central to the business mission of Midrex, both in purpose and in practice. Midrex has built its reputation on supplying sustainable technological solutions that deliver the results our customers want. We achieve this by identifying specific customer and market needs and then applying a synergy of our engineering expertise, commercial acumen and field experience.

Midrex has made small, incremental improvements to its technology over the years as well as some rather radical changes. However, throughout our history, the process of innovation has remained solid and improvements are well studied before being introduced. These are big reasons why the MIDREX® Process is known for performance and reliability.

Midrex R&D involves and engages employees throughout the company. It is not unusual for an engineer or technician to stay involved with an idea or suggestion during the R&D process including participating in the testing and taking the results to the field. Likewise, most of the R&D staff have found him or herself serving as a member of a project task force or a commissioning and start-up team.

Those of us who call the Midrex Research & Development Technology Center home: the materials scientists, chemists, engineers, technicians and administrative staff, have the opportunity to add to the legacy of Midrex R&D – to be the inspiration for what is possible, the developer of what is practical and the provider of what is profitable. ■
Over the past 15 years, the transformation of our rapidly growing global society to a low carbon based production economy has been a hot topic of discussion. The intention is for 80% of the CO₂ reduction to come from new concepts and approaches with the remaining 20% coming from process development. The larger fraction of the reduction (80%) can only be achieved by a transfer of global energy/power production away from carbon containing fuels. Since this falls outside the direct influence of the iron and steel industry, we must focus on the process improvements portion of the reduction (20%). While there is no immediate known and proven path to totally eliminate carbon from the iron and steel production cycle, the use of natural gas, (i.e., bringing more energy into the cycle via hydrogen versus carbon), can act as a bridge technology for the transfer between carbon and non-carbon based energy systems. Use of HBI and DRI produced with natural gas allows flexibility for the EAF steel production route as well as for the integrated BF/BOF steel production.

Thus far efforts to reduce carbon usage and CO₂ production since the beginning of the 21st century have reduced the European Union (EU) share of CO₂ production to approximately 10% of the world total. Notwithstanding this, each country and every company therein has its own timeline for reducing CO₂ intensity, and plant life cycles and the speed at which carbon-lean energy sources are adopted must be considered.

Within the last 50 years, energy consumption by industry has been reduced by 30%, and the main driver behind it has been technology development. Now the thermodynamic limits are close to the consumption levels and it will become more difficult to achieve further significant reduction levels. Therefore, we must look to better use clean energy sources, such as natural gas, to supplement production technologies.
IRON AND STEEL TECHNOLOGY

Steel is essential to the modern world. Thanks to its strength and its properties of formability, steel is one of the most versatile and adaptable engineering materials available. It is the material of choice for a wide range of applications ranging from the construction of bridges and buildings, to automotive and machine parts, as well as food packaging, power generation and aerospace engineering. The major end-use industries include construction (35%), automotive (18%) and mechanical engineering and metal goods (each 14%). Steel’s recyclability also makes it a key material for sustainable development [1].

There are two general methods of crude steel production in use in the 21st century: the basic oxygen furnace route (BOF) and the electric arc furnace route (EAF), as shown in Figure 1. The BOF route converts iron ores to steel via blast furnaces (BF) or smelting reduction (SR) processes and basic oxygen furnaces (BOF). The EAF route converts steel scrap and/or direct reduced iron (DRI) and/or hot briquetted iron (HBI) from direct reduction (DR) processes to steel via electric arc furnaces (EAF).

Iron ores, which are iron oxides with an iron content of 60% or greater, must first be reduced into iron by removing the oxygen bound to the iron either by melting in the BF or with the help of reducing agents, mainly carbon monoxide (CO) and hydrogen (H₂) in a DR process. Iron reduction is the most energy intensive step in the steel production process, consuming approximately 90% of the primary energy required to make steel. EU crude steel production is today almost evenly divided between the BF-BOF and the Scrap-EAF routes. In 2013, BF-BOF accounted for 60% of EU27 production and Scrap-EAF the remaining 40%. Although other iron and steel production processes, such as the COREX®/FINEX®-BOF route or the DR/EAF route are used in different parts of the world, they have little-to-no significance for the EU [2].

