Scrap Supplements & Alternative Ironmaking 10
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SSAI I - Myrtle Beach, 1993

SSAI II – Myrtle Beach, 1996

SSAI III – Trinidad, 1999

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Specialty Conferences

SSAI IV - Baltimore, 2004

SSAI V – Baltimore, 2008

SSAI VI – Baltimore, 2012

SSAI VII – Orlando, 2017

SSAI VIII- Orlando, 2020

SSAI IX - Orlando, 2023

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Organized By:

Jan van der Stel, Tata Steel Europe
Joe Poveromo, RMI Global Consulting
Jose Noldin, GravitHy
Angelo Manenti, Metal Consulting LLC
Zane Voss, CIX Inc
Tom Battle, Extractive Metallurgy Consultants
Mitren Sukhram, Hatch Associates
Ko-Ichiro Ohno, Kyushu University
Karim Badr, RHI Magnesita

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AIST Direct Reduction Technology Committee

OVERVIEW OF DIRECT REDUCTION & ALTERNATIVE IRONMAKING PROCESSES & PRODUCTS

Joseph J. Poveromo

Raw Materials & Ironmaking Global Consulting

Joe.poveromo@rawmaterialsiron.com

Jan van der Stel

Tata Steel The Netherlands

Jan.van-der-stel@tatasteeleurope.com

Ironmaking Processes

- Hot metal processes to feed oxygen converters or electric arc furnaces,
- Direct reduction processes to feed
  - DRI/HBI to electric arc furnaces or to produce HBI to feed blast furnaces, oxygen converters, etc,
  - DRI to smelting/melting processes to produce merchant pig iron or hot metal to feed oxygen converters or electric arc furnaces
- Direct reduction or hot metal processes to process waste oxides from either EAF mini-mills or fully integrated plants.

DIRECT REDUCED IRON (DRI/HBI)

Reductant	coal-based			gas-based		
Process Vessel	Rotary Kiln	Rotary Hearth	Fluid Bed	Shaft Furnace	Fluid Bed	Furnace
Iron bearing material	lump ore	fines	fines	pellets, lump ore	fines	fines
Process	SL/RN DRC others	Inmetco Fastmet	Circofer	Midrex EnergironHyL	FINORED (FINMET) Iron Carbide Circored HyFor	ZESTY

color red: not commercialized

DRI/HBI PRODUCTION TRENDS

DRI/HBI production dominated (80 %) by gas based shaft furnace processes

(MIDREX, HyL Energiron, 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 (North America, MENA, CIS only) 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, Finex, HIsmelt, RHF/SAF;

  Now: DRI (gas based)/melter

- **Melter:** SAF, OSBF, EAF, other

Development of Competitive Hot Metal Processes

➔ **Avoid:**

Cokemaking,

Sintering,

Pelletizing steps

Preceding Blast Furnace.

Hot Metal Production Processes

Reductant	Coke	Coke	Coal-based (with biomass possibilities)				
Process Vessel	Blast furnace	Cupola	Smelting reduction	Smelting reduction	RHF/SAF	RHF	Electrolytic Cell
Iron Bearing Material	Sinter Pellets Lump	Scrap Waste oxides Iron ore fines	Iron ore Fines	Pellets Lumps	Iron ore fines Waste oxides	Iron ore fines	Iron ore fines
Process	Blast furnace	OxyCup	FINEX, HyREX	COREX	Iron Dynamics	ITmk3	Molten Oxide Electrolysis (MOE, Boston Metal)
		Tecnored*	Hismelt		Fastmelt		
	Mini blast furnace		HIsarna		Redsmelt		
			AISI		Primus (multiple hearth)		Siderwin (ArcelorMittal)
			DIOS				
			Circosmelt				
	*charcoal/biomass option			Blue font indicates process not commercialized			

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

Fundamental Technical Challenges

Challenges for:
Smelting Reduction processes

- Attack of refractories by FeO-rich slag
- Low carbon efficiency, high gas volumes: high coal rates
- Drainage of liquids due to absence of coke
- High dust losses with fines-based processes
- High capital costs

Fundamental Technical Challenges

Challenges for:
Fluidized Bed processes

- Drying, pre-heating of ore fines
- Sticking of iron ore fines
- Temperature control
- Dust losses
- Gas cleaning, handling
- Product discharge

Fundamental Technical Challenges

Challenges for:
RHF/melter, RHF/smelter processes

- Production of consistent DRI:
  - RHF processes – production of quality Greenballs, Briquettes
- Materials handling
- Process control of coupled processes
- Gas cleaning

Engineering, Scale-up, Maintenance

Challenges of moving directly from pilot to commercial scale without a demonstration plant:

- Iron Carbide
- Circored
- Iron Dynamics (RHF/SAF)

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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 – Primetals, Posco
- HIsmelt – Rio Tinto; JV Partners: Nucor, Mitsuibishi, Shougang; now Molong
- Iron Dynamics – SDI
- Fastmet/Fastmelt, ITMk3 – Kobe, SDI
- Primus – ArcelorMittal, Paul Wurth (SMS)
- Other processes being backed by steel companies: ArcelorMittal, Posco, Nucor, VoestAlpine, SSAB, others; iron ore companies: VALE, BHP, RioTinto, Fortescue, and others

OVERVIEW OF DIRECT REDUCTION & ALTERNATIVE IRONMAKING

PRODUCTS

DR & Alternative Iron Products

Definitions

- DRI: Direct Reduced Iron where Iron oxide feedstock exits in same form as entered (pellets in, pellets out; lumps in, lumps out);
- HBI: Hot Briquetted Iron where 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 (SiO2), alumina (Al2O3), calcia (CaO), magnesia (MgO). These remain in the oxide form in DR processes

- Reduction:
  - $Fe_2O_3 + 3CO = 2\,Fe + 3CO_2$
  - $2Fe_2O_3 + 3H_2 = 2\,Fe + 3H_2O$
  - $(Fe_2O_3 > Fe_3O_4 > FeO > Fe)$

Typical Chemistry Of Metallics

	Prompt Scrap [%]	Pig Iron Hot Metal [%]	DRI/HBI [%]
Fe	98.0	94.5	93.0
Metallization	100	100	95.0
Metallic Fe	98.0	94.5	88.6
FeO	0	0	6.6
Carbon	0	4.5	1.5
Acidic gangue	1.0	1.0	2.2
Basic gangue, other	1.0	0	1.1

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

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
  - Most grades – Mostly EAF production
    - 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

Conclusions

- New pyrometallurgical process development is costly ($100' Ms) 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.

Thank you!

- Questions?