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DIRECT FROM MIDREX

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HBI PRODUCTION TRIAL WITH DIRECT REDUCED IRON FROM A COLD AGGLOMERATED BRIQUETTE

Low NOx Burners and
Burner Control Systems:
Improving Operations, Safety,
and Compliance in DRI Plants

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 COMMENTARY

When the Denominator Changes



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The iron and steel industry relies heavily on specific consumption metrics to evaluate plant performance. In direct reduction plants, consumption of natural gas, electricity, water, and other resources is typically reported per tonne of direct reduced iron (DRI) produced. These metrics provide valuable benchmarks for comparing operations and identifying opportunities for improvement.

However, these comparisons often depend on an important, and increasingly questionable, assumption: that a tonne of DRI represents a consistent basis of comparison.

That assumption can be misleading. Iron ore quality is becoming more

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VINCENT CHEVRIER

variable, gangue levels are increasing, and producers are seeking greater flexibility in the feedstocks they can utilize. At the same time, DRI products can vary significantly in metallization and carbon content. Gangue, unreduced iron oxide, and carbon all contribute mass, and in some cases value, to the final DRI product. As a result, one tonne of DRI produced in one plant may not represent the same amount of metallic iron, nor the same value to a steelmaker, as one tonne produced in another. This can lead to conclusions that appear intuitive but are not necessarily correct. Consider the following hypothetical cases:

Case A (Premium DRI): A plant processes high-grade pellets (67.5% Fe) and produces DRI with 95% metallization and 2.8% carbon. Natural gas consumption is 2.55 Gcal/t DRI.

Case B (Lower-Grade DRI): A plant processes lower-grade pellets (64.0% Fe) and produces DRI with 91% metallization and 1.5% carbon. Natural gas consumption is 2.40 Gcal/t DRI.

At first glance, Case B appears more efficient because it consumes less natural gas per tonne of DRI produced. However, when normalized to the amount of metallic iron delivered, the picture changes. Case A requires 2.86 Gcal per tonne of metallic iron, while Case B requires 2.96 Gcal per tonne of metallic iron.

The apparent efficiency advantage disappears because the denominator has changed.

As the direct reduction industry evolves, comparisons based solely on tonnes of DRI may no longer provide a complete picture of plant performance or product value. A more meaningful benchmark may be specific consumption per tonne of metallic iron produced, while also recognizing the contribution of carbon contained within the product.

Benchmarking, process optimization, and even technology selection should increasingly reflect two realities: the need to process a broader range of iron ore feedstocks and the importance of DRI quality, particularly metallization and carbon content.

Ultimately, steelmakers are not purchasing tonnes alone. They are purchasing metallic iron and the value that the DRI delivers to the steelmaking process.

If metallic iron is the true product being delivered, perhaps it is time to reconsider how performance is measured.



This issue of *Direct From Midrex* features a collaborative article with Vale, highlighting HBI production trials conducted at the Midrex Research & Development Technology Center, and a feature article explaining the underlying chemistry of NO_x formation and the technologies used to reduce it. In addition, News & Views announces the *2025 World Direct Reduction Statistics*, the 15th anniversary of Midrex India and recognizes a MIDREX Plant celebrating a decade of leadership in HBI production.



HBI PRODUCTION TRIAL WITH DIRECT REDUCED IRON FROM A COLD AGGLOMERATED BRIQUETTE



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INTRODUCTION

Cold-agglomerated briquettes (CBQ) made from iron ore fines are being developed as a promising new feed material for ironmaking. Their main advantage is the potential to lower carbon emissions by reducing the need for traditional heat-intensive agglomeration processes such as sintering. While pelletizing itself is not heat intensive, the combined processes of grinding and pelletizing are energy intensive due to their significant electrical power requirements. Laboratory studies and commercial-scale trials have shown that CBQ can achieve the physical, chemical and metallurgical properties needed for effective use in direct reduction (DR) shaft furnaces, and they have also been successfully used in blast furnaces (BFs).

In a DR shaft furnace, reduced iron can be discharged

either hot or cold. When discharged hot, it can be sent directly to an Electric Arc Furnace (EAF) or compacted into hot briquetted iron (HBI), which offers better resistance to reoxidation during storage and transport. Because HBI quality depends on the characteristics of the DRI feedstock, it is important to confirm that DRI produced from CBQ can be converted into HBI that meets industrial standards.

This article highlights hot-briquetting trials conducted at the Midrex Research & Development Technology Center using DRI produced from oxide pellets, CBQ, and blends of the two. The resulting HBI was evaluated for chemical composition, physical strength, and weathering resistance to determine whether CBQ-based HBI can match the performance of conventional pellet-based HBI and satisfy industrial requirements.

OBJECTIVES & PHYSICAL PROPERTIES

To evaluate the suitability of cold agglomerated briquettes (CBQ) as a feedstock for producing high-quality hot briquetted iron (HBI), this study focuses on comparing the performance of CBQ-derived HBI with conventional pellet-based HBI across chemical, physical and weathering characteristics under industrially relevant conditions. It should be noted that the present work does not examine the suitability of CBQ for use in direct reduction (DR) shaft furnaces, as this aspect is addressed separately in other studies. The study adopts the following objectives:

- Evaluate the feasibility of CBQ as a DR feedstock by determining whether DRI produced from cold agglomerated briquettes can be successfully converted into HBI.
- Compare CBQ-based HBI with conventional pellet-based HBI in terms of chemical composition, physical characteristics such as density and strength, and overall quality.
- Assess the effect of blending ratios (CBQ and pellets) on HBI performance.
- Verify compliance with industrial specifications for HBI, including density and mechanical strength.
- Determine weathering resistance of CBQ-based HBI and compare its reoxidation behavior with pellet-based HBI during outdoor storage-like conditions.
- Confirm the potential of CBQ to support lower-carbon ironmaking while maintaining or improving product performance.

