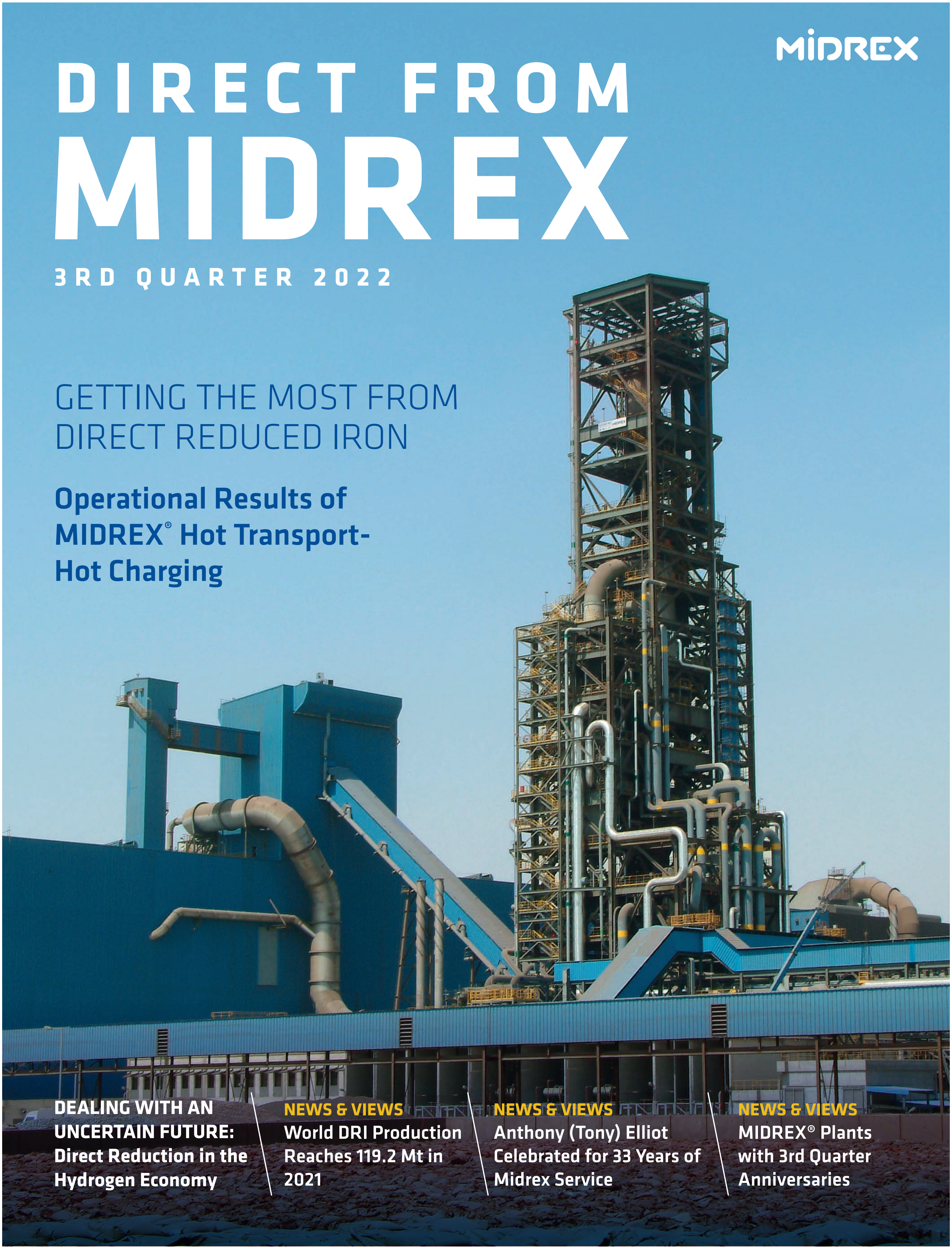
DIRECT FROM MIDREX

3RD QUARTER 2022



GETTING THE MOST FROM DIRECT REDUCED IRON

Operational Results of MIDREX® Hot Transport-Hot Charging

DEALING WITH AN UNCERTAIN FUTURE: Direct Reduction in the Hydrogen Economy

NEWS & VIEWS World DRI Production Reaches 119.2 Mt in 2021

NEWS & VIEWS Anthony (Tony) Elliot Celebrated for 33 Years of Midrex Service

NEWS & VIEWS MIDREX® Plants with 3rd Quarter Anniversaries

COMMENTARY

MIDREX® PROCESS MEETS THE CHALLENGES

By John Teeters
Director - Engineering
Midrex Technologies, Inc.

Sometimes we take our history for granted, but that's not always a negative thing. When I first started at Midrex in 1996, just out of university, the 6.65-meter shaft furnace was a relatively new and crucial step for us. We talked about a "MEGAMOD" plant design, as if it were a stretch for our capabilities. Apart from the COMSIGUA HBI plant in Venezuela, all of the latest contracted plants were designed to produce DRI only (we didn't call it CDRI [cold DRI] back then, as we didn't have a proven option for producing HDRI [hot DRI]). We were treading carefully on our first attempts at feeding oxide to a furnace with a vertical conveyor, we were installing the first of our oxide coating and oxygen injection systems, and we were just starting to talk about developing 3D models of our plants as an input for engineering. And no single direct reduction module had ever produced one million tons of DRI in a year.

The year 2004 ushered in serious diversity with respect to product demands of our customers, including higher capacity HBI plants and combo plants that could produce both CDRI/HBI or CDRI/HDRI. These capacity and product diversity demands required the integration of centrifugal process gas compressors into the process and the development of hot transport conveyors, a product cooler external to the reduction furnace, and a myriad of additional upgrades and innovations. None of these was a trivial development, and our Engineering team experienced the growing pains of implementing previously unproven technologies. Sometimes, as we move ahead, we don't fully appreciate the effort that it takes to reach these achievements.

The fascinating aspect of being in the "middle of the battle" has been to see how our teammates developed solutions for and responded to each of these challenges. I have always been impressed by the sheer talent and determination that the various teams at Midrex demonstrate, particularly in Engineering. We have a diverse team continually growing in its capabilities. Over the past year we have brought fantastic new teammates onboard (who don't yet fully understand what kind of ride they're in for). We are fortunate to have experienced team members who serve as the "backbone" and provide necessary mentoring by sharing their lessons learned, some of which have come with a lot of "bumps and bruises." We have the right people to meet the oncoming challenges, and we will continue to grow as we look for additional outstanding talent that fits our company culture.

So, what kind of challenges do we face in 2022? Producing DRI with "green" hydrogen is at the top of the list. Tightening environmental requirements will require new, improved abatement technologies. Demands for digitalization and automation will press us to provide enhanced offerings in plant control systems. Solutions for using lower-grade ores will bring economic advantages to the DR market. And maybe the biggest challenge will be getting it all done in the midst of increasing demand for DRI bolstered by global initiatives to decarbonize the market.

We have a talented team that has developed technologies which we are ready to offer now: MIDREX Flex™ provides the technology for transitioning a natural gas-based plant to operate with up to 100% hydrogen. And for customers who want to produce DRI with 100% hydrogen from day one, we have the MIDREX H2™ solution available.

Years from now, as we look back on 2022, these challenges and technologies will be proven and a part of our history that we may take for granted as well.

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This issue of *Direct From Midrex* includes an article describing the various systems available from Midrex for hot transport/hot charging of DRI, with actual operating results, and an article providing insights into the road ahead for direct reduction technology in the Hydrogen Economy. In addition, News & Views recognizes the MIDREX Plants with third quarter anniversaries and celebrates the 33-year career of Anthony (Tony) Elliot.

GETTING THE MOST FROM DIRECT REDUCED IRON

OPERATIONAL RESULTS OF MIDREX® HOT TRANSPORT-HOT CHARGING

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INTRODUCTION

The introduction of the hot discharge furnace for producing hot briquetted iron (HBI) not only made it safer and easier to transport direct reduced iron (DRI) as a merchant product, it led to the development of methods for transporting and charging hot DRI (HDRI) into an electric arc furnace (EAF) to take advantage of the sensible heat in the HDRI. The result is increased productivity and yield, as well as reducing the need to inject carbon to balance the EAF heat, thus lowering carbon dioxide (CO_2) emissions.

By using one of three hot transport systems – hot transport vessels (HTV), hot transport conveyor (HTC), and HOTLINK® – HDRI can be charged to an EAF at up to 650° C.

