Hydrogen Steelmaking

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GM – Business Development

Sustainable Energy Economy Workshop

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MIDREX

Midrex at a Glance

World leader for direct reduction ironmaking technology and aftermarket solutions for the steel industry.

At Midrex, our employees have decades worth of experience and are driven to create value every day. Our core values are the foundation of our company and essential to our success. And our corporate activities are conducted according to the highest ethical and professional standards.

Charlotte, NC

Headquarters
+ 4 offices

50 Years

Commercial operations

R&D

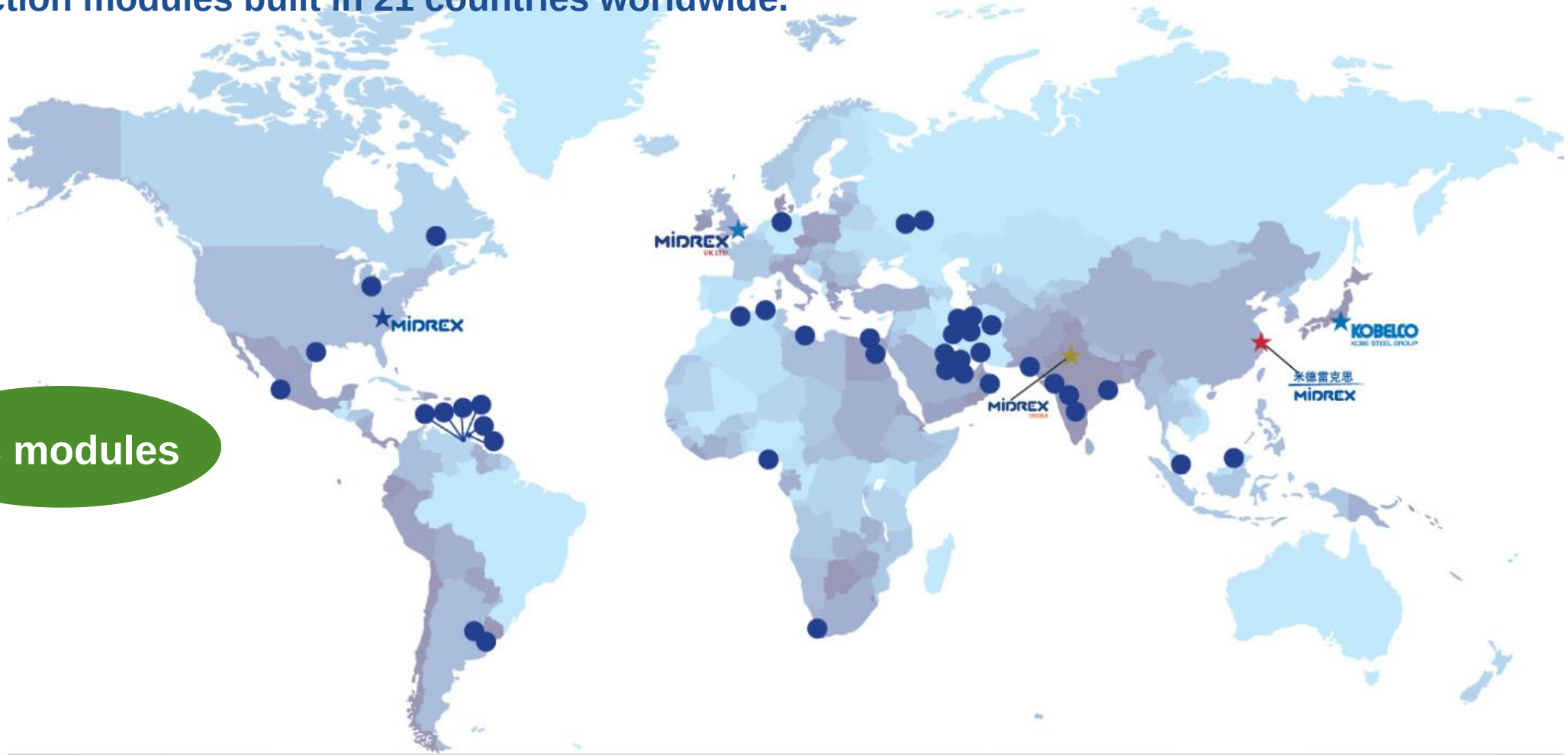
State-of-the-art R&D center

90+

Modules around the world

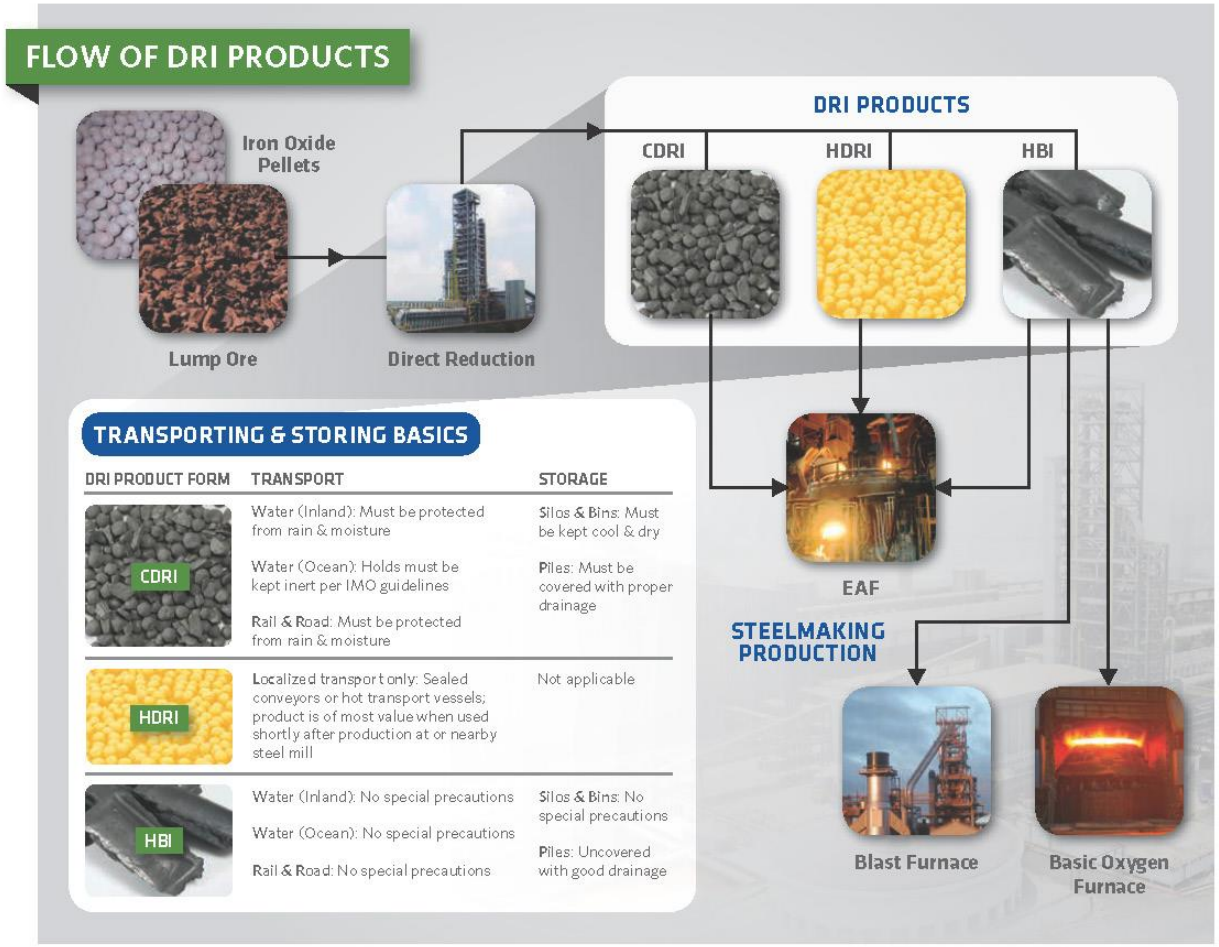
Midrex around the world

Since 1969, there have been MIDREX® shaft furnace direct reduction modules built in 21 countries worldwide.