The chemical compositions of the CBQ and oxide pellets used in this study are shown in **Table 1**, while their physical properties are summarized in **Table 2**. Both materials were produced from similar iron oxide sources. This ensured a consistent starting point for evaluating how feedstock type influences DRI and HBI performance.

DRI PREPARATION FOR HBI TRIALS

Using the Large Reduction Furnace (LRF) at the Midrex Research & Development Technology Center, CBQ and oxide pellets were reduced in a fixed bed within an externally heated retort. The oxide feedstocks were reduced using a syngas mixture of H₂, CO, CO₂, H₂O, CH₄, and N₂, designed to mimic natural gas-based reduction conditions in a MIDREX® Reduction Furnace. While the LRF does not replicate the exact conditions of a direct reduction (DR) shaft furnace, it is designed and operated to produce direct reduced iron (DRI) with properties representative of material produced in a commercial shaft furnace, enabling meaningful comparative evaluation of different feedstocks.

The LRF operating temperature was maintained between 700 and 850 °C, which is similar to the reduction zone temperature of a MIDREX reduction furnace. Temperature adjustments were made as needed based on the characteristics of each oxide feedstock. After reaching the target metallization level, the reduced material was cooled under a nitrogen atmosphere to prevent reoxidation. In this work, the DRI was not carburized to reduce the number of test variables. The material was then discharged and screened to remove -3 mm fines.

Oxides	Fe (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	P (%)	Mn (%)	CaO (%)	MgO (%)	Na ₂ O (%)	LOI (%)
CBQ	66.12	2.06	0.21	0.013	0.09	1.38	0.05	0.42	1.3
Pellet	68.16	1.33	0.37	0.016	0.06	0.82	0.04	0.015	-

TABLE 1. Chemical quality of the oxides (CBQ & pellet)

Oxides	Size (mm)	Tumbler (%>6.3 mm)	Abrasion (%<0.5mm)	CCS (daN)
CBQ	25 x 21 x 13	88.6	10.1	326
Pellet	8-18 (diameter)	94.8	5.0	300

TABLE 2. Physical quality of the oxides (CBQ & pellet)

Three LRF batches were used to produce the CBQ DRI sample, and two batches were used for the pellet DRI sample. After blending these LRF batches, the composite samples for CBQ-DRI and pellet-DRI were prepared. Chemical analyses, including metallic iron and carbon content, were performed on these composite CBQ-DRI and pellet-DRI samples.

Using the composite DRI samples, four DRI blends (approximately 250 kg each) with various mixing ratios were prepared for the briquetting trials:

- 1) 100% CBQ DRI
- 2) 50% CBQ DRI / 50% pellet DRI
- 3) 30% CBQ DRI / 70% pellet DRI
- 4) 100% pellet DRI



FIGURE 1. Composite DRI samples for CBQ-DRI (left) and pellet-DRI (right)

HOT BRIQUETTING

With the four DRI blends prepared, the research team turned to the hot briquetting process. Each DRI blend was preheated to above 750 °C under inert atmosphere in the LRF and then transferred to a commercial-scale hot briquetting (HB) machine (Figure 2). The material was fed into the briquetting rolls using a screw feeder. The resulting HBI pieces measured approximately 48 mm × 134 mm × 32 mm and weighed about 800g each. Each batch required approximately two minutes of operation.

The operating parameters of the HB machine were identical for each trial. After briquetting, the HBI samples were air cooled and collected for chemical analysis (metallization and carbon content) and physical testing, including density, tumble strength and drop strength.



FIGURE 2. Commercial-scale HB machine and the discharged HBI at Midrex R&D Center

WEATHERABILITY EVALUATION

A weatherability test was conducted to assess the relative weathering resistance of the HBI samples. The test compared weight changes during an eight week outdoor exposure period. Five HBI pieces from each batch were placed on an outdoor table under identical environmental conditions (Figure 3, top of page 6).

Every two weeks, the samples were collected and dried in an oven at 120 °C under a nitrogen atmosphere. After drying, the samples were weighed to measure any weight gain or loss. The samples were then returned to the test stands to continue the test.

At the end of the eight week period, chemical analyses for metallic iron and carbon content were performed on each HBI sample. These results were used to support the weatherability assessment based on the measured weight changes.

RESULTS
CHEMICAL ANALYSIS

The composite chemical analyses of CBQ-DRI and pellet-DRI, presented in Table 3, indicate that both materials achieved consistently high metallization and low carbon levels. The DRI feedstock was intentionally produced at a higher metallization and lower carbon levels than is typically achieved in commercial operating plants to ensure uniform metallization and carbon across all test materials. This approach eliminated metallization and carbon as an experimental variable, allowing the effects of other factors on HBI quality to be evaluated independently.

As anticipated, CBQ-DRI exhibited slightly lower total iron content due to its inherently lower iron concentration, while pellet-DRI showed marginally higher metallic iron content. The chemical compositions of the four DRI sample batches with the various mixing ratios were calculated on a prorated basis using the composite CBQ-DRI and pellet-DRI analyses. Chemical analyses were also performed on the HBI products generated from these four DRI batches. Table 4 presents the metallization (%), total Fe (%), metallic Fe (%), and carbon (%) for both



FIGURE 3. Appearance of HBI weathering test

Sample Description	DRI Chemical Analysis (%) – Analyzed value			
	Met	T-Fe	M-Fe	C
Composite CBQ-DRI	99.59	93.41	93.03	0.12
Composite Pellet-DRI	99.01	95.89	94.94	0.13

TABLE 3. Chemical Analyses for the composite DRI samples

Sample Batch Description	DRI Chemical Analysis (%) before Hot Briquetting – Prorated value				HBI Chemical Analysis (%) after Hot Briquetting – Analyzed value			
	Met	T-Fe	M-Fe	C	Met	T-Fe	M-Fe	C
100% CBQ	99.59	94.65	93.03	0.12	96.13	92.35	88.78	0.06
50% CBQ/ 50% Pellets	99.30	94.65	93.98	0.12	97.17	93.76	91.11	0.06
30% CBQ/ 70% Pellets	99.19	95.15	94.37	0.13	93.97	93.17	87.55	0.09
100% Pellets	99.01	95.89	94.94	0.13	93.30	93.85	87.57	0.07

TABLE 4. Chemical Analyses for DRI and HBI

the corresponding DRI feed and resulting HBI product for each batch. Overall, the DRI batches maintained uniformly high metallization levels above 99%, whereas the HBI samples displayed greater variability but remained within acceptable metallization levels above 93% across varying CBQ mixing ratios. The carbon contents of the DRI samples were maintained low, to achieve the consistently homogeneous carbon level for all sample batches.

