Pellets for an Evolving Global Iron and Steel Scenario

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Agenda

Overview of competing steel production routes: DRI/scrap/EAF vs BF/BOF

Process routes for reducing steel production CO2 emissions

Role for increase in pellets consumption for growing DRI sector and BF sector

Ways to cope with a potential shortage of DR grade pellets

Expected changes in pellet properties

Preview of other (non-pellet) alternative ironmaking processes

Competing steel production routes: DRI/scrap/EAF vs BF/BOF,

"

World Steel Association 2022 Data								
Region	Pig Iron MT	Total Steel MT	Pig Iron/ Steel	BOF Steel MT	BOF Steel %	EAF Steel MT	EAF Steel %	EAF feed
EU	71	136	0.52	76	56	60	44	scrap/pig/DRI
Other Europe	15	44	0.34	16	37	28	63	scrap/pig/DRI
CIS	61	84	0.73	52	62	32	38	
North America	29	111	0.26	34	31	77	69	scrap/pig/DRI
South America	30	43	0.70	29	67	14	33	
Africa	3	15	0.20	2	16	13	84	DRI
Mid East	3	44	0.07	3	6	41	94	DRI
Asia	1063	1350	0.79	1094	81	257	19	
China	864	1018	0.85	906	89	112	11	
Oceania	4	6	0.67	5	77	1	23	
Totals	1279	1833	0.70	1311		522		

Global Changes in EAF vs BF/BOF Steel Production

Since 1990:

Steep decline of percentage (not absolute) EAF capacity in China as most growth was in BF/BOF steel production,

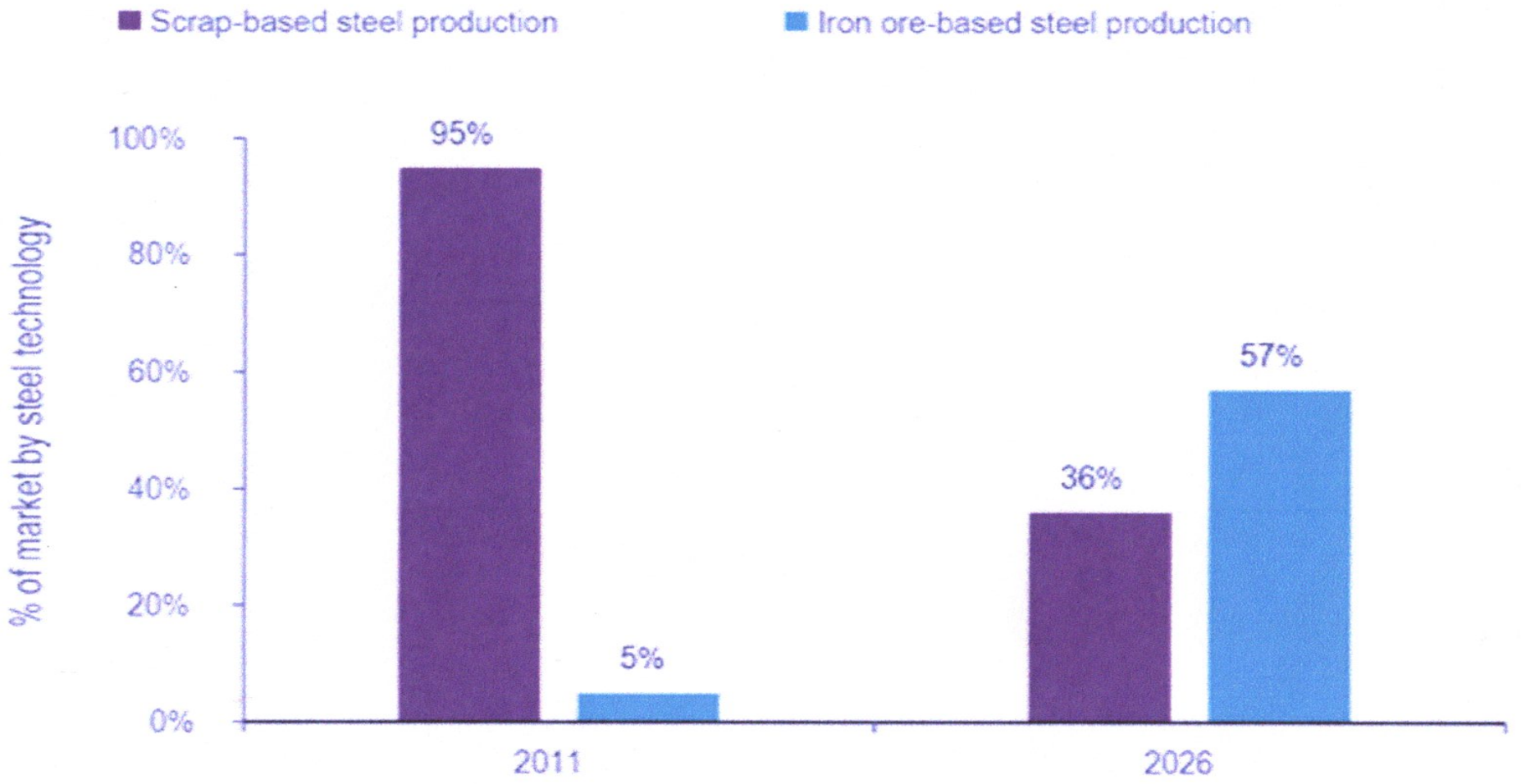
Continous growth in EAF in USA, Mexico (to >70 %)

Since 2010:

Gradual increase in BF/BOF capacity in India,

Dramatic increase in BF/BOF capacity in SE Asia as virtually all new capacity is BF/BOF in Malaysia, Vietnam, Indonesia; formerly region had relied upon EAF production including some DRI/EAF plants.

SHARP SHIFT IN TECHNOLOGY TOWARDS BOF STEELMAKING UNDERWAY IN SE ASIA



Source: Fastmarkets, SEAISI estimates

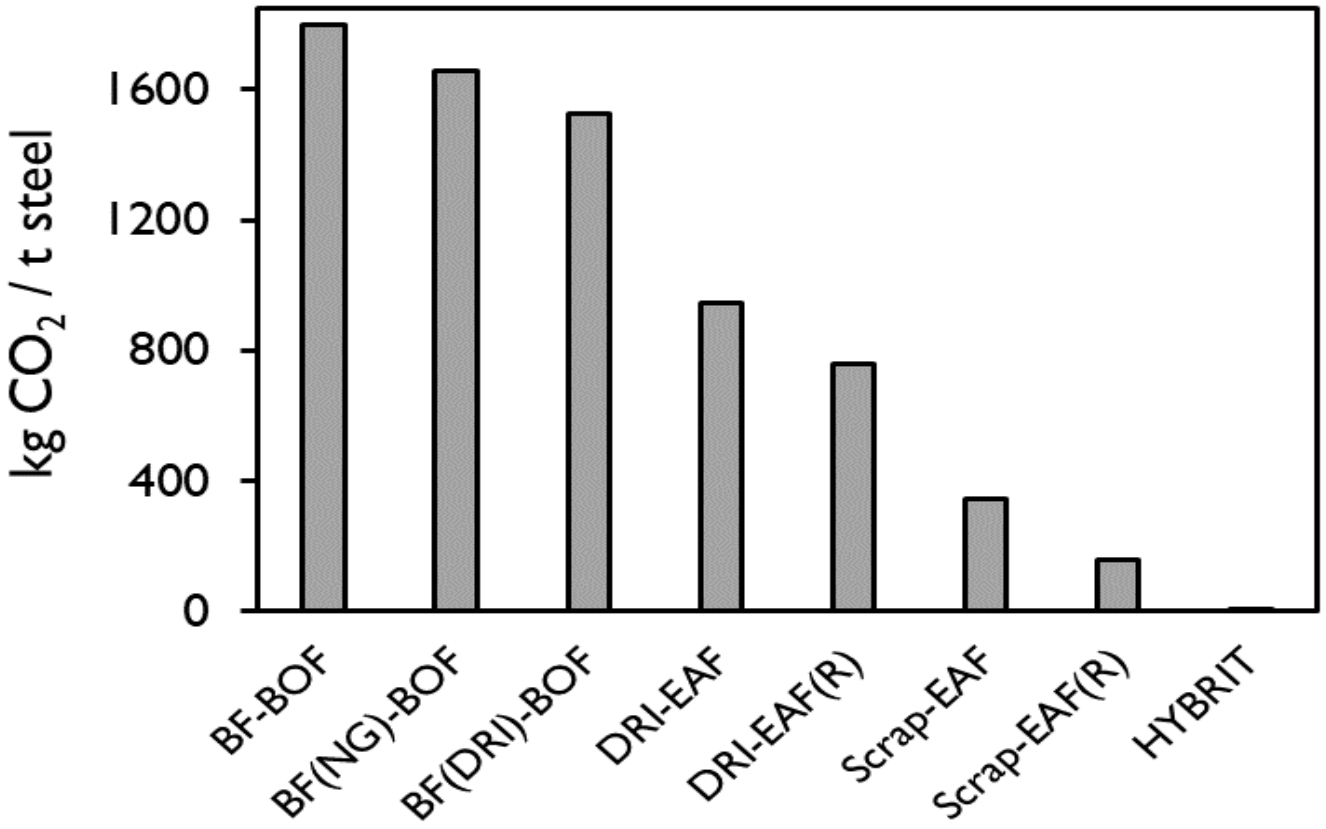
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Process routes for reducing steel production CO2 emissions

- Scrap, DR grade ore, Pellets, H2, natural gas reduce CO2 compared to BF sinter, coke, coal

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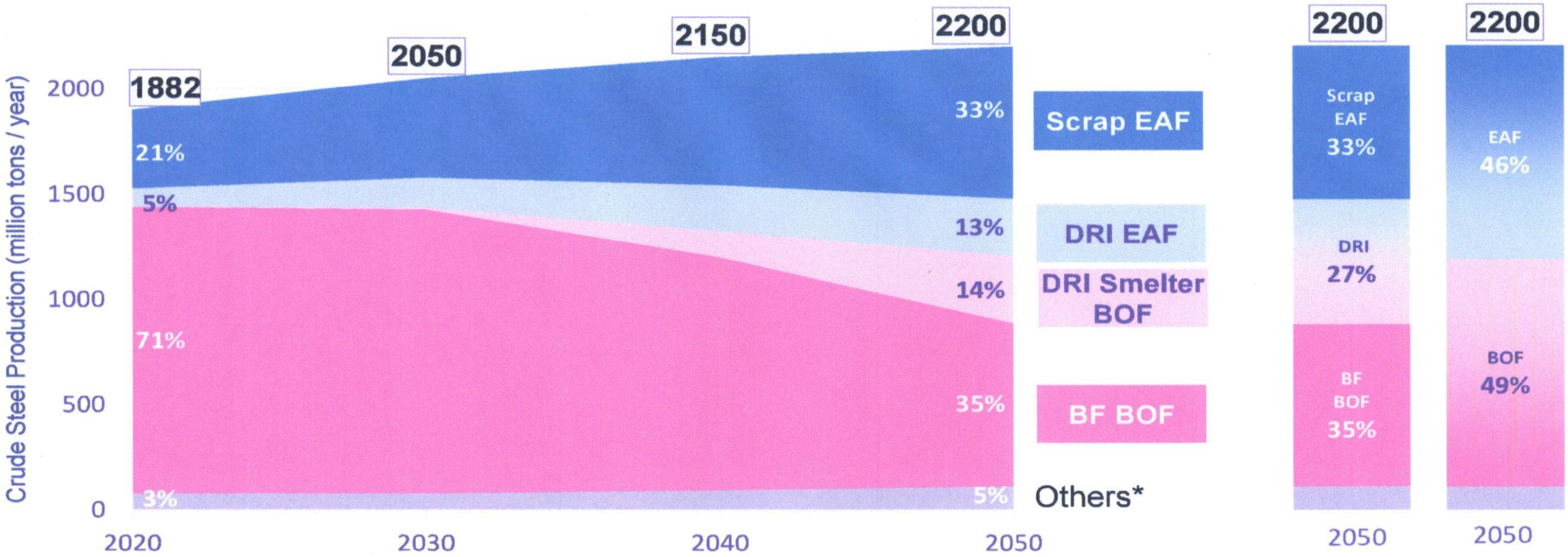
Continuum of possibilities



NG: natural gas
R: renewables

PRIMETALS TECHNOLOGIES

Crude steel production routes 2020 thru 2050



*Others includes coal based DRI, Induction Furnaces, Smelt Reduction (Corex / Finex), Open Hearth Furnaces and breakthrough technologies

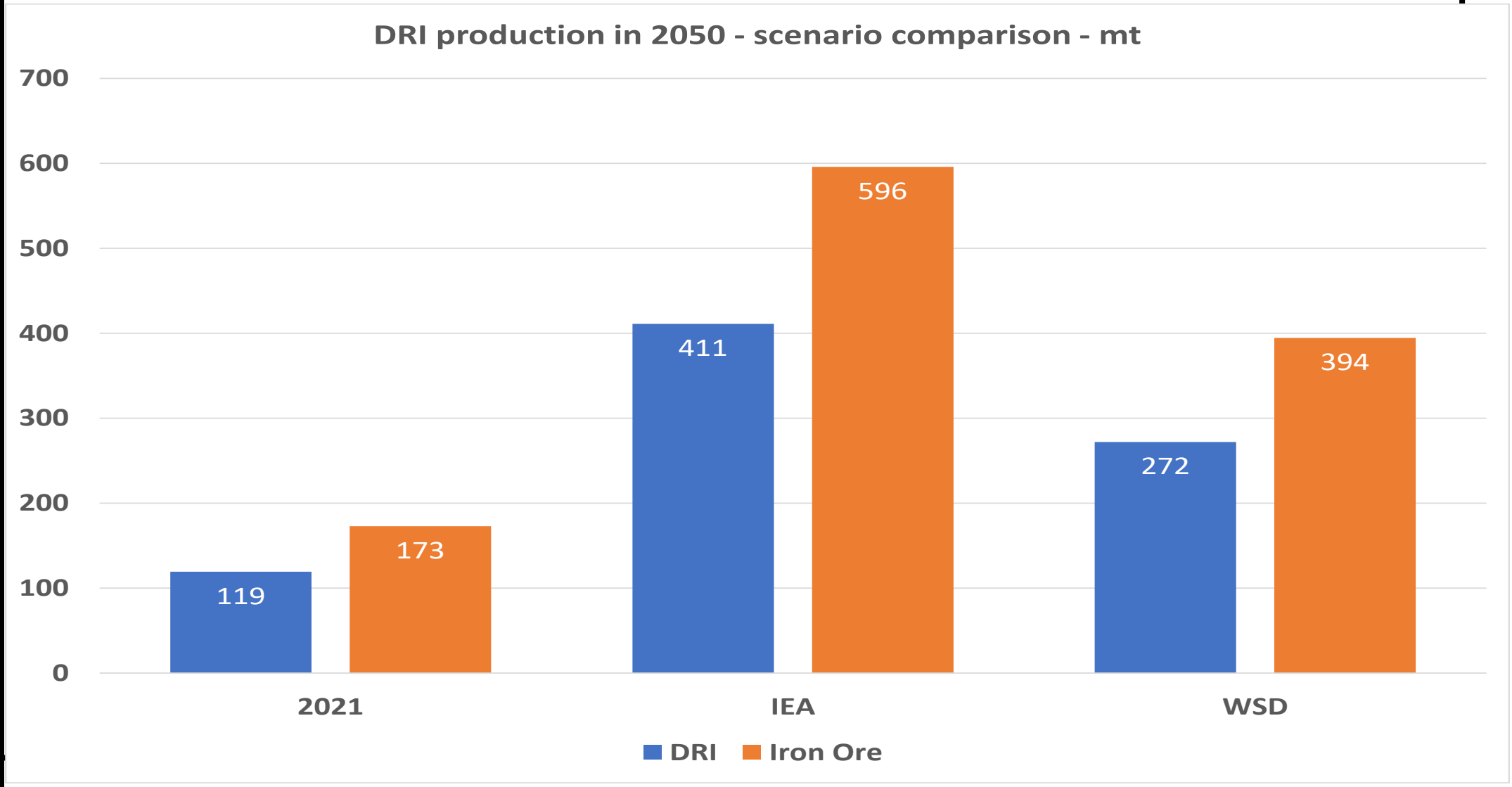
Source: Primetals Technologies Model

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Role for increase in pellets consumption for growing DRI sector and BF sector