93 modules

Direct Reduced Iron (DRI)



Disclaimer: DRI is used as the generic name of CDRI, HDRI and HBI

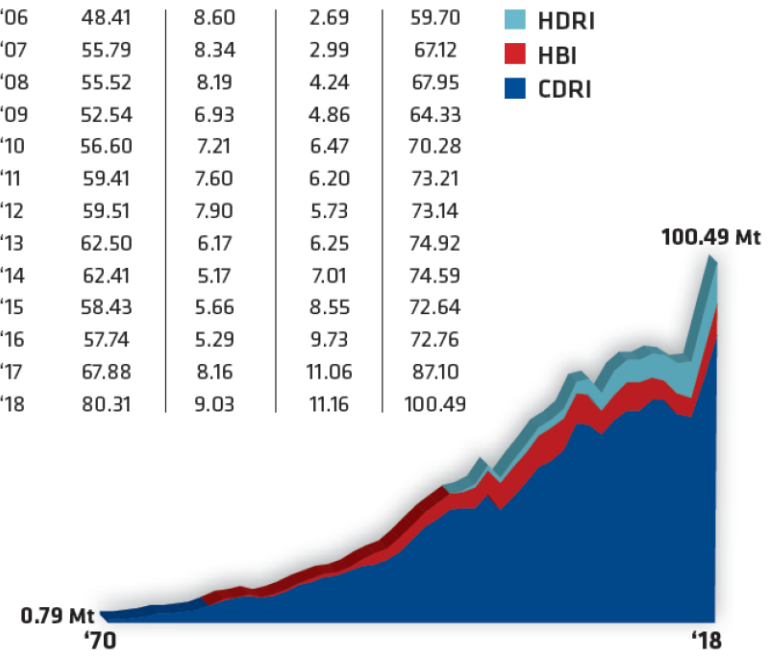
DRI Production

- New plants and improved market conditions boosted world DRI production by nearly 20% in 2017, exceeding 87 million tons
- DRI now represents about 16% of worldwide EAF charge mix
- Top producing nations:
  1. India
  2. Iran
  3. Russia
  4. Mexico
  5. Saudi Arabia

World DRI Production by Year (Mt)

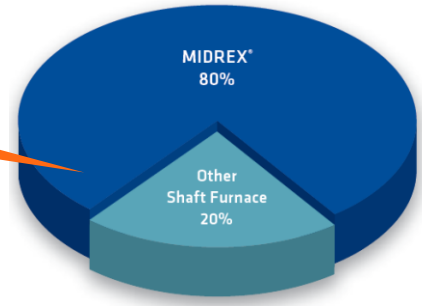
Source: Midrex Technologies, Inc.

Year	Total	Year	Total	Year	CDRI	HBI	HDRI	Total
1970	0.79	'88	14.09	'06	48.41	8.60	2.69	59.70
'71	0.95	'89	15.63	'07	55.79	8.34	2.99	67.12
'72	1.39	'90	17.68	'08	55.52	8.19	4.24	67.95
'73	1.90	'91	19.32	'09	52.54	6.93	4.86	64.33
'74	2.72	'92	20.51	'10	56.60	7.21	6.47	70.28
'75	2.81	'93	23.65	'11	59.41	7.60	6.20	73.21
'76	3.02	'94	27.37	'12	59.51	7.90	5.73	73.14
'77	3.52	'95	30.67	'13	62.50	6.17	6.25	74.92
'78	5.00	'96	33.30	'14	62.41	5.17	7.01	74.59
'79	6.64	'97	36.19	'15	58.43	5.66	8.55	72.64
'80	7.14	'98	36.96	'16	57.74	5.29	9.73	72.76
'81	7.92	'99	38.60	'17	67.88	8.16	11.06	87.10
'82	7.28	'00	43.78	'18	80.31	9.03	11.16	100.49
'83	7.90	'01	40.32					
'84	9.34	'02	45.08					
'85	11.17	'03	49.45					
'86	12.53	'04	54.60					
'87	13.52	'05	56.87					



