

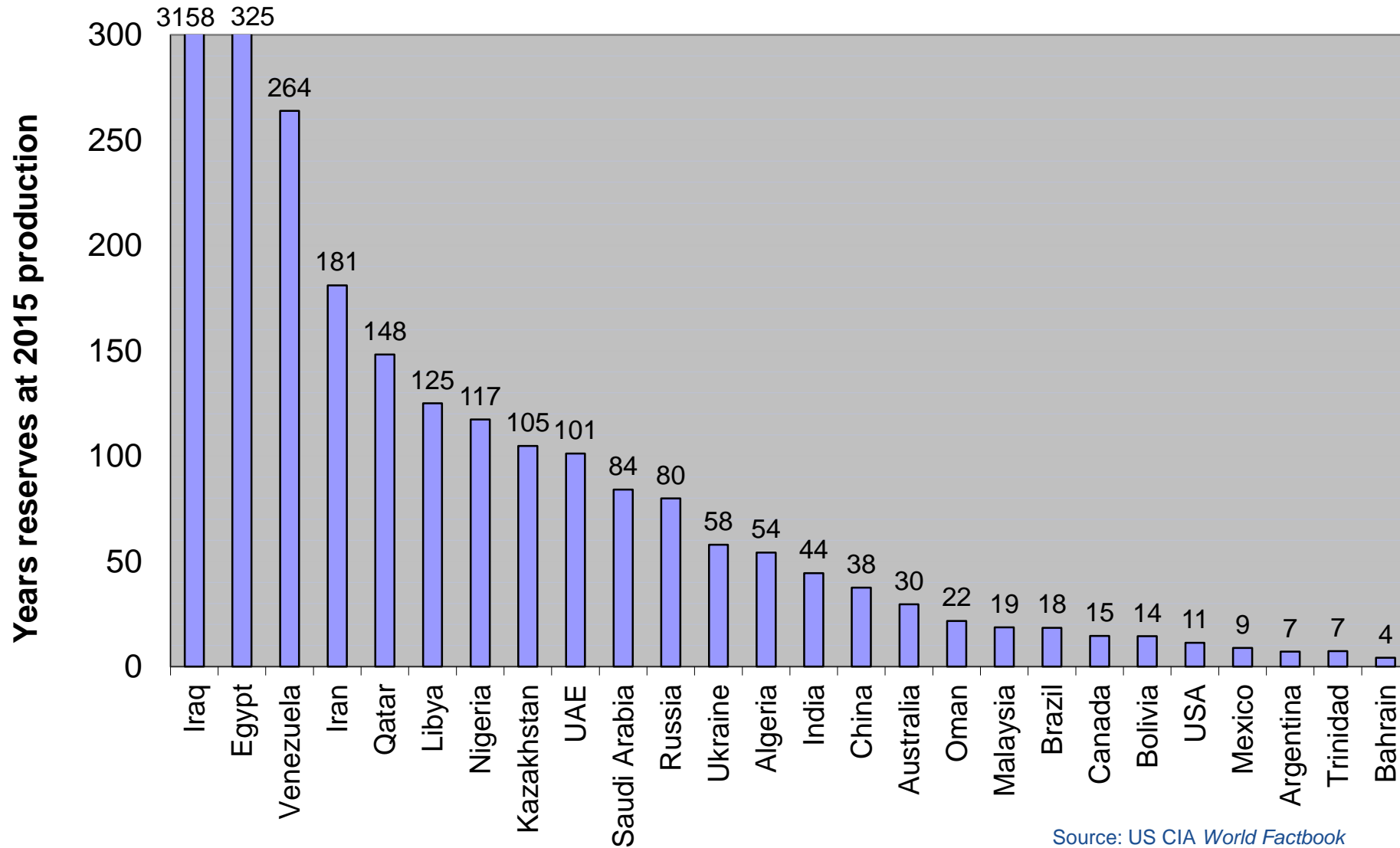
# Midrex Process Overview

February 2019  
[www.midrex.com](http://www.midrex.com)

**MIDREX**

© 2019 Midrex Technologies, Inc. All rights reserved.