Key to the success of its hot transport/hot charging (HT/HC) systems is the experience Midrex gained from designing the hot discharge furnace for Sabah Gas Industries (now Antara Steel Mills) in 1984. The MIDREX® Hot Discharge Furnace has proven to be a keystone technological development that makes possible the innovative combination plant design which gives operators the ability to respond quickly and effectively to changing market conditions.

HT/HC of DRI is technically challenging and requires close and complete coordination between the DRI plant and the steel mill. Special handling is required for HDRI to protect it from exposure to air and prevent reoxidation and loss of temperature from the time it is discharged from the reduction furnace to when it is charged into the EAF.

This article discusses the benefits and challenges of transporting HDRI from the direct reduction plant to the melt shop and the solutions available from Midrex.

THE ORIGIN OF HDRI

When the hot discharge furnace was designed for the first MIDREX HBI Plant, which was started up in 1984, the stage was set for the addition of HDRI as another product option. The MIDREX Shaft Furnace operates at a relatively low pressure (≤1 barg), which simplifies the charging and discharging systems. The most important innovations embodied in the hot discharge furnace design are how it barometrically seals while discharging HDRI and how uniform material flow is maintained. Two dynamic seals accomplish the same task that would require more than 20 mechanical valves and five lock hoppers if the furnace were designed to operate at a pressure of 5-6 barg. The lower pressure operation of the reduction furnace and the bottom seal leg/product discharge chamber (PDC) arrangement are of particular importance in a MIDREX Combination Plant to achieve true simultaneous discharge of cold DRI (CDRI) and HDRI while maintaining consistent chemistry throughout the material bed and uniform material flow in the furnace.

BENEFITS OF HOT CHARGING DRI

Hot charging DRI is a proven method for effectively lowering the cost per ton liquid steel (tls). There are two primary benefits of hot charging DRI to an EAF:

1. Increased furnace productivity and lower energy costs for melting.
2. Reduction in the amount of pollutants per ton liquid steel.

The productivity boost results from shorter tap-to-tap times, which are made possible by the sensible heat retained in the HDRI which reduces the amount of electric energy and/or carbon injection needed to achieve melting temperature of the DRI.

For example, in ***Table I*** we have estimated that productivity can be increased from 4-17% when charging HDRI vs. CDRI in an EAF and the energy savings, which can range from 28-105 kWh/tls, based on actual HDRI chemistry.

HDRI Charged (%)	Productivity Increase (%)	Energy Savings (kWh/tls)
20	4	28
40	8	52
60	12	80
80	17	105

Assumptions:
1. 600° C HDRI temperature to EAF
2. 100 tls tap weight
3. 80 MVA transformer
4. 0.85 power factor
5. 0.1% steel tap carbon
6. 1600° C steel tap temperature
7. 90% steel yield

TABLE I. *Estimated Operating Results Charging HDRI in EAF*

Hot charging DRI also reduces the total amount of pollutants produced per ton of liquid steel. By utilizing the sensible heat contained in HDRI rather than releasing it to the atmosphere, hot charging DRI provides environmental benefits in three ways:

1. Shorter time spent melting the DRI lowers EAF emissions
2. Lower electricity demand from the utility reduces power plant emissions per ton of liquid steel
3. Reduced amount of carbon injected for heating and melting results in less CO_2 emissions

Actual operating results achieved by Tosyali Algérie show a >27% reduction in power required/mt of steel, a >28% improvement in tap-to-tap time and a subsequent 30% reduction in power on time, resulting in >41% more heats/day when charging 100% HDRI vs. 100% CDRI ***(see Table II)***.

	EAF FEED		
	100 % CDRI	100 % HDRI	NOMINAL (80% HDRI/ 20% CDRI)
Power (kWh/t)	650	470	500
Tap-to-tap time (min)	60	43	48
Power on time (min)	50	35	38
Production (avg heats/day)	24	34	30

TABLE II. *Results of Charging HDRI vs. CDRI (reported by Tosyali Algérie)*

Midrex and its Construction Licensees have supplied 13 hot discharge plants equipped with hot transport since 1990: seven producing HDRI/CDRI, six producing HDRI/HBI. This represents nearly 20.0 million metric tons of installed capacity ***(see Table III, next page)***.

METHODS AND CRITERIA FOR HOT TRANSPORT/HOT CHARGING DRI

In order to reap the operating benefits from hot charging DRI, it is essential to keep the HDRI at a consistently high temperature regardless of the distance between the MIDREX Plant and the EAF melt shop. Midrex offers three systems for plants equipped with a hot discharge reduction furnace that minimize temperature loss and prevent loss of metallization due to reoxidation of the HDRI during transport:

- HOTLINK
- Hot Transport Conveyor (HTC)
- Hot Transport Vessel (HTV)

Important factors to consider are whether the installation is greenfield or retrofit, installation cost, operating cost, generation of fines, temperature loss, carbon loss, ease of operation, and reliability. The system for transporting HDRI is mainly chosen based on distance to the melt shop in accordance with *Table IV*.

Figure 1 shows a breakdown of the various methods of hot transporting/hot charging used by MIDREX Plant from 2011 through 2021.

Plant	Location	Design Capacity (Mt/y)	HT/HC System	Products
Essar Steel* I & II	Hazira, India	0.88	HTV	HDRI/HBI
Essar Steel* III	Hazira, India	0.44	HTV	HDRI/HBI
Essar Steel* IV	Hazira, India	1.00	HTV	HDRI/HBI
Essar Steel* V	Hazira, India	1.5	HTV	HDRI/HBI
Hadeed E	Al-Jubail, Saudi Arabia	1.76	HTC	HDRI/CDRI
Lion DRI	Banting, Malaysia	1.54	HTV	HDRI/HBI
Jindal Shadeed	Sohar, Oman	1.5	HOTLINK	HDRI/HBI
JSW Projects Ltd.	Toranagallu, Karnataka, India	1.2	HTC	HDRI/CDRI
Jindal Steel & Power	Angul, India	1.8	HTC	HDRI/CDRI
ESISCO	Sadat City, Egypt	1.76	HTC	HDRI/CDRI
SULB	Hidd, Bahrain	1.5	HTC	HDRI/CDRI
Tosyali Algérie I	Bethioua (Oran), Algeria	2.5	HTC	HDRI/CDRI
Algerian Qatari Steel	Bellara, Algeria	2.5	HTC	HDRI/CDRI

** now ArcelorMittal/Nippon Steel Limited (India)*

TABLE III. *MIDREX Plants with Multi-Product Capability*

Distance between Shaft Furnace and EAF	Hot Transport Method
0 – 40 meters	HOTLINK
40 – 200 meters	HTC or HTV
> 200 meters	HTV

TABLE IV. *Suggested Distances for Hot Transport Systems*

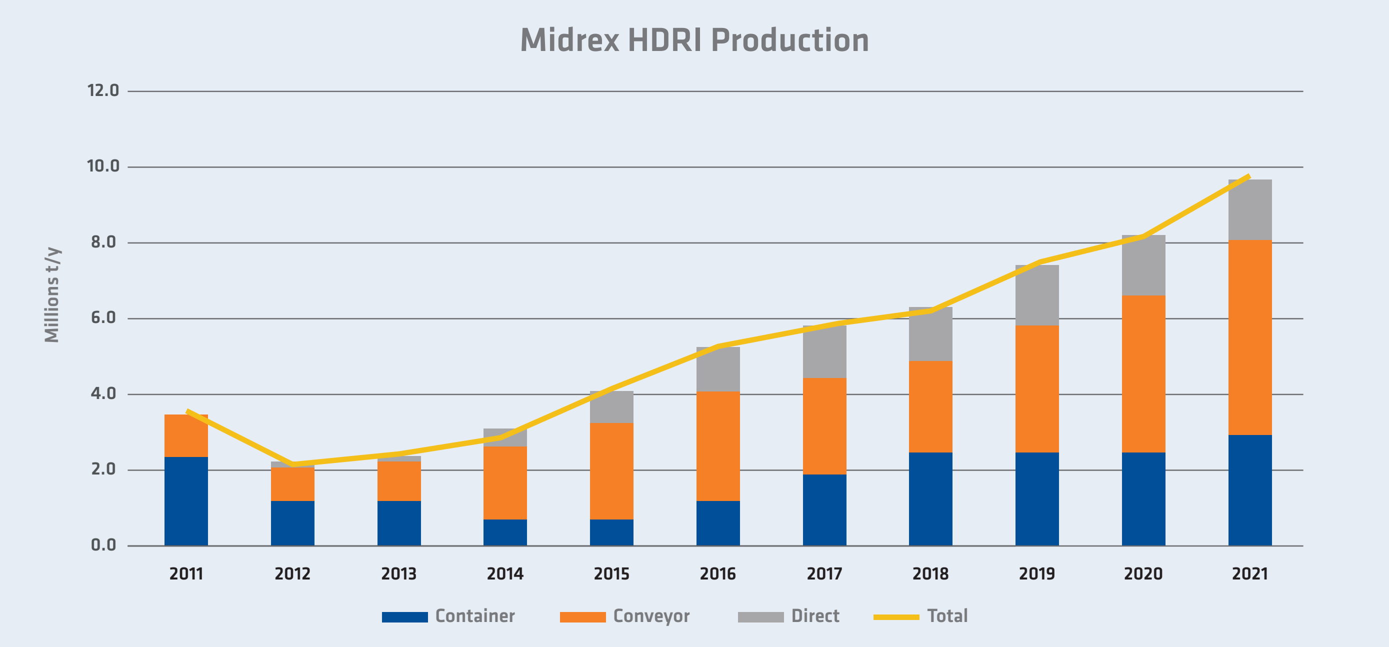

FIGURE 1. *HDRI Production by MIDREX Plants 2011-2021*

There are three separate tasks that must be accomplished within the flowsheet in all transport systems:

1. Discharge the DR furnace at a controlled continuous rate.
2. Transport the HDRI to the melt shop.
3. Feed the HDRI to the EAF at a controlled rate at the appropriate time that the EAF requires it in the heat cycle.

Because melt shops operate with frequent maintenance shutdowns and DR furnaces only shut down once every 1.5 years, it is necessary to have a second avenue for the HDRI to go when the EAF is between campaigns. What to do with the DR furnace production during EAF downtime is dependent on market strategies of the producer.

There are three options for the HDRI when the melt shop is not in operation:

1. Cooling and storing the cooled DRI for later use
2. Hot briquetting and either selling the briquettes or storing for later use
3. Transporting the HDRI to another EAF

PROCESS DESCRIPTION OF HOT TRANSPORT SYSTEMS

HOTLINK

HOTLINK delivers HDRI to an adjacent EAF at up to 700°C directly from the reduction furnace positioned just outside and above the exterior wall of the EAF melt shop ***(see Figure 2)***. HDRI is discharged into a surge bin and then fed by gravity directly to the EAF with minimum heat loss. Low-velocity, gravity transport keeps physical degradation of the HDRI to a minimum and the sealed design of the HOTLINK system ensures there is no reoxidation of the HDRI. HOTLINK is available with options to produce HBI or CDRI when the EAF is offline without the need to stop DRI production.

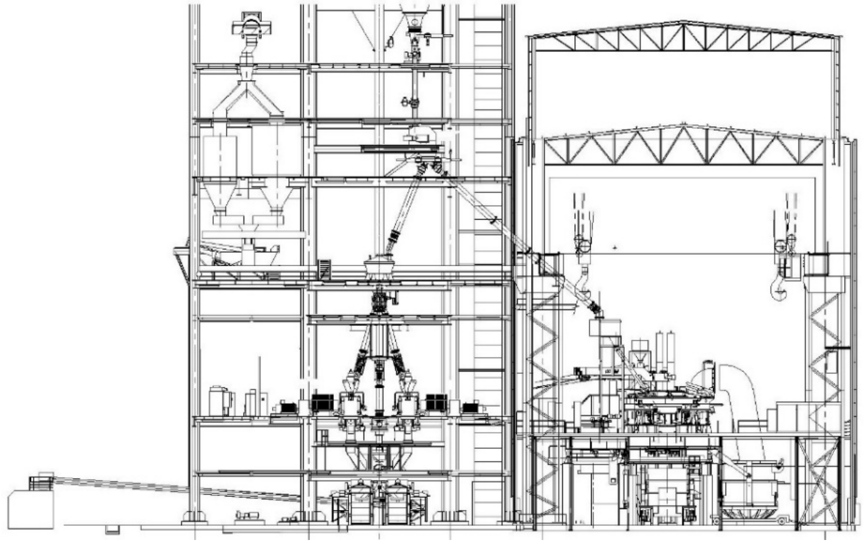

FIGURE 2. *Schematic of HOTLINK-EAF Arrangement*

The first HOTLINK plant is in Oman and is owned and operated by Jindal Shadeed and has produced nearly 10 million tons of HDRI since 2012.

A second-generation HOTLINK Plant (HOTLINK 2G) was built for ESISCO in Egypt. In HOTLINK 2G, the HDRI storage bin is direct coupled with the PDC and located in the furnace tower. In addition, a short, horizontal hot transport conveyor is used to convey HDRI from the storage bin to the EAF. HOTLINK 2G allows the furnace tower to be lowered by 12 meters.

Hot Transport Conveyor (HTC)

FIGURE 3. *HTC Between MIDREX Plant (Hadeed E) & Melt Shop*

HTCs are specially designed, covered, and insulated bucket -type conveyors to transport HDRI for distances up to 200 meters. The HTC system continuously transports HDRI from the discharge of the MIDREX Shaft Furnace via an inclined bucket conveyor into storage bins located directly above the EAF. This allows the MIDREX Shaft Furnace to discharge HDRI at a significantly lower elevation than the EAF. HTCs have lower energy and maintenance costs and generate less fines than pneumatic transport systems.

HTC systems are operating at Hadeed in Saudi Arabia ***(shown in Figure 3, previous page)***, Jindal Steel & Power Limited in India, JSW in India, SULB in Bahrain, and Tosyali Algérie I and AQS in Algeria.

Hot Transport Vessel (HTV)

HTVs are refractory-lined containers typically with a capacity of 45-90 metric tons. HDRI exits the MIDREX Shaft Furnace and is discharged into these containers, which are then transported by truck or rail to the steel mill and placed in an automated overhead receiving station by the scrap charging crane. From here, the HDRI can be discharged directly into the EAF. A telescoping device seals the opening of the HTV to the discharge feeder and initiates the HTV isolation valve operating sequence. HTVs are ideal when the distance from DRI plant to EAF is greater than 100 meters. They maintain the HDRI under inert conditions throughout the entire fill–transport–discharge cycle to minimize loss of metallization and retain maximum temperature.

The HTV method has been used in India since 1998 by ArcelorMittal/Nippon Steel India (formerly Essar Steel) and was operated by the Lion Group in Malaysia from 2007 until the Lion DRI plant was shuttered in 2017.

OPERATION DETAILS AND RESULTS

Direct Charging by HOTLINK (Original HOTLINK design)

Direct charging is perhaps the simplest of the HT/HC systems. After the material is discharged from the furnace and depressurized, the HDRI is alternately fed into two EAF feed bins to adapt the continuous DR furnace discharge to the batch feeding that an EAF requires. The HDRI is fed at a controlled rate to a feed leg that feeds the EAF directly using only gravity as the means of transport.

Equipment Description at Jindal Shadeed (downstream of PDC)

- HDRI bin feeders – Vertical screw feeders to meter DR furnace output and fill HDRI surge bins.
- HDRI feed bins – to provide surge between DR furnace continuous operation and EAF batch operation. On load cells for loss-in-weight feed control
- HDRI feeder to EAF – Rotary feeder to control feed rate to the EAF

Results of operation

In January 2016, the steel mill reported EAF electricity consumption of ~529 kWh/tls while using ~75% HDRI, ~25% HBI, and scrap. The MIDREX Shaft Furnace was operated using 85% blast furnace-grade pellets with higher gangue content than DR-grade pellets. HDRI carbon content was 1.8% and metallization was 93-94%. HDRI was discharged at a temperature of ~650° C and was charged into the EAF at a temperature of 622° C.

Advantages

- Minimal moving parts
- Lowest power consumption
- Easiest logistics
- Low manpower requirements
- Lowest inert gas usage
- Lowest temperature (and carbon) loss

Disadvantages

- Taller DR furnace tower
- Retrofited to existing melt shop
- Long chute to EAF could result in HDRI breakage

Process description (HOTLINK 2G)

HOTLINK 2G was developed to shorten the height of the DR furnace tower, and is installed at ESISCO in Egypt. In HOTLINK 2G, HDRI is discharged and held in one feed bin before it is transported horizontally by conveyor to the melt shop. By using a short horizontal conveyor and one surge bin, 12 meters in the height of the DR furnace tower were eliminated.

A disadvantage of this flowsheet is that it is not possible to know the precise discharge rate (by weight) of the DR furnace because the HDRI feed bin will be emptying and filling at the same time. Also, there is a lag between discharge of the HDRI bin and the feed of the HDRI to the EAF, which forces the melt shop to plan ahead for changes to feed rate.