MIDREX® Technology produced nearly 80% of shaft furnace DRI

2018 World Shaft Furnace Production by Process



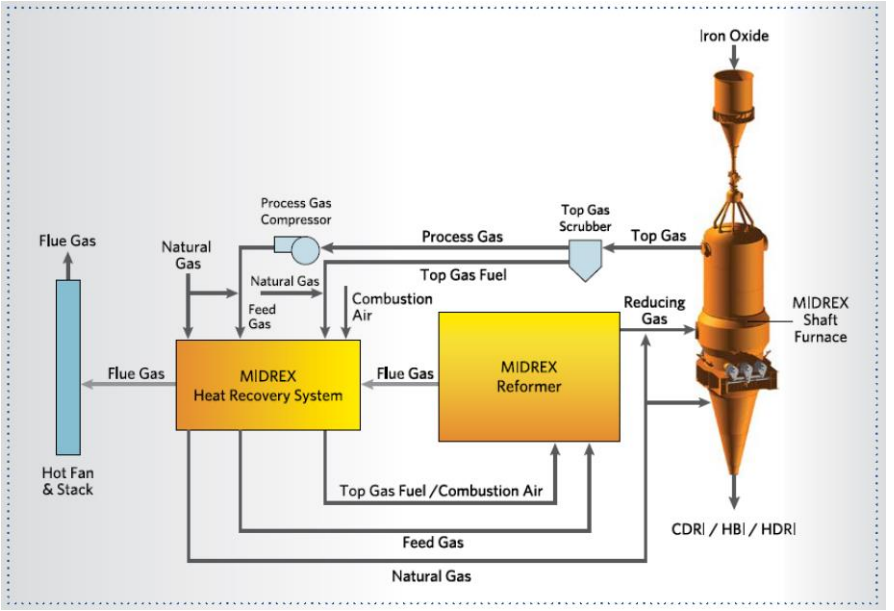
Total World Production: 100.5 Mt

	2016	2017	2018
MIDREX®	78.8%	79.0%	79.9%
Other Shaft Furnace	21.2%	21.0%	20.1%

Source: Midrex Technologies, Inc.

MIDREX NG® process

- First plant built in 1969 – celebrating 50 years!
- Over one billion tons of iron produced by the MIDREX process
- Iron ore is reduced to metallic iron in the MIDREX Shaft Furnace by Hydrogen (H_2) and Carbon monoxide (CO)
- The MIDREX Reformer generates the reducing gas from Natural Gas and the recycled CO_2 and H_2O from the shaft furnace. The reducing gas composition is typically 55% H_2 and 36%CO (H_2/CO ratio ~1.5)
- Midrex plant with other syngas can operate with H_2/CO between 0.4 and 3.5
- Carbon is produced in the DRI by CH_4 and CO



Furnace Reactions	Heat	Description
$Fe_2O_3 + 3\ H_2 \leftrightarrow 2\ Fe + 3\ H_2O$	Endothermic	Reduction by H_2
$Fe_2O_3 + 3\ CO \leftrightarrow 2\ Fe + 3\ CO_2$	Exothermic	Reduction by CO
$3\ Fe + CH_4 \leftrightarrow Fe_3C + 2\ H_2$	Endothermic	Carburization
$3\ Fe + CO + H_2 \leftrightarrow Fe_3C + H_2O$	Exothermic	Carburization