PHYSICAL ANALYSIS

Apparent Density

The apparent density results (the average of five HBI samples for each batch) show a clear trend with respect to CBQ content. As the proportion of CBQ in the feed increased, the average density of the HBI also increased. At the same time, the variation between samples decreased, indicating more consistent product quality (Figure 4).

This suggests that CBQ-based DRI compacts more effectively during briquetting, resulting in denser and more uniform HBI. Larger CBQ seems to help achieve better compaction when the operation condition of the feeder maintains the same. Higher density is an important property, as it is typically associated with improved handling characteristics such as higher mechanical strength and lower reactivity during storage and transport.

Tumble and Drop Strength

The mechanical strength of the HBI samples was evaluated using tumble and drop tests. Tumble tests were conducted with ISO 15967:2007. Drop tests were also conducted with Midrex standard procedure (4 drops from a height of 5m).

Tumble Index was consistently above 95%, and Abrasion Index was low for all samples.

Shatter Index results were also favorable. The HBI produced from 100% CBQ and the 50/50 blend showed performance comparable to the pellet-based HBI. The 30% CBQ blend showed a slightly lower drop strength, although the reason for this difference is not known. Despite this, all samples demonstrated sufficient mechanical durability for industrial use (Table 5).

Overall, the results confirm that incorporating CBQ into the feed does not negatively affect the mechanical strength of the final HBI product.

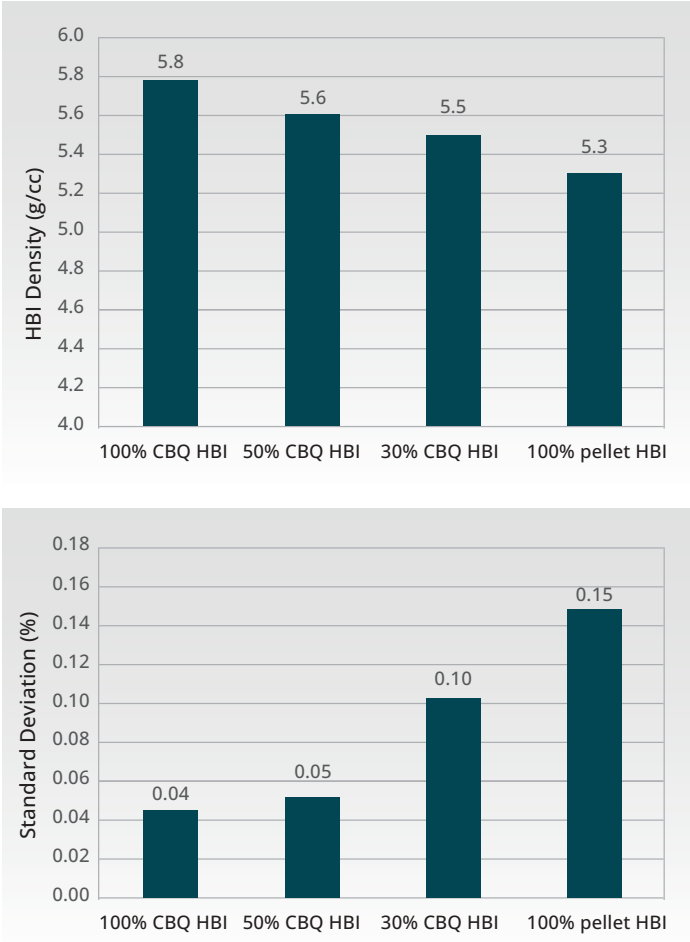


FIGURE 4. Average and Standard Deviation for the apparent densities

Weatherability Performance

The weatherability test showed differences in performance depending on the CBQ content. Over the eight-week exposure period, all samples experienced some weight gain, indicating reoxidation of metallic iron. The extent of weight gain was lower (on average) for samples with higher CBQ content: The 100% CBQ HBI showed the smallest average increase in weight,

	100% CBQ HBI	50% CBQ HBI	30% CBQ HBI	100% pellet HBI
Tumble Index (%)	95.7	96.4	95.6	95.9
Abrasion Index (%)	2.2	1.4	1.8	2.2
Shatter Index (%)	98.6	98.7	97.2	99.0

TABLE 5. Tumble/Drop Strength for HBI

while the 100% pellet HBI showed the largest. However, most results are within one standard deviation. The variation between individual samples of each composition (as shown by the standard deviation bars in **Figure 5**) is decreasing with increasing CBQ content, indicating a more consistent product.

The measured reductions in metallization after exposure followed the same trend as the weight changes, confirming that the weight gain was primarily due to reoxidation. The improved weathering resistance observed with increasing CBQ content is primarily attributed to the higher density of the resulting HBI. As CBQ content increased, briquette density increased, reducing porosity and limiting the ingress of oxygen and moisture. The relationship is consistent with previous Midrex weatherability test results which have shown that higher and more uniform HBI density is associated with improved weathering resistance. The improved weatherability performance indicates that HBI made with CBQ will have similar or better stability during storage and transport, resulting in lower yield losses from oxidation.