Equipment description (downstream of PDC)

- HDRI bin feeders – Only PDC wiper bar to meter DR furnace output and to control feed to the single HDRI Feed Bin.
- HDRI feed bin – to provide surge between DR furnace continuous operation and EAF batch operation. On load cells to determine HDRI level in the bin.
- HDRI feeder to EAF – Rotary feeder operating in a volumetric basis to control feedrate to the EAF

Results of operation

We have limited experience with HOTLINK 2G because ESISCO has been able to run at full capacity only a short time due to commercial reasons.

Advantages

- Shorter furnace tower than for First Generation HOTLINK
- Lowest power consumption
- Low manpower requirements
- Low inert gas usage
- Low temperature loss
- Low number of drops and low heights of dropping HDRI – less breakage

Disadvantages

- Requires more advanced planning and foresight by melt shop
- Allows only intermittent feedback of DR furnace discharge rate
- Provides only volumetric control of EAF feed (not controlled by loss-in-weight)
- Possibility of exposing HDRI to air at conveyor transport points with potential for increased temperature and carbon loss

Hot Transport Conveyor (HTC)

Process description

After depressurizing the PDC, the HDRI is metered into the conveyor by a rotary feeder. The rotary feeder both meters volumetrically and distributes the HDRI across the width of the bucket apron conveyor. Transportation to the melt shop is by metallic apron conveyor which can be inclined up to 34°. The width of the buckets and speed of the conveyor are based on the rated capacity of the conveyor. The maximum lift, capacity, and length of one conveyor is limited by the strength of the chains. The entire conveyor is enclosed and an inert gas is injected along the length to minimize metallization and carbon loss.

At the discharge of the conveyor, the HDRI is diverted to fill one of two HDRI feed bins before discharging to the EAF. The bins act as a surge capacity with loss in weight measurement and are sized so each bin will hold at least enough HDRI for one heat of the EAF. The bins are mounted on load cells to indicate the weight of HDRI in the bin. During operation, one bin is filled while the other is being emptied.

The HDRI is discharged by a rotary feeder, which discharges to a chute that goes into the roof of the EAF. The EAF operator controls the rotary feeder rate according to the heat charging cycle.

Results of operation

The operational results shown in ***Table V (next page)*** have been reported by an operating MIDREX Plant with a hot transport conveyor system.

Benefits

- 17.78% power savings
- 12.86% tap-to-tap time savings
- 20% productivity increase by reducing tap-to-tap time
- Reduced emissions by retaining sensible heat in HDRI, which 1) lowers electricity demand (reduced power plant emissions per ton of steel), and 2) reduces energy requirement in EAF (less carbon injection, which reduces amount of CO_2 emissions)
- 20 kWh/tls electricity savings for every 100° C increase in HDRI temperature (at least 120 kWh savings when charging at least 600° C HDRI)
- 0.5-0.6 kg/tls electrode savings
- 1.8-2.0 kg/tls refractory savings

SULB, which is equipped with an HTC system, set an annual production record in 2018 and a new monthly production record in 2019, averaging 215 t/h. Over 1.0 million tons of HDRI were sent directly to the steel mill in 2019, while more than 60% of the balance was exported by ship as CDRI. HDRI temperature (at the PDC) exceeded 650° C, metallization was 94.9%, and carbon was 2.28%.

Advantages

- Able to feed multiple EAFs as long as they are close enough to the DR furnace tower
- Precise control of HDRI feed to EAF

Disadvantages

- Requires careful coordination with melt shop for placement of bins and conveyor support structure
- Conveyors require maintenance, however long term have proven to be reliable.
- Requires a higher quantity and careful application of seal gas to maintain HDRI metallization and carbon.

	PDC Discharge	EAF Feed
Temperature (° C)	510.4	498.0
Carbon (%)	2.52	2.12
Metallization (%)	93.99	92.02
HDRI Production rate (tph)	158.3	158.3
Utilities	*Cold DRI*	*HDRI*
Power (kWh/Ton liquid)	557	458
Tap to Tap Time (Min.)	70	61
Power-On Time (Min.)	55	48
Electrode Consumption (kg/Ton)	1.16	1.0
Production (Avg. Heats/day)	19	24

TABLE V. *HTC Operational Results*

Hot Transport Vessel (HTV)

The capacity of HTVs is determined by several factors including head room of the roadway to the melt shop, discharge capacity of the DR furnace, heat size of the EAF, and manageable size of the vehicle (truck or rail). In the case of the Lion plant in Malaysia, the transportation of the HTVs from the loading point at the DR furnace is via rail-based shuttle cars to the buffer transport station. From there, the HTVs are loaded by bridge crane onto rubber-tired trucks that transport the HDRI to the changing bays of the melt shops. Once at the EAF charging bay, the HTVs are lifted from the transport trucks by EAF charging cranes to an HDRI charging stand that is located above each EAF. After positioning the HTV in the charging stand, the vessel is connected to the discharge pipe and the hot conveying system of the charging stand. HDRI is charged via a hot conveyor into the EAF at feed rates according to the actual melting process requirements of the EAF. For emergency situations, HDRI can be discharged via a chute to the ground level.

Equipment descriptions

- Loading Equipment – After exiting the PDC, the HDRI is fed alternately by one of three vertical screw feeders into HTVs. The HTVs are then loaded onto the vehicles for transport to the melt shop.
- Transport Equipment – The vehicles to transport the vessels to the melt shop can be either rubber-tired carriers or flatbed railcars. The method of transport depends on the plant layout. Rubber-tired vehicles are much more versatile with regards to timing the vessels and routing; however, they require more manpower and maintenance to operate. Lion has 15 fabricated containers and three trucks to feed both melt shops.

- Unloading Equipment – Vessels are unloaded from the vehicles by the melt shop crane. Alternately, special vehicles can be used to unload the vessels without assistance from the crane. These vehicles can have either hydraulic beds that lower the vessel (along with a mobile stand) or arms that lift the vessels off the vehicle and place them in a stationary stand. The melt shop crane then places the vessels in a charging stand to be discharged to the EAF by feeder/conveyor (the charging stand concept was patented by Midrex in 2010).

Results of operation

- Melt shop benefits:
  - Shorter tap-to-tap times (increased productivity and yield)
    - Reduced by 3 minutes (45-ton HTV)
    - Reduced by more than 5 minutes (90-ton HTV)
- Electricity and electrode savings
  - Heats using one 90-ton HTV charge of HDRI saved average of 60 kWh/t liquid steel (equates to 120 kWh/t savings when using 100% HDRI charge)
  - Electrode savings over 8-month period averaged 0.3 kg/t liquid steel
- Decreased moisture in EAF charge
  - No moisture in HDRI (0.75% moisture in HBI from water-quenching)
  - HDRI has 1.0-1.5% higher metallization

Challenges

- Essar Steel (now AM/NS India) initially had problems with HDRI plugging at the discharge of the vessels. This was resolved by making the outlets larger and keeping an inert atmosphere in the vessel during long wait times.
- Lion reported breaking the chassis of both transporters due to road conditions and the weight the trucks were carrying.
- Lion reported problems with plugging of the feed pipes dust collection to the vessels and rupturing of the telescoping chute after a short time
- Lion reported they were experiencing about 50° C temperature loss between the PDC and the charge hopper of the EAF. Further continuous monitoring of the vessels in transit demonstrated that the closed vessels only experienced a 2° C temperature loss per hour, which proved that the primary temperature losses were occurring during the loading and unloading of the vessels.

Advantages

- Easiest method to implement as a retrofit
- Able to feed multiple EAFs even if they are a long distance apart
- DR plant can be located relatively far from the melt shop

Disadvantages

- Large capital cost because of the number of HTVs required
- Large manpower requirement
- Ties up melt shop building crane for loading containers into charging stand
- Logistically challenging

CONCLUSION

Three distinctive operations are involved in producing and using HDRI, each of which poses technical challenges and requires specific conceptualization, engineering, and implementation efforts:

1. Hot discharging DRI from the reduction furnace
2. Transport the HDRI to the melt shop
3. Charging HDRI into the EAF

Hot transporting/charging DRI is most economically realized when the decision is made in advance of the design and construction of a "greenfield" plant. However, the flexibility of the MIDREX Process allows for modifying an existing HBI plant equipped with a hot discharge reduction furnace or for retrofitting an older plant currently producing CDRI. Careful evaluation of the plant layout should be considered when proposing a method of hot transport. It is not a simple formula involving only distance to the melt shop, although the distance is one of the major factors.