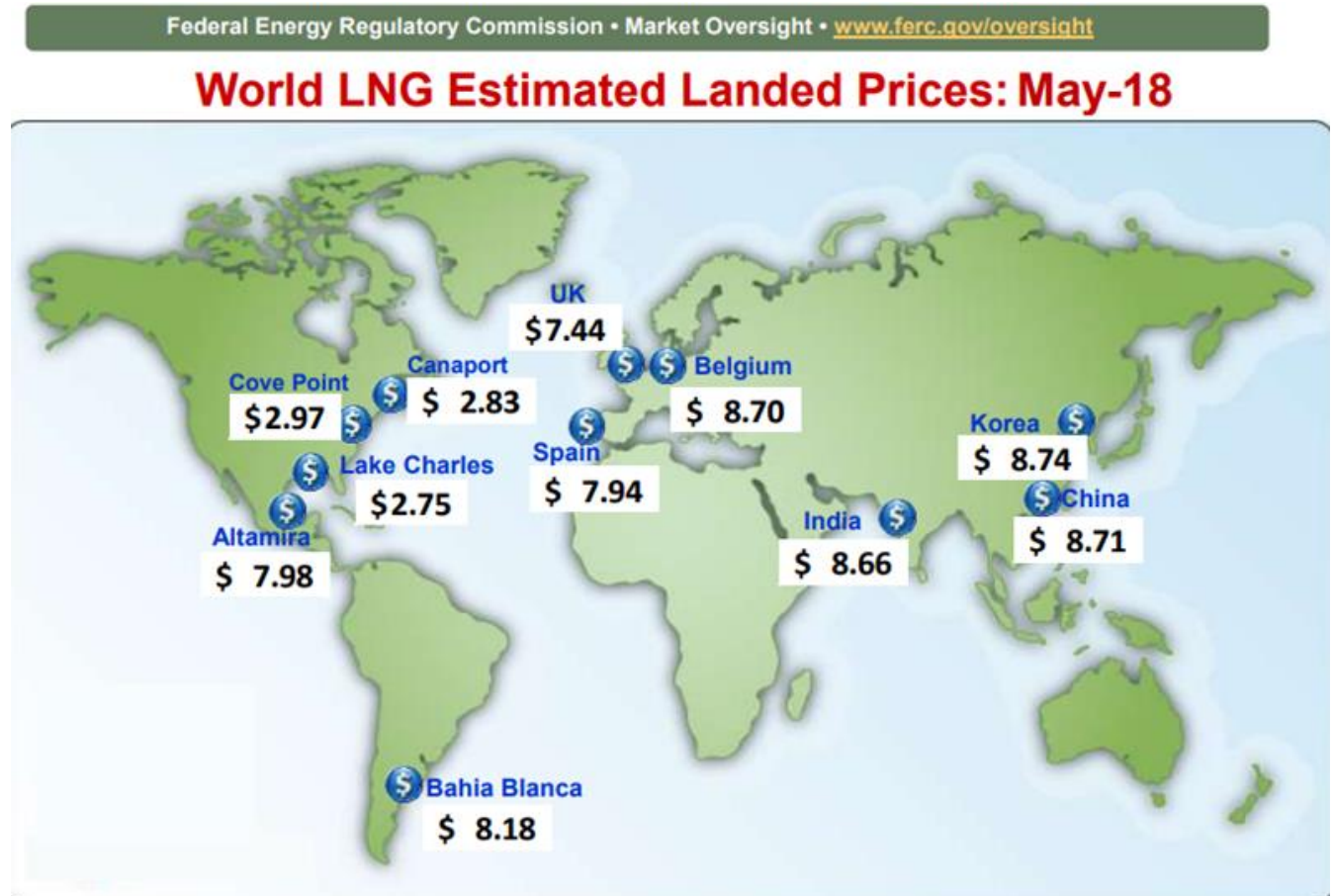
# There's Plenty of Natural Gas



Source: US CIA World Factbook

# Natural Gas Pricing

- In 2015, landed LNG prices were \$6-7/MMBtu, which made NG direct reduction feasible
- 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



