Midrex Process Overview February 2019 www.midrex.com

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There's Plenty of Natural Gas



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Natural Gas Pricing



- Now prices at \$8-9/MMBtu, which makes NG direct reduction challenging but possible
- We agree with the generally held belief that landed prices for most of the world will remain around \$9/MMBtu in 2018\$ for the next decade and probably beyond
- USA prices will remain around \$3/MMBtu (also 2018\$), which is very attractive for NG direct reduction
- USA has by far most success with fracking; rest of the world is attempting it, but with much less success

Federal Energy Regulatory Commission • Market Oversight • www.ferc.gov/oversight

World LNG Estimated Landed Prices: May-18





MIDREX® Plants



	Capacity				
Plant	Country	Start-Up	(tpy)	Product	Status
Nu-Iron	Trinidad	2006	1,600,000	Cold DRI	Operating
Al-Tuwairqi	Saudi Arabia	2007	1,000,000	Cold DRI	Operating
Essar Module V	India	2007	1,500,000	Hot DRI & HBI	Operating
Hadeed Mod E	Saudi Arabia	2007	1,760,000	Hot & Cold DRI	Operating
Qatar Steel Module 2	Qatar	2007	1,500,000	Cold DRI & HBI	Operating
LGOK Module 2	Russia	2007	1,400,000	HBI	Operating
Lion Group	Malaysia	2008	1,540,000	Hot DRI & HBI	Operating
Jindal Shadeed	Oman	2011	1,500,000	HOTLINK & HBI	Operating
Essar Module VI	India	2011	1,500,000	Hot DRI & HBI	Operating
SULB	Bahrain	2013	1,500,000	Hot & Cold DRI	Operating
Tuwairqi Steel Mills	Pakistan	2013	1,280,000	Cold DRI	Operating
Jindal Steel & Power	India	2014	1,800,000	Hot & Cold DRI	Operating
JSW Toranagallu	India	2014	1,200,000	Hot & Cold DRI	Operating
ESISCO	Egypt	2015	1,760,000	HOTLINK & CDRI	Operating
voestalpine Texas	USA	2016	2,000,000	HBI	Operating
Iran – 23 modules	Iran	2006-18	23,770,000	Cold DRI	Operating
LGOK Module 3	Russia	2017	1,800,000	HBI	Operating
Tosyali Steel	Algeria	2018	2,500,000	Hot & Cold DRI	Construction
Algerian Qatari Steel	Algeria	2019	2,500,000	Hot & Cold DRI	Construction
Iran – 4 modules	Iran	2018-19	4,850,000	Cold DRI & HBI	Construction
Cleveland-Cliffs	USA	2020	<u>1,600,000</u>	HBI	Construction
Total			59,860,000		



Nu-Iron



Product: Cold DRI for use in Nucor meltshops



Direct Reduction Iron Co. (Al-Tuwairqi Group)



Product: Cold DRI for use in on-site meltshop

Start-Up: Module I: May 2007, Module II: December 2007

(both relocated from Mobile, Alabama, USA)

Capacity: 2 X 500,000 tpy CDRI

Location: Dammam, Saudi Arabia



Hadeed Module E

First hot transport conveyor

Furnace Type: MIDREX Hot Discharge (7.15 m I.D.)

Products: Hot DRI (0-100%) and/or Cold DRI (0-100%)

Hot DRI Transport: Mechanical Conveyor (Aumund)

Start-Up: July 2007

Capacity: 1.76 million tpy DRI

Location: Al-Jubail, Saudi Arabia





Qatar Steel Module II

Furnace Type: MIDREX Hot DRI MEGAMOD[®]

(6.65 m l.D.)

- Products: HBI & Cold DRI Combination (50:50)
- Start-Up: July 2007
- Capacity: 1.50 million tpy DRI/HBI
- Location: Mesaieed, Qatar





Lebedinski GOK 2

World's largest operating HBI module

Furnace Type: MIDREX HBI MEGAMOD[®] (6.65 m I.D.)

- Products: HBI (100%)
- Start-Up: October 2007
- Capacity: 1.40 million tpy HBI
- Location: Gubkin, Russia





Lion DRI

Furnace Type: MIDREX Hot Discharge MEGAMOD (6.65 m ID)

Products: Hot DRI (0-100%)

and/or HBI (0-65%)

Hot DRI Transport: Containers (Batch) by Rail/Truck

Start-Up: May 2008

Capacity: 1.54 million tpy DRI/HBI

Location: Banting, Malaysia





Jindal Shadeed



Furnace Type: Products: Hot DRI Transport: Start-Up: Capacity:

MIDREX MEGAMOD[®] (6.65 m I.D.) Hot DRI (0-100%) and HBI (0-70%) HOTLIN[®] gravity feed system (> 700 deg. C) 2010

apacity: 1.50 million tpy Hot DRI & HBI

Location: Sohar, Oman





Tuwairqi Steel Mills





SULB

Furnace Type:

Products:

HDRI Transport:

Start-Up: Capacity: Location: MIDREX MEGAMOD[®] Hot Discharge Furnace (7.15 m ID) Hot DRI (0-100%) and/or Cold DRI (0-100%) Mechanical Conveyor (6 months after MEGAMOD) January 2013 1.50 million tpy HDRI / CDRI Bahrain



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JSW Steel (COREX[®]/MIDREX[®])

MIDREX MEGAMOD[®] Furnace Type: Hot Discharge Furnace (7.15 m ID) Reducing Gas: COREX export gas CO_2 Removal: Linde PSA Gas Heater: Linde Products: Hot DRI (0-100%) and/or Cold DRI (0-100%) Mechanical Conveyor HDRI Transport: Start-Up: 2014

1.20 million tpy HDRI/CDRI Capacity:

Location: Toranagallu Karnataka State, India









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JSW DOLVI COG Addition

Furnace Type:MIDREX MEGAMOD®
Cold Discharge Furnace (6.65 m ID)Reducing Gas:Addition of COG to furnaceProduct:cold DRIStartup:2014Capacity:1.5 million tpy CDRILocation:Dolvi, India







Jindal Steel & Power: World's First MXCOL[®] Plant with Gasifier

Furnace Type: MIDREX MEGAMOD[®] Hot Discharge Furnace (7.15 m ID) **Coal Gasification** Reducing Gas: Lurgi Gasifier: CO₂ Removal: Technip MDEA Gas Heater: Linde Products: Hot DRI (0-100%) and/or Cold DRI (0-100%) Mechanical Conveyor HDRI Transport: Start-Up: 2014 Capacity: 1.80 million tpy HDRI Location: Angul, Odisha, India





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ESISCO

Furnace Type:MIDREX MEGAMOD®
(Hot Discharge Furnace 7.15 m ID)Products:Hot DRI (0-100%) and/or Cold DRI
(0-100%)HDRI Transport:HOTLINK® 2G

Horizontal Mechanical Conveyor

Start-Up: 2015

- AUMUND
- Capacity: 1.76 million tpy HDRI/CDRI
- Location: Sadat City, Egypt







Voestalpine Go West: World's Largest HBI Module

Furnace Type: MIDREX MEGAMOD® Hot Discharge Furnace (7.15 m ID) Product: HBI Start-Up: September 2016 Capacity: 2.0 million tpy Location: Corpus Christi, Texas USA





Lebedinski GOK III

Furnace Type:MIDREX MEGAMOD®Hot Discharge Furnace (7.15 m ID)Products:HBIStart-Up:April 2017Capacity:1.80 million tpyLocation:Gubkin, Russia





Tosyali Steel First 2.5 Mtpy MIDREX[®] Plant

Furnace Type:

MIDREX MEGAMOD[®] Hot Discharge Furnace

Products: HDRI/CDRI

HDRI Transport: Mechanical Conveyor

Start-Up: 4Q 2018

Capacity: 2.5 million tpy HDRI/CDRI

Location: Arzew, Algeria





SMS group



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Algerian Qatari Steel

MIDREX MEGAMOD[®] Furnace Type: Hot Discharge Furnace HDRI/CDRI Products: HDRI Transport: Mechanical Conveyor 2nd half 2019 Start-Up: Capacity: 2.5 million tpy

HDRI/CDRI

- Location:
- Jijel, Algeria





SMS group





Cleveland-Cliffs

Furnace Type:MIDREX MEGAMOD®
Hot Discharge FurnaceProduct:HBIAdjustable carbon:1st MIDREX ACT™Start-Up:mid 2020Capacity:1.9 million tpyLocation:Toledo, OH USA

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MIDREX[®] Process Hot Discharge/Transport Options





Key Points

- MIDREX Plants located next to a steel mill (EAF) should charge HDRI to take advantage of the sensible heat (500-550°C).
- Midrex offers three methods for hot charging
- A second product stream from the DR Plant, either cold DRI or HBI, is required to maximize production in the event the steel mill cannot accept the HDRI

Reference Plants for MIDREX Hot Charging Methods

HOTLINK[®] (distances <40m) Hot Transport Conveyor (distances <200m) Hot Transport Vessels (distances >100m) MIDREX



ESISCO (Egypt)

Not shown: Jindal Shadeed (Oman)



Hadeed Mod E (Saudi Arabia)

Others not shown: JSPL Angul I (India) SULB (Bahrain) JSW (India) Tosyali Steel and AQS Steel (Algeria)



Lion (Malaysia)

Others not shown: Essar I-V (India)

