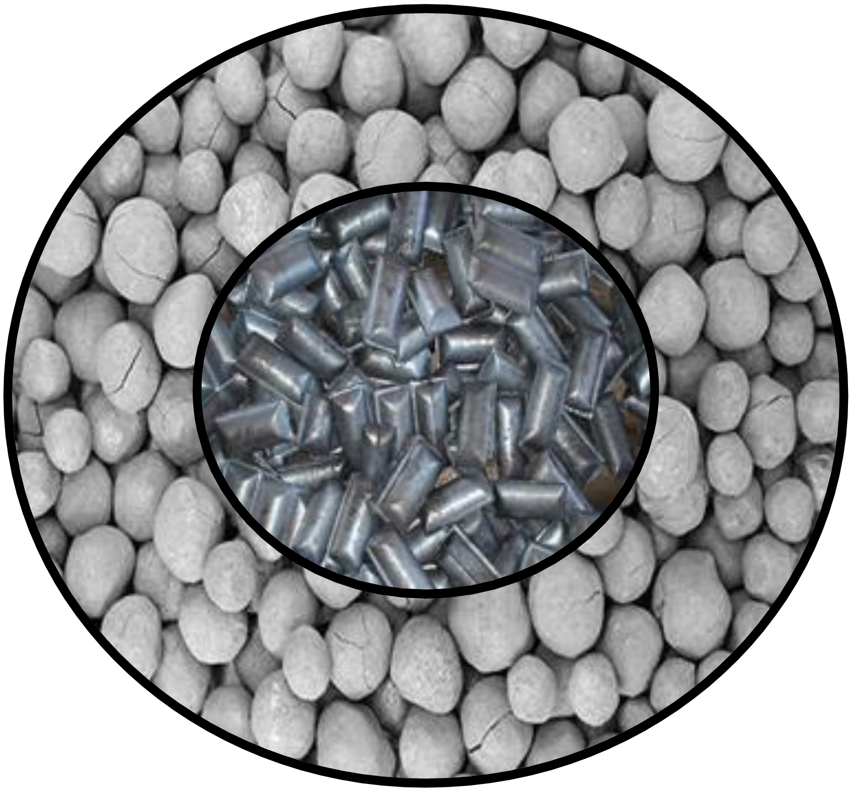
DRI UPDATE

SIMA
Sponge Iron Manufacturers Association
Indian voice for the ore based metallic & steel industry



MAY, 2021

Editor

Dear Readers,

As you know we are passing through unprecedented crisis created by COVID-19 pandemic. This has severely impacted not only our daily life schedule but is also affecting our economy. Undoubtedly these are trying times. But trying times bring out best of our ability. I am sure we will emerge more stronger and wiser. Indian sponge iron and steel industry have risen to the occasion and contributing in the supply of oxygen and other required resources for the welfare of humanity. This is a matter of great satisfaction and pride. We congratulate not only our members but entire steel industry.

As per World Steel Association, India continues to be world largest sponge iron producer during 2020. As per Joint Plant Committee under Ministry of Steel sponge iron production during 2020-21 was 34.155 million tones.

This issue apart from statistics of 2020-21 brings three relevant articles on Engineering the Green Revolution on Ironmaking - A Minimally Impacting Route to the De-Carbonisation of existing Ironmaking plants by Tenova HYL, detailed analysis on Outlook for Seaborne DR Grade Pellet Supply by International Iron Metallics Association (IIMA) and Steelmaking Through Induction Furnace Route - Quality and Energy Conservation by Electrotherm.

We hope you all are doing well and wish you all a safe and healthy life.

Deependra Kashiva

Executive Director

Engineering the Green Revolution of Ironmaking – A Minimally Impacting Route to the De-Carbonisation of Existing Ironmaking Plants

Paolo STAGNOLI[1], Andre ESTERHUIZEN[2] and Praveen CHATURVEDI[3]
[1]Tenova SpA, ITALY, [2]Tenova Pyromet, SOUTH AFRICA and [3]Tenova Technologies Pvt Ltd, INDIA

INTRODUCTION

Steel, unlike many other structural materials such as concrete or even polymers, is an indefinitely recyclable material that can be used, re-molten and re-used without loss of quality and with an efficiencyof 80-90% depending on applications. Steel is everywhere in everybody's life: vehicles, house appliances, buildings, bridges, rails are only examples of the countless steel applications. Steel is undoubtedly one of the pillars of the transition from a linear to a circular economy. In 2019, the world produced 1,86bn tons of steel (about ten times more than in 1950), and the World Steel Association predicts the production to reach 2,7bn in 2050.