Cleveland-Cliffs

Under Construction – Expected Startup: Q2 2020

Capacity: 1.6 million tpy HBI

Furnace Type: MIDREX MEGAMOD®
7.15 m Hot Discharge Furnace

Reformer: 18 Bays

Products: 100% HBI with flexible carbon

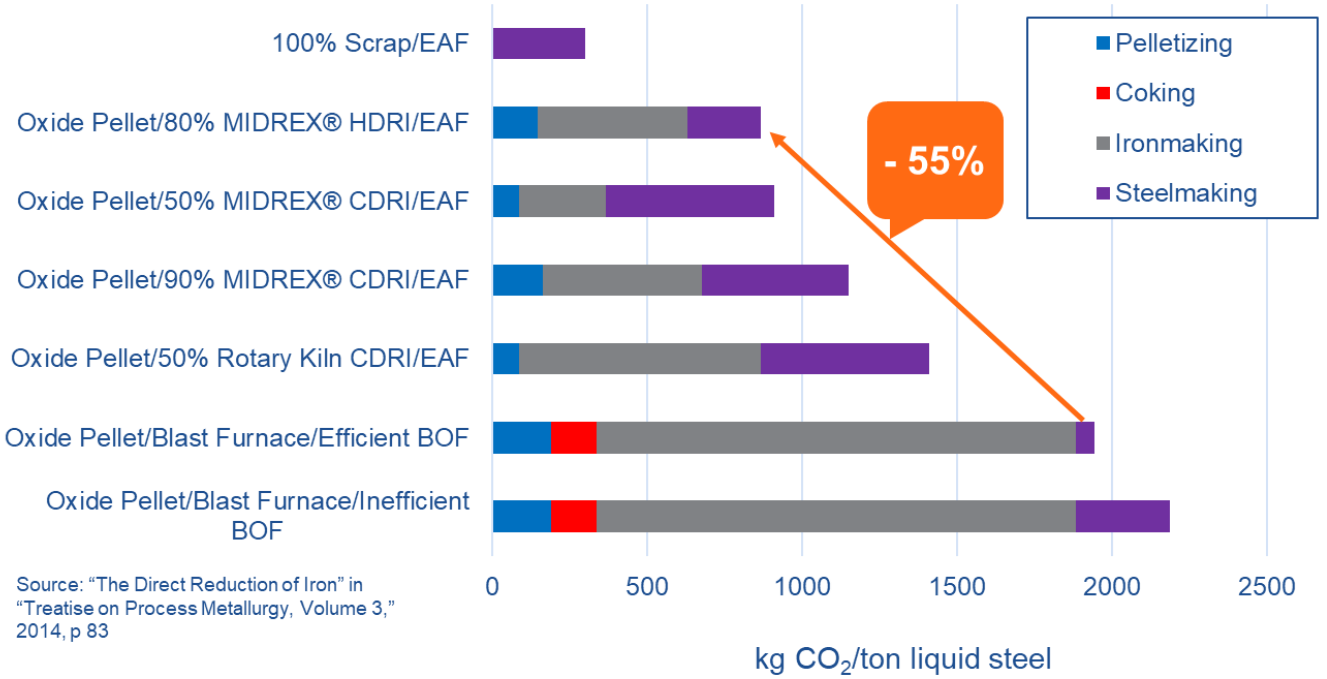
Location: Toledo, Ohio USA

Scope: Proprietary Engineering, Key Process Equipment Supply, bulk material supply, Field Services, Training.

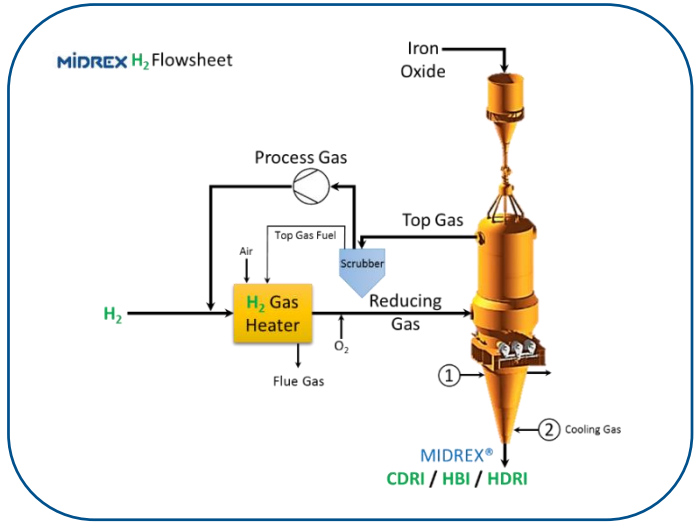
Features: 11” MA-1 Tubes, Lo-Nox Main Burners, 7 Briquette Machines Utilizing 2 Briquette Cooling Conveyors, flue gas hot fan, ACT™.