- **Impact of Increased DRI Production on DR Pellet Demand**
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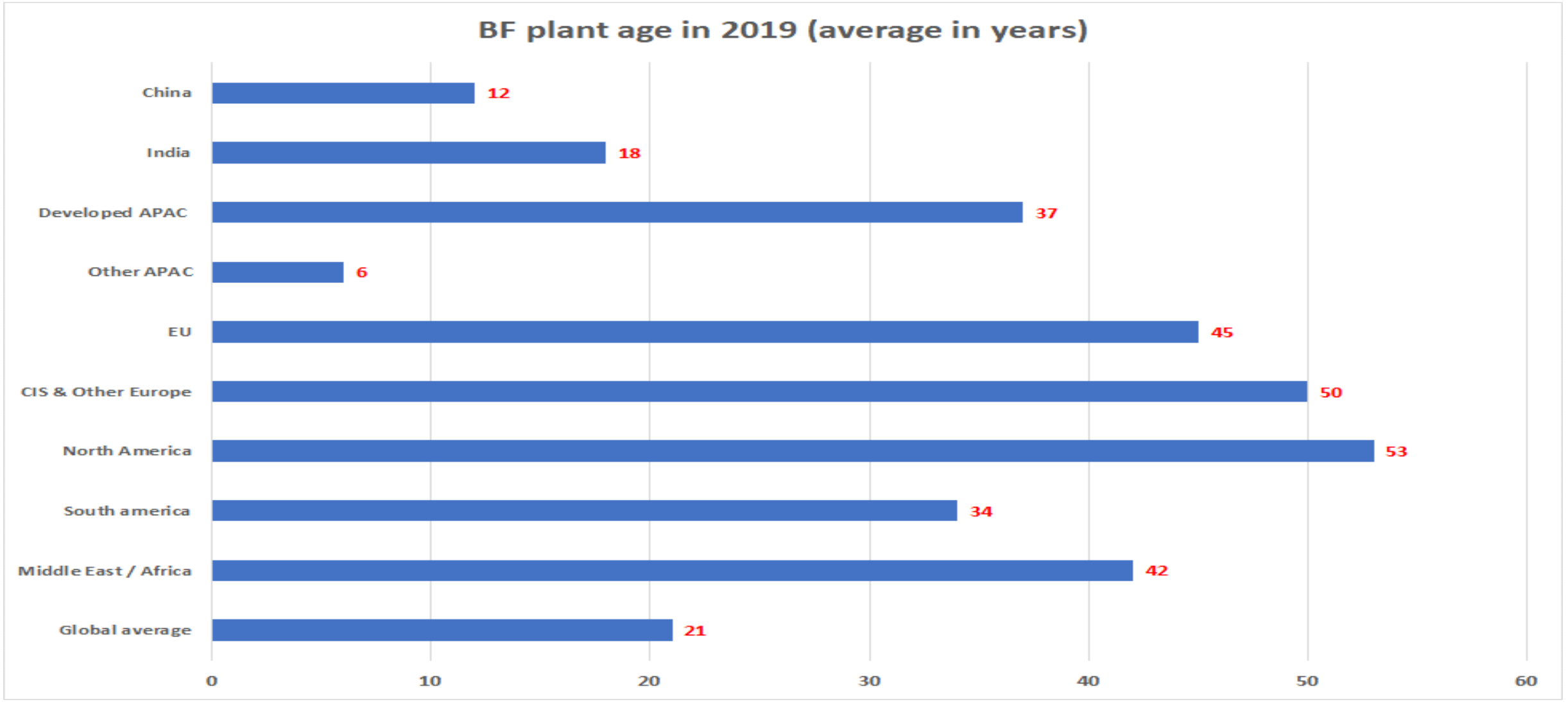
Increased pellet consumption in BF sector

- **CO2 emission benefits of increased pellet (vs. sinter) consumption**
  - **lower CO2 emissions in pelletizing (0.04/0.08) vs sintering (0.22)**
  - **lower CO2 emissions in BF if increased pellet consumption features lower SiO2, Al2O3 levels that reduce BF slag volumes==➔ need lower SiO2 fluxed pellets**

All-pellet BF operations are common in North America, Scandanavia but less likely to spread further in Europe as sinter plants still needed for recycling in plant waste oxides; nevertheless, BF pellet consumption will increase in Europe

However, more than 80 % of global BF/BOF production is in Asia-Pacific region where sinter is the predominant iron bearing material and will remain so for two reasons: young age of facilities and the Australian iron ore base; again, as in Europe, there will be some increase in BF pellet consumption in the Asia Pacific region: increased pellet production in China, seaborne pellet supply from India, Brazil, Ukraine, Canada, others.

Majority of BF/BOF Steel Production in China, India, Developing APAC where BF/BOF < 15 years old: expect focus on reducing CO2 with existing BF/BOF plants

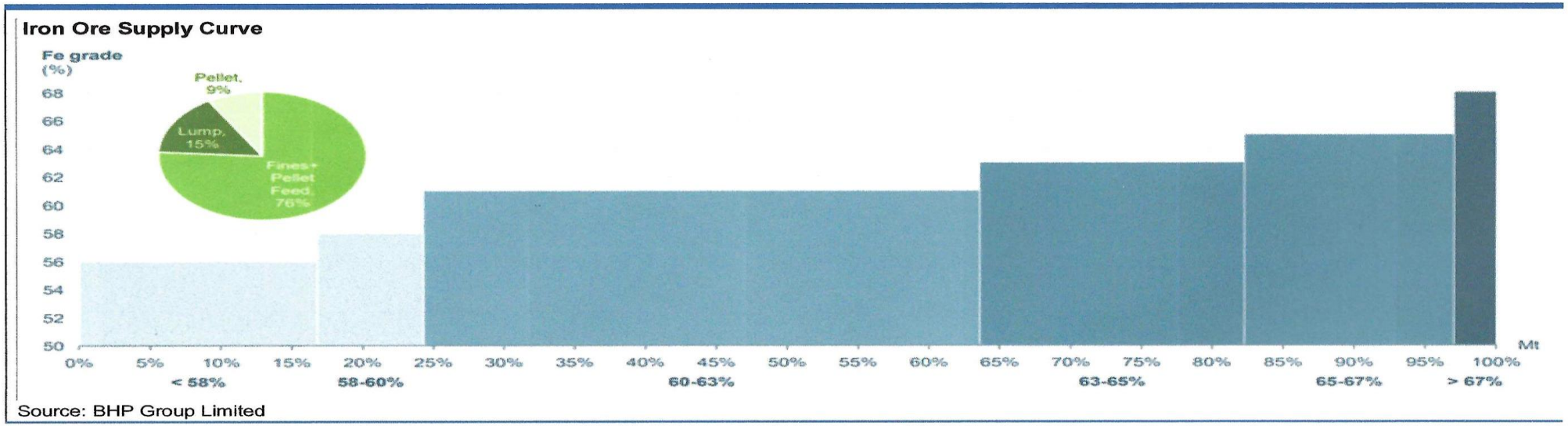


Australian ore supply: In addition to chemistry challenges shown below, Australian hematite ores are more difficult to beneficiate/pelletize; existing and planned magnetite projects face hugh CAPEX, OPEX obstacles

Iron Ore Supply – Pilbara

Iron ore supply implications - the Pilbara challenge

- Iron ore supply curve by quality band – BHP says only 3% is EAF quality.
- Iron ore for DRI feed requirements as per Midrex; minimum Fe content 66%, SiO2+Al2O3 less than 3.5% (and ideally 2%) and phosphorous max of 0.08%
- Pilbara hematite ores 58%-62% Fe (typically) with SiO2+Al2O3 in the range 4-9% and >50% of seaborne ore supply



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Coping with a potential shortage of DR grade pellets

Impact of Increased DRI Production on DR Pellet Demand - 1

- **Projected increase in DR pellet demand from 173 MT to circa 400 – 600 MT by 2050 not likely to be met by DR quality pellets due to a shortage of DR grade pellet feed, hence much attention is now focused on using BF grade pellets in DRI shaft furnaces followed by smelting/melting step in electric smelting furnaces (SAF, OSBF, Crisp, etc) to produce hot metal to feed existing BOF steelmaking furnaces**
- **Following projects are proceeding:**
  - **Thyssenkrupp Steel's tkH2Steel project involves a 1.2 mt Midrex DR plant, coupled with a smelter to produce "electric hot metal," comparable to BF hot metal, to be fed directly to the BOF**
  - **Tata Steel Ijmuiden's transition to green steelmaking will involve DR plants coupled with electric melters, to feed hot metal to existing BOF converters**
  - **ArcelorMittal's planned 2.5 mt DR plant at Dunkerque will also include an intermediate electric furnace ahead of the EAF**
- **Smelting solution being studied by iron ore producers in Western Australia whose Pilbara ores are difficult and expensive to beneficiate; studies include various fines-based reduction steps followed by smelting step**

Impact of Increased DRI Production on DR Pellet Demand - 2

- **Other DRI ironbearing materials: Lump ore, briquettes: (maybe 10-25 % of ironbearing feed):**

Limited options for seaborne supply of lump ore

- **Kumba's high grade Sishen lump**
- **Potential supply from Baffinland Iron**
- **Captive sources (India, Venezuela, etc) of DR lump ore will not be exported**

Vale has developed its own cold-briquetting technology and has two briquetting plants (6 MTPY) starting up in Brazil, with bulk DR trials planned for 2023;
concern for large BF operation: absence of high temperature properties;

Expected changes in pellet properties

Expected changes in pellet properties

DR grade pellets - no changes expected

- Maximize Fe (>67%), minimize SiO_2, Al_2O_3 (< 3 %), other elements
- maximize physical strength, optimize size range
- maximize reducibility, minimize sticking tendency
- impact of reduction by H_2 vs CO requires further study

BF grade pellets (for BF use)

- preference for low silica fluxed pellets to reduce slag volumes and maintain overall reducibility, high temperature properties when pellets replace sinter; - both to realize full CO_2 emission reduction benefits

BF grade pellets (for DRI use)

- need for low silica fluxed pellets less important

Preview of other (non-pellet) alternative ironmaking processes

Iron ore for alternative ironmaking processes

Nearly all alternative ironmaking processes (aside from shaft furnace DRI) do not involve using pellets:

Commercial smelting reduction processes: FINEX, HIsmelt, Tecnored

FINEX – commercial plants at Posco; projects elsewhere face hugh CAPEX hurdles

HIsmelt – commercial plant in China; projects in China, Vietnam, USA, elsewhere; need biomass reductants to be "green"

Tecnored – cupola-type process; first commercial plant starting up, concern for biomass availability, consistency

Pig iron nugget processes – not yet successful

Fines based DRI, HBI processes – see next slide

Early stage novel processes: flash ironmaking, microwave (BioIron), electrochemical processes (MOE[Molten Oxide Electrolysis], Electra, molten salt electrolysis, molten sulfide electrolysis, chlor-iron, acidic electrolyte electrolysis, others)

Fines-based DRI technologies

- **Only fines-based DR plant currently in operation at Orinoco Iron in Venezuela, using the natural gas-based Finmet process, (renamed FINORED), uses upgraded sinter feed fines and produces HBI.**
- **The Circored process, developed as a H_2-based, fluidized bed direct reduction process using fine iron ores. An industrial scale plant (0.5 mt HBI capacity) in Trinidad operated intermittently 1999-2005. Metso Outotec is now relaunching the process with a number of process variants,**
- **An emerging iron ore concentrate-based DR technology, HYFOR (HYdrogen-based Fine Iron Ore Direct Reduction), is being developed by Primetals Technologies at the Voestalpine site at Donawitz in Austria.**

Thank you!