The most common primary production route uses the blast furnace (BF) in combination with the basic oxygen furnace (BOF). The best available technology (BAT) benchmark in Europe for emission of the blast furnace route is 1,475 kg CO₂ per ton crude steel (CS). Due to continuous optimization, the industry is already approaching the theoretical minimum of 1,371 kg CO₂/ tCS. Therefore, further substantial emission reduction is only possible through the implementation of new breakthrough technologies. Key areas of process development are Carbon Capture and Storage (CCS) or Use (CCU) in combination with fossil fuels and hydrogen as innovative reducing agents for the reduction process [1].
REDUCTION OF CO₂ INTENSITY

Depending on the separation of iron and oxygen, the iron and steel industry is one of the more energy-intensive industries. It is expected to contribute to the climate targets and to reduce greenhouse gas emissions (GHG) significantly by 2050. For example, the German iron and steel industry consumed 6% (554 PJ) of the total German end-use energy demand and caused 4% (41 Mt CO₂) of the total GHG emissions in 2011 [3]. Since the pre-industrial era, the concentration of GHG in the atmosphere has risen steadily from below 300 ppm (1900) to 400 ppm in May 2013 [4], as shown in Figure 2.

In order to maintain a chance to keep global warming below 2°C compared with the pre-industrial age, the maximum threshold is considered to be 450 ppm; however, this would be reached in 30 years at current emission reduction levels. Drastic emission reduction is necessary across the world to achieve this target. As suggested by the Intergovernmental Panel on Climate Change (IPCC) for developed countries, the EU targets a reduction in GHG emissions of 80-95% by 2050. This target is in line with the recommendations to decrease global emissions by 50%.

That roadmap for a competitive low-carbon economy by 2050 requires examination of possible cost-efficient paths toward reducing EU domestic greenhouse gas emissions by 80% by 2050 (Figure 3).

According to the commission’s report, European industry would have to cut back its emissions below 1990 levels by 34-40% by 2030 and by 83-87% by 2050. In this context, the commission and the European Parliament invited industrial sectors to develop their own low-carbon roadmap.

Studies confirm that the EU commission target without a radical transfer of the energy systems is far beyond the reach of the steel sector. From an economic perspective, only 10% emissions reduction per ton of steel is possible between 2010 and 2030 and 15% between 2010 and 2050. Also, there is very high potential for CO₂ mitigation from innovative technologies in which steel cannot be replaced by any other material, indicating that European climate targets hardly can be reached even without considering steel production [5].

STEEL INDUSTRY TECHNOLOGY TREND

If the steel industry is to continue producing in Europe and retaining its global competitiveness while “de-carbonizing” its operations, substantial research must continue into carbon-lean technologies. Further major reduction in emissions has been the subject of a number of scientific studies and programs in recent years. The ULCOS program, set up in 2004, has made a major contribution to the issue. The initiative, which includes major European steel producers, was supported by the European Commission. It has evaluated the technical CO₂ reduction potential of over 80 existing and potential technologies, out of which it identified technologies with a long-term emissions reductions potential of more than 50%. These include the blast furnace with top gas recycling (BF-TGR), bath smelting (HISARNA) and direct reduction. These technologies must be investigated further in R&D programs including pilot and demonstration plants. All breakthrough technologies rely on the development of CCS and/or the transfer from carbon to hydrogen as reducing agent to unfold their full abatement potential (Figure 4).
In future decades of this century, the traditional model of the integrated steelworks (i.e., taking in iron ore as a raw material and reducing it to metallic iron) will come under great challenge (Figure 5). Since the year 2000, the amount of steel made per year has doubled from 800 Mt to 1.6 Bt, but there is something quite important about the last 15 years of steel production compared with everything that came before.

Fifteen years is about the time required for steel products to enter into the scrap cycle [6]. Starting from scrap and using the electric arc furnace (EAF) rather than the blast furnace to make steel could result in a significant change in the carbon footprint of the steel production cycle. However, as long as scrap remains fairly scarce, production economics will tend to favor the BF-BOF route. But what happens when new steel enters the scrap cycle and a transfer from carbon to renewable energy takes place? There could be a shift towards EAF metallurgy for new units and a more or less constant level of BF-BOF units.

COMBINATION OF PROCESS ROUTES
There are two primary limitations related to replacing carbon intensive steel production: plant lifetime and the availability of carbon-lean energy. Iron and steel production units have lifetimes measured in decades. Almost all existing blast furnace plants in the world have the latest technical standards and will remain in production until the middle of the century. Therefore, a technology change can be implemented only when a new investment is planned. The DR/EAF route could be a new approach for an integrated plant in the future.

The availability of renewable or carbon-lean energy on a continuous basis for more than 8,500 hours per year is not entirely within the influence of the metallurgical industry. Today we have technologies available to reduce the CO₂ intensity further, but every company and country has its own timeline for this process.