# MIDREX® Plants

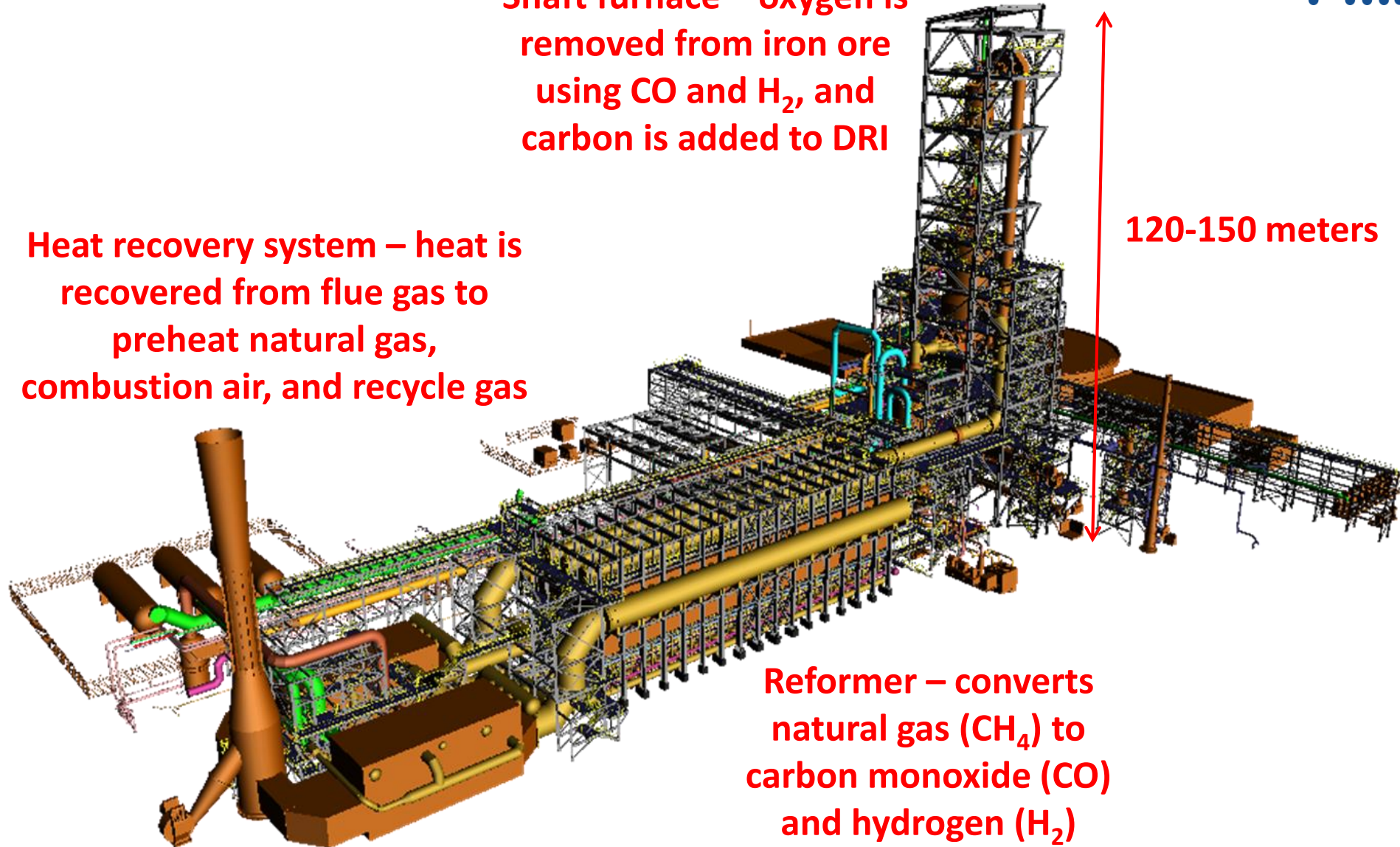


Plant	Country	Start-Up	Capacity (tpy)	Product	Status
Nu-Iron	Trinidad	2006	1,600,000	Cold DRI	Operating
Al-Tuwairqi	Saudi Arabia	2007	1,000,000	Cold DRI	Operating
Essar Module V	India	2007	1,500,000	Hot DRI & HBI	Operating
Hadeed Mod E	Saudi Arabia	2007	1,760,000	Hot & Cold DRI	Operating
Qatar Steel 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
<b>Total</b>			<b>59,860,000</b>		

Shaft furnace – oxygen is removed from iron ore using CO and H<sub>2</sub>, and carbon is added to DRI

Heat recovery system – heat is recovered from flue gas to preheat natural gas, combustion air, and recycle gas

120-150 meters



Reformer – converts natural gas (CH<sub>4</sub>) to carbon monoxide (CO) and hydrogen (H<sub>2</sub>)

# Nu-Iron

MIDREX

Product: Cold DRI for use in Nucor meltshops

Start-Up: December 2006

Capacity: 1.60 million tpy CDRI

Location: Point Lisas, Trinidad & Tobago



# Direct Reduction Iron Co. (Al-Tuwairqi Group)

MIDREX



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

MIDREX

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

MIDREX

Furnace Type: MIDREX Hot DRI MEGAMOD®

(6.65 m I.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

MIDREX

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

MIDREX

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

Products: Hot DRI (0-100%) and HBI (0-70%)

Hot DRI Transport: HOTLIN® gravity feed system (> 700 deg. C)

Start-Up: 2010

Capacity: 1.50 million tpy Hot DRI & HBI

Location: Sohar, Oman



# Tuwairqi Steel Mills

MIDREX

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

Products: Cold DRI, hot DRI future

Hot DRI Transport: Future

Start-Up: 2013

Capacity: 1.28 million tpy cold DRI (hot DRI future)

Location: Karachi, Pakistan



# SULB

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

MIDREX



**YAMATO**  
S T E E L



# JSW Steel (COREX<sup>®</sup>/MIDREX<sup>®</sup>)

MIDREX

Furnace Type: MIDREX MEGAMOD<sup>®</sup>  
Hot Discharge Furnace (7.15 m ID)  
Reducing Gas: COREX export gas

CO<sub>2</sub> Removal: Linde PSA  
Gas Heater: Linde  
Products: Hot DRI (0-100%) and/or  
Cold DRI (0-100%)

HDRI Transport: Mechanical Conveyor  
Start-Up: 2014  
Capacity: 1.20 million tpy HDRI/CDRI  
Location: Toranagallu Karnataka State, India



# JSW DOLVI COG Addition

MIDREX

Furnace Type: MIDREX MEGAMOD®  
Cold Discharge Furnace (6.65 m ID)  
Reducing Gas: Addition of COG to furnace  
Product: cold DRI  
Startup: 2014  
Capacity: 1.5 million tpy CDRI  
Location: Dolvi, India





# Jindal Steel & Power: World's First MXCOL<sup>®</sup> Plant with Gasifier

MIDREX

Furnace Type: MIDREX MEGAMOD<sup>®</sup>  
Hot Discharge Furnace (7.15 m ID)  
Reducing Gas: Coal Gasification  
Gasifier: Lurgi  
CO<sub>2</sub> Removal: Technip MDEA  
Gas Heater: Linde  
Products: Hot DRI (0-100%) and/or  
Cold DRI (0-100%)  
HDRI Transport: Mechanical Conveyor  
Start-Up: 2014  
Capacity: 1.80 million tpy HDRI  
Location: Angul, Odisha, India