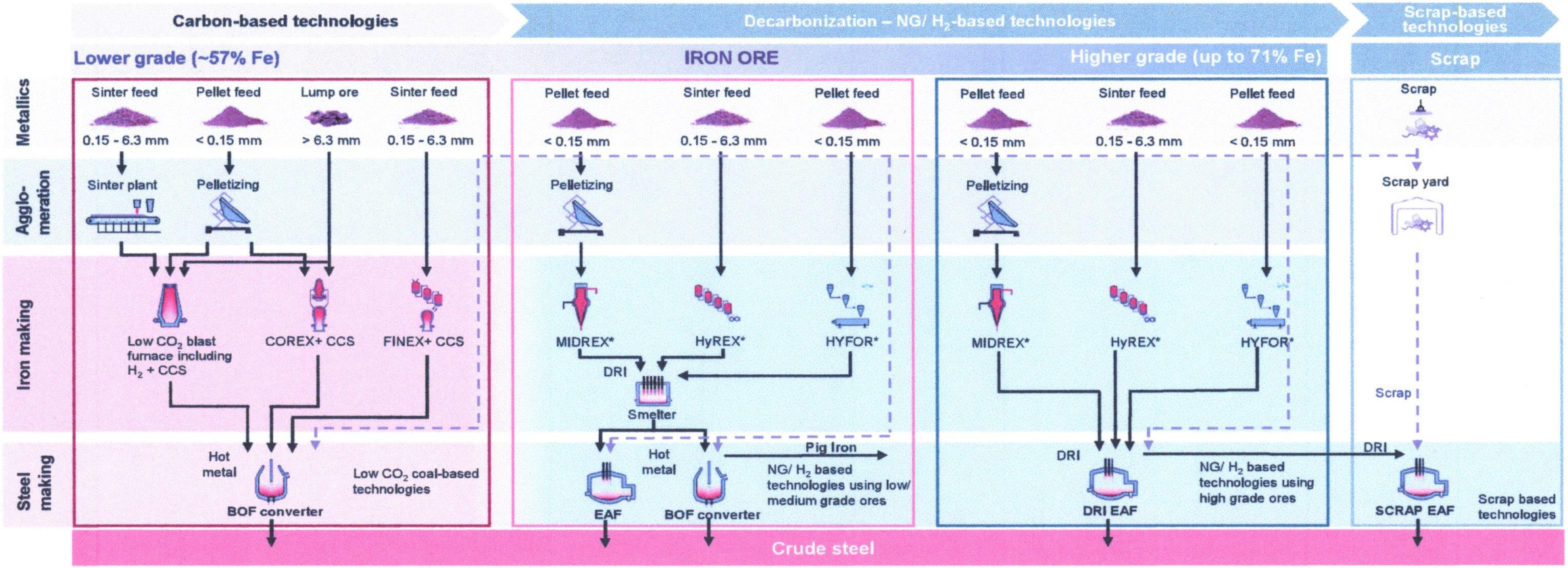
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The 5th SYMPOSIUM on IRON ORE PELLETIZING and its sustainable development

Appendix - slides from earlier presentations

PRIMETALS TECHNOLOGIES

Transitioning towards low-carbon steelmaking (2020 ⇨ 2050)



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Iron Ore for a Changing Ironmaking Landscape

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World Iron Ore Production, Exports 2019

Country	Production MT	Exports MT
Australia	917	836
Brazil	397	376
China	249	0
India	233	28
Russia	107	16
Ukraine	76	39
South Africa	71	66
Iran	61	13
Canada	59	54
USA	47	11
Sweden	29	16
Mexico	22	1
Peru	17	16
Mauritania	12	12
Chile	10	7
Others	77	54
Totals	2384	1545

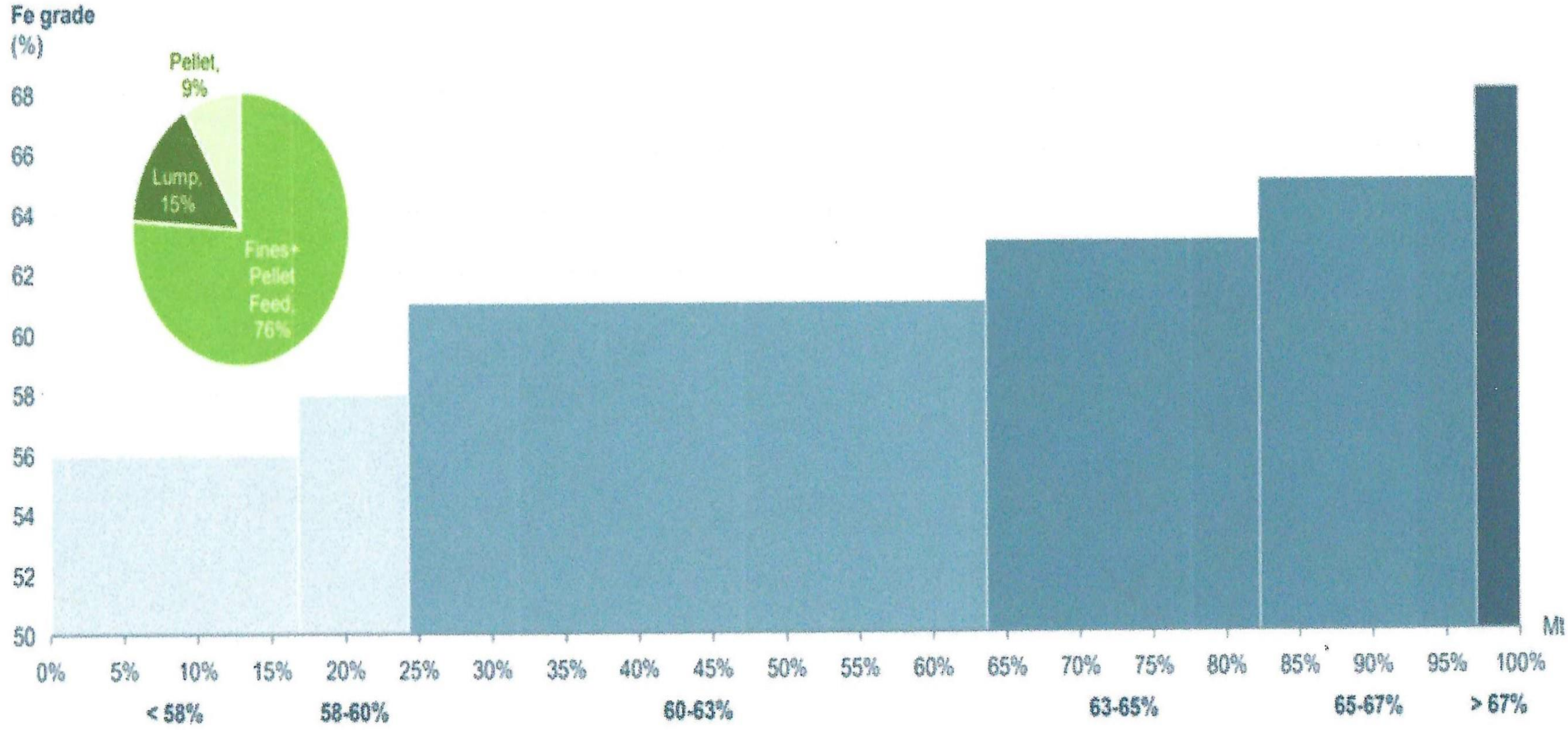
Source: RMG

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Global Seaborne Iron Ore Trade 2019

	Importer		China	Japan	S. Korea	Taiwan	Europe	Other
MT	Total							
Exporter								
Australia	815		665	69	54	17	3	7
Brazil	376		228	31	10	4	38	65
South Africa	66		43	3	5	0	13	2
Canada	54		11	8	4	2	22	7
Ukraine	39		14	2	1	1	2	19
India	28		24	2	1	0	1	0
Iran	13		13	0	0	0	0	0
Sweden	16		1	1	0	0	8	6
Russia	16		8	1	0	0	5	2
Peru	16		15	1	0	0	0	0
Mauritania	13		6	0	0	0	4	3
Chile	7		7	1	0	0	0	0
Others	93		34	1	0	0	2	56
Totals	1,552		1,069	120	75	23	98	

Iron Ore Supply Curve



Source: BHP Group Limited

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BLAST FURNACE – Primary Iron Bearing Raw Materials

- **Sintering Process**: sintering process is the primary BF feed material globally outside of North America due to availability, cost of globally sourced sintering ore fines, low and medium grade, and ability to recycle steel plant waste oxides
- **Pelletizing Process**: Pelletizing needed to agglomerate fine sized concentrates upgraded from lower grade ores in regions lacking natural sintering ores. Pellets became dominant feed in North America and Scandanavian countries as older, smaller sinter plants were shutdown. Pellets, along with lump ore, continue as minority burden components in high sinter burdens
- **Natural Lump Ore**: lump ore continues as minority (5-20%) burden material usually with high sinter burdens

DIRECT REDUCTION RAW MATERIALS - Ironbearing

- **Ironbearing materials quality is important: in direct reduction processes the only chemical change is removal of oxygen from ore while the remaining constituents stay with direct reduced iron product but increase in concentration (about 1.5 times) due to the removal of oxygen. These affect process economics of subsequent EAF melting vessel. By contrast, smelting reduction processes (including the blast furnace) provide the formation of a refining slag that captures much of the iron ore gangue. The key chemistry requirements for DR grade pellets are:**

- **Fe > 67 %;**
- **acidic gangue (SiO2+Al2O3+TiO2) preferably below 2 %, but acceptable below 3 %**
- **low levels of steelmaking impurities: P, Mn, S**
- **residuals (Cu + Ni + Cr + Mo + Sn) should be lower than in prime scrap**

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DIRECT REDUCTION RAW MATERIALS - Ironbearing

. **DR grade pellets are usually 100 % of charge in DRI shaft furnaces except in countries with local lump ore where such lump ore is minority (10-40%) burden component: Venezuela, India, Mexico;**

. **DR grade pellets locally produced in Russia, Venezuela, India, Mexico while seaborne DR grade pellets from Brazil, Canada, Sweden, others feed DRI plants in MENA, USA, elsewhere; DR grade pellets also produced in MENA region but with DR grade pellet feed from mainly Brazil**

O **Lump ore, locally sourced, continues to be used as the primary ironbearing material, in coal based rotary kiln DRI processes, mainly in India, South Africa**

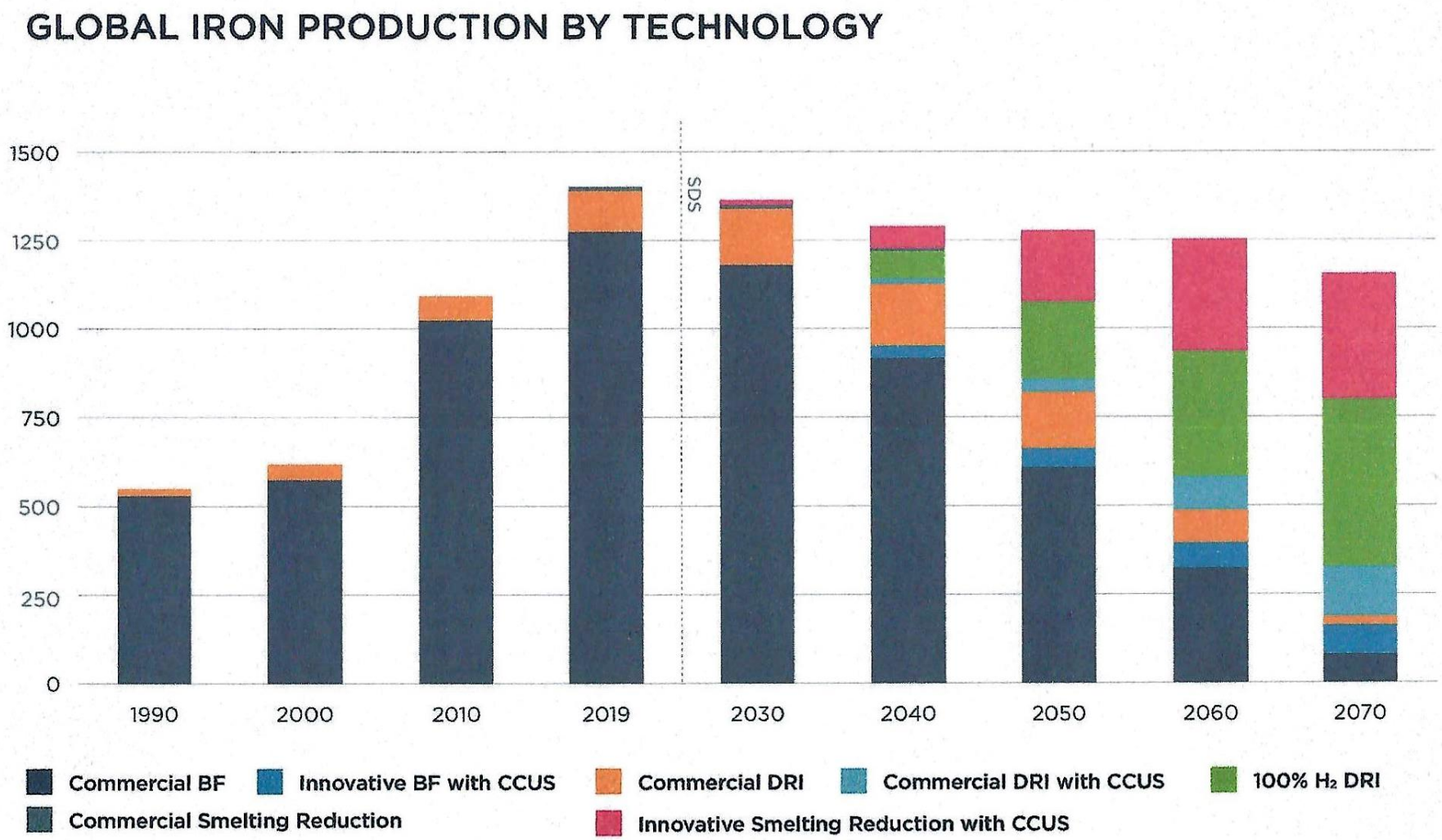


FIG. 1: Global iron production by technology in the "sustainable-development scenario" (SDS) from 2020 onward according to the International Energy Agency (BF: blast furnace; CCUS: carbon capture, utilization, and storage; DRI: direct reduced iron)

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Challenges Facing Transition to Scrap/DRI/EAF Steelmaking Route Globally (ex-Asia)

Globally, BF/BOF producers face:

- **CAPEX challenges in switching to Scrap/DRI/EAF processes**
- **OPEX challenges in cost/availability of DR grade pellets**
- **OPEX challenges in cost/availability of natural gas now and H2 in future**
- **Competitive cost challenges in OPEX, CAPEX investment recovery, especially for EU producers, already at cost disadvantage compared to Asian producers,**
- **Need for CBAM (carbon border adjustment mechanisms) to compensate steel producers in countries moving faster towards CO2 emission in relation to steel producers in countries moving much more slowly in reducing CO2 emissions (e.g. China)**

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Challenges Facing Transition to Scrap/DRI/EAF Steelmaking Route in Asia