Considering all these trends in iron and steel metallurgy in the next few decades, the question becomes what is now the best available technology for a new production unit? A possible answer can be found in the decision by voestalpine to build an HBI plant in Texas, USA, to produce iron metallics for its BF-BOF steelworks in Europe, as well as to be a source of merchant product to sell to other steelmakers (Figure 6). The 2.0 Mtpy MIDREX® Direct Reduction Plant designed to produce HBI, is the largest of its kind in the world, and is seen as a landmark development. The start-up is planned the first
half 2016. US natural gas prices were a key factor in the decision.

The potential for HBI to be used in the BF-BOF steelmaking route, rather than just in EAF-based steelmaking, could work to the advantage of European iron and steelmakers under the target of CO₂ reduction. The use of HBI to boost BFs with limited hot metal capacities while contributing to a smaller carbon footprint of an integrated steelworks could prove attractive to other steelmakers worldwide (Figure 7). This story is not new. HBI has been used successfully by steelmakers in the USA in BF-BOF steel making for 25 years, so there is no technology risk associated with using it compared with breakthrough technologies like TGR-BF and Smelting Reduction.

**CONCLUSION**

The transformation of our society to a low carbon based production economy is an inevitability which the steel industry must face. The European Union crude steel production is today almost entirely divided between the BF-BOF and the Scrap-EAF routes. Depending on the separation of iron and oxygen, the iron and steel industry, which is one of the most energy-intensive industries, is expected to contribute to achieving climate change targets and to reducing GHG emission significantly by 2050. All breakthrough technologies developed by programs like ULCOS rely on the development of CCS and/or the transfer from carbon to hydrogen as reducing agent to unfold their full abatement potential. The use of clean-burning natural gas can act as a bridge technology for the transfer between the energy systems. Direct reduction and HBI allow broad flexibility for the EAF steel production route, as well as for integrated BF-BOF steel production in the quest to reduce CO₂ intensity.
Research and development (R&D) is an essential investment for a technology company such as Midrex. R&D keeps the pipeline filled with improvements to existing processes and equipment and is the catalyst for innovation that leads to new technological solutions. R&D takes an incredible amount of time, effort and resources. Midrex and its parent company, Kobe Steel Ltd. (KSL), recognize this and have consistently made R&D a priority throughout the company’s history by dedicating the proper resources to this purpose.

R&D, itself, can take several roles depending on the type and the objective (Figure 1). In academic and institutional circles, it is a means of obtaining new knowledge that may or may not have a practical use. Industrial R&D also seeks to obtain knowledge but that knowledge must be applicable to a company’s business and result in improvements to existing products and the introduction of new products that anticipate a need in the marketplace.

For Midrex, R&D is deeply engrained in company culture. It began almost 50 years ago with a hand-picked group of engineers and scientists that made up the first Midrex Technical Center. Drawing on their varied technical expertise in thermal processing, gas reforming and industrial furnace design, they came up with an innovative way to produce a highly metalized iron product directly from iron ore without melting it. Their innovative idea became the MIDREX® Direct Reduction Process. Their legacy is the world's most productive, reliable and commercially successful direct reduction technology.

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<th>TYPE</th>
<th>OBJECTIVE</th>
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<tr>
<td>Basic</td>
<td>Seek more complete knowledge or understanding of a subject</td>
<td>Advance scientific knowledge; may be in areas of present or potential commercial interest</td>
</tr>
<tr>
<td>Applied</td>
<td>Gain knowledge or understanding to determine how specific needs could be met</td>
<td>Discover new, specific knowledge related to commercial potential of products, processes or systems</td>
</tr>
<tr>
<td>Developmental</td>
<td>Apply research knowledge or understanding to demonstrate validity and practicality</td>
<td>Prove commercial feasibility of products, processes or systems through design and operation of prototypes or simulators</td>
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**FIGURE 1 Objectives & Roles of R&D**
The original Midrex Technical Center served as the technology learning center from its early Surface Combustion days. Today, the Midrex R&D Technology Center is continuing that tradition. The Technology Center has three primary roles: to be the catalyst for innovation within Midrex, to support the business operations of Midrex and KSL, and to serve as experts in direct reduction technology. People, process and facilities/equipment are key to fulfilling these roles.

INNOVATION & IMPROVEMENT

Midrex has built its business on a “renewable technology” concept, a self-sustaining cycle that blends science, engineering and real world experience to constantly renew and improve innovative ideas. The R&D Technology Center is the linchpin in the MIDREX® Technology Cycle.