HOTLINK

This system involves putting the HDRI bins in the DR furnace tower and feeding the melt shop directly via a feed leg. It is the simplest and lowest operating cost method. It provides the advantages of a precise weight controlled EAF feed, absolutely no possibility of exposure to atmosphere before it enters the EAF, and no mechanical transport parts to maintain. The biggest disadvantages are that it raises the DR furnace height significantly and careful coordination with the melt shop supplier during the layout of the integrated plant is required.

HOTLINK 2G loses a few of the advantages mentioned above because the feed to the EAF and the discharge of the DR furnace is volumetrically controlled, which is less precise. Additionally, there is also the possibility of exposure to oxygen at the transport point to the conveyor and the mechanical conveyor requires maintenance and control. However, it does lower the DR furnace tower due to the horizontal transport of the HDRI, but close coordination with the melt shop supplier is still necessary for support and routing of the conveyor through a congested area of the melt shop.

Hot Transport Conveyor (HTC)

To date, HTCs have been the most popular option for a greenfield site. The system has been well proven and improvements in sealing the conveyor to prevent metallization and carbon loss ensure that this will continue to be the trend. It has the advantage of lowering the DR furnace tower, as well as providing a reliable and controllable HDRI feed rate to the EAF. Consideration of the melt shop layout is important up front, as well as the operating parameters of the EAF. HDRI bins need to be sized to accommodate the heat size of the EAF and space needs to be reserved in the melt shop for the bins, as well as for a good route to the top of the HDRI bins for the conveyor. Maximum inclination angle and length of the conveyor must be approved on a case-by-case basis by the conveyor supplier.

Hot Transport Vessel (HTV)

If a melt shop exists on the site before the DR furnace site is planned and there is not a good route for an HTC, using HTVs is often the only choice. In some cases, HTVs can be the best choice for new melt shops, such as if the client will be charging multiple small furnaces with HDRI. HTVs should not be considered if there is a possibility of another viable method because it is the most capital intensive and logistically challenging of the Midrex HT/HC systems.

For long term operation, lowest OPEX will tend to govern, so the best option will depend on temperature of HDRI into the EAF and overall plant availability. As a result, HOTLINK or HOTLINK 2G should prove to be more economical than the HTC or HTV options over the life of the plant.

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(Note: This article is based on a paper titled, "Operational Results of Hot Charging DRI" by Brian Voelker and Sean Boyle, which was presented at the AISTech 2022 Exposition & Conference in Pittsburgh, PA)

DEALING WITH AN UNCERTAIN FUTURE

Direct Reduction in the Hydrogen Economy

By TODD ASTORIA, *Director, Research & Technology Development*

INTRODUCTION

The steel industry is being faced with exciting opportunities: new fuels, the mitigation of greenhouse gas (GHG) emissions, new technologies, and new raw materials are all leading to discussions and ideas that would not have been possible even a few short years ago. Unfortunately, new opportunities also cause new uncertainties which can complicate decisions that have long investment timelines. The direct reduction of iron ore using the MIDREX® Process can help mitigate these uncertainties by providing unparalleled flexibility for raw materials, fuels, and product offerings.

This article will discuss the evolving market opportunities and uncertainties and show how direct reduction technology offerings can help meet these future requirements.

GROWTH OF DIRECT REDUCED IRON (DRI)

In 2020, the International Energy Agency (IEA) projected the growth of several ironmaking process routes in their Energy Technology Perspectives. The projections are summarized in ***Table I***.

	DRI Production (Mt/y)		
	DRI	Smelting Reduction (SR)	DRI+SR
2019	115	11	127
2030	167	11	179
2040	269	70	342
2050	411	202	613

TABLE I. *Summary of ironmaking routes from the IEA Energy Technology Perspectives 2020*

The IEA projects that DRI could grow to over 400 Mt/y production by 2050. That would represent rapid growth of iron production through the direct reduction route considering that the total production in 2019 is shown as 115 Mt/y. The same IEA projection shows a decline in the conventional blast furnace (BF) route for ironmaking. The projection would be a major shift away from the near monopoly of the BF route for ironmaking. The future production by process is unknowable; however, the market and technology uncertainties driving the projections can be analyzed.

One of the major factors is the increased attention being given to the environmental impacts of ironmaking. Overall ironmaking contributes between 7% to 9% of the total worldwide greenhouse gas emissions (also referred to as carbon mitigation or avoidance). The discussion on how to reduce the emissions from ironmaking is driving much of the uncertainty related to projections for the various ironmaking routes.

The following discussion will examine the technological impacts of various carbon mitigation or avoidance schemes for natural gas or hydrogen-based direct reduction technologies.

WHY IS HYDROGEN-BASED DRI GAINING INTEREST?

Natural gas-based direct reduction technologies have an intrinsic reduction in carbon dioxide intensity compared to the coal-based routes. The overall governing reactions are shown as follows:

EQUATIONS

$$CH_4 + H_2O \Leftrightarrow 3\,H_2 + CO \quad (1)$$
$$CH_4 + CO_2 \Leftrightarrow 2\,H_2 + 2\,CO \quad (2)$$
$$3\,C + 2\,FE_2O_3 \Leftrightarrow 4\,FE + 3\,CO_2 \quad (3)$$
$$3\,H_2 + FE_2O_3 \Leftrightarrow 2\,FE + 3\,H_2O \quad (4)$$
$$3\,CO + FE_2O_3 \Leftrightarrow 2\,FE + 3\,CO_2 \quad (5)$$

Equations (1) and (2) are the reforming reactions for CH_4. Equation (3) is the reduction of hematite to metallic iron by carbon, and Equations (4) and (5) are the reduction of hematite to metallic iron by hydrogen and carbon monoxide, respectively. Using the respective molecular weights, the theoretical minimum carbon dioxide intensities for Equations (3), (4), and (5) can be calculated, as shown in ***Table II.***

Equation (4) shows that carbon emissions can be completely avoided by reducing the iron with hydrogen. Equation (3) results in a lower stoichiometric emission of CO_2 than Equation (5) simply because the CO in Equation (5) already has an oxygen atom bound to the C. Conventional direct reduction can operate across a wide range of H_2/CO ratios. The effect of H_2/CO ratio on the carbon dioxide intensity can be seen in ***Figure 1***.

Figure 1 covers a range of industrially relevant H_2/CO ratios. The lower range of 0.5 H_2/CO ratio is observed when high CO and CO_2 containing gas is supplied to the direct reduction facility. For example, COREX® plants paired with the MIDREX Process operate with an H_2/CO ratio in this range. The higher end of the range is observed when steam methane reformers (SRM) provide the syngas to the direct reduction plant. H_2/CO ratios even higher than 3 are possible; however, ***Figure 1*** shows that the curve will continue to approach zero CO_2 intensity asymptotically as the H_2/CO ratio increases.

	Stoichiometric ton CO_2 product per ton Fe
Equation (3)	0.59
Equation (4)	0.00
Equation (5)	1.18

TABLE II. *Stoichiometric CO_2 Intensity for Selected Reactions*

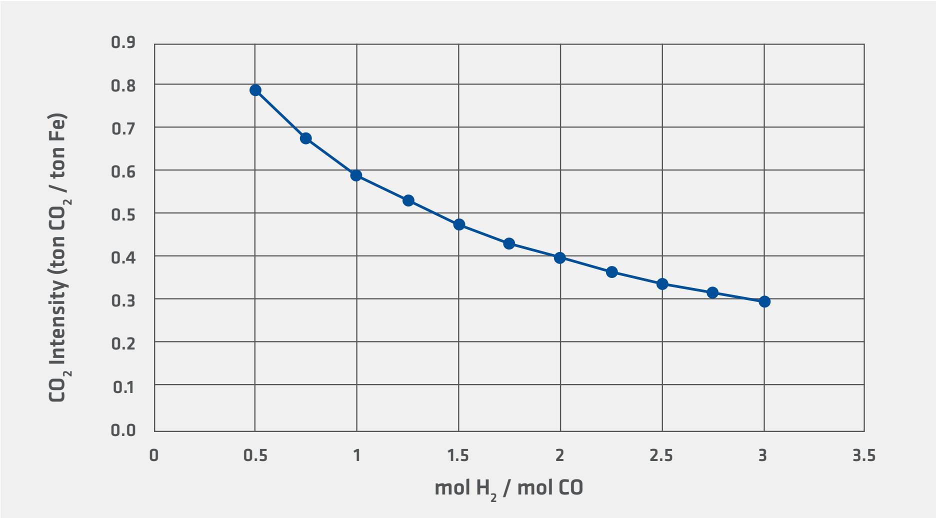

FIGURE 1. *Stoichiometric CO_2 for a Range of Reducing Gas Compositions*

The CO_2 intensity has been treated from a pure chemical reaction point-of-view up to this point. ***Figure 1*** also shows the importance of the reforming techniques and gas recycling systems in natural gas-based direct reduction facilities. All of the major natural gas-based direct reduction technologies operate with a method to process and recycle the spent reducing gases back to the shaft furnace. Because of the recycle loop and other processing requirements, the actual emissions calculated here do not reflect the actual observed CO_2 emissions reported from the industrial facilities. In the industrial application, the CO_2 emission can be approximated from the natural gas consumption. Generally, direct reduction facilities operate with emissions of approximately 0.5 ton CO_2/ton DRI (typical DRI produced from DR-grade pellets contains around 90% total Fe).