**MXCOL<sup>®</sup>**

# ESISCO

MIDREX

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

Capacity: 1.76 million tpy HDRI/CDRI

Location: Sadat City, Egypt



# Voestalpine Go West: World's Largest HBI Module

MIDREX

Furnace Type: MIDREX MEGAMOD®

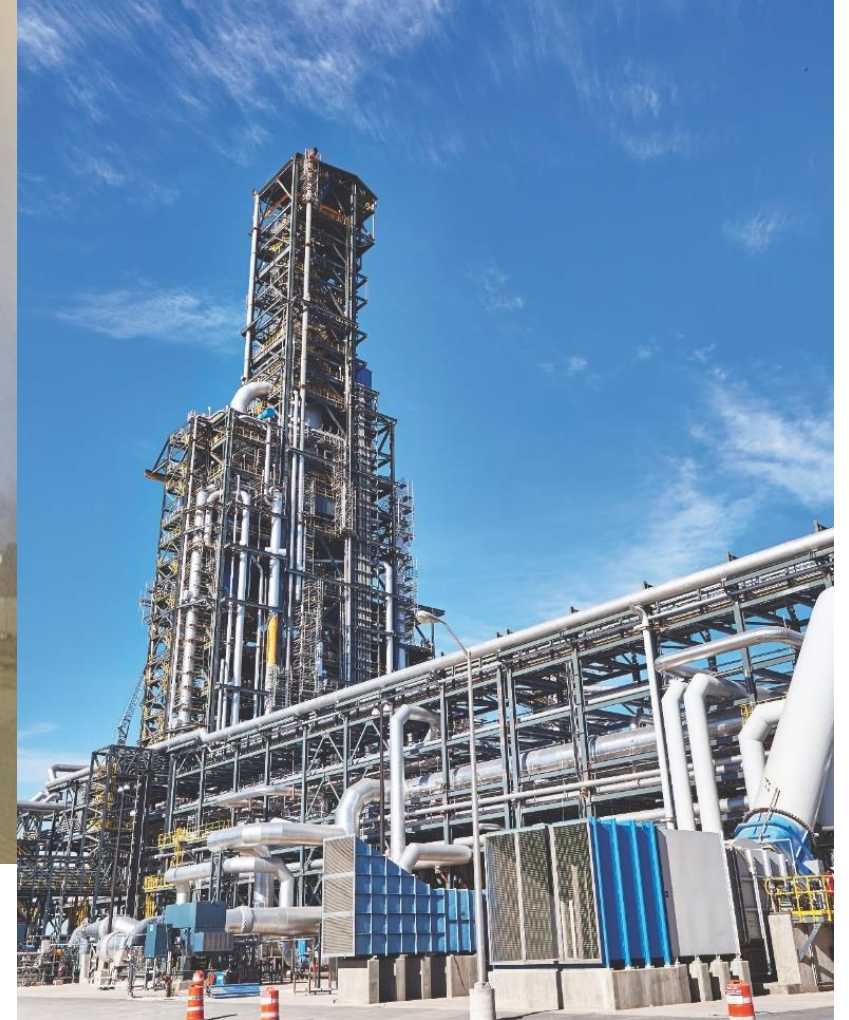
Hot Discharge Furnace (7.15 m ID)