CONCLUSION

This study provides clear evidence that producing high-quality HBI from cold agglomerated briquettes (CBQ) is feasible, and that CBQ can serve as a viable alternative to conventional oxide pellets with-

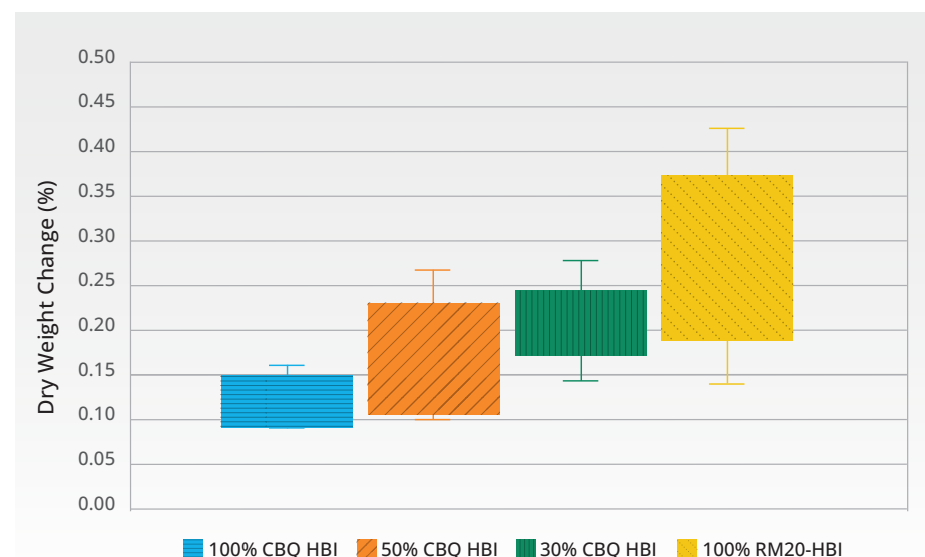


FIGURE 5. *Variance of the weight change for the individual HBI after 8 weeks*

out compromising product performance. The testing and accompanying results of this study ultimately demonstrate that CBQ is a viable DR feedstock, through:

- Consistent briquetting quality across different blend ratios of CBQ
- Apparent density exceeding 5.0 g/cm³, meeting DRI(A) transport requirements; CBQ-based material achieved higher density than industrial DRP benchmarks, with the trend expected to persist at industrial scale.
- Mechanical strength (tumble, abrasion, and drop resistance) is comparable to pellet-based HBI
- Improved weathering performance compared to pellet-based HBI,

resulting in lower metallization losses due to reoxidation during storage and transport.

The results show that increasing CBQ content can improve both density and weathering resistance, without negatively affecting mechanical strength. This suggests that CBQ-based HBI may offer operational and quality benefits beyond simple equivalency to pellets. CBQ represents a promising development in DR feedstock technology, particularly as the industry continues to focus on reducing carbon emissions.

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Low NOx Burners and Burner Control Systems

Improving Operations, Safety, and Compliance in DRI Plants



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INTRODUCTION

The reformer is the thermal heart of a MIDREX® Plant. Multiple burners fire continuously to sustain the high temperatures required to reform natural gas and recycled process gases into the reducing atmosphere that converts iron oxide to metallic iron. In a process defined by continuous operation and tight energy budgets, burner performance has always mattered. What has changed is the external environment in which that performance is evaluated.

Emissions regulations for NOx are tightening across all major steelmaking regions. At the same time, various economic incentives to reduce NOx have been embedded in environmental

policies worldwide. Meanwhile, the transition from the previous EN 746:2010 to ISO 13577:2023 has materially raised the baseline for burner control system design and compliance.

For operators of existing MIDREX Plants, what may begin as a compliance question also presents an operational opportunity. Low NOx burners and modern burner control systems offer improvements in energy efficiency, combustion stability, and plant safety. This article explains the underlying chemistry of NOx formation, the technologies used to reduce it, and the key considerations in evaluating burner upgrades for operating DRI plants.

WHAT IS NO_x AND WHY DOES IT MATTER?

Nitrogen oxides (NO_x) are a group of gases produced during high-temperature combustion. The two primary species of concern are nitric oxide (NO) and nitrogen dioxide (NO₂), although other oxides, including nitrous oxide (N₂O), may be present in smaller quantities. NO_x is a significant constituent of photochemical smog and is harmful to human health, causing respiratory conditions such as asthma. It also contributes to the formation of ground-level ozone and fine particulate matter (PM_{2.5}) and is implicated in acid rain and reduced visibility. Nitrous oxide is also a potent greenhouse gas with ozone-depleting properties.

In combustion systems, NO_x is generated through three principal mechanisms:

- **Thermal NO_x** is the dominant pathway in high-temperature applications. It arises when molecular nitrogen in the combustion air or furnace atmosphere is oxidized at flame temperatures above 1,525 °C (2,780 °F) as described by the Zel'dovich mechanism.
- **Fuel-bound NO_x** arises when the fuel itself contains nitrogen, as is the case with coal or heavy fuel oils. This pathway is generally not a concern when firing commercially available natural gas or propane.
- **Prompt NO_x** forms when hydrocarbon radicals in fuel-rich flame regions react with atmospheric nitrogen in the earliest stages of combustion. It contributes less than thermal NO_x to overall levels in high-temperature processes but becomes more significant in the fuel-rich zones characteristic of staged-combustion burner designs.

In MIDREX Plants, thermal NO_x is the mechanism of primary concern. The reformer operates at high temperatures and continuously burns significant volumes of fuel gas. Both the burner design and the control of combustion conditions (peak flame temperature and the flame's chemical environment) are therefore important levers for managing NO_x output.