In the commercial direct reduction facility, the recycled gas does not contain pure reductants (i.e., hydrogen and carbon monoxide). Because of the gas processing and recycling loops the actual gas compositions have to be calculated.

Figure 2 is calculated to illustrate the sensitivity of the gas compositions for H_2 and CO for a theoretical reducing gas. In ***Figure 2***, the ratio of H_2 and CO is held high enough compared to the oxidizing H_2O and CO_2 to produce DRI of industrially relevant reduction degree. There is also a small percentage of N_2 and CH_4 which is not shown in the graph and is the reason why the H_2 and CO compositions sum to 87 vol%.

One of the technological options for carbon avoidance is the substitution of green hydrogen for fossil-fuel derived hydrogen. Green hydrogen is assumed to be hydrogen that is produced with no associated CO_2 emission. When green hydrogen is introduced into the direct reduction facility, the concentration of hydrogen in the recycling gas will increase.

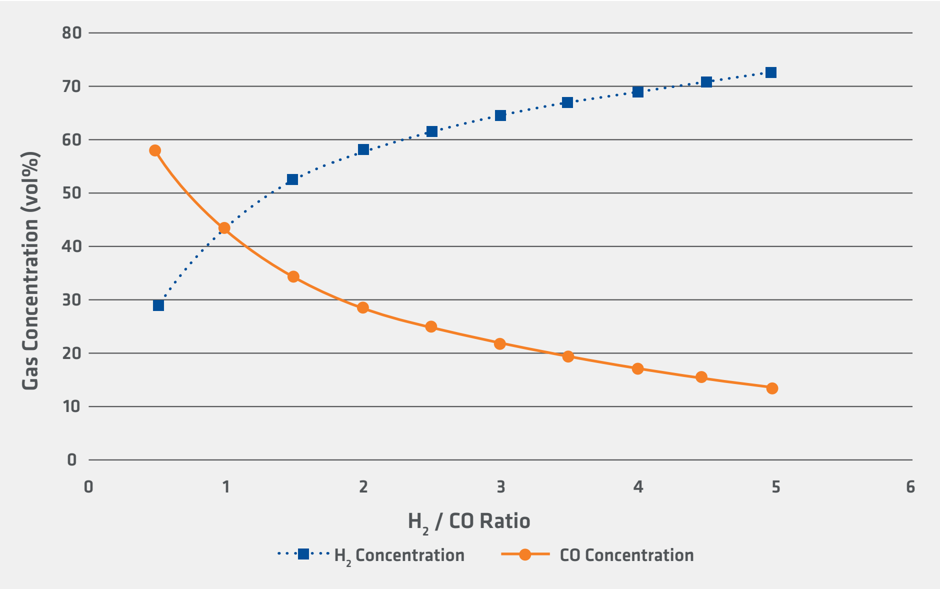

FIGURE 2. *Illustrative Gas Concentration of H_2 and CO for a Range of H_2/CO Ratios*

One of the uncertainties that the industry faces is how the direct reduction processes will be changed by increased hydrogen in the recycling gas loops. Direct reduction facilities have already operated commercially with H_2/CO ratios of 3 or higher. Using the conservative basis in ***Figure 2***, industrial direct reduction facilities have operated above 65 vol% H_2 and in some cases above 70 vol% H_2 in the recirculating gas loops.

The desire to directly avoid CO_2 emissions by substituting green hydrogen for CH_4 is driving much of the interest in direct reduction along with the IEA forecast for the growth of ironmaking by routes other than the blast furnace.

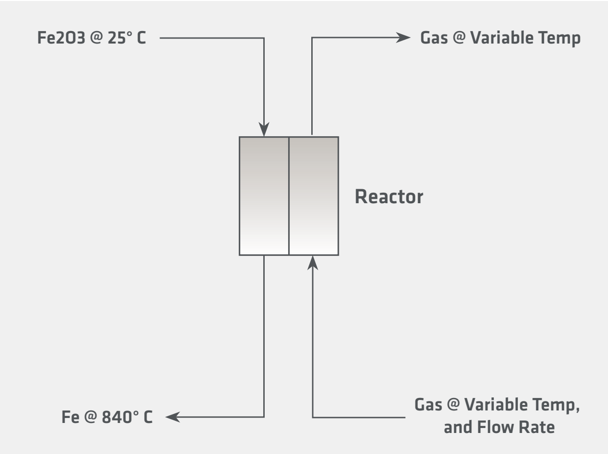

FIGURE 3. *Graphic Representation for the Thermodynamic Calculation*

SENSITIVITY STUDY

The preceding section addressed the driving force for why hydrogen-based direct reduction is gaining interest. In this section we will examine some of the implications of increasing hydrogen reduction for the heat balance of a direct reduction shaft furnace. For the purpose of this discussion, several theoretical cases have been setup according to the conditions illustrated in ***Figure 3***.

In *Figure 3*, hematite is introduced at 25˚C and calculated to adiabatically react fully to metallic iron with a fixed exit temperature of 840˚C, which is industrially relevant, as it is within the range of temperatures that are generally encountered in countercurrent direct reduction. The heat balances are calculated with several inlet gas sensitivities, which are shown in *Table III.* The exit gas temperature and composition are calculated according to the inlet gas compositions. Note that the calculation is purely stoichiometric and does not consider the kinetics or any limiting chemical equilibrium. The conditions for the sensitivity and the graphs showing the results are presented on the following page.

Figures 4 and 5 illustrate the differences in the heat requirements for reduction by H_2 and reduction by CO. In the calculation, 100% H_2 requires significantly higher flow rates compared to reduction by CO. However, even for the 100% H_2 case, it is noteworthy that that inlet gas temperature and flow rates for the sensitivity are within the range of industrially observed operating conditions.

IMPACTS FOR DIRECT REDUCTION

The purpose of the direct reduction plant is to produce DRI of sufficient metallization and temperature for the downstream users. Previously, cold direct reduced iron (CDRI) was discharged from the furnace at near ambient temperature. However, hot direct reduced iron (HDRI) and hot briquetted iron (HBI) are now the most important DRI products due to their improved energy efficiency or superior material handling properties. The hot discharge application in direct reduction has the additional operational constraint

Inlet Gas Composition	Inlet Gas Temperature (° C)	Inlet Gas Flow Rate (Nm³/ t Fe)
100% H_2	800	~1400 to ~2600 (for H^2)
100% CO	900	~600 to ~1400 (for CO)
	1000	