Product: HBI

Start-Up: September 2016

Capacity: 2.0 million tpy

Location: Corpus Christi, Texas USA



# Lebedinski GOK III

MIDREX

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



# Tosyali Steel

## First 2.5 Mtpy MIDREX<sup>®</sup> Plant

MIDREX

Furnace Type: MIDREX MEGAMOD<sup>®</sup>

Hot Discharge Furnace

Products: HDRI/CDRI

HDRI Transport: Mechanical Conveyor

Start-Up: 4Q 2018

Capacity: 2.5 million tpy HDRI/CDRI

Location: Arzew, Algeria



Fer et L'acier



# Algerian Qatari Steel

MIDREX

Furnace Type: MIDREX MEGAMOD®  
Hot Discharge Furnace

Products: HDRI/CDRI

HDRI Transport: Mechanical Conveyor

Start-Up: 2<sup>nd</sup> half 2019

Capacity: 2.5 million tpy

HDRI/CDRI

Location: Jijel, Algeria



# Cleveland-Cliffs

MIDREX

Furnace Type: MIDREX MEGAMOD®  
Hot Discharge Furnace

Product: HBI

Adjustable carbon: 1<sup>st</sup> MIDREX ACT™

Start-Up: mid 2020

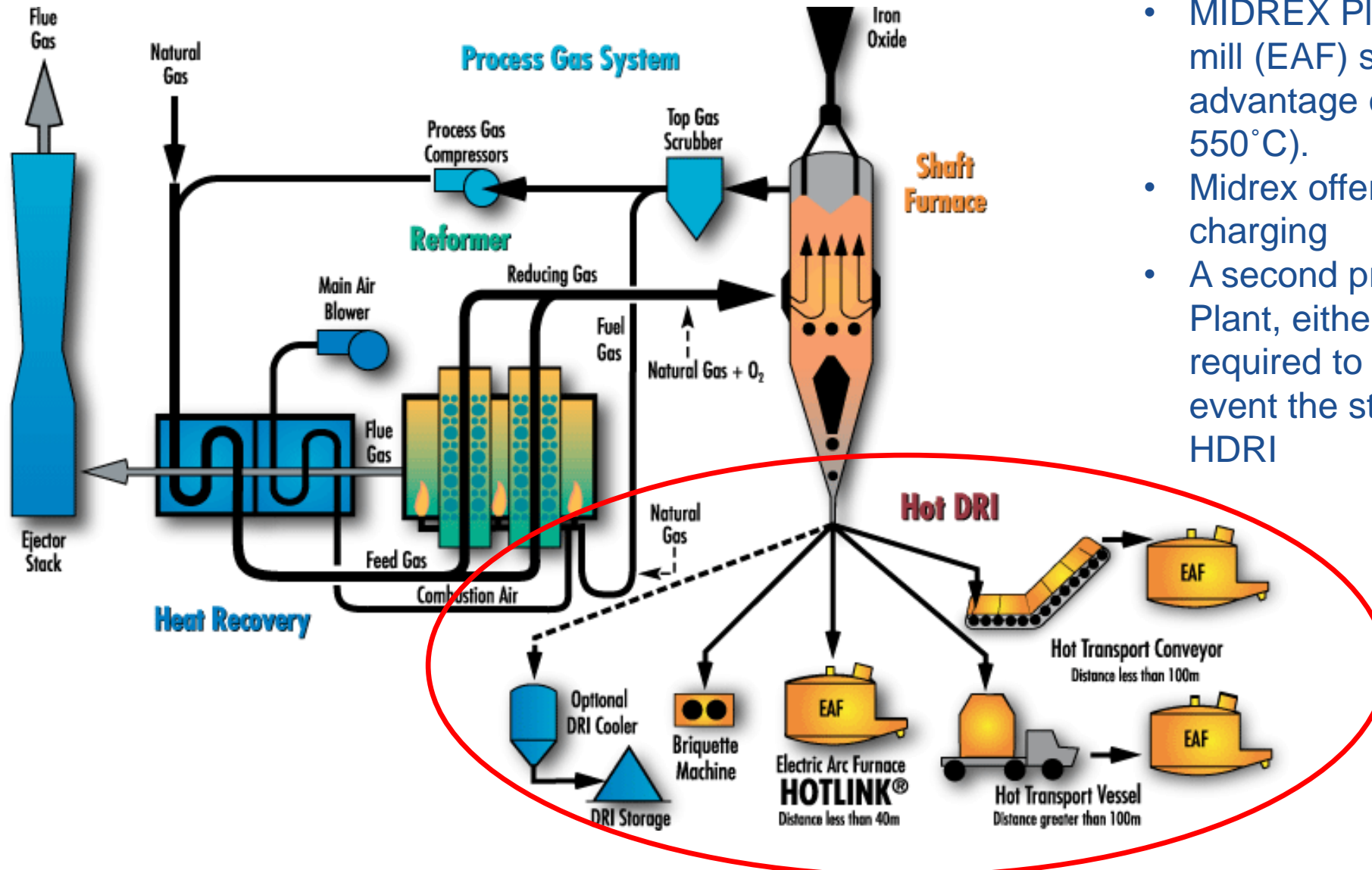
Capacity: 1.9 million tpy

Location: Toledo, OH USA



# MIDREX<sup>®</sup> Process Hot Discharge/Transport Options

MIDREX



## 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

MIDREX

**HOTLINK®**  
(distances <40m)



**ESISCO (Egypt)**

Not shown:  
Jindal Shadeed (Oman)

**Hot Transport Conveyor**  
(distances <200m)



**Hadeed Mod E (Saudi Arabia)**

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

**Hot Transport Vessels**  
(distances >100m)



**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	X
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

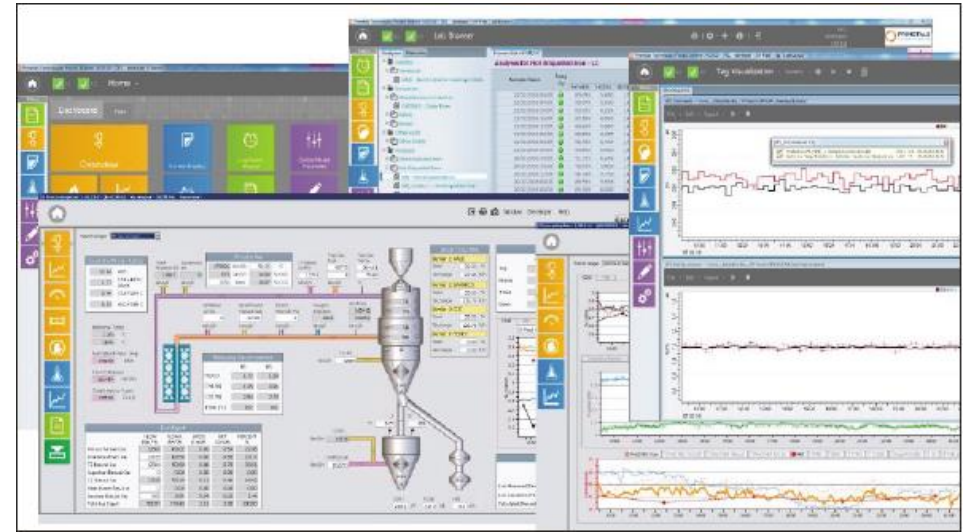


- Higher capacity shaft furnaces– up to 2.5 Mtpy of DRI
- 7.65 meter I.D. furnace, larger MIDREX<sup>®</sup> Reformer
- MXCOL<sup>®</sup> using coal gasifier
- Coke oven gas injection to MIDREX<sup>®</sup> Shaft Furnace
- TRS<sup>™</sup> for use of coke oven gas in MIDREX<sup>®</sup> Plant
- Hot transport options: containers, conveyor, and HOTLINK<sup>®</sup> gravity feed
- Flexibility for cold DRI, hot DRI, HBI in any combination
- MIDREX<sup>®</sup> High Performance Iron (HPI)
- DRI cooler
- MIDREX<sup>®</sup> 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<sup>®</sup> Expert Control System – enables prediction of DRI metallization and carbon levels