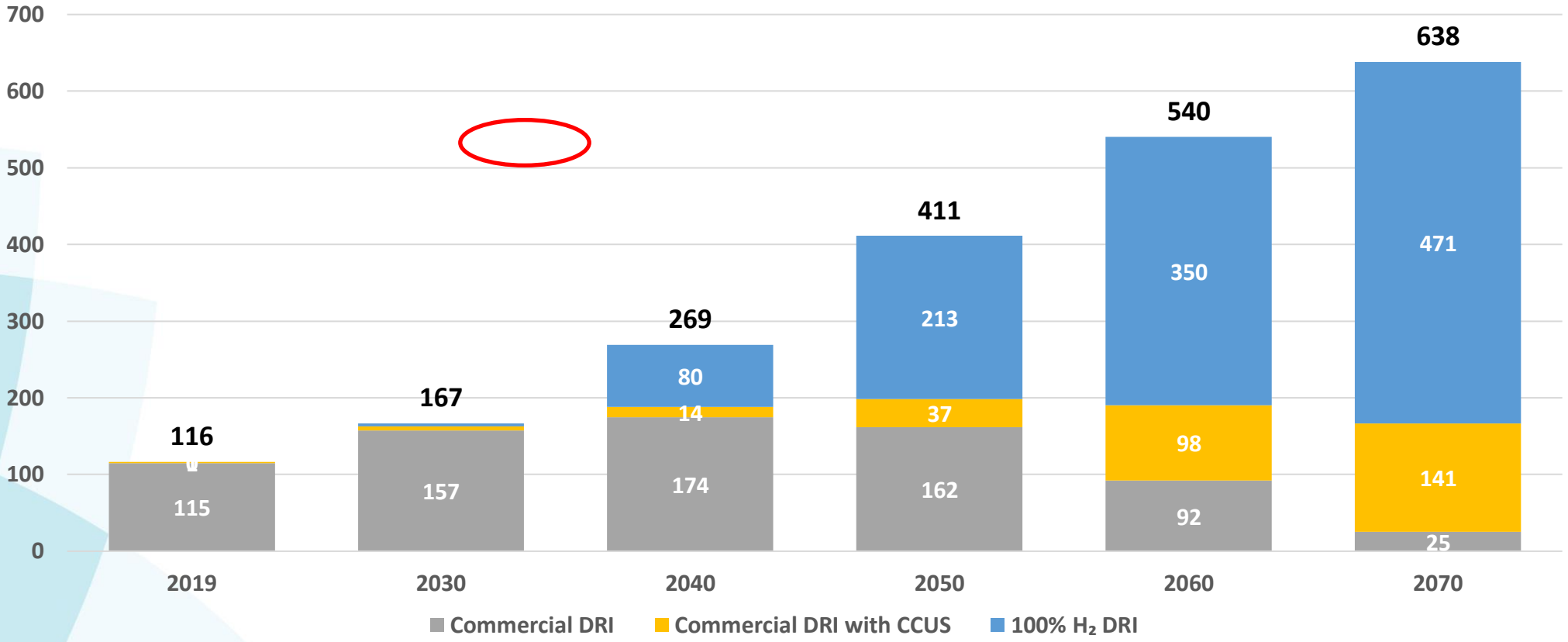
Young age, CAPEX already in place of existing Asian BF/BOF facilities,

Asia DRI raw material challenges: high cost of natural gas, H2; reliance upon Australian iron ore base that is less suitable for DRI processes

Limited Scrap Availability in short, intermediate term; expect long term surplus in Asia,

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DRI production according to IEA's sustainable development scenario -



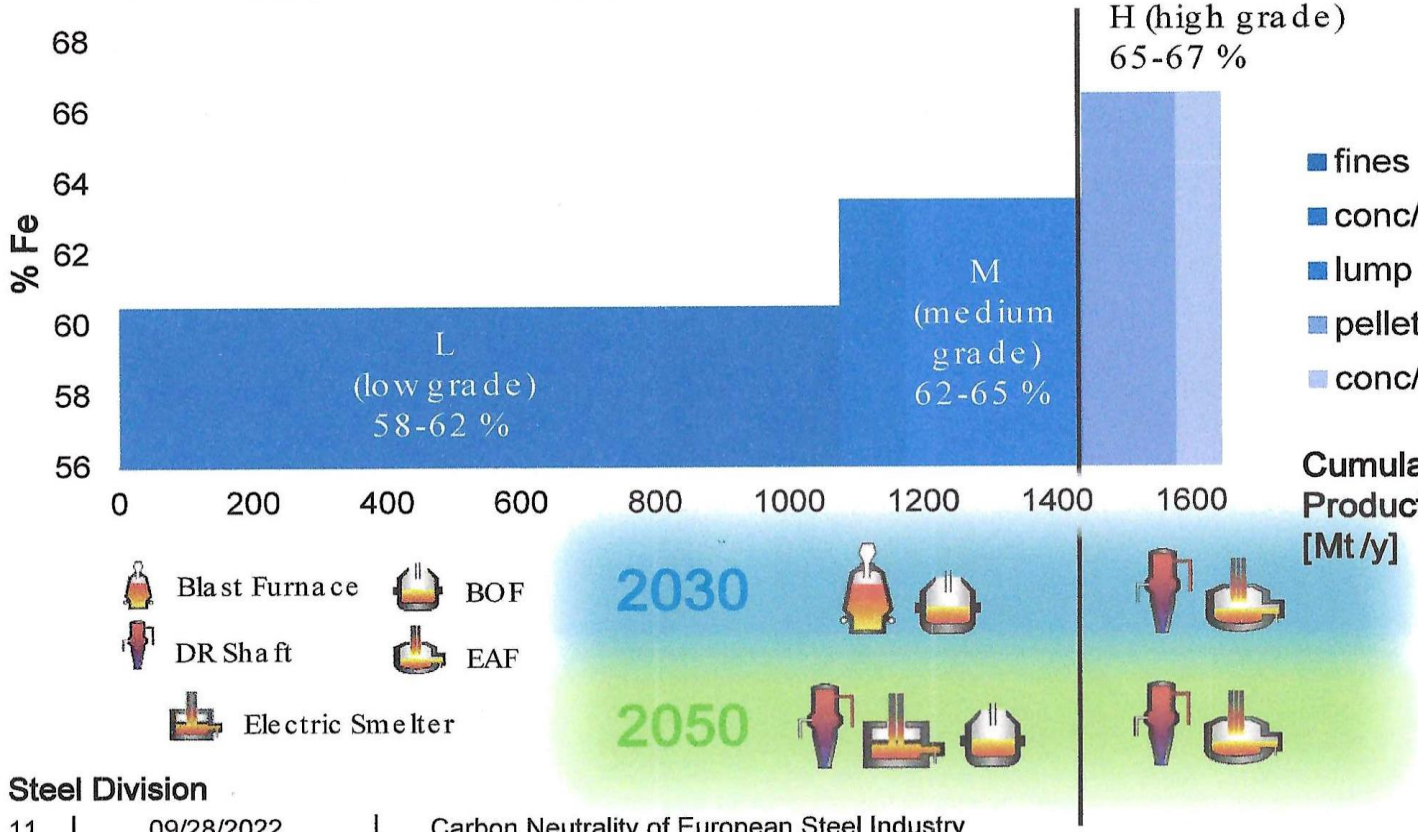
Quality requirements: DR grade iron ore

As the EAF is the principal consumer of DRI, its quality and technological requirements indirectly tend to dictate iron ore specifications, in essence:

- Fe content as high as possible, minimum 66%, ideally ≥67%
- Acid gangue content (SiO_2 + Al_2O_3) as low as possible, maximum 3.5%, ideally maximum 2% (also TiO_2 <0.2-0.35%, ideally <0.15% - depending on process)
- CaO up to 2.5%
- MgO up to 1%
- Phosphorus (as P_2O_5) as low as possible, ideally ≤0.015%, but maximum up to 0.08%, depending on the final steel product
- Sulfur as low as possible, maximum 0.025%, ideally maximum 0.015%
- Na_2O + K_2O 0.2% max.
- Metallic impurities such as Cu, Cr, Ni, V, as low as possible

It’s a different story for HBI charged to the more flexible blast furnace

TRANSFORMATIONSTEELMAKING
IRON ORE PRODUCTS BY QUALITY

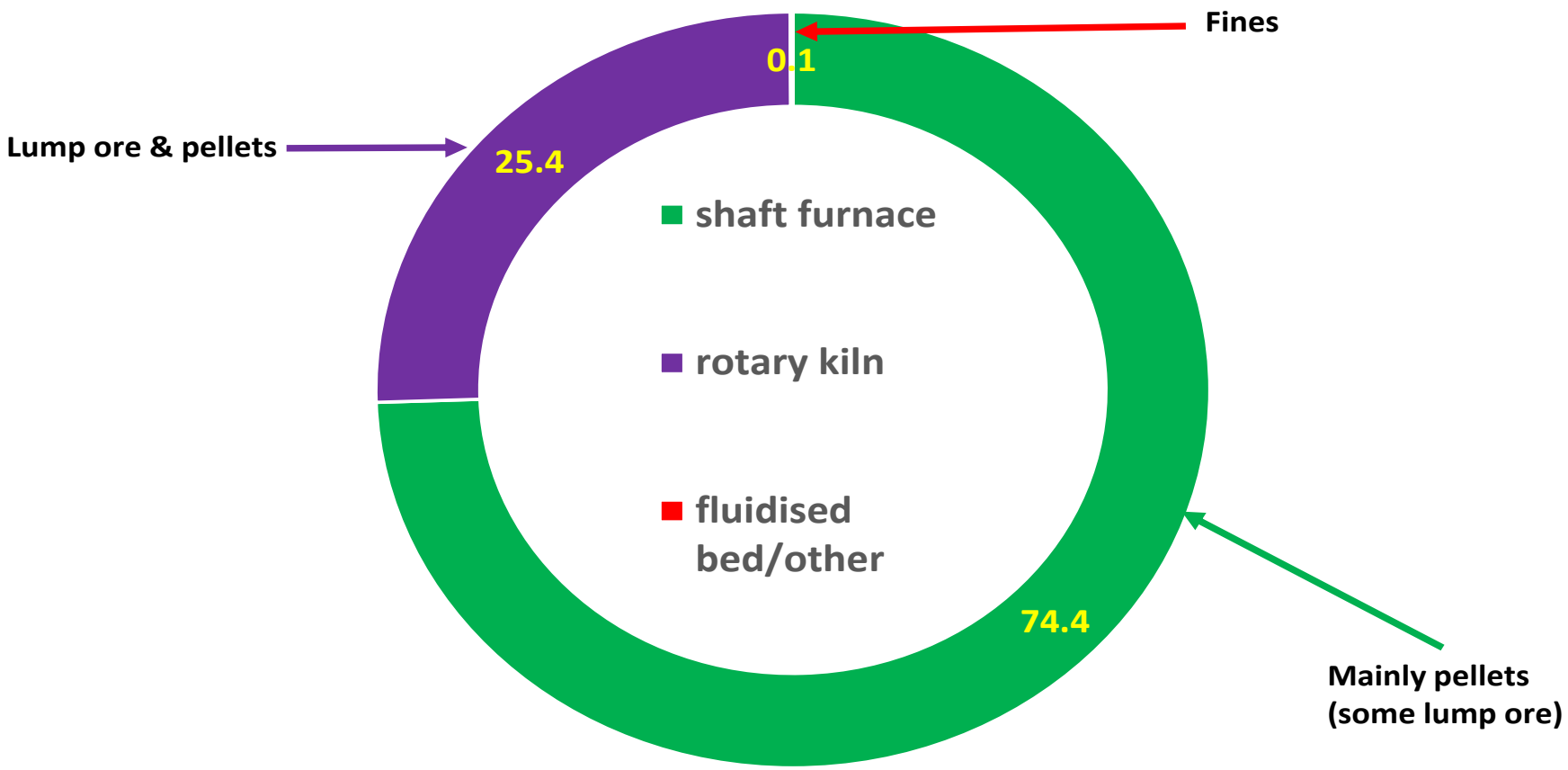


- World iron ore market is dominated by low and medium grade iron ores
- Focus on replacement of BF/BOF by DR/EAF process route requires development of an adapted metallurgical concept for steel-making from L/M grades starting from DR process

voestalpine
ONE STEP AHEAD.

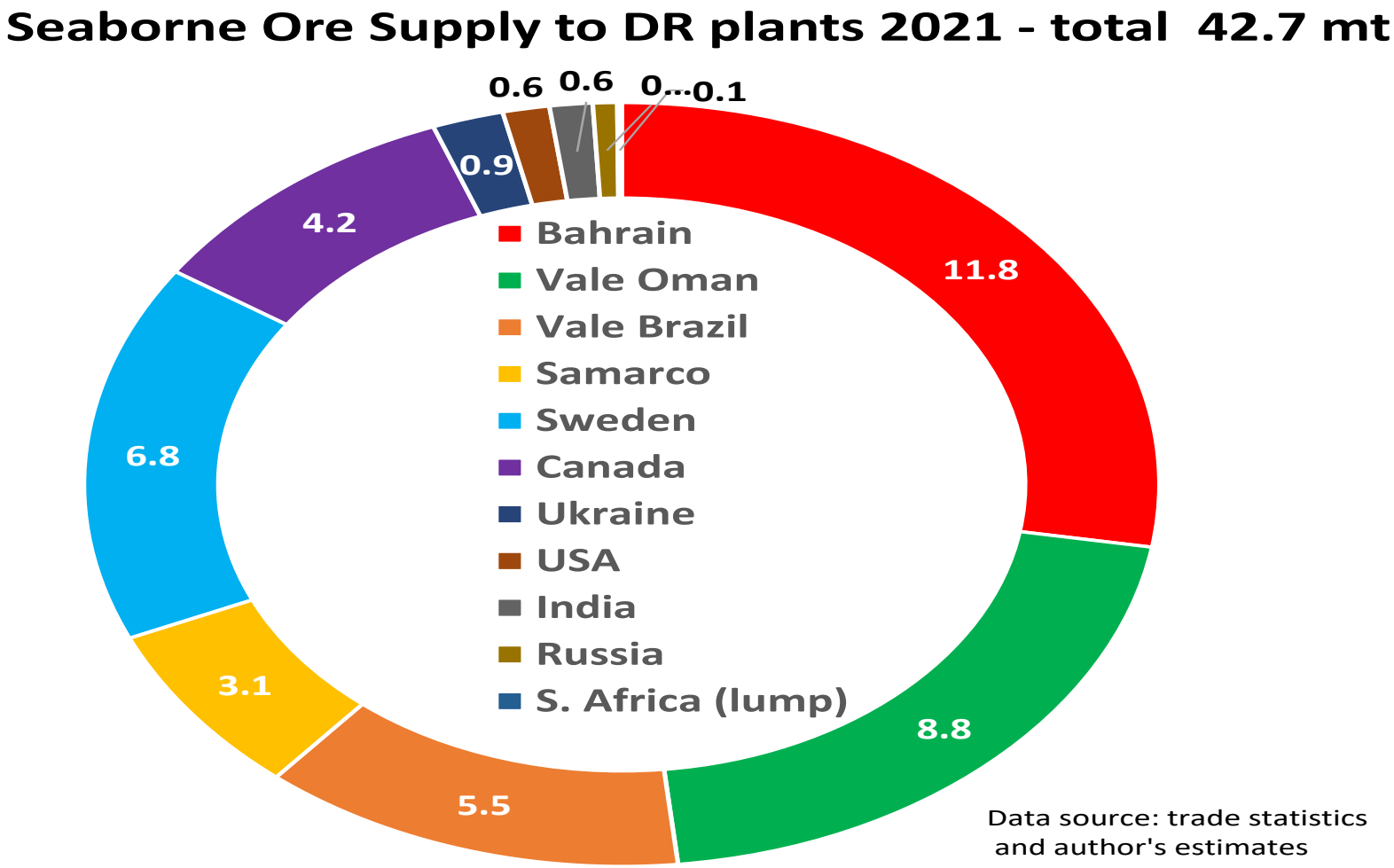
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DRI production by process 2021