TABLE III. *Calculation Case Sensitivities*

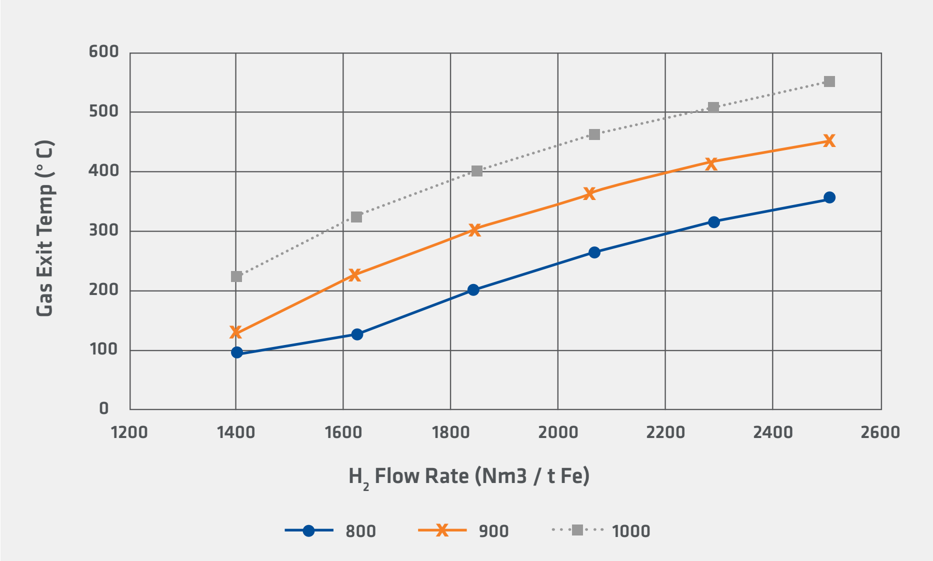

FIGURE 4. *Sensitivity for Gas Exit Temperature for H_2 Reducing Gas*

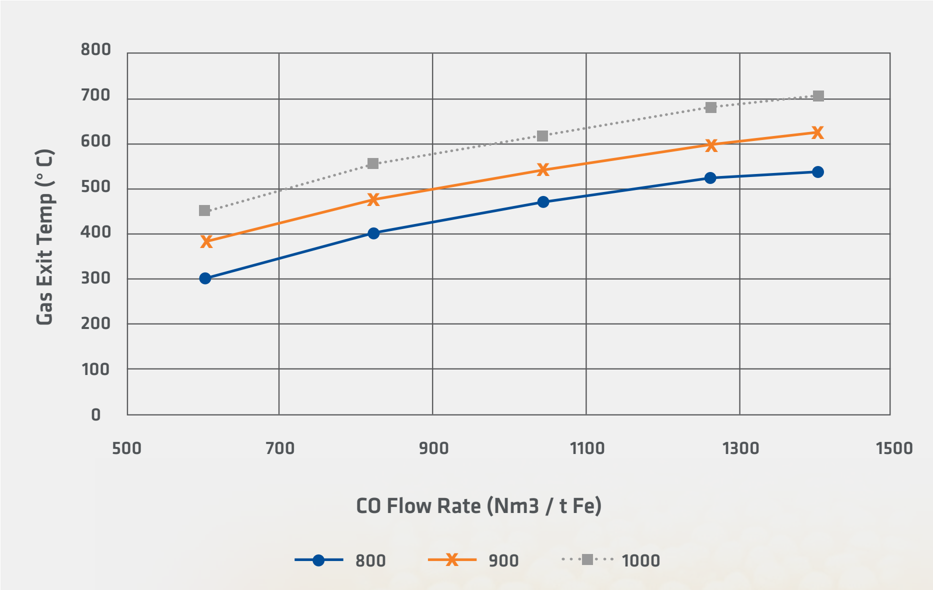

FIGURE 5. *Sensitivity for Gas Exit Temperature for CO Reducing Gas*

that high material discharge temperature is desirable and must be maintained. The rest of the discussion will focus only on HDRI or HBI applications.

The calculations shown previously chose the DRI temperature specifically to match the conditions required for HDRI or HBI production. These conditions give rise to the costs and benefits of avoiding carbon dioxide emissions versus the need to maintain product quality and plant productivity.

It is clear that increasing use of green hydrogen can be employed to directly avoid the emission of carbon dioxide from the direct reduction facility. However, as shown in the preceding sensitivity analysis, the hydrogen reduction reaction is more endothermic than the corresponding carbon monoxide reduction reaction. ***Figure 5*** also indicates that the required process change to offset this higher endothermic load is to increase the flow of recycled gas to the shaft furnace.

Since the shaft furnace is an adiabatic countercurrent moving bed reactor, it is clear that the recycled gas that is introduced to the shaft furnace bustle must carry all the energy needed to satisfy the shaft furnace heat balance requirements. The main process change to offset the addition of green hydrogen to the direct reduction process is to simply increase the flow rate of gas that is circulated to the shaft furnace bustle.

The overall advantage for direct reduction is the proven operation that has significantly reduced direct CO_2 emissions when compared to the conventional blast furnace route. Although the supply and economics of green hydrogen is currently uncertain, it seems likely that continuing environmental and greenhouse gas emission concerns will drive interest in this fuel as a path toward carbon dioxide emission avoidance. The direct reduction plant has the option to begin transitioning to green hydrogen as it becomes available on the market. The primary modification that can be envisioned is that at some point, the recycle gas compressors capacity may need to be upgraded. The impact and discussion on other unit operations becomes technology and case specific.

CONCLUSIONS

Direct reduction is experiencing a surge of interest due to changing market pressures for environmental concerns, especially greenhouse gas emissions. The advantage of avoiding carbon dioxide emissions directly through the use of green hydrogen is complicated due to uncertainty as to when green hydrogen will be available at the scale needed for ironmaking. Direct reduction has the technological capability to operate with up to 100% H_2 as the reductant. Just as importantly, direct reduction is flexible in the fuels that it can use.

Direct reduction facilities have already demonstrated commercial operation across a wide range of process conditions. In particular, for green hydrogen as fuel, direction reduction has a demonstrated track record for H_2/CO ratios of 0.5 to 3.0 or higher. Because of the gas recycling systems, the direct reduction plant can be designed for high energy efficiency across a wide range of fuels. This inherent process flexibility is critically important when the fuel supplies of the future are not certain.

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(Note: This article is based on a paper titled, "Direct Reduction Dealing with an Uncertain Future" by Todd Astoria, which was presented at the AISTech 2022 Exposition & Conference in Pittsburgh, PA)

Midrex News & Views

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World DRI Production Reaches 119.2 Mt in 2021

MIDREX PUBLISHES *WORLD DIRECT REDUCTION STATISTICS*

Global direct reduced iron (DRI) production in 2021 was 119.2 million tons (Mt), up by 13.7% from the revised 104.8 Mt produced in 2020, and up 10.2% from the previous record of 108.1 Mt in 2019. From 2016, worldwide DRI output has grown by almost 44.4 Mt, or nearly 61%.

The top five DRI-producing countries in 2021 were:

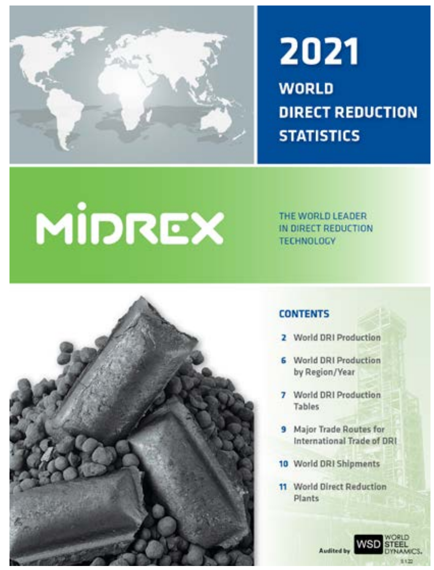
1. India: 39.11 Mt
2. Iran: 31.85 Mt
3. Russia: 7.89 Mt
4. Saudi Arabia: 6.13 Mt
5. Mexico: 5.83 Mt

The production of hot DRI (HDRI), which is fed directly to a nearby melt shop for energy savings and to improve productivity, was 13.8 Mt, a 21.2% increase compared to 2020, and made up 11.6% of the total in 2021. The production of hot briquetted iron (HBI) – a compacted form of DRI ideally suited for shipping and for use in the blast furnace – is estimated to have been 10.4 Mt, a 9.3% increase over 2020 and a 7.4% increase over 2019.

MIDREX Plants produced 70.85 Mt in 2021, a 12.3% increase compared to 2020. The production in 2021 was calculated from 41.68 Mt confirmed by MIDREX Plants located outside of Iran (a 17.5% increase over 2020) and 29.17 Mt estimated for MIDREX Plants in Iran. Over 9.7 Mt of HDRI were produced by MIDREX Plants worldwide, which were consumed in nearby steel shops to assist them in reducing their energy consumption per ton of steel produced and increasing their productivity.

MIDREX Technology continued to account for ~80% of worldwide production of DRI by shaft furnaces. MIDREX Plants have produced a cumulative total of approximately 1,250 Mt of all forms of DRI (CDRI, HDRI, and HBI) through the end of 2021.

2021 World Direct Reduction Statistics is available for download at **www.midrex.com**



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.

Midrex News & Views

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Anthony (Tony) Elliot Celebrated for 33 Years of Midrex Service

"My days of traveling to plants around the world might be coming to an end," Elliot acknowledged, "but my heart will always be where I began my career – in the control room and on and around the structures and equipment of a MIDREX Plant."

Earlier this month, at the annual International Conference on MIDREX® Technology (a.k.a. Operations Seminar) held this year in Budapest, Hungary, Midrex personnel and plant operators from around the world joined in thanking Anthony (Tony) Elliot for his contributions to the success of the MIDREX Process and the performance of MIDREX Plants.