LOW NO_x BURNER DESIGN

Burner designs that lower flame temperature or reduce oxygen availability at the hottest part of the flame can substantially reduce NO_x output by disrupting the thermodynamic conditions that favor thermal NO_x production— without sacrificing heat output or flame stability. Several strategies are used to achieve this, often in combination:

- Premixing homogenizes fuel and air distribution before ignition, producing a larger, more evenly tempered flame with lower peak temperatures compared to diffusion-flame designs.
- Two-stage (staged) combustion introduces a portion of the combustion air at the burner throat, creating an initial fuel-rich primary zone where peak temperatures are suppressed. Secondary air is introduced downstream to complete combustion at lower peak temperatures.
- Flame geometry manipulation produces wider, flatter flames that distribute heat over a larger area, reducing hot spots, or longer flames that extend heat release over a greater volume. The appropriate geometry depends on the process requirements of the specific application.
- Surface-stabilized combustion uses a physical surface to anchor the flame and further moderate temperature distribution.

Computational fluid dynamics (CFD) modeling has been used to compare the thermal performance of low NO_x and conventional burner designs in the MIDREX reformer environment (Figures 1-2). The results show that low NO_x burners produce flame geometries similar to those of conventional burners and exhibit no increased tendency toward reformer tube impingement, an important reassurance for plant operators evaluating retrofit feasibility. The implications for heat transfer performance and efficiency are reflected in the operational benefits discussed later in this article.

BURNER CONTROL SYSTEMS

A burner control system (BCS)—sometimes called a burner management system (BMS)—is the control and safety architecture that governs burner startup, operation, and shutdown. It integrates three categories of hardware: field sensors and detectors (pressure switches, flow and temperature transmitters, and flame monitors); a processing unit, typically a Safety PLC; and safety interlocks and shutdown controls, including isolation valves in block-and-bleed arrangements (Figure 3).

The purpose of a BCS is to prevent the formation of combustible atmospheres inside the reformer firebox that could result in a firebox explosion. Hazards managed by a BCS include improper purging, incorrect fuel-to-air ratios, excessive pressure or temperature, and gas leaks.

In a MIDREX Plant, the BCS manages two categories of burners: auxiliary (aux) burners, used during reformer heat-up and startup sequences, and main burners, which maintain normal operating temperatures. Aux burners present a more complex safety challenge because they must be lit individually, historically by hand torch, in a coordinated sequence.

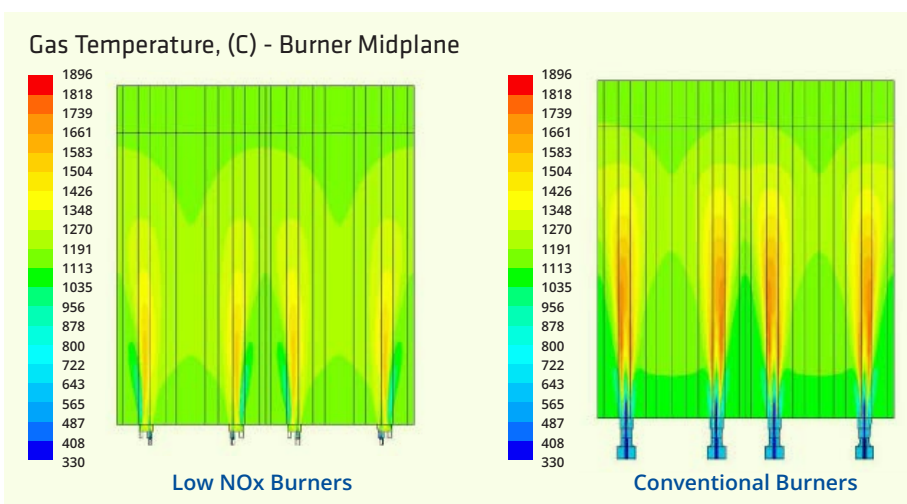


FIGURE 1. CFD analysis of flame geometry, showing similar flame geometries. There is no indication that low NO_x flame patterns are more prone to reformer tube impingement.

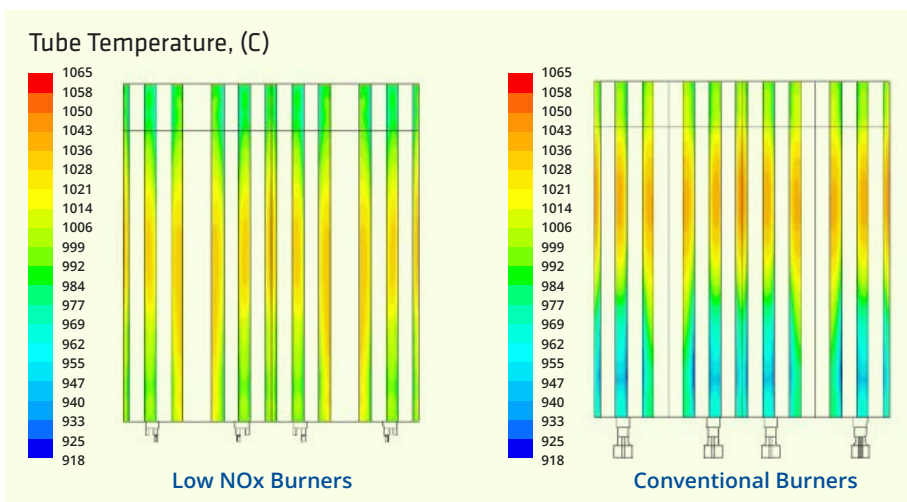


FIGURE 2. CFD analysis of heat release, showing a more even heat flux distribution on the reformer tubes with low NO_x burners.