Lowering CO_2 emissions

- DR + EAF heavily favored over BF + BOF
- CO_2 Emissions depend on DRI / scrap ratio
- Long-term solution is MIDREX H_2™ for hydrogen based ironmaking



Source: "The Direct Reduction of Iron" in "Treatise on Process Metallurgy, Volume 3," 2014, p 83



ArcelorMittal commissions Midrex to design demonstration plant for hydrogen steel production in Hamburg

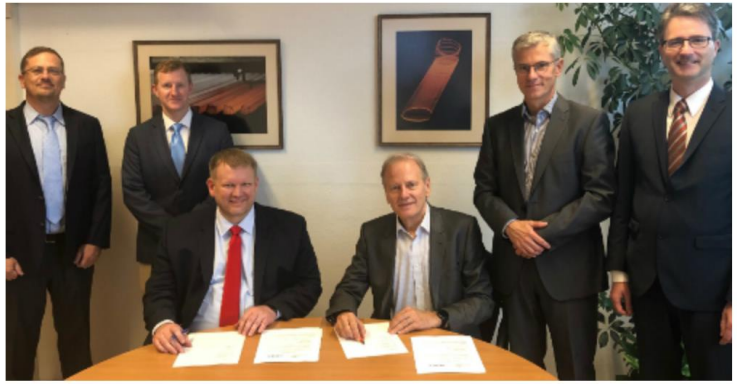
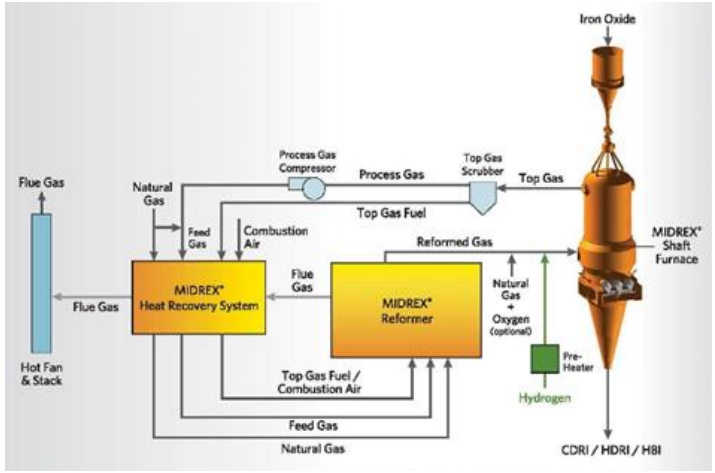
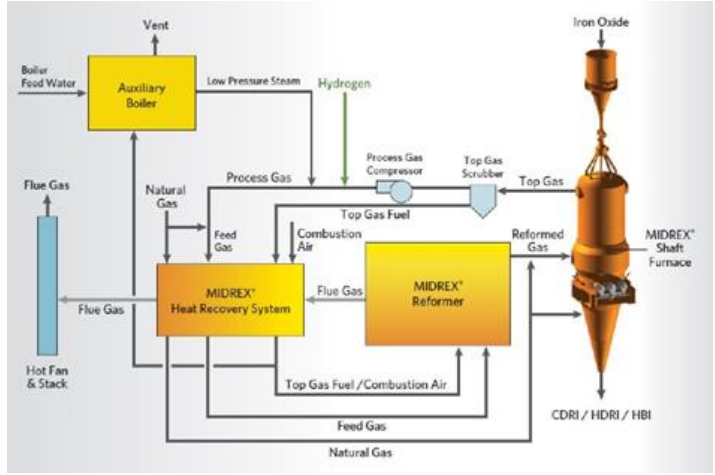


Photo: At the signing ceremony in Hamburg (from left to right): Vincent Chevrier, Todd Astoria and KC Woody from Midrex with Dominique Vacher, Dr Uwe Braun and Matthias Schad from ArcelorMittal.

MIDREX NG® with Hydrogen

- Up to 30% of NG can be substituted by Hydrogen without changing the process.
- Hydrogen may need to be pre-heated depending on quantities added.
- Rough calculations for Cleveland-Cliffs: 1.6 MTPA (200 ton/h), up to 16,000Nm^3/h of NG* can be replaced by 48,000Nm^3/h of H_2
- Hydrogen can be increased in the process as it becomes available with minor equipment modifications.

