OVERVIEW OF DIRECT REDUCTION & ALTERNATIVE IRONMAKING PROCESSES & PRODUCTS

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ironmaking processes

- **hot metal processes to feed oxygen converters or electric arc furnaces,**
- **direct reduction processes to feed electric arc furnaces or to produce DRI/HBI to feed blast furnaces, oxygen converters, etc,**
- **direct reduction or hot metal processes to process waste oxides from either EAF mini-mills or fully integrated plants.**

DIRECT REDUCED IRON (DRI/HBI)

coal-based			gas-based	
Rotary Kiln	Rotary Hearth	Fluid Bed	Shaft Furnace	Fluid Bed
lump ore	fines	fines	pellets, lump ore	fines
SL/RN DRC others	Inmetco Fastmet	Circofer	Midrex HyL	FINMET Iron Carbide Circored

DRI/HBI PRODUCTION TRENDS

DRI/HBI production dominated (> 75 %) by gas based shaft furnace processes (MIDREX, HyL, etc) using pellets, lump ore

Regions with low cost, local coal, iron ore: India, South Africa, China, etc, smaller scale coal-based DRI processes (rotary kiln) will continue

COAL BASED DRI IN NORTH AMERICA

EAF penalty for coal ash, gangue; economy of scale issues too difficult for merchant (or even captive) plants producing DRI as an end product

Coal based DRI process can feed a hot metal process- SAF, HIsmelt, etc, with coal ash, sulfur, ore gangue removed by the slag.

Low natural gas prices now favor gas based shaft furnace processes

Process Routes for Hot Metal Production

Single Vessel Processes

Blast furnace, cupola, smelter

Multi-vessel processes

Production of DRI followed by smelting or melting step:

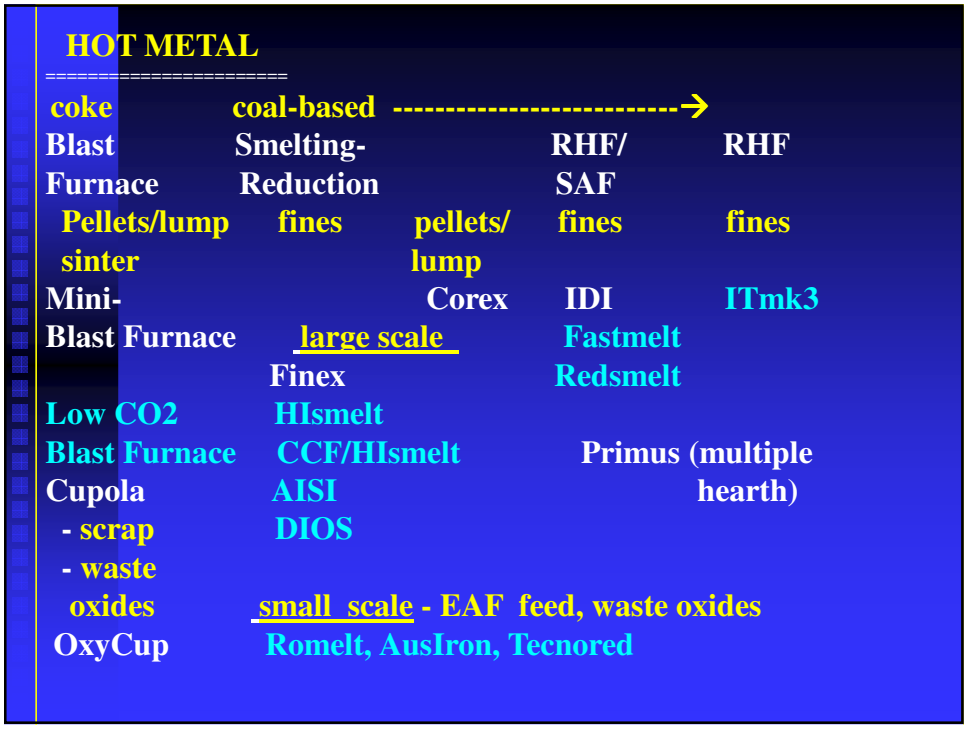
Corex, HIsmelt, RHF/SAF

Development of Competitive Hot Metal Processes

➔ avoid cokemaking, sintering steps preceding blast furnace.

HOT METAL

coke	coal-based ----------→			
Blast	Smelting-		RHF/	RHF
Furnace	Reduction		SAF	
Pellets/lump	fines	pellets/	fines	fines
sinter		lump		
Mini-		Corex	IDI	ITmk3
Blast Furnace	large scale		Fastmelt	
	Finex		Redsmelt	
Low CO2	HIsmelt			
Blast Furnace	CCF/HIsmelt		Primus (multiple	
Cupola	AISI		hearth)	
- scrap	DIOS			
- waste				
oxides	small scale - EAF feed, waste oxides			
OxyCup	Romelt, AusIron, Tecnored			



Alternatives for Hot Metal production.