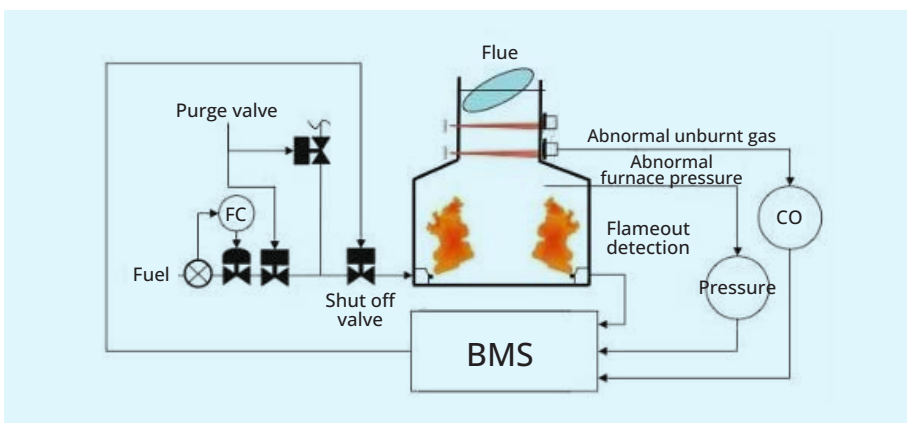


FIGURE 3. Schematic of a burner management system (BMS), illustrating the integration of field sensors, isolation valves, and safety interlocks that govern burner startup, operation, and shutdown.

THE STANDARDS LANDSCAPE

Three standards are relevant to MIDREX Plant operators evaluating BCS.

- NFPA 86:2023 is the U.S. standard for ovens and furnaces and defines baseline safety requirements for burner systems in North American applications.
- EN 746:2010 was the previous international standard for industrial thermoprocessing equipment. It has now been formally withdrawn.
- ISO 13577:2023 is the current international standard, covering industrial furnaces and associated processing equipment—specifically Part 2, combustion and fuel handling systems. Adopted in September 2024, it is not yet harmonized with regional regulatory frameworks but represents the direction for future international projects and new plant construction.

For existing plants, ISO 13577 compliance is not mandatory unless local regulations or insurers impose new requirements. However, the standard introduces a number of improvements in both safety and operational performance. Voluntary adoption merits serious consideration.

Most current Midrex Plants were originally designed to meet NFPA 86. The most significant change introduced by EN 746 / ISO 13577 is the requirement for automatic ignition and individual flame monitoring on all aux burners. Under previous practice, aux burners were lit manually with a torch—a labor-intensive, time-consuming, and inherently hazardous procedure performed at elevation in a high-temperature setting. Automatic spark ignition eliminates this need for personnel to physically light each burner, while continuous UV flame monitoring on every aux burner allows the control system to trip individual burners that extinguish rather than initiating a full reformer shutdown and re-purge sequence.

Although the capital cost of equipping a reformer with spark transformers, spark igniters, flame eyes, flame relays, and individual solenoid block valves is high, the increase in operating cost is small, and the operational benefits are significant. These include reduced purge occurrences, fewer refractory thermal cycles, faster plant startups, and improved visibility of burner status in the control system.

In addition, ISO 13577 imposes more rigorous standards for isolation valves, requiring automatic valves to comply with EN 161 and manual valves with EN 331. Previous practice using FM-approved valves is no longer sufficient. Related to this is the requirement for automatic valve proving systems: pressure

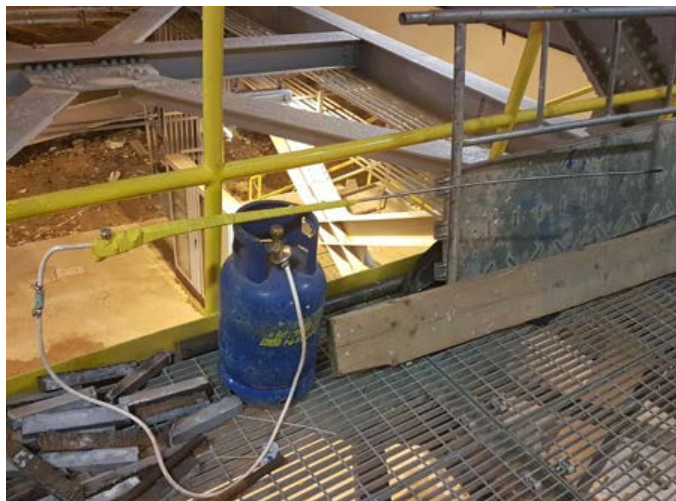


FIGURE 4. Manual ignition of auxiliary burners using a propane torch: a labor-intensive and inherently hazardous procedure that ISO 13577 replaces with automatic spark ignition.

switches integrated into the block-and-bleed train test for valve leakage before each startup, replacing the manual bubble tests previously performed during annual outages. This improves both safety and maintenance efficiency.

Additional changes address air/fuel ratio monitoring, with requirements for increased instrumentation and safeguards, and more rigorous documentation of maintenance activities.



European Union	India	Germany	Japan	United States
Industrial Emissions Directive (IED): Sets NOx thresholds below 100 mg/Nm ³ , driving widespread adoption.	National Clean Air Programme (NCAP): Targets a 20–40% reduction in particulate matter in non-attainment cities, thereby indirectly boosting low NOx adoption.	Federal Immission Control regulations (BImSchV): Enforce strict NOx limits for large combustion plants (100 mg/Nm ³), prompting retrofits.	Act on Rational Use of Energy: Energy conservation law promoting energy efficiency and conservation, including adoption of technologies that reduce emissions and save energy.	Emission Reduction Credits (ERC) marketplace: Facilities can earn regional tradeable Emission Reduction Credits by reducing NOx emissions below baseline levels.
Fit for 55 package: Reduce overall greenhouse gas emissions by 55% by 2030, creating greater economic incentives for adoption.	CPCB Mandates: Continuous emissions monitoring required for all thermal power plants as part of the 17 highly polluting industry categories.	Subsidies: Federal Ministry for the Environment funds industrial-scale projects for climate protection technologies under the Environmental Innovation Program.	Tokyo Metropolitan Government (TMG) Enforcement: TMG enforces strict, localized ordinances to limit NO _x emissions, with fines for noncompliance.	Inflation Reduction Act: Provided significant funding for industrial decarbonization, reflecting broader policy direction toward incentivizing emissions reduction.