Steel Mill Profitability



ECONOMICS OF HOT DRI CHARGING

Basis: Arabian Gulf location

	Type of DRI feed		
	CDRI	HDRI	
DRI volume (Mtpy)	1.40	1.68	
EAF heat size (t)	200	200	
Feed mix (DRI/scrap)	90/10	90/10	
DRI charge temp (°C)	25	600	
Tap-to-tap time (min)	65	54	
Steelmaking capacity (Mtpy)	1.38	1.65	
Liquid steel cash cost (\$/t)	X+10	Х	
Profit margin (\$/t)	150 (assumed)	160	
Yearly profit (M\$)	207	264	
Additional profit (M\$)	-	57	
Profit margin (\$/t)	100 (assumed)	110	
Yearly profit (M\$)	138	182	
Additional profit (M\$)	-	44	
Profit margin (\$/t)	50 (assumed)	60	
Yearly profit (M\$)	69	99	
Additional profit (M\$)	-	30	

New Technologies and Products



- Higher capacity shaft furnaces- up to 2.5 Mtpy of DRI
- 7.65 meter I.D. furnace, larger MIDREX® Reformer
- MXCOL® using coal gasifier
- Coke oven gas injection to MIDREX[®] Shaft Furnace
- TRS[™] for use of coke oven gas in MIDREX[®] Plant
- Hot transport options: containers, conveyor, and HOTLINK® gravity feed
- Flexibility for cold DRI, hot DRI, HBI in any combination
- MIDREX[®] High Performance Iron (HPI)
- DRI cooler
- MIDREX[®] Adjustable Carbon Technology (ACT) up to 4.0% DRI carbon
- New catalyst formulations
- Higher capacity briquette machines up to 70 tph
- Low NOx reformer burners
- Flue gas hot fan
- DRIpax[®] Expert Control System enables prediction of DRI metallization and carbon levels

Advanced Process Modeling: DRIpax[™]

- DRIpax incorporates the MIDREX[®] Superdata model, which performs mass and energy calculations using online-measurements, feed materials and product analyses
- Additional modeling in DRIpax enables accurate predictions of DRI metallization (% of iron in the metallic form) and carbon levels to greatly reduce off-spec product
- Installed at Qatar Steel MIDREX[®] Plant: typical DRI quality is 94.6% metallization and 2.4% carbon
- Meltshop benefits:
 - Lower electricity, electrode, refractory consumptions
 - Shorter power on time
 - Increased yield







Next Step: DRIpax[™] Expert System

- The expert system makes operational suggestions based on DRIpax calculations
- In advisory mode, suggestions are executed only after acceptance by the operator
- In closed-loop mode, the system can automatically make changes
- Benefits:
 - Early detection of undesired process conditions
 - Standardized control philosophy
 - Control actions are small and frequent
 - Stabilized product quality due to expert system control
 - Generates diagnoses and corrective actions to avoid or settle undesired process conditions
 - Flexible system design allows for expandability and easy adjustment of rules and diagnoses to plant requirements





MIDREX[®] Adjustable Carbon Technology (ACT)



- Usually carbon is added to DRI by natural gas addition; this lowers the shaft furnace temperature (endothermic)
- ACT uses carbon monoxide (CO) to increase DRI carbon (exothermic)
- A CO-rich gas is mixed with natural gas and injected into the MIDREX[®] Shaft Furnace
- Benefits:

Carbon content adjustable from 1.5-4%

Increase in carbon achieved while maintaining DRI temperature

- Higher quality carbon: 90-92% of carbon as Iron Carbide (Fe_3C)
- Can be used for Cold DRI, hot DRI, or HBI
- Can be used in existing or new plants
- Moderate CAPEX

MIDREX® Process Flexibility



- MIDREX Process has flexibility to produce DRI with carbon levels from 1.5-4% and discharge temperatures up to 700° C by operational modifications
- Optimal level depends on meltshop oxygen and offgas capabilities, casting and rolling capacity, and other factors
- Three hot charging options: HOTLINK, hot transport conveyor, hot transport vessels
- Charging DRI at 600° C and 3.0% carbon results in tap-to-tap times as short as 43 minutes and electricity consumption under 400 kWh/t

Natural Gas-Based DR Emissions Advantages



- Natural gas has less carbon per energy unit than coal
- Therefore, carbon emissions for gas-based DR are less than for coal-based options
- The DR/EAF route (standard flowsheet) has one-half the CO₂ emissions of a blast furnace/BOF
- With MIDREX[®] Carbon Capture, emissions are reduced by half again (~25% of BF/BOF)

Show Me the Numbers: Steelmaking CO₂ Emissions



Source: Midrex calculations

CO₂ production (kg CO₂/ton liquid steel)



Show Me the Numbers: Steelmaking Energy



Source: Midrex calculations

Total energy (MJ/ton liquid steel)



MIDREX H₂TM (MIDREX Green Hydrogen)



 Ultimate low CO₂ ironmaking solution: produce pure hydrogen using low carbon energy source and use H₂ in shaft furnace to make DRI

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- Since 1969, MIDREX[®] Plants have produced over 1 billion tons of DRI using 60% hydrogen
- Midrex process modeling and laboratory experiments demonstrate feasibility of using almost pure hydrogen to make DRI in a MIDREX[®] Shaft Furnace
- New MIDREX[®] Plants can be built to use hydrogen or existing plants converted
- Major issue is producing hydrogen economically with low CO₂ emissions

Thank you!

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