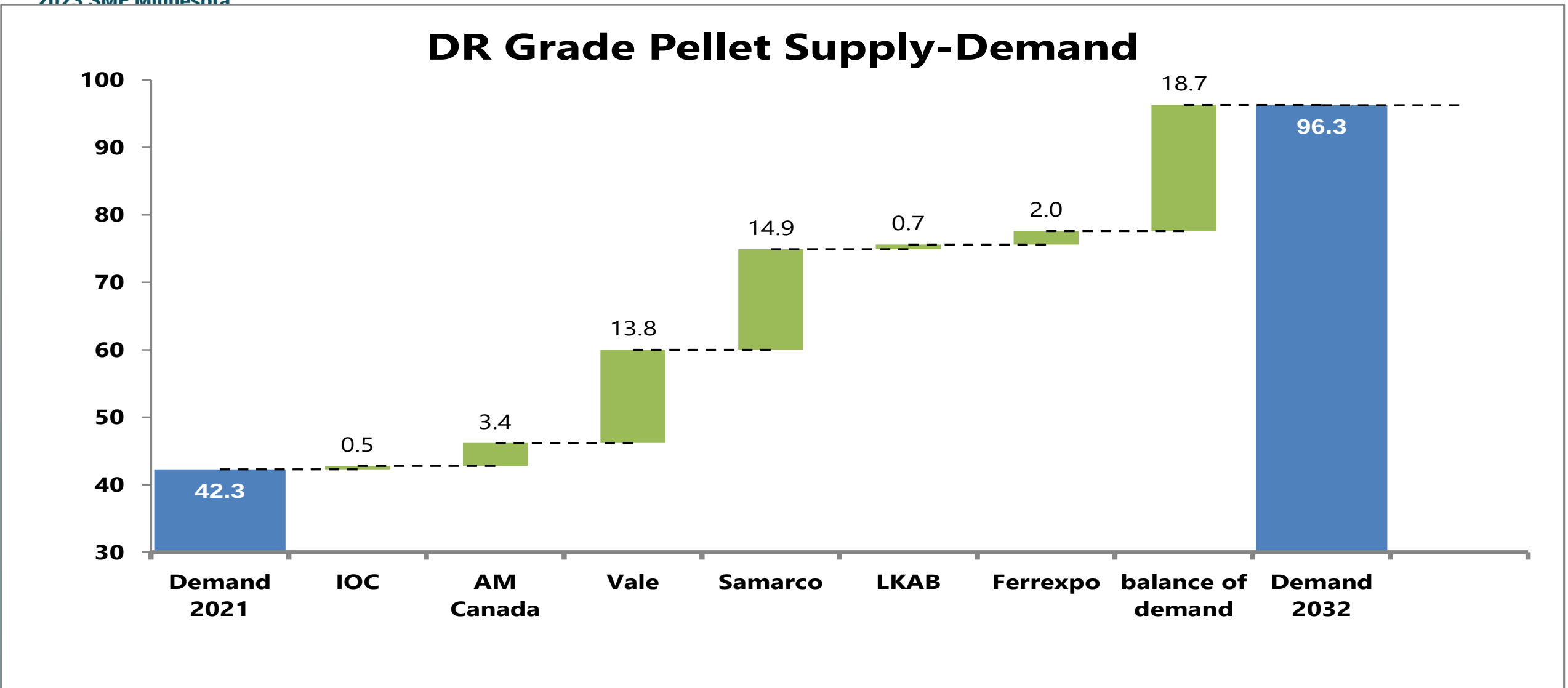
Data source: Midrex Technologies

Seaborne ore supply to DR plants 2021



Comparable calculated pellet demand in 2021 = 42.3 mt

DR grade pellets: supply-demand



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Potential solutions to shortage of DR grade pellets

- DR pellet projects (high CAPEX) and lump ore
- use of BF pellets as DR feedstock with use of intermediate smelting step between DR and BOF steelmaking plant
- integration of pellet plant with DRI production (limited scale of pellet plant, CAPEX issue)
- use of fines-based DR technologies
- use of other iron ore agglomerates (cold bonded briquettes, pellets)

DR pellet projects

- **Revival of dormant pellet projects:**
  - **New Millennium Iron's LabMag/KeMag projects in Canada**
  - **Mesabi Metallics' project in Nashwauk MN**
  - **various joint venture projects in Mauritania, e.g. Guelb El Aouj**
- **Current projects (pending/planning):**
  - **JV projects involving Mauritania: by ArcelorMittal, Sabic/Hadeed and Emirates Steel)**
  - **Champion Iron evaluates producing DR grade pellets at ex-Wabush pellet plant in Canada**
  - **Cargill, in JV with Blastr Green Steel, studying a >5 mt greenfield pellet plant in Norway**
  - **Metso Outotec supplying equipment to Vulcan Pelletizing LLC for 6 MTPY pellet plant at Sohar Oman, operational by the end of 2023?.**

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Pelletising plants integrated with DR plants

- There are currently two DR plants with adjacent pelletising plants using seaborne pellet feed:
  - Tosyali Algerie (with its integrated ore beneficiation plant) - announced Phase 2 development with the same model, and
  - SULB DRI plant, adjacent to Bahrain Steel Pellet Plants.
- Tata Steel IJmuiden's planned DR plant will utilise pellets from its existing onsite pelletising plant.
- Emirates Steel and iron ore producer SNIM in Mauritania in a feasibility study for a JV iron ore pelletising plant.

Seaborne pellet feed supply: required for pellet plants built at steel plant sites

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Currently, commercial availability of DR quality pellet feed is limited to a few suppliers:

- Anglo American's Minas Rio operation in Brazil (8 MTPY DR grade pellet feed supplied to Bahrain Steel), but high-grade BF pellet feed is also supplied to the DR sector;
- Champion Iron's Bloom Lake mine in eastern Canada, increasing share of DR-grade concentrate with a feasibility study underway for 69% Fe concentrate;
- Tacora Resources (ex-Scully Wabush mine), supplies some concentrate to DR pellet plants
- Compañia Minera del Pacífico in Chile produces some high-grade magnetite concentrates;
- Kaunis Iron in Sweden (2 MTPY) of high-grade concentrate with plans to expand production
- CSN Mineração plans to increase capacity at the Casa de Pedra mine in Brazil from 33 mt up to 108 mt by 2033 – pellet feed availability, including DR grade, will increase significantly

- New greenfield projects at various stages of development include Black Iron's Shymanivske project in Ukraine (first phase 4 mt, second phase 8 mt 68% Fe pellet feed), several projects in Scandinavia (Nordic Iron Ore and Beowulf Mining, Sweden, Tacora Resources, Norway , and various magnetite projects in Australia (incl. FMG's Iron Bridge, Hawsons Iron, Magnetite Mines' Razorback and Grange Resources' Southdown projects). Australia magnetite projects face huge CAPEX hurdles.

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Use of other iron ore agglomerates

- **Going back to the early 1970s, development of cold-bonded iron ore agglomerates has been something of a holy grail for the industry.**
- **Vale has developed its own cold-briquetting technology and has two briquetting plants (6 MTPY) currently under construction in Brazil. Some successful BF trials and a DR basket test have been completed, with bulk DR trials planned for 2023; my concern for BF operation is absence of high temperature properties; better potential for partial use in DR reactors.**
- **Champion Iron is also evaluating cold-bonded pelletising.**

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Role for NAFTA Blast Furnaces in EAF Steel Production: Producing Merchant Pig Iron

- Blast furnace production of merchant pig iron to displace imported (Brazil, Russia, Ukraine) pig iron (> 5 MTPY)
- Currently, one pig caster at Cliffs Indiana Harbor and also one just installed at Stelco Lake Erie; latter initially not used in favor of more profitable sheet steel production, now being used
- USSteel announced:
- - pig caster project at Gary plant, to feed USS Big River Steel EAF plant and USS Fairfield EAF; startup in 1Q23
- - JV with SunCoke to produce pig iron for BRS at USS Granite City using
- USSteel pellets, Gateway SunCoke

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Canada Transition to EAF Flat Steel Production

- **ArcelorMittal Dofasco – plan to switch from BF/KOBM to DRI/scrap/EAF steel production by 2027; already operating one scrap/hot metal/EAF; source DR grade pellets from AM Mines Canada; local scrap**
- **Broken ground on construction**
- **Algoma – plan converting from BF/BOF to EAF; single large BF, metallics challenge: scrap deficient region, no iron ore equity; high CAPEX for iron ore/DRI, feed EAF with BF hot metal**
- **Stelco – no announced plans; just completed reline of Lake Erie BF 1; excess coke capacity;**

- **==➔ government subsidies planned for AM Dofasco, Algoma; all face carbon taxes; subsidies, carbon taxes not likely in USA**

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EU Future Growth of DRI/EAF Steel Production to Reduce CO2 Emissions

- **Established BF/BOF producers will gradually make transition to scrap/DRI/EAF steel production:**
  - **pilot plant, demo plant, H2 studies through 2025**
  - **2025-2030 – first wave of conversions: 15 MTPY out of current capacity of 80 MTPY of hot metal capacity to be closed in favor of scrap/DRI/EAF production: SSAB, Salzgitter, Voest Stahl, TKS, Tata Ijmuiden, ArcelorMittal (Bremen, Eisenhuttenstadt, Dunkerque)**

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Implications for Future Iron Ore Demand

- USA – continued increase EAF flat rolled mini-mill production decreases USA pellet demand demand; tempered hopefully by BF merchant pig iron production
- Canada – major switch to EAF production reduces pellet demand by 50 - 75 % in 2025-2030 period,
- Europe – major transition to DRI/EAF production begins in 2025-2030 period, increased demand for DR grade pellets will be relaxed by adoption of DRI/smelting combinations while major decreases in sintering ore demand expected.
- Asia (including China, SE Asia) – major recent (<15 years) BF/BOF investments suggest that major focus will be on reducing CO2 emissions within context of BF/BOF production: limited impact on iron ore; expect increased pellet demand at expense of sintering ore demand but sinter will remain major iron bearing feed.

==➔ limited impact on iron ore demand until 2025-2030 period when major changes occur

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CONCLUSIONS AND FUTURE DIRECTION

- **Iron ore resources are adequate for blast furnace ironmaking;**
- **Reserves of lower grade ore that can be upgraded to high quality concentrates are also more than adequate.**

- **For direct reduction ironmaking, the projected major increase in the DRI/EAF steelmaking production will face a shortage of DR grade pellets but there are two avenues available to address this:**
- **In China and in much of the developing world, the scrap reservoir will increase sharply through the 2030-2050 period; thus scrap could be used in large percentages in the DRI/scrap/EAF steel processing route, up to the limits imposed by steel quality, increased scrap also for the BF/BOF route**
- **In the developed world (NAFTA, EU, Japan, etc) the scrap reservoir will only grow incrementally but the DRI route could modified by adding melting step such that:**

a) BF grade iron ore could be used, as the melting step provides a refining function and

b) existing BOF/caster facilities could continue to be used.

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Thank you!

- **Questions?**

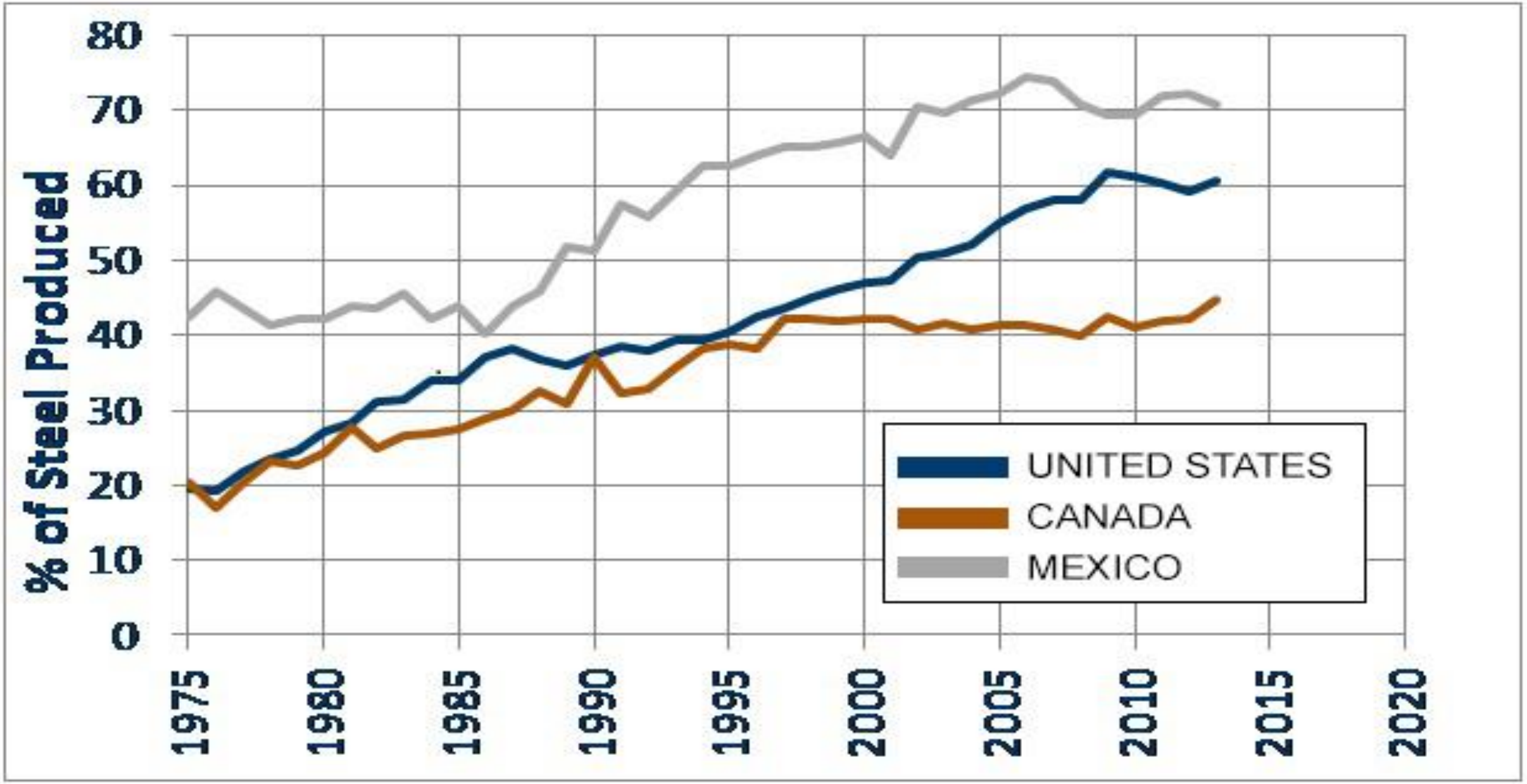
- joe.poveromo@rawmaterialsiron.com
- phone 610 442 3527