TABLE 1. *Economic incentives for low NOx burner adoption by region.*

MARKET CONTEXT AND INCENTIVES

According to industry market research, the global market for low NOx burner technology is estimated at approximately USD 1.79 billion in 2026 and is projected to reach approximately USD 2.18 billion by 2033, driven by increasingly stringent emissions regulations and continued investment in cleaner, more efficient industrial combustion systems. The economic case for adoption is reinforced by a growing array of regulatory and financial incentives across key DRI markets (Table 1).

Beyond regulatory compliance, low NOx burners offer several operational and environmental advantages. Most directly, they reduce the NOx-related environmental and health impacts described above. Burners with more controlled, uniform combustion typically consume 5–10% less fuel than conventional designs, thereby reducing operating expenditure. More uniform combustion also delivers stable operation over a wide load range, with more even heat distribution across the reformer tubes, potentially extending service life.

By addressing NOx at the source, low NOx burners may also reduce the need for downstream abatement equipment. Finally, adoption supports compliance with tightening NOx limits across key markets and contributes to broader decarbonization commitments, increasingly a factor in how steelmakers

are evaluated by regulators, insurers, investors, and other ESG stakeholders alike.

RETROFIT CONSIDERATIONS FOR EXISTING MIDREX PLANTS

Retrofitting low NOx burners and upgraded control systems to an existing MIDREX Plant requires attention to several plant-specific factors.

- Burner geometry compatibility is the starting constraint. Retrofit burners are typically required to be drop-in replacements that match the existing flange geometry, hose connections, and mounting arrangements of the original installation. Midrex Technologies has worked with Bloom Engineering to develop a low NOx Type A burner (Figure 5, following page) that matches the dimensional envelope of the standard MIDREX Type A burner, enabling replacement without modification to the surrounding reformer structure.
- Main air blower capacity may require evaluation. Low NOx burners using staged-air combustion impose higher pressure drops across the air circuit than conventional burners. Depending on the margin available in the existing blower, an upgrade may be required.

- NO_x suppression via air staging is a primary combustion-side lever. Controlling the introduction (sequence and proportion) of combustion air, rather than delivering it all at the burner throat, allows peak flame temperatures to be managed and NO_x output to be reduced. This is a function of burner design rather than a separate system, but it interacts with the air-side hydraulics of the reformer and should be assessed as part of any retrofit study.

A structured retrofit evaluation thus encompasses a system process review to assess current plant performance and identify necessary process changes; equipment evaluations to determine retrofit capability and feasibility; and a control systems review covering existing BCS hardware and the instrumentation and processing upgrades required for ISO 13577 alignment. It also includes a capacity review to identify and address any debottlenecking requirements, as well as a financial review that incorporates CAPEX/OPEX projections, applicable emissions regulations, and available government incentives.

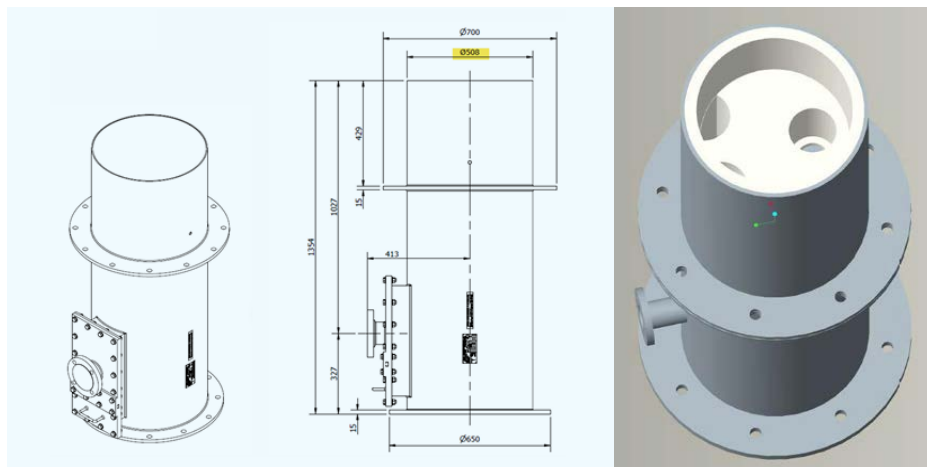


FIGURE 5. Low NO_x Type A burner.

CONCLUSION

The combination of tightening emissions regulations, shifting international standards, and demonstrated operational benefits makes evaluating low NO_x burners and modern BCS a timely consideration for MIDREX Plant operators. ISO 13577:2023 defines a higher baseline for combustion safety that, while not yet mandatory for existing plants in all jurisdictions, represents the direction of travel for regulatory and insurance requirements. The operational case, including improved fuel efficiency, greater combustion stability, safer and faster startups, and reduced maintenance

burden, stands independently of the compliance question.

For MIDREX Plant operators, the technology now exists to retrofit low NO_x burners that match existing reformer geometry while delivering measurably lower NO_x output and more uniform heat distribution. MIDREX Technologies supports this transition, from process and equipment review through to control system design and economic analysis, ensuring that any upgrade is appropriately scoped and sequenced to deliver maximum value over the plant's operating life.