# Advanced Process Modeling: DRIpax™

MIDREX

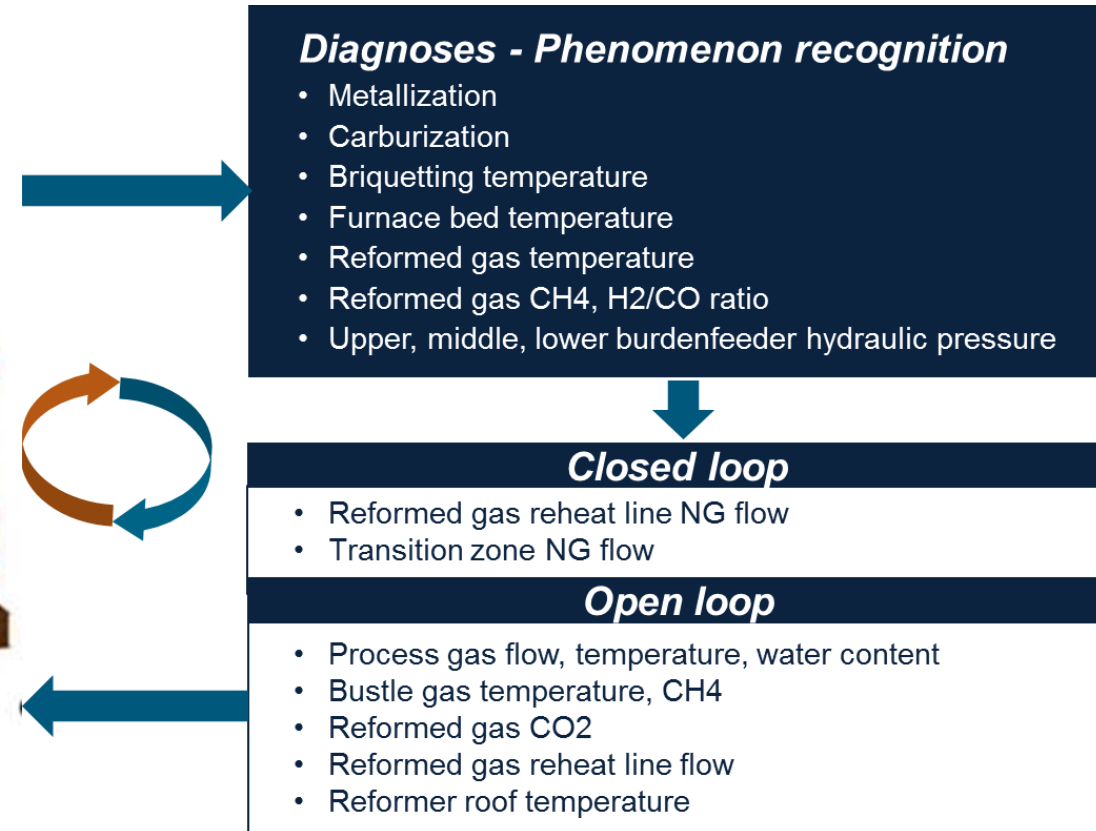
- DRIpax incorporates the MIDREX® Superdata model, which performs mass and energy calculations using online-measurements, feed materials and product analyses
- Additional modeling in DRIpax enables accurate predictions of DRI metallization (% of iron in the metallic form) and carbon levels to greatly 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

MIDREX

- 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<sup>®</sup> Adjustable Carbon Technology (ACT)

MIDREX

- 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<sup>®</sup> 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 ( $\text{Fe}_3\text{C}$ )
  - Can be used for Cold DRI, hot DRI, or HBI
  - Can be used in existing or new plants
  - Moderate CAPEX