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Appendix

- Trends in BF/BOF vs scrap/DRI/EAF steel production
- Global scrap trade
- Scope 1,2, 3 Emissions: raw material supply chain and raw material processes: cokemaking, sintering, pelletizing; ironmaking processes
- DR grade pellet supply/demand details
- Decline in sintering ore fines quality
- Other Options for EU Low CO2 Steel Production
- Melting/Smelting DRI for BOF

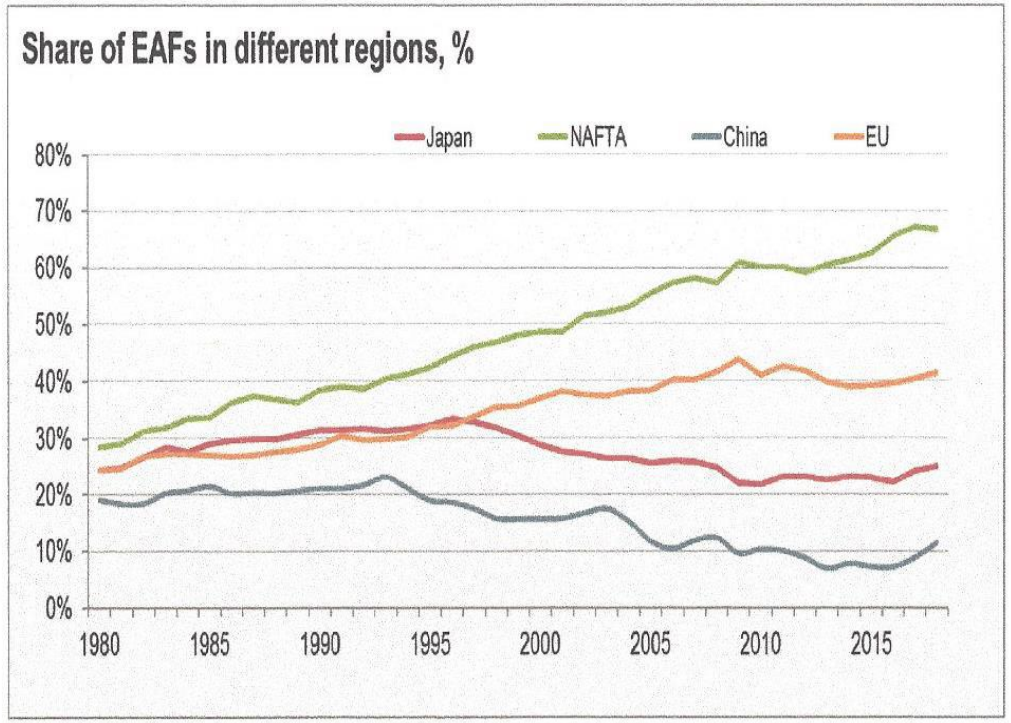
Growth of EAF Steel Production NAFTA



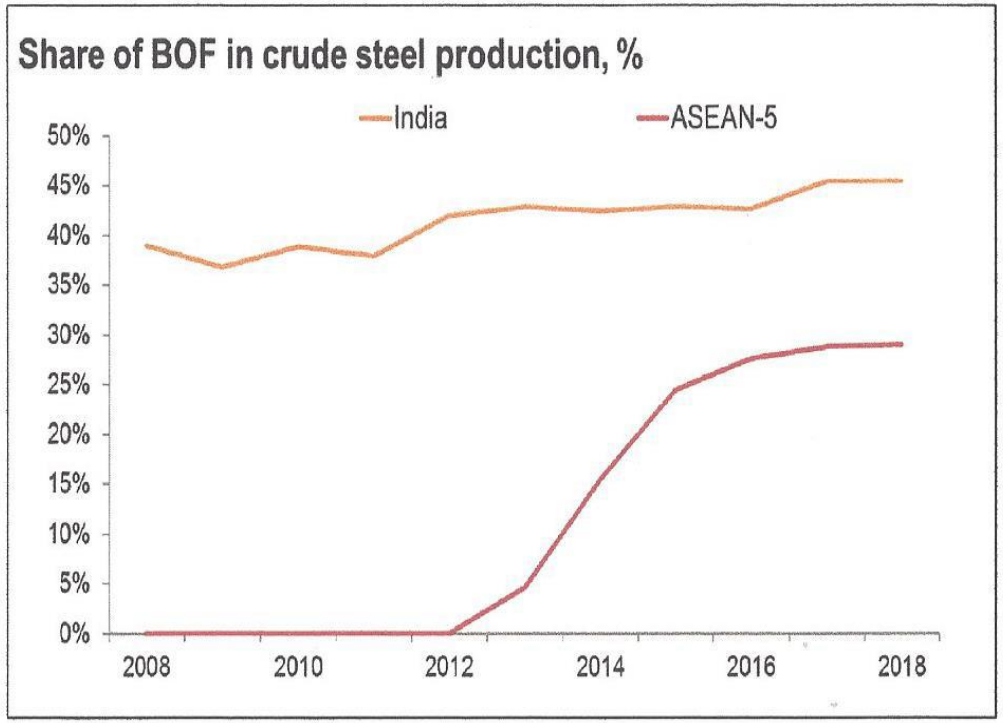
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Steel production shows different characteristics at different regions

- Japan, US and EU, three scrap surplus regions, had a similar level for the share of EAFs in total steel output in 1980's…



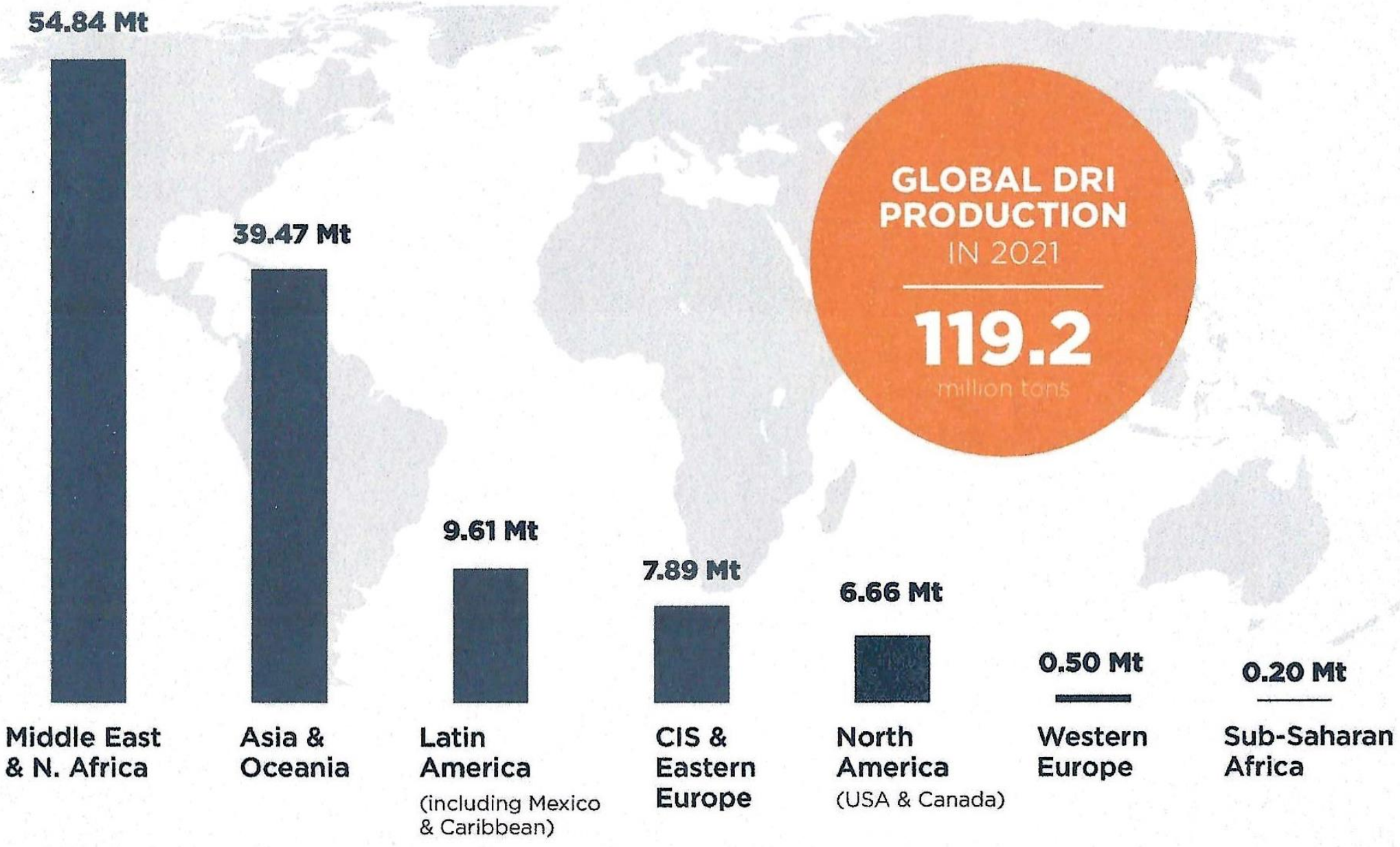
- Share of BOFs showing growth in India and ASEAN



Source: worldsteel

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2021 WORLD DRI PRODUCTION BY REGION



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Global Scrap Trade, 2021 MT

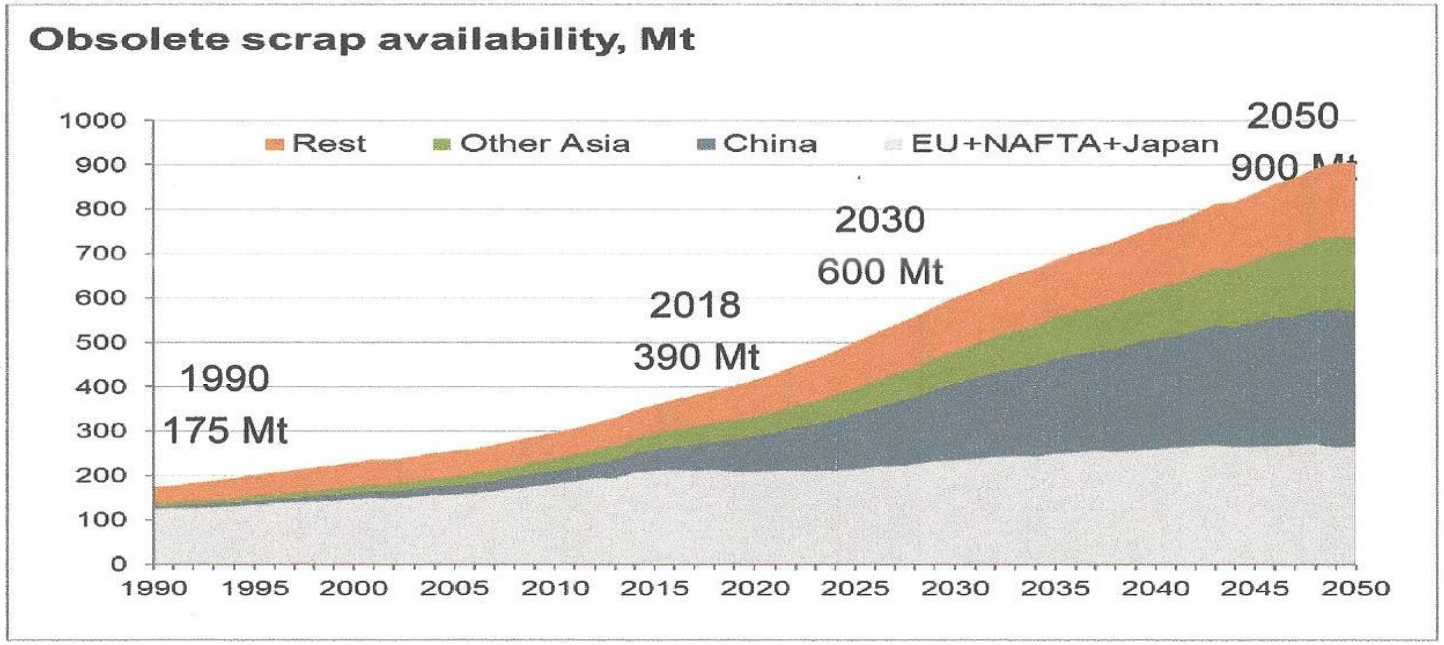
Region/ Country	Total Exports	Extra Regional Exports	Excluding Intra Regional Trade	Total Imports	Extra Regional Imports	Net Exports
EU 27	47.9	19.3	28.6	34.0	5.5	13.9
other Europe	10.9	8.2	2.6	25.6	23.0	-14.7
CIS	5.1	4.1	1.1	1.5	0.4	3.7
USMCA	23.3	14.9	8.4	9.3	0.9	14.0
Other Americas	3.8	3.5	0.3	1.1	0.9	2.6
MENA	5.5	5.2	0.4	5.3	4.9	0.2
China	0	0	0	0.6	0.6	-0.6
Japan	7.3	7.3	0	0.1	0.1	7.2
Other Asia	3.2	0.3	2.9	32.1	29.2	-28.9
Oceania	2.8	2.7	0.1	0.2	0.1	2.6
World	109.8	62.8	44.4	109.8	65.5	

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Limited Short and Intermediate Availability of Scrap in Asia

- **Total Global Scrap Trade only circa 110 MT in 2021**
- **Asia region is a major net importer of scrap**
- **Some current major scrap exporting countries may restrict scrap outflows to protect availability for local steel producers as part of decarbonization efforts,**
- **Scrap exporting is already restricted by a number of countries**