Soon after Kobe Steel acquired Midrex in 1983, a procedure was established to regularly review MIDREX® Direct Reduction Technology in order to identify opportunities for innovation and improvement. The Technology Improvement Program (TIP) is guided by a joint KSL-Midrex steering committee, which considers performance data from existing plants and emerging market trends then assigns specific engineering and R&D tasks. A New Technology Notice (NTN) is prepared, which gives the background of the project, new design features, advantages and disadvantages, risk assessment and cost estimate.

The two essential ingredients for producing direct reduced iron (DRI) are iron ore and reducing gas. Midrex R&D labs have tested more than 7,000 iron-bearing materials since the early days in Toledo, Ohio. The state-of-the-art minerals processing lab in the current Technology Center allows Midrex to test and analyze various iron ores, as well as alternative iron-bearing and non-ferrous materials and to provide laboratory and start-up support for MIDREX® Process Licensees and potential clients. Some of the testing protocols developed over the years by Midrex have become ISO standards.

The Technology Center has been instrumental in expanding the direct reduction industry by developing alternative sources of reducing gas for the MIDREX® Process including coal
gasification, coke oven gas (COG) and process synthesis gas. Pilot and demonstration-scale facilities used in commercializing and improving the natural gas-based MIDREX® Process, the coal-based FASTMET® Process and the COG-based Thermal Reactor System™ (TRS®) have been constructed and operated at the Technology Center. Data obtained from the pilot unit at the Technology Center was used to build the FASTMET® Demonstration Plant at KSL’s Kakogawa Works in Japan.

FACILITIES AND EQUIPMENT
The R&D facility has been modified, expanded and upgraded several times since Midrex Corporation was established in Charlotte, NC, over 40 years ago, and its name has been changed to reflect its evolving role in the Midrex business model. Today it is known as the Midrex Research & Development Technology Center and is the focal point for R&D activities of Midrex and KSL including various metallic reduction technologies, advanced gas reforming methods and equipment, as well as ferrous and non-ferrous materials testing.

The Technology Center is located on six acres in Pineville, North Carolina, USA, just south of the Midrex Corporate Offices in Charlotte. Facilities include a 15,000 square-foot office/laboratory building, and 21,500 square-feet of bench-and pilot-scale buildings with pelletizing, briquetting, and reduction capabilities. In addition, the facility houses a 9,000 square-foot warehouse. All of this allows Midrex to simulate all direct reduction-related activities – from raw materials preparation to DRI melting.

The Technology Center has two fully automated and instru-
mented pilot facilities to simulate commercial operating conditions of MIDREX® Direct Reduction Technology. The two multi-purpose facilities are moving packed beds with recirculating gas systems capable of producing 0.25-1.0 ton of DRI per hour.

A demonstration-scale plant for the Thermal Reactor System™ (TRS™), a coke oven gas option for producing DRI in a MIDREX® Shaft Furnace jointly developed by Praxair and Midrex, has been constructed adjacent to the office/laboratory building.

A major area of expertise is bench-scale and laboratory-scale work, which includes raw materials and catalyst testing and evaluation, DRI reduction and strength testing, heat processing of ferrous and non-ferrous materials, coal reactivity and evaluation of pelletizing and briquetting techniques. Larger scale raw materials and catalyst tests under actual operating conditions can be arranged and supervised in the field by Technology Center personnel.

VISION AND PURPOSE

The reputation of Midrex is embodied in how its people develop, adapt and apply technology to solve problems and meet challenges. Having a good idea is not enough. It’s what is done with an idea that makes it memorable, sustainable and successful.

Throughout its history, Midrex has attracted highly motivated, creative people for its R&D function—people with talents ranging from mathematical modeling, metallurgy and chemistry to a variety of engineering disciplines. They have provided the vision and purpose to transform ideas into equipment, systems and processes that have become synonymous with performance, reliability and technical excellence.

Within Midrex there is a long-standing tradition of involving as many employees as possible in the R&D activities of the company. A Midrex engineer will be involved in some type of R&D work at least once during his or her career. Likewise, Technology Center scientists and technicians will spend time outside of the laboratory at MIDREX® Plant sites, mining facilities and proprietary equipment suppliers.

This is evident in the experience and perspective of members of the Technology Center management and staff.

Dr. Chevrier brings to the Midrex R&D function 13 years of melt shop experience with Usinor/Arcelor (now ArcelorMittal S.A.), J&L Specialty Steel and Keywell, LLC. His first-hand experience with melt shop raw materials management, the use of alternative iron units in EAF charge blends and metal recycling provides Chevrier a unique perspective.