# MIDREX® Process Flexibility

MIDREX

- 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

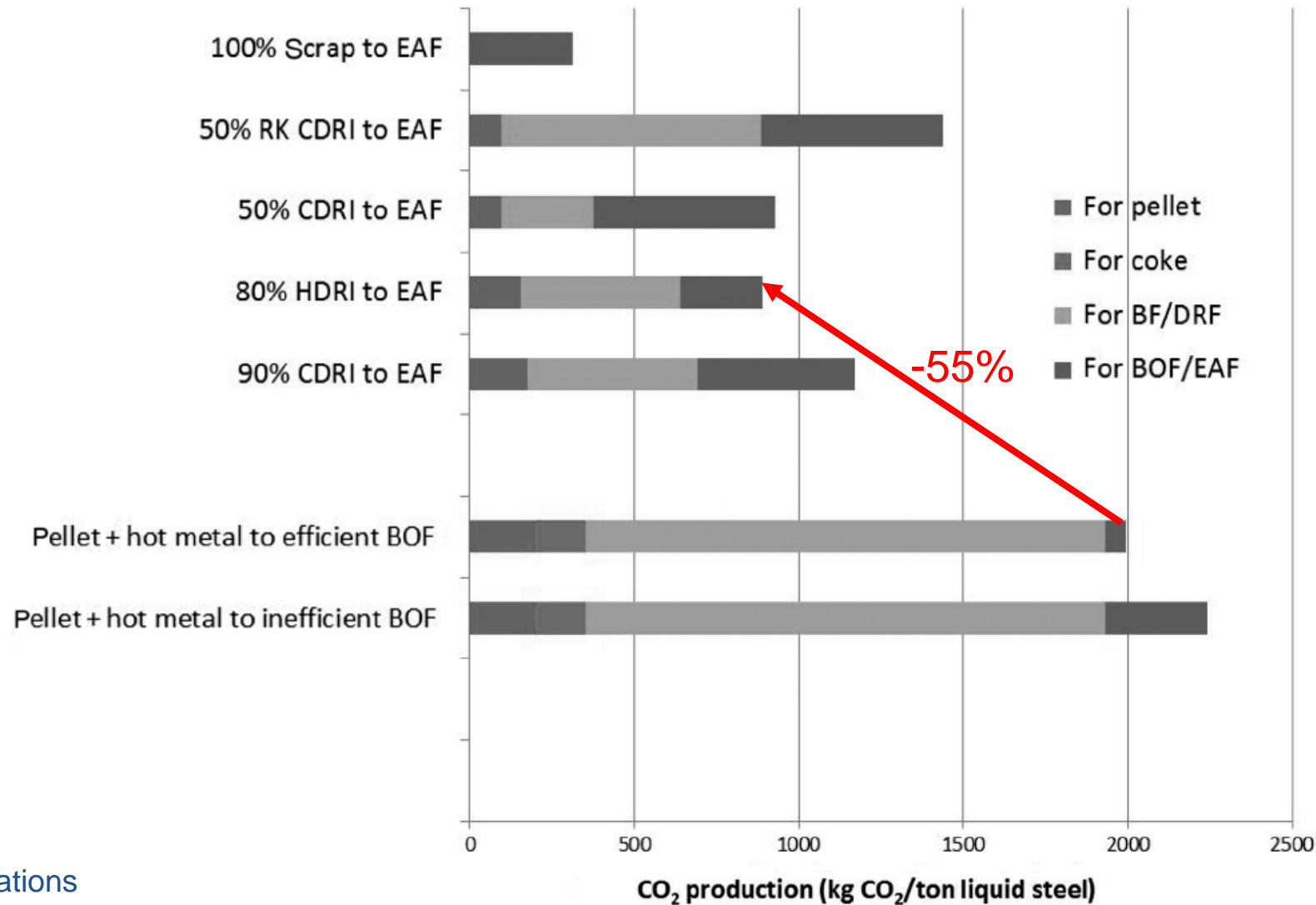
# Natural Gas-Based DR Emissions Advantages

MIDREX

- 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 CO<sub>2</sub> emissions of a blast furnace/BOF
- With MIDREX<sup>®</sup> Carbon Capture, emissions are reduced by half again (~25% of BF/BOF)