Obsolete scrap wave approaching



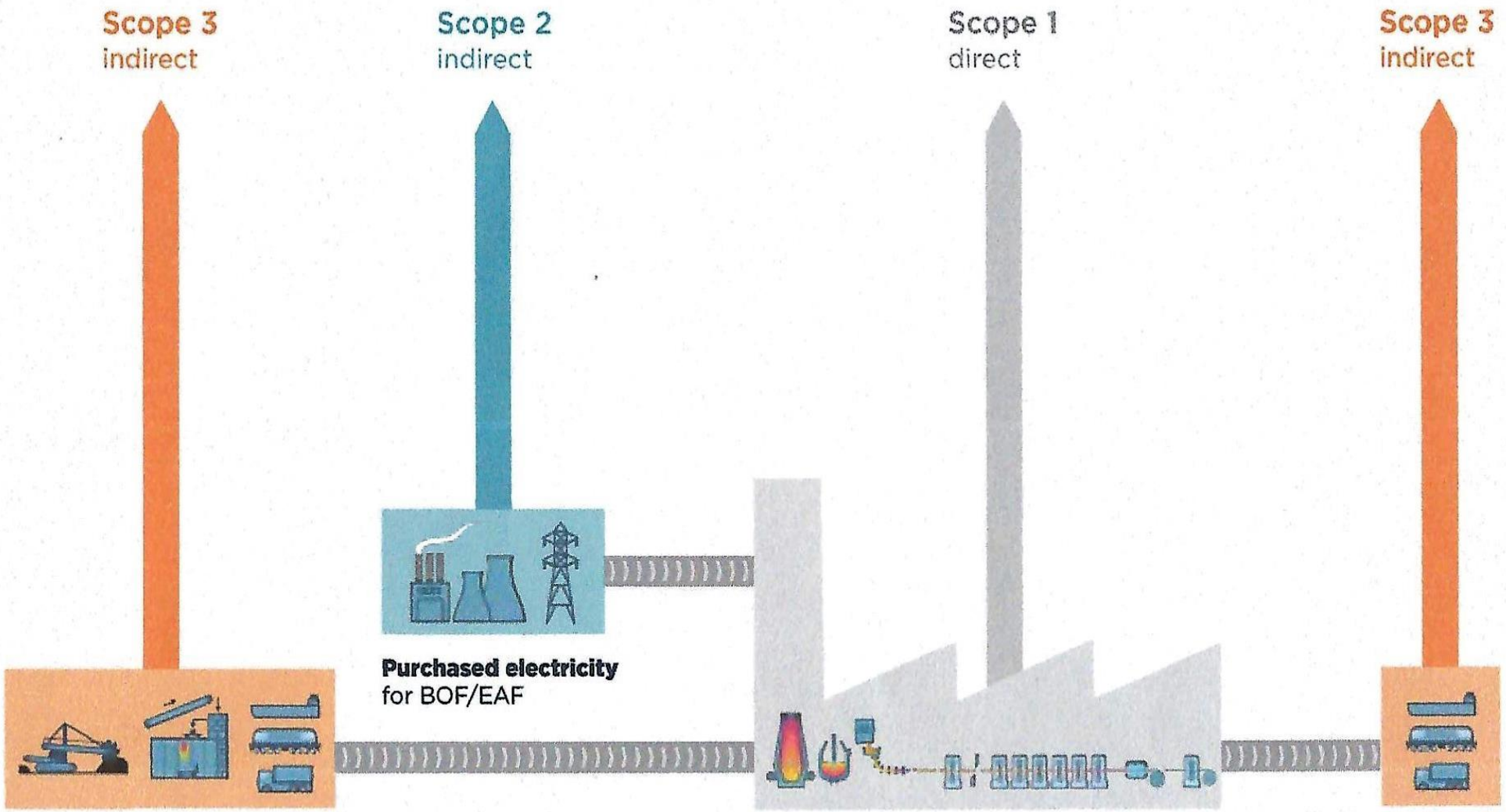
- Obsolete scrap availability estimates
  - EU+NAFTA+Japan: 210 Mt in 2018, 235 Mt in 2030, 265 Mt in 2050
  - China: 65 Mt in 2018, 175 Mt in 2030, 300 Mt in 2050
  - Other Asia: 40 Mt in 2018, 75 Mt in 2030,165 Mt in 2050
  - Rest: 70 Mt in 2018, 120 Mt in 2030, 170 Mt in 2050

worldsteel ASSOCIATION

Source: worldsteel scrap availability model

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SCOPE DIVISION OF PRODUCTION EMISSIONS



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CO2 emission aspects of mining and transportation of raw materials: iron ore, coal

- **Coal Mining** — **kg CO2/ton of coal**
- ***mainly due to methane gas emissions***

- **Small, deep underground mines in China — 0.6 – 0.8**
- **Larger scale mines in Shanxi province, China — 0.3**
- **Large, open pit mines in Australia — <0.2**
-
- **Iron ore mines** — **kgCO2/ton of ore**

- ***lower CO2 emissions mainly with electrical power, fuel use in mobile equipment, processing facilities*,**
-
- **Iron ore concentrate and pellet feed — 0.05 – 0.10**
- **DSO (direct shipping ores) — < 0.05**

- **Need to add transportation costs (rail to port; seaborne vessels) to above**

CONTRIBUTION OF RAW MATERIAL PROCESSING STEPS TO CO2 EMISSIONS

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- **Coal ----------→ coke ovens + PCI plant 0.27 tons CO2/ton**
- **Iron ore, additives-----→ sinter plant 0.22 tons CO2/ton**
- **Iron ore, additives-----→ pellet plant –magnetite ore 0.04 tons CO2/ton**
  pellet plant -hematite ore 0.08 “ “

Blast furnace 1.28 tons CO2/ton
(with slag granulation, 0.96 “ “
top gas to power plant)

DRI shaft furnace 0.45 tons CO2/ton
(CH4 gas)

MEASURES TO REDUCE CO2 EMISSIONS – SINTERING, PELLETIZING, COKEMAKING

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- **Sintering process –**
- **replace carbon (coke breeze, anthracite) with biomass fuel sources: charcoal**
- **utilize "green" H2 or natural gas as ignition furnace fuel,**
- **switch to "green" electricity sources for fans, drives, etc,**
- **other: waste gas recirculation, advanced process control.**
- **Pelletizing process –**
- **replacing carbon (coke breeze, anthracite) with biomass (such as charcoal) fuel sources for hematite ore pelletizing; VALE in Brazil conducting trials**
- **utilize "green" H2 or natural gas as burner fuel**
- **plasma torch based induration burners using "green" electricity**
- **switch to "green" electricity sources for fans, drives, etc, (see comments above for sintering),**
- **use of magnetite ores in pelletizing does not require carbon so, for example, Mesabi Range producers and LKAB in Sweden, by pelletizing magnetite ore, already are producing greener pellets.**
- **Coke ovens –**
- **green opportunities are limited to green electricity for motors, fans, etc.;**
- **CDQ (coke dry quenching) provides some BF coke rate reduction; therefore some CO2 reduction benefit**

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CO2 emission reduction: blast furnace/BOF and shaft furnace DRI processes

- **Blast Furnace process**
- **injection of H2, syngas to replace injection of coal and natural gas,**
- **charging of metallics such as HBI, prepared scrap**
- **Increased use of pellets**
- **Other coke rate reduction steps: plasma enhanced increased blast temperatures**

BF Process Issue:

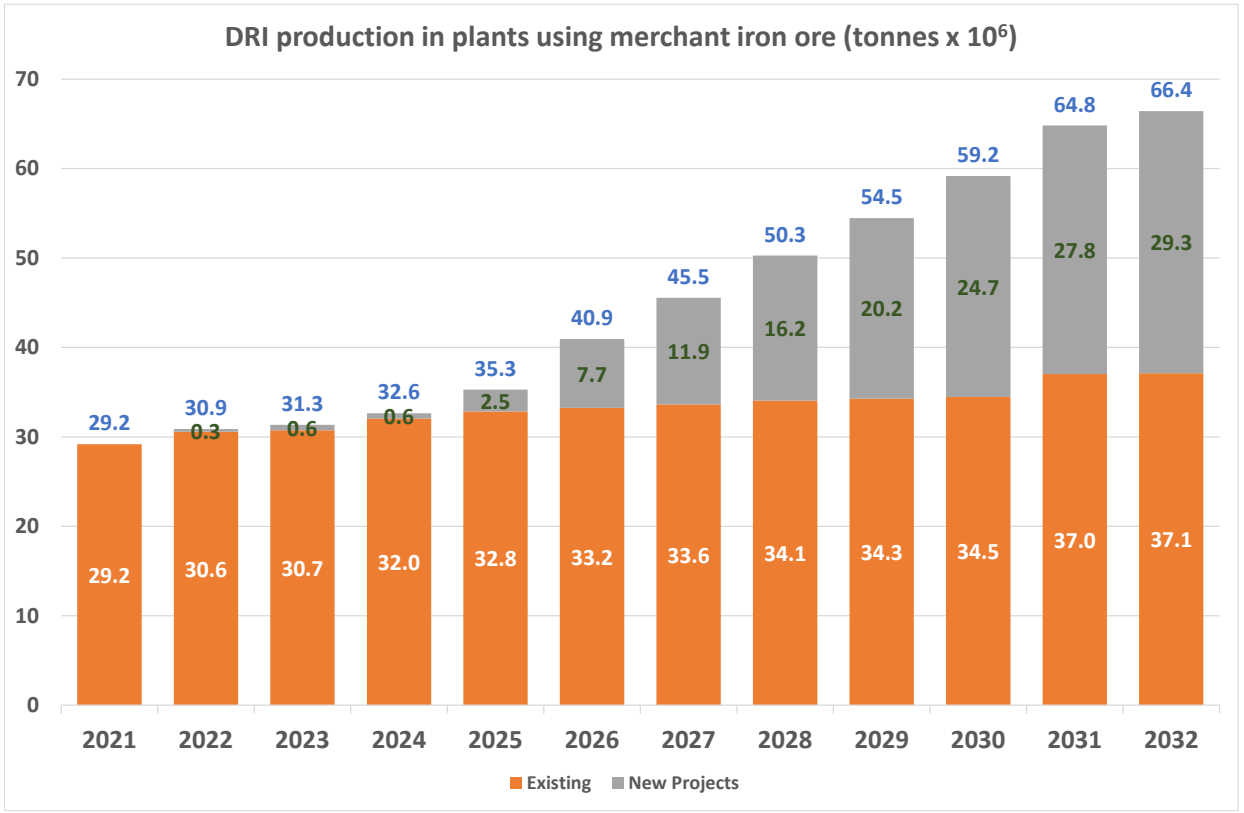
What is the minimum BF coke rate to ensure permeability of gases/liquids: 250, 200 or < 200 kg/T ?

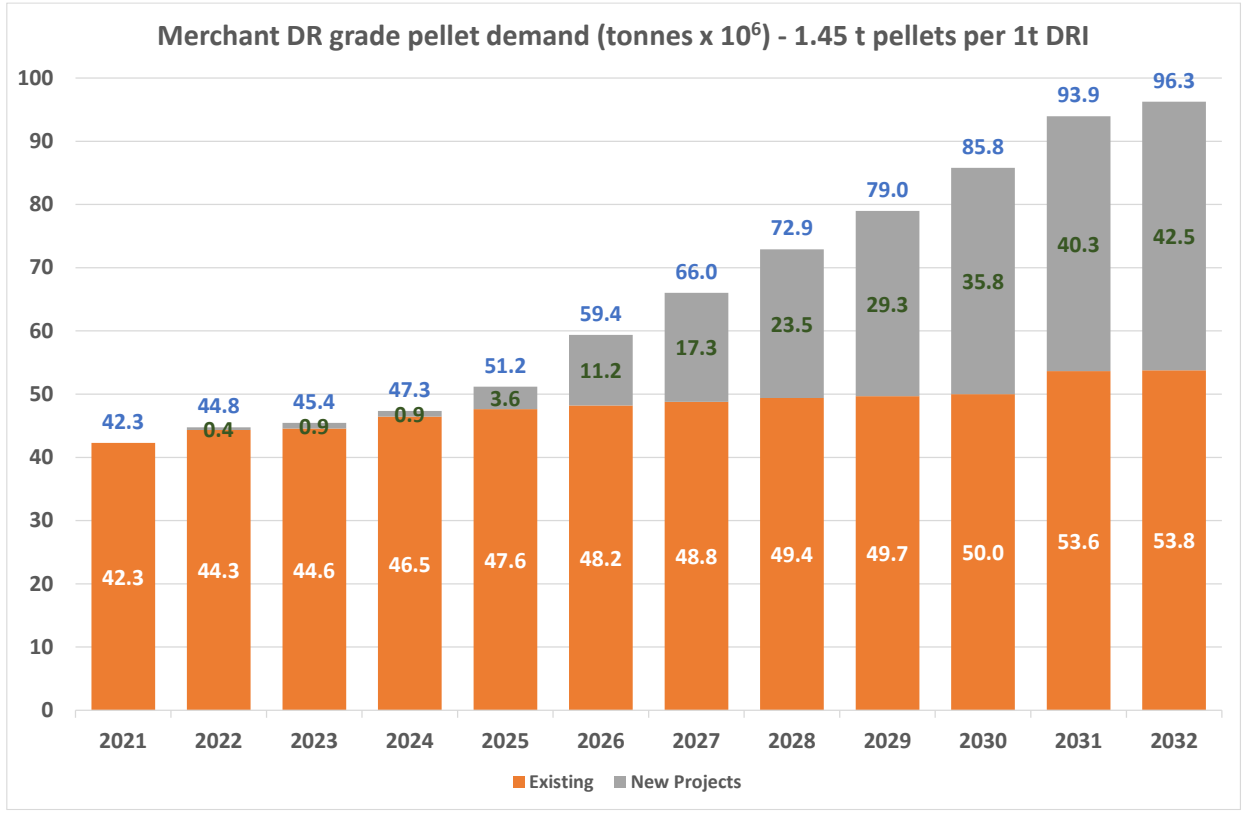
BOF process

- **Use increased percentage of scrap**

- **Direct reduction process: using H2 as the reducing gas in place of methane**

DRI production and merchant pellet demand





Countries with DR plants using purchased pellets: Argentina, Trinidad, USA, Germany, Algeria, Libya, Egypt, Saudi Arabia, Qatar, UAE, Oman, Malaysia
+ Bahrain which uses pellets based on purchased pellet feed