Chevrier takes seriously the Technology Center’s role in developing the technical expertise of Midrex. “It takes 3-5 years to develop a Midrex engineer,” according to Chevrier. “Young engineers on assignment at the R&D Technology Center gain a deeper understanding of the, “how’s and why’s”, of MIDREX® Technology by working shoulder-to-shoulder with permanent staff experts,” Chevrier said.

“R&D is in the DNA of Midrex,” Chevrier observed. “We (the Technology Center) are the catalyst for innovation and improvement, which involves the entire company.”
JAYSON RIPKE, PH.D., QP,  
Metallurgical and Materials Engineering; Manager – Technology Center Operations

Dr. Ripke has more than 15 years of commercial and technical experience with all aspects of processing ferrous and non-ferrous materials. His first involvement with MIDREX® Technology was as a graduate engineering researcher in 1997 when he successfully made pig iron nuggets in the laboratory based on the Kobe Steel ITmk3® process technology.

Ripke possesses a unique understanding of how R&D programs are structured, funded and implemented from his previous managerial and executive roles at Cliffs Natural Resources and Cardero Iron Ore Company, Ltd. “The hands-on experience of setting up multi-million dollar R&D facilities was instrumental in bringing in the renovation and expansion of the Midrex Research & Development Technology Center on budget and on schedule,” Ripke said. “Knowing what goes into creating and managing a successful R&D project contributed greatly to planning, engineering and building the state-of-the-art facility we have today.”

URVASHI SRIVASTAVA, PH.D.,  
Chemical Engineering; Metallurgist – Mineral Processing

Dr. Srivastava has been involved in analyzing and processing iron-bearing materials for almost 10 years. Her work has included the reduction of iron oxides with various types of sustainable and renewable reducing agents, strategies for processing low-grade iron ores and the agglomeration of fine iron ore concentrates.

Srivastava is currently the lead in a program to develop a new catalyst for the MIDREX® Reformer. She developed the iron ore pelletizing procedure and testing methods used by Midrex and set up the new minerals processing laboratory. “In order for the metallic iron market to continue growing, we must constantly broaden the range of raw materials that can effectively be processed into direct reduced iron and other highly metallized materials,” Srivastava said. “This not only involves methods and techniques for agglomeration and beneficiation but also how these materials affect the reactivity of catalyst for the MIDREX® Reformer and other operational aspects of the MIDREX® Process.”
DANIEL ZUFFEREY,  
Chemical Engineering; Metallurgist – Mineral Processing

Zufferey has been involved in setting up chemistry laboratories at MIDREX® Plants throughout the world and establishing laboratory operating, quality control and safety procedures. During 15 years at Midrex, in addition to his laboratory work, Zufferey has participated in teams with Midrex engineers on plant start-ups and has worked with key customers to monitor the quality of raw materials and to review laboratory data for accuracy.

Zufferey assists in the management of Technology Center operations in four main areas: customer support, project-related testing and analysis, quality control and facility capabilities development.

“Most of what occurs in a MIDREX® Plant involves chemistry,” Zufferey observed. “Being able to use my education, training and experience to help Midrex customers better understand, test and analyze the materials they use and the products they make is very gratifying.”

A TECHNOLOGY LEGACY

Before Midrex was a company, there was a Midrex Technical Center. R&D has been the centerpiece of the Midrex business model from its inception because technology must be constantly re-engineered and re-invented to remain relevant.

The Midrex R&D function has played a significant role in all of the major innovations and improvements of MIDREX® Technology (see “Major Midrex Technology Developments” on page 10). Just like the original MIDREX® Process pioneers, the management and staff of the Technology Center use their experience and expertise to transform ideas and concepts into marketable realities and helping transfer them from the laboratory to the plant site.

Midrex and KSL continue to invest in the equipment, facilities and personnel that have made the Midrex Research and Development Technology Center the preeminent R&D facility in the direct reduction industry. The Technology Center is dedicated to advancing the knowledge and understanding of the techniques, methods, materials and equipment that comprise the world's most reliable, productive and safe direct reduction technology. In addition, the Technology Center is looking beyond direct reduction for new ways to utilize MIDREX® Technology... in the spirit of innovation.
News & Views

The 2015 International Conference on MIDREX® Technology was held October 18-22 in Barcelona, Spain, with participants coming from 16 countries. The annual conference for MIDREX® Process Licensees was hosted by the management and staff of Midrex Technologies and attended by 45 representatives from 16 MIDREX® Plants, as well as personnel from Midrex Construction Partners, Kobe Steel, Ltd., Primetals Technologies and Paul Wurth.