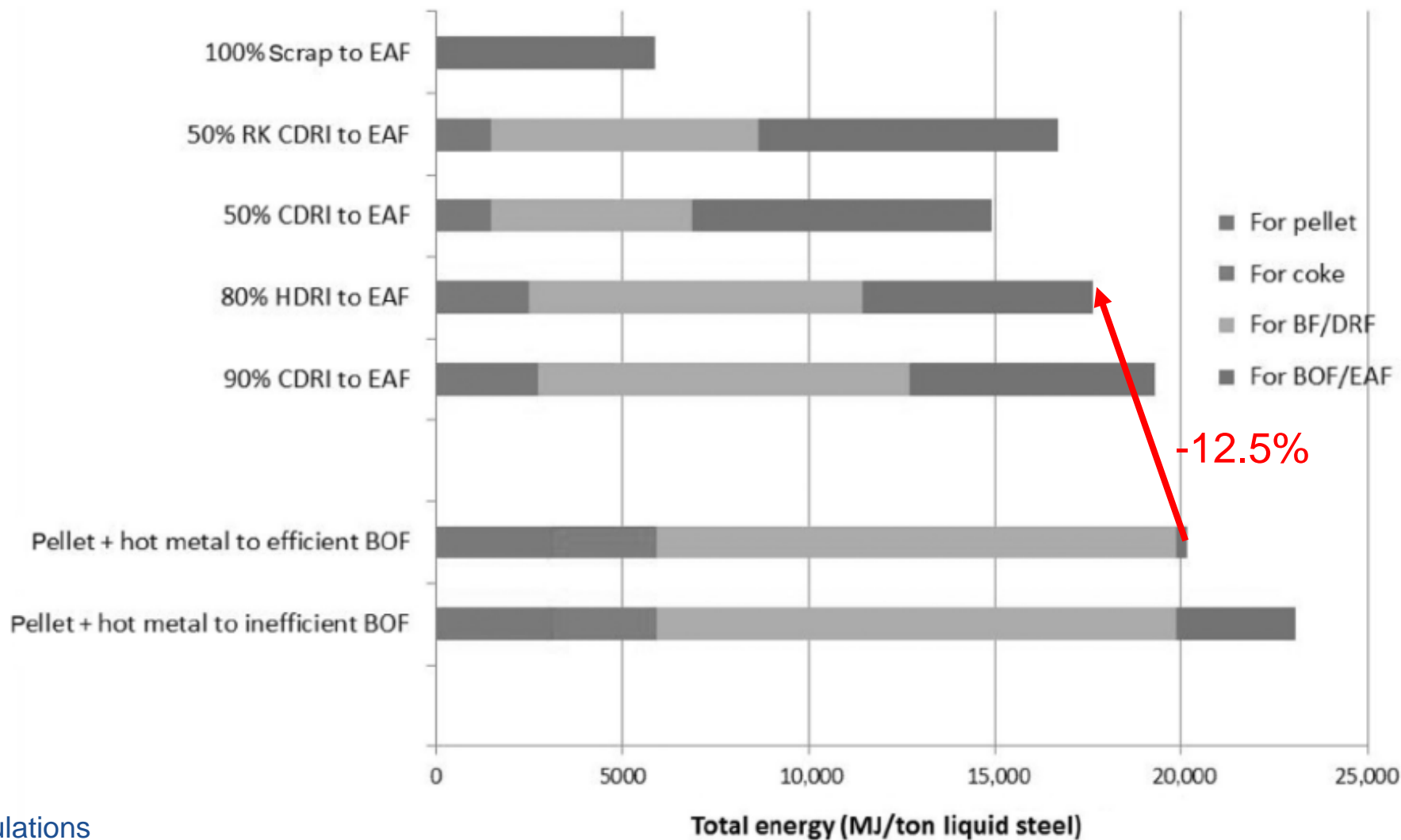


# Show Me the Numbers: Steelmaking CO<sub>2</sub> Emissions



Source: Midrex calculations

# Show Me the Numbers: Steelmaking Energy

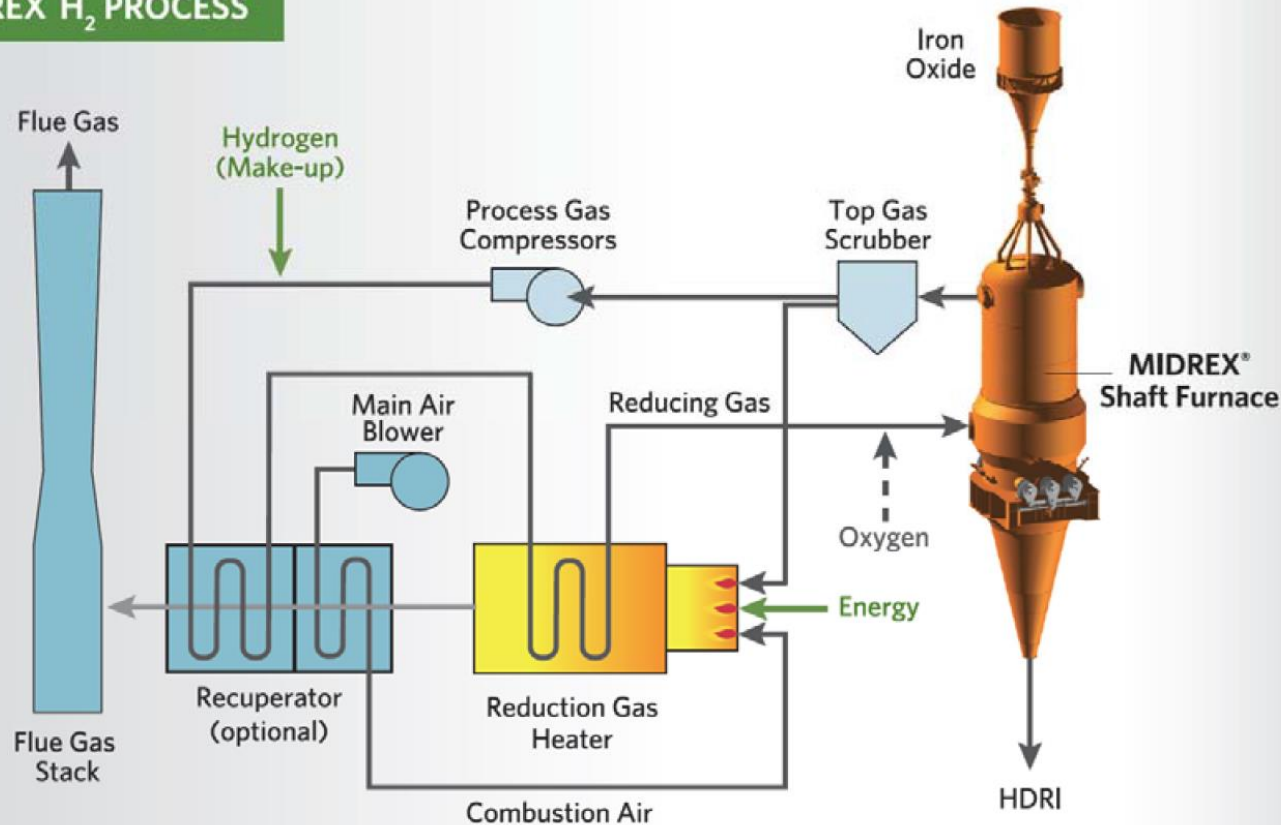


Source: Midrex calculations

# MIDREX H<sub>2</sub><sup>TM</sup> (MIDREX Green Hydrogen)

MIDREX

## MIDREX H<sub>2</sub> PROCESS



- Ultimate low CO<sub>2</sub> ironmaking solution: produce pure hydrogen using low carbon energy source and use H<sub>2</sub> in shaft furnace to make DRI
- Since 1969, MIDREX<sup>®</sup> 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<sup>®</sup> Shaft Furnace
- New MIDREX<sup>®</sup> Plants can be built to use hydrogen or existing plants converted
- Major issue is producing hydrogen economically with low CO<sub>2</sub> emissions

The background of the slide is a blue-tinted photograph of an industrial facility, likely a refinery or chemical plant. It features a complex network of steel structures, including tall distillation columns, horizontal pipes, and walkways. The lighting is bright, suggesting a clear day.

**Thank you!**

[www.midrex.com](http://www.midrex.com)

**MIDREX**

© 2019 Midrex Technologies, Inc. All rights reserved.