1st-stage	output	2nd-stage	output	process concepts
1. Shaft furnace	pre-red. ore	Melter/gasifier	HM	Corex
		Smelter	HM	AISI
	DRI/HBI	SAF	HM	Midrex / Hylsa 4M /
		EAF + scrap	steel	Technored
2. Fluidized beds	pre-red. ore	Smelter	HM	DIOS / Hismelt-Circofer
	DRI/HBI	SAF	HM	Circofer / Circored /
		EAF + scrap	steel	Finmet / Fior
	Fe_3C	EAF	steel	Iron Carbide
	pre-red. ore	Melter/gasifier	HM	FINEX
3. Rotary hearth	DRI	Smelter	HM	Ausmelt 2stage
		SAF	HM	Fastmet-Fastmelt /
		EAF + scrap	steel	Iron Dynamics / Inmetco /
				Redsmelt / Comet /....
4. Others	-	Smelter	HM	Romelt / Ausmelt / ...
Ore pre-heater	ore	Smelter	HM	Hismelt / ...
Cyclone	molten pre-red.	Smelter	HM	CCF

Obstacles to Alternate Hot Metal Process Development

- Fundamental Technical Challenges
- Engineering, Scale-up, Maintenance
- Competing Process Routes
- Competing Alternate Iron Materials
- Changing Economic Conditions
- Need for Long –Term Financial Backing
- Need for Strategic Partner

Competing Alternate Iron Materials & Scrap

- **direct reduced iron (DRI),**
- **form of DRI known as hot briquetted iron (HBI)**
- **pig iron**
- **liquid hot metal**

Obstacles to Alternate Hot Metal Process Development

- Fundamental Technical Challenges
- Engineering, Scale-up, Maintenance
- Competing Process Routes
- Competing Alternate Iron Materials
- Changing Economic Conditions – changes in prices of process inputs and competing materials
- Need for Long –Term Financial Backing
- Need for Strategic Partner

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Processes Already Developed or With High Chance of Success

- Corex, Finex – VAI, Posco
- HIsmelt – Rio Tinto; JV Partners: Nucor, Mitsuibishi, Shougang
- Iron Dynamics – SDI
- Fastmet/Fastmelt, ITMk3 – Kobe, SDI
- Redsmelt – Severstal/Paul Wurth
- Primus –ArcelorMittal/Paul Wurth

OVERVIEW OF DIRECT REDUCTION & ALTERNATIVE IRONMAKING

PRODUCTS

DR & Alt Iron Products

- Definitions
  - DR: Direct Reduction. Reduce iron oxide to metallic iron without melting. Unreduced ore compounds remain as undesirable oxides
  - DRI: Direct Reduced Iron. Iron oxide feedstock exits in same form as entered (pellets in, pellets out; lumps in, lumps out)

Definitions (cont.)

- HBI: Hot Briquetted Iron: DRI that has been hot (1200 F, 650 C) briquetted to a high density pillow shaped briquette
- Hot Metal: Molten iron in liquid form, above 2500 F, 1370 C
- Pig Iron: Solid product of the iron blast furnace
- Residuals: Undesirable elements such as copper, nickel, chromium, tin, sulfur molybdenum, phosphorous

Definitions (cont.)

- Gangue: Rock minerals in the iron ore such as silica (SiO_2), alumina (Al_2O_3), calcia (CaO), magnesia (MgO). These remain in the oxide form in DR processes
- Reduction:
  - $Fe_2O_3 + 3CO = 2Fe + 3CO_2$
  - $2Fe_2O_3 + 3H_2 = 2Fe + 3H_2O$
  - ($Fe_2O_3 > Fe_3O_4 > FeO > Fe$)

Product Chemistry

- From iron ore feedstock
  - Residuals will be about 1.45 x ore analysis
- From waste oxides
  - Residuals will be about 1.45 x feed analysis
- C, S & P are process dependent

Product Chemistry (Iron Ore Based)

	Hot M	Pig Iron	DRI	HBI
Fe	93	93	93	93
C	4.3	4.3	0.8 – 4.0	0.8 – 2.0
Mn	0.2 – 0.5	0.2 – 0.5	.02	.02
Si	0.5 – 1.0	0.5 – 1.0	0	0
P	0.30-0.60	0.30-0.60	0	0
P2O5	0	0	0.5 – 1.0	0.5 – 1.0
S	0.04-0.06	0.04-0.06	.02	.02
Gangue	0	0	3 - 7	3 – 7

Material Handling

	Hot M	Pig Iron	DRI	HBI
Shipment	Insulated	Open	Covered	Open
Storage	Insulated	Open	Covered	Open
Grab	No	Yes	Yes	Yes
Magnet	No	Yes	Yes	Yes
Conveyor	No	No	Yes	Yes
Bins	No	No	Yes	Yes

Energy Attributes v SOP

	Hot M	Pig Iron	DRI	HBI
Blast Fce	NA	NA	++++	++++
BOF	=	NA	++	+++
EAF	++++	++	--	--
Induction	++++	=	-	-

Chemistry Attributes v SOP

	Hot M	Pig Iron	DRI	HBI
Blast Fce	NA	NA	++++	++++
BOF	=	---	+++	+++
EAF	++++	++++	+++	+++
Induction	=	=	-	-

Steelplant Operations

	Hot M	Pig Iron	DRI	HBI
Blast Fce	NA	NA	??	Yes
BOF	Yes	Yes	??	Yes
EAF	Yes	Yes	Yes	Yes
Induction	??	Yes	??	??

Steel Products

- Flat Products
  - **Drawing Quality – Mostly BOF production**
    - Requires low levels of undesirable elements
    - Requires iron ore for BF, or PI, DRI or HBI (for EAF)
  - **Commercial Quality (includes Plate) – Both BOF & EAF -** Can be made from steel scrap
- Long Products – Mostly EAF production
  - **Most grades can be made from steel scrap**

Conclusions

- No single correct answer
- Local conditions important
- Steel product chemistry critical in selection of melting feedstocks
- Energy costs usually determine process location
- Waste oxides usually have high levels of residuals

Conclusions (cont.)

- New pyrometallurgical process development is costly ($100'sM) and long term (several years, 5 to 20)
- Several new processes have reached commercial status while others are close to commercialization
- Other new processes are under development and may prove successful or not
- The end