Elliot, who began his direct reduction-related career in 1975 as a process engineer at Dálmine Siderca in Argentina (now DálmineTenaris) and joined Midrex in 1989, has been "the face of Midrex" to operators of MIDREX Plants for the past 23 years in his role as Manager of Technical Services.

"I have enjoyed my various assignments through the years, but I have found my current role to be the most rewarding," Elliot said.

"I primarily serve as the interface between Midrex and its Process Licensees on technical issues. I work collaboratively with plant operators to provide technical insight, troubleshoot problems, advise on best practices to improve their operation, and build rapport through annual plant visits."

He considers integrity and commitment as the keys to his success. "Integrity, because as the liaison between the plants and Midrex, I must strive to provide truthful recommendations that are balanced and beneficial to both parties. Commitment, because we want our clients to succeed and we are dedicated to helping them accomplish that in every way possible."

In addition to his technical services activities, Elliot gathers the data to produce the internal Plant Operations Report, which is the basis for the "Plant Operations Summary" article in the second quarter issue of Direct From Midrex each year; the annual World Direct Reduction Statistics (a.k.a., the Stats Book); and he serves as coordinator of the technical program for the annual International Conference on MIDREX® Technology (a.k.a., Operations Seminar).

Elliot earned a bachelor's degree in chemical engineering from Buenos Aires University and added a master's degree in business administration (MBA) from the University of North Carolina – Charlotte. He enjoys traveling and spending time with his family.

Although this was his last Operations Seminar as coordinator, Elliot will continue to support the technical services activities of Midrex from Charlotte in 2023.

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MIDREX® Plants with 3rd Quarter Anniversaries

Midrex is known for designing, engineering, and servicing reliable direct reduction plants, as well as for making certain that these plants have long and successful operating lives. This issue of ***Direct From Midrex*** recognizes the start-ups of Hadeed E in Al Jubail, Saudi Arabia (15 years), Qatar Steel DR-2 in Mesaieed, Qatar (15 years), ArcelorMittal Lázaro Cárdenas in Lázaro Cárdenas, Mexico (25 years), Al Ezz Dekheila Steel – Alexandria (EZDK) Module II (25 years), ArcelorMittal/Nippon Steel India III in Hazira, Gujurat, India (30 years), and ArcelorMittal Canada 2 in Contrecoeur, Quebec, Canada (45 years).

Hadeed E

Started up 15 years ago in the 3rd Quarter
Location: Al Jubail, Saudi Arabia
DR plant: MIDREX® (I of 4 modules)

- Start-up: July 2007
- Flowsheet: MIDREX NG™ (combination plant)
- Products: HDRI/CDRI
- Capacity: 1.76M tons

Hadeed (Saudi Iron and Steel Company) is a fully-owned affiliate of Saudi Basic Industries Corporation (SABIC). It began operating in 1979 and added two MIDREX® DR Modules in 1982-83 (Hadeed A & B), a third in 1992 (Hadeed C), and a dual discharge HDRI/CDRI module (Module E) in 2007. Hadeed E has produced almost 24 million tons of DRI since its initial start-up in 2007, averaging 93.7% product metallization. The module is equipped to use seawater for cooling and feed gas, combustion air, and natural gas preheat to increase energy efficiency and productivity. Hadeed E primarily produces hot DRI (HDRI), which is transported to the melt shop via an insulated conveyor system. It is also equipped with a product cooler for use when the melt shop does not require HDRI.

Read more about Hadeed at:
http://www.hadeed.com.sa/

Qatar Steel 2

Started up 15 years ago in the 3rd Quarter
Location: Mesaieed, Qatar
DR plant: MIDREX (1 of 2 modules)

- Start-up: July 2007
- Flowsheet: MIDREX NG™ (combination plant)
- Products: CDRI/HBI
- Capacity: 1.5M tons/year

Qatar Steel 2 is a unique plant design: a combination plant (hot discharge furnace capable of dual product operation) equipped with a product cooler, which allows the production of hot briquetted iron (HBI) and cold DRI (CDRI). Qatar Steel 2 has produced 19.85 million tons of DRI products since it was started up in July 2007. Together with Qatar Steel 1, a 400,000 t/y MIDREX Module, which was started up in August 1978, Qatar Steel has accounted for almost 48.2 million tons of DRI and HBI. Qatar Steel Company (QASCO) began commercial operation in 1978 as the first direct reduction-electric arc furnace (DR-EAF) steel mill in the MENA Region. The company became wholly owned by Industries Qatar (IQ) in 2003 and is now known as Qatar Steel.

Read more about Qatar Steel at:
https://www.qatarsteel.com.qa/

ArcelorMittal Lázaro Cárdenas

Started up 25 years ago in the 3rd Quarter
Location: Lázaro Cárdenas, Michoacán, Mexico
DR plant: MIDREX

- Start-up: July 2007
- Flowsheet: MIDREX NG
- Products: CDRI
- Capacity: 1.2M tons/year

The steel mill commenced operations in 1976 as a government-owned company known as Sicartsa (Siderúrgica Lázaro Cárdenas – Las Truchas). In the early 1990s, Sicartsa I was sold to Grupo Villacero and Sicartsa II was acquired by Ispat International (now ArcelorMittal International). Sicartsa I was acquired by ArcelorMittal in 2006 to create what is now ArcelorMittal Lázaro Cárdenas. Over its 25 years of operation, AM Lázaro Cárdenas has averaged more than its annual rated capacity in producing close to 36.1 million tons of CDRI.

Read more about ArcelorMittal Lázaro Cárdenas at: **https://northamerica.arcelormittal.com/our-operations/arcelormittal-mexico.**

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MIDREX® Plants with 3rd Quarter Anniversaries

Al Ezz Dekheila Steel - Alexandria (EZDK) Module II

Started up 25 years ago in the 3rd Quarter
Location: El Dikheila, Egypt
DR plant: MIDREX® (1 of 3 modules)

- Start-up: September 1997
- Flowsheet: MIDREX NG
- Products: CDRI
- Capacity: 0.8 million tons/year

The integrated direct reduction/electric arc furnace (DR/EAF) steelworks located west of Alexandria in El Dikheila, Egypt, began life in as Alexandria National Iron & Steel Company (ANSDK) in 1982. Al Ezz Dekheila Steel – Alexandria operates three MIDREX® Modules, which supply the melt shop with 80% of its metallic charge, with high-grade scrap making up the remainder. Through 2021, Al Ezz Dekheila Steel – Alexandria (EZDK) Module II has produced almost 21 million tons of DRI, which is a yearly average above its original rated annual capacity of 0.8 million tons.

Read more at:
https://www.ezzsteel.com/ezz-steel-plants/alexandria-steelmaking-plant

ArcelorMittal/Nippon Steel India III

Started up 30 years ago in the 3rd Quarter
Location: Hazira, Gujurat State, India
DR plant: MIDREX (1 of 6 modules)

- Start-up: August 1997
- Flowsheet: MIDREX NG
- Products: HBI/HDRI
- Capacity: 0.65 million tons/year

ArcelorMittal/Nippon Steel India (AM/NS), a joint venture of ArcelorMittal and Nippon Steel, is an integrated flat carbon steel manufacturer with a crude steel capacity of nine million tons/year. AM/NS operates six MIDREX Modules in addition to a blast furnace and two COREX® plants to supply its ironmaking requirements. AM/NS India III has produced over 14 million tons of DRI since it initial start-up. The module includes a hot discharge furnace and is equipped to produce HBI and HDRI.

Read more about ArcelorMittal/Nippon Steel India at:
https://www.amns.in

ArcelorMittal Canada 2

Started up 45 years ago in the 3rd Quarter
Location: Contrecoeur, Quebec, Canada
DR plant: MIDREX (1 of 2 modules)

- Start-up: August 1977
- Flowsheet: MIDREX NG
- Products: CDRI
- Capacity: 0.65 million tons/year

The steel mill in Contrecoeur, Quebec, Canada, began operations in 1972 as Sidbec-Dosco. The MIDREX Modules were started up in April 1973 (AM Canada 1) and August 1977 (AM Canada 2). The company was privatized and sold to Ispat International in 1994 (now ArcelorMittal International). The Contrecoeur works was renamed AM Long Products Canada in 2016. AM Canada 2 has produced more than 28.2 million tons of CDRI in its 45 year operational career.

Read more about ArcelorMittal Log Products at:
https://long-canada.arcelormittal.com/en

Lauren Lorraine: **Editor**

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Midrex Technologies, Inc.

All references to tons are metric unless otherwise stated.

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