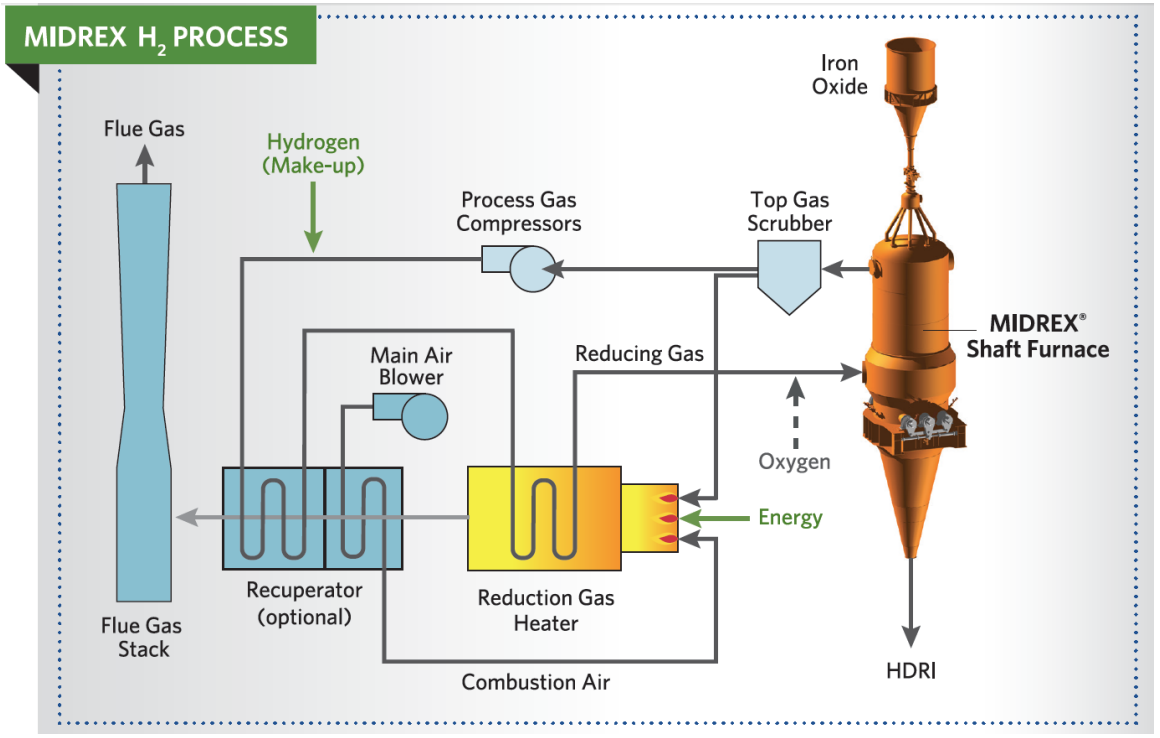




*Assumes net heating value 8800 kcal/Nm^3

MIDREX H_2®

- For 1.4% carbon in DRI, the bustle gas composition is ~90% hydrogen, balance CO, CO_2, H_2O and CH_4
- 100% hydrogen is possible: carbon in DRI needs to be optimized with the meltshop
- Hydrogen consumption is approx. 650 Nm^3/t DRI (54kg/t).
- For a MIDREX® plant the size of Cleveland-Cliffs, that's approx. 130,000Nm^3/h of H_2
- ~650MW per MIDREX® plant (at 200Nm^3/h of H_2 per 1MW).
- Needs >30 of the largest PEM Electrolyzer recently ordered (20MW)



Conclusions

- MIDREX NG® is a proven technology for industrial production of iron, using “fossil” hydrogen at scale. The process can reduce CO_2 emissions by 50%-80% over traditional BF-BOF.
- Direct reduction can be a bridge technology for ironmaking as Hydrogen becomes available at scale
- New plants can be built or existing plants can be converted to 100% H_2 as the Hydrogen economy evolves
- Green hydrogen production volumes need to increase by 30x – 100x to supply one MIDREX® plant
- Scale up to demonstration plant will be needed at ArcelorMittal Hamburg
- Hydrogen production costs must be competitive: steelmaking is a very competitive business with small margins





Thank you