New DR projects based on purchased ore

New DR plants	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
HBIS	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Baosteel Zhangjiang				0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AM Hamburg				0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Salzgitter phase 1				0.3	1.5	2.1	2.1	2.1	2.1	2.1	2.1
TKS phase 1					1.0	1.5	2.0	2.5	2.5	2.5	2.5
AM Bremen					0.5	1.5	2.0	2.0	2.0	2.0	2.0
AM Gijon				0.5	1.5	2.0	2.3	2.3	2.3	2.3	2.3
AM Dunkirk						0.5	1.5	2.0	2.5	2.5	2.5
H2GreenSteel Sweden				0.5	1.5	2.1	2.1	2.1	2.1	2.1	2.1
Rogesa/Saarstahl						0.5	1.5	2.0	2.5	2.5	2.5
AM Gent							0.5	1.5	2.0	2.5	2.5
DRI d'Italia							0.5	1.0	1.5	2.0	2.5
Salzgitter phase 2								0.5	1.5	2.1	2.1
Salzgitter - Wilhelmshafen								0.5	1.5	2.0	2.5
TKS phase 2									0.5	1.5	2.0
Total	0.3	0.6	0.6	2.45	7.7	11.9	16.2	20.2	24.7	27.8	29.3

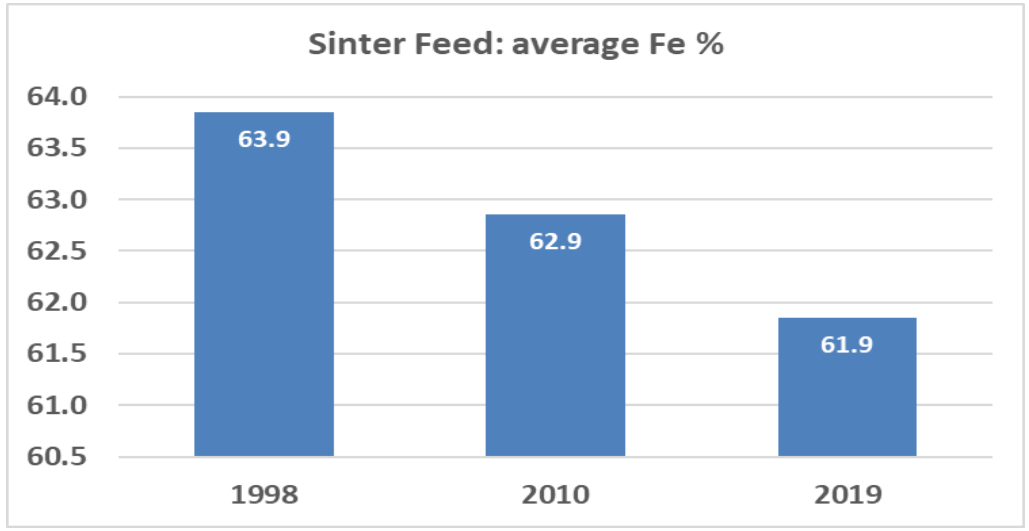
DR projects based on purchased iron ore not included:
Liberty Steel Galati, Liberty Steel/SHS @ Dunkirk, H2Green Steel Spain, AM Eisenhuettenstadt. GravitHy Fos-sur-Mer, LISCO Misurata, POSCO Roy Hill. POSCO Vale, Essar Saudi Arabia, Baosteel/Saudi Aramco, Delong/TEDA - Saudi Arabia, JFE-Emirates Steel, UAE, restart of AM Saldanha Bay, AQS expansion

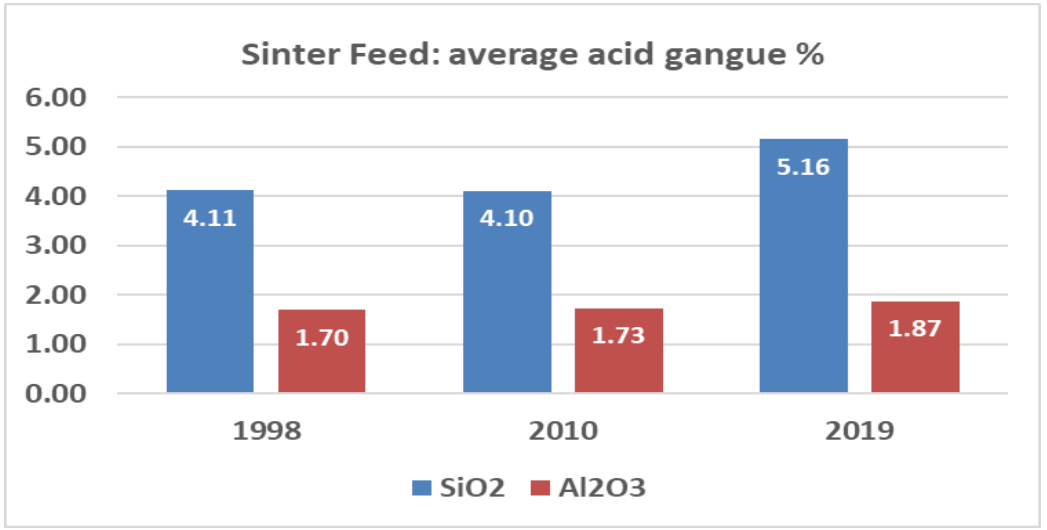
DR projects based on captive or domestic iron ore not included:
LebGOK #4, Mikhailovsky, NLMK, OMK Russia, Severstal Russia, Metinvest, Tosyali Algerie #2, AM Dofasco, Rio Tinto Canada, Tata Steel IJmuiden, HYBRIT

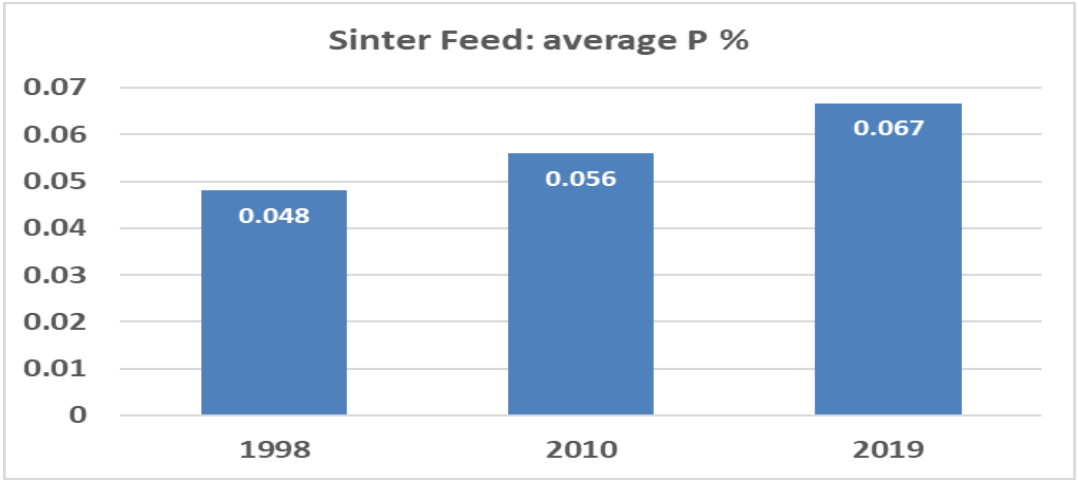
Supply-side assumptions

- Both Canadian pellet producers, IOC and AMMC (ArcelorMittal Mines Canada), have plans to increase supply to the DR sector. AMMC recently announced plans to upgrade 100% of its 10 mt pellet capacity at Port Cartier to DR-grade, no doubt aimed at its captive DR plants in Canada and Europe. Rio Tinto is understood to be studying a merchant HBI plant to be located on the St. Lawrence Seaway, using IOC pellets.
- Samarco restart phases 2 and 3 should be in operation by 2032, representing a return to full capacity production of 30 mt, with 60% assumed to be as DR grade.
- Vale is assumed to reach capacity pellet production of about 55 mt before 2032, of which 50% is assumed to be DR grade in 2032.
- Bahrain Steel produced 12 mt pellets in 2021, in excess of nameplate capacity of 11 mt and this analysis assumes no incremental supply of DR grade material by 2032.
- We assume no incremental supply of DR grade pellets from US producers by 2032 (Cleveland Cliffs exported a modest volume in 2021). It is assumed that production of DR grade pellets by US Steel, starting in 2024, will be consumed domestically, due to the high cost of logistics to export ports.
- By 2032 Russian/Ukrainian DR grade pellets are assumed to be used domestically, except those from Ukrainian producer Ferrexpo (which has no iron or steel production and is geographically well-situated for the European market).

Iron ore quality development







Data source: Raw Materials & Ironmaking Global Consulting

Other Options for EU Low CO2 Steel Production

1) Import Ore-based metallics (pig iron, DRI, HBI) from low-cost sources (Russia, Brazil, Iran?, Canada): sovereign risk issues for all except Canada: Update: Russian invasion of Ukraine removes Russian metallics and limits Ukraine metallics; continued challenges with Iran (sanctions) and Venezuela (collapse in HBI production)

2) Install melter step after on-site DRI production to produce liquid hot metal to feed existing BOF facilities and to utilize lower cost BF grade pellets: OPEX, CAPEX savings – see details

3) Utilize some existing BF operations to feed hot metal/pig iron to newly installed EAF operations, no EU announcements yet

Melting/Smelting DRI for BOF - 1

- **Long standing use of SAF (submerged arc furnaces) for ferroalloy production globally,**
- **Limited experience with smelting DRI for hot metal production:**
- **- Long time use of Hatch process (electric smelting furnace) to smelt DRI made from titanomagnetite lump ore at RTIT (Rio Tinto Iron Titanium) Plant in Sorel,**

- Highveld: melting DRI from VTM (vanadium titanomagnetite) ore produced in rotary kiln DRI process

- SDI IDI (Steel Dynamics, Inc; Iron Dynamics Inc) hot metal process: SAF smelting of lower grade DRI produced in RHF from steel plant waste oxides: 250 KT/yr since circa 2001

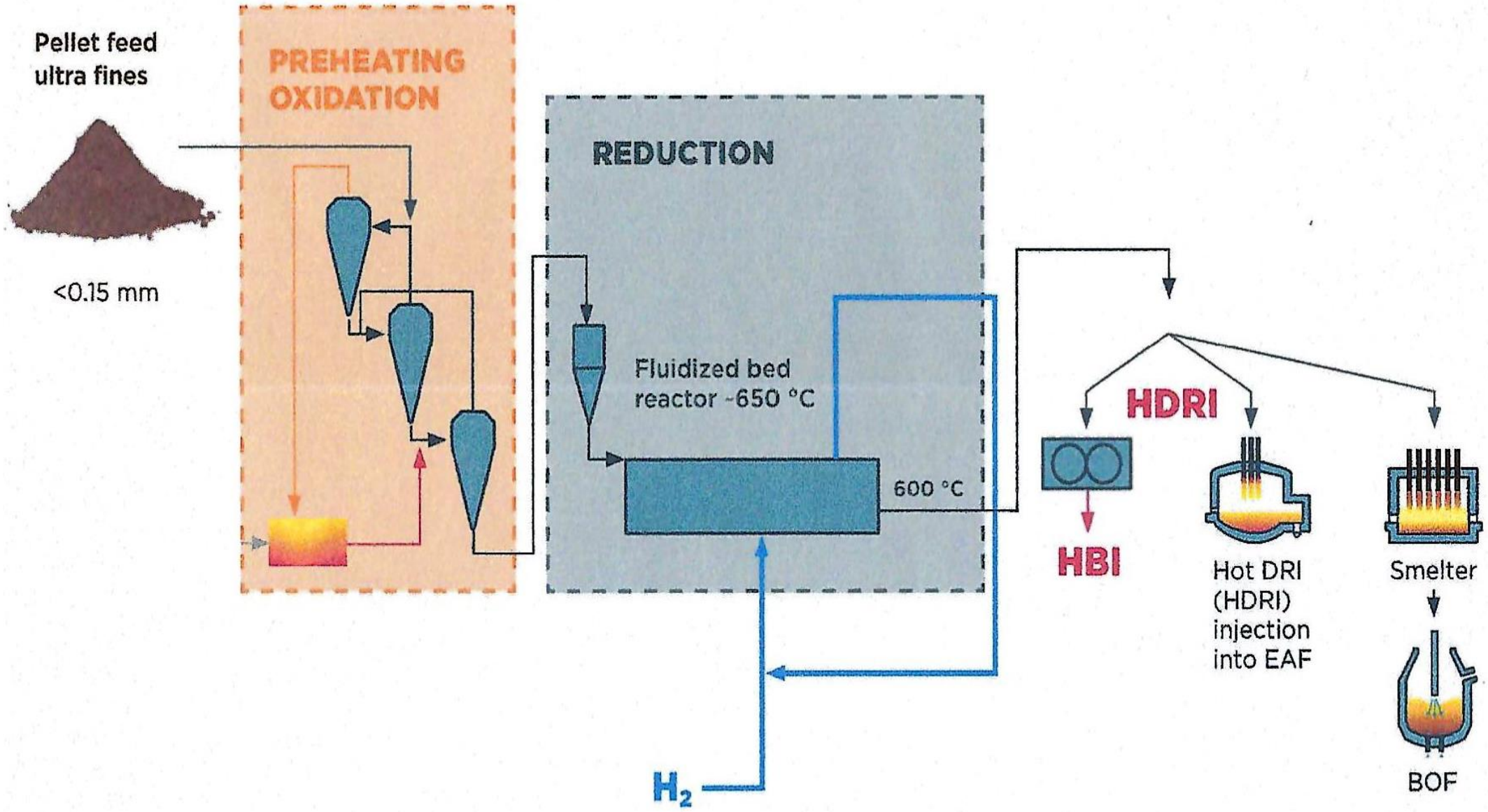
- Projects under study (but not yet financed) involving Tenova HyL DRI shaft furnace production of either VTM ore (Black Rock Metals) in Canada followed by OSBF (Open Slag Bath Melting) or Petmin (BF grade pellets) followed by conventional EAF to produce pig iron

Melting/Smelting DRI for BOF - 2

- **Many equipment options for Melting/Smelting**
- **Hatch – Crisp Process**
- **SMS Demag – SAF**
- **Primetals/RHI – Smelter**
- **Tenova – OSBF or conventional EAF**
- **MetsoOutotec - OSBF**

- **Learning curves are expected for each combination of DRI and melting furnace, but ultimate success highly probable**

HYDROGEN-BASED FINE-ORE REDUCTION (HYFOR)



CONCLUSIONS AND FUTURE DIRECTION

- **Reductants: lower coke rates in surviving BF operations requires high quality coke; Global met coal reserves are adequate but will be extended by techniques to utilize as much as 50 % non coking coals while sufficient progress in environmental control has been made in both slot oven by product and heat recovery cokemaking. The slot oven by product route also has an important role in maintaining the steel plant energy balance.**

- **Natural gas will play an increasing role both as a DRI reductant and as a BF injectant. Ultimately, H2 gas, when economically available, will play a major role as a DRI reductant and as a BF injectant.**