News & Views

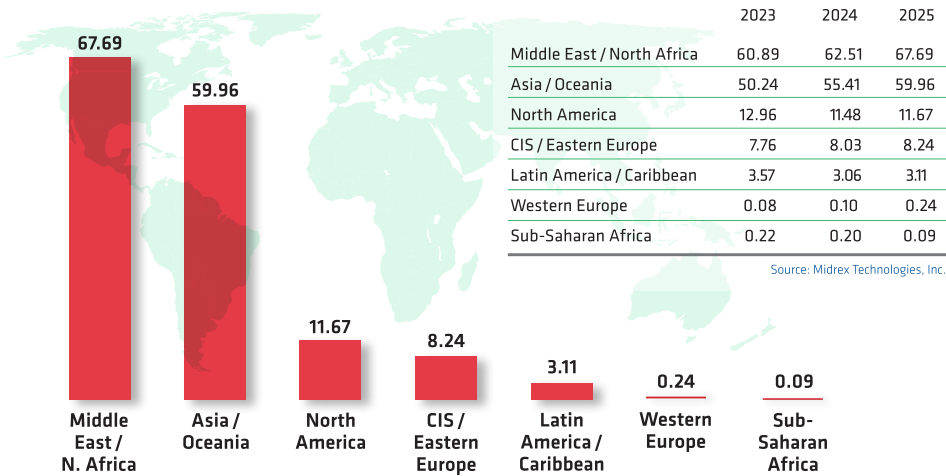
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2025 World Direct Reduction Statistics
151.0 million tons (Mt) produced globally

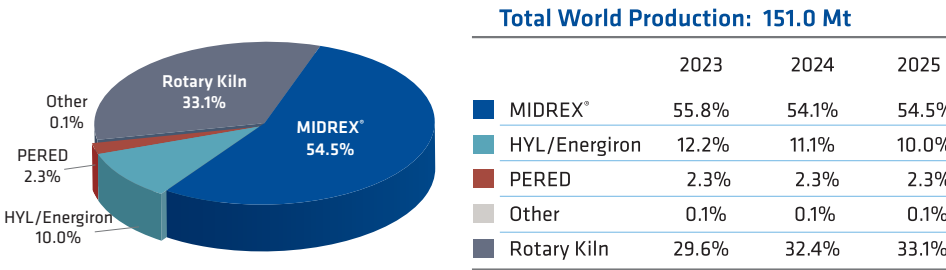
Global direct reduced iron (DRI) production in 2025 reached a new record of 151.0 million tons (Mt), surpassing the previous record of 140.8 Mt set in 2024 by 10.2 Mt, or 7.2%. Since 2020, worldwide DRI production has increased by 46.2 Mta (44.0%), reflecting continued growth in both gas-based shaft furnace and coal-based rotary kiln production.

MIDREX® Plants produced a record 82.3 Mt of DRI during 2025, exceeding the prior record of 76.2 Mt in 2024 by 6.1 Mt, or 8.0%. The MIDREX® Process supplied 54.5% of total global DRI production and accounted for 81.5% of all shaft furnace DRI output worldwide.

2025 World DRI Production by Region (Mt)



2025 World DRI Production by Process



Midrex Technologies, Inc. compiles and publishes *World Direct Reduction Statistics* annually as a resource for the global iron and steel industry. To prepare the annual statistics, Midrex requests inputs from every known direct reduction producer either directly or indirectly through partner organizations. Where plant information is not available directly or indirectly from producers, Midrex obtains the information from publicly available data.

World Steel Dynamics (WSD) audits the data collection and preparation processes used by Midrex to confirm that the methodology and accuracy of the data to be published is representative of the global direct reduction industry in a given year.



2025 World Direct Reduction Statistics is available for download at: midrex.com/world-dri-statistics

News & Views

The full news articles are available on www.midrex.com

→ Midrex India's 15th Anniversary



This year, Midrex India proudly marks its 15th anniversary, celebrating a decade and a half of growth, innovation, and dedication to supporting the iron and steel industry. Since its founding, the team has played an important role in advancing MIDREX technology throughout the region, delivering expertise, fostering strong customer relationships, and contributing to the company's global success.

Established in 2011 to support the region's expanding ironmaking industry, the office has played a key role in advancing MIDREX technology across India. Key milestones include the 2014 start-up of India's first MxCol® gasification plant at Jindal Steel and Power and the JSW Toranagallu COREX® export gas DRI plant, demonstrating the versatility of MIDREX technology across diverse ironmaking applications. The Midrex India team recently gathered for a special office celebration at the end of August, honoring this significant milestone and looking ahead to the next chapter of growth and accomplishment.



→ Ceres Report



As the U.S. steel industry prepares for a wave of critical infrastructure investments, a new analysis commissioned by Ceres and developed with input from Midrex highlights direct reduced iron (DRI) as the leading pathway for future growth. With many blast furnaces and coke ovens nearing the end of their operational lives, decisions made today will shape American steel production for decades.

The study found that DRI mills are the lowest-cost option for new facilities,

offering production costs competitive with imported pig iron while strengthening domestic supply chains. Beyond economics, flex-fuel DRI technology provides greater operational flexibility and significantly reduces environmental impacts, cutting greenhouse gas emissions by 40%, and local air pollution by 80% compared with traditional blast furnaces.

Midrex is also proud to sponsor Ceres' Climate Week NYC events on September 23, continuing the conversation around innovative, lower-emissions solutions for the future of iron and steel-making.



→ Plant Anniversary | ArcelorMittal Texas HBI



ArcelorMittal Texas HBI recently celebrated its 10th anniversary, marking a decade of operational excellence and continuous improvement in Portland, Texas. Since startup in 2016, the 2.0 million-ton-per-year facility has become a leading producer of high-quality hot briquetted iron (HBI), supporting lower-carbon Electric Arc Furnace (EAF) steelmaking through natural gas-based direct reduction technology.

The facility reached a major milestone in September 2025 by setting a world monthly HBI production record. The facility also maintained strong performance throughout the year, with 2025 production exceeding 90% of the annual record achieved in 2023. Over the past decade, the plant has demonstrated clear and sustained improvements in natural gas consumption efficiency, further strengthening its competitiveness and sustainability.

Lauren Lorraine: Editor

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