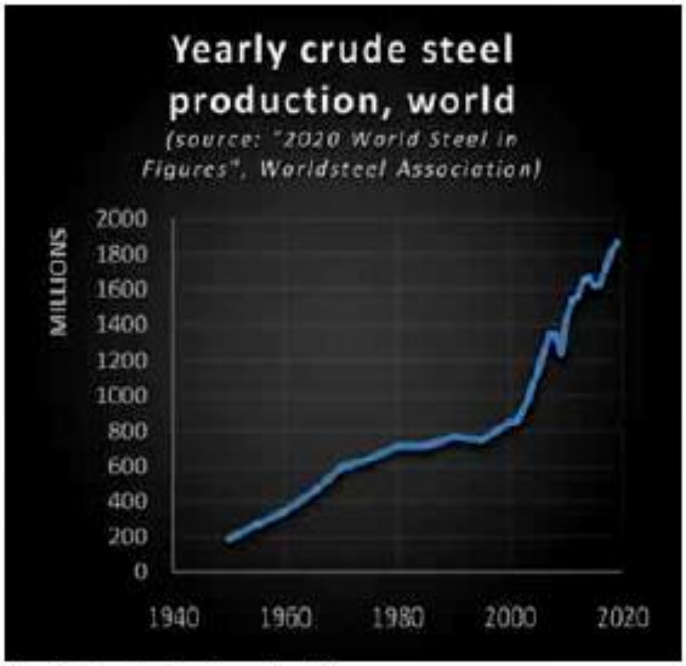


Fig.1: Crude Steel production

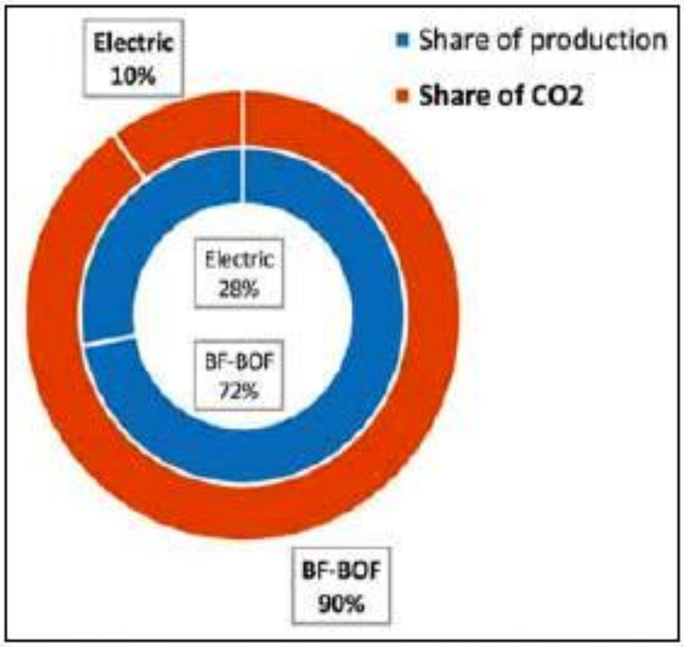


Fig.2: Different routes, different CO_2 intensity for the production of steel

Depending on sources, the steelmaking industry is claimed to be responsible for about 12-15% of the total worldwide emissions of greenhouse gases.Steelmaking routes are very different in this respect: in the current EU context, where CO_2 intensity of electric power generation is about 290g/kWh, electric steelmaking generates about 400-500kg of CO_2 per ton of liquid steel whereas the integral cycle (via blast furnace and converter) remains at about 1600-1800kg per ton depending on the age and efficiency of the installation. As of 2019, 72%of the steel in the world came from BF-BOF route mostly processing iron ore, while only about 28% is producedvia the electric process,therefore 90% of the CO_2 generated for the production of steel came from the plants based onBlast Furnace-Converter route.

Ironmaking is anyway inevitable. Many high-end steel grades tolerate very low content (1000 ppm or less) of tramp elements such as copper, which is, unfortunately, abundant in recycled scrap (up to 4500 ppm in low-grade, cheaper scrap). Moreover, as the cycle of use and re-melt repeats, this average content of pollutants keeps on increasing as, for instance, copper wires remain entrapped within the body of a car or a dishwasher being demolished. But even if we imagine that a process for removing tramp elements from the liquid willeventually become available,there simply would not be scrap enough in the market to cover for a continuously increasing steel consumption. In mature markets (like north America) the available scrap covers about 50% of the total need of raw materials.

Industrial Alternatives to the BF-BOF Route: Directly Reduced Iron

The cleanest, least impacting, industrially-proven technology for ironmaking is reportedly the direct reduction of iron ore pellets using Natural Gas instead of Coke, coal or lignite to generate the reductant mix. The NG-based direct reduction is achieved by cracking the molecules of hydrocarbons to form a mix of CO and Hydrogen, whereas the carbon-based reduction processes such a s BF operate by partially oxidizing the charged Carbon to CO only. Some technologies use external reformer for cracking natural gas to generate hydrogen and carbon monoxide. For the case of the ENERGIRON® scheme, (ENERGIRON® is the DRI Technology jointly developed by Tenova and Danieli) the natural gas is directly fed to the process for in-situ reforming of hydrocarbons for a more efficient generation of reducing gases and the possibility of using the same scheme for any energy source. Once the iron oxides in the ore are reduced to solid metallic iron pellets (DRI), the hot pellets are fed into an EAF where they are molten using electricenergy and refined by injecting oxygen to remove the excess Carbon and reach the required temperature.It is also possible to blend up to 30% DRI pellets in the burden of a Blast Furnace to increase productivity andreduceCoke and PCI consumption.

Depending on Carbon intensity of the power generation in the context where the plant operates, producing 1ton of liquid steel through DR-EAF route producesat least 50% less CO_2 emissions than the conventional BF-BOFroute.The emissions can be even less if one leverages in full the peculiar features of the ENERGIRON™ Direct Reduction technology:the scheme includes by default a CO_2 absorption system that selectively removes CO_2 from the process gas stream for CCU/CCS applications. Additionally, ENERGIRON® modules allow use of variable percentages of Hydrogen in the feed and, eventually, the use of pure Hydrogen as fuel.

Thanks to the inherent flexibility of this technology, operating at high pressure and temperature and using the same DRI pellets as catalyst for the reforming, ENERGIRON® scheme has been chosen as basis for the first hydrogen-based steelmaking facility in the world, currently under construction and expected to be operative in 2021. According to the preliminary studies of the consortium of owners, the total emissions per ton of crude steel produced will be well below 50kg, thirty times less than the emissions of a conventional BF-BOF cycle.

The production of DRI worldwide has been continuously growing. The "shale gas revolution" has significantly lowered the cost of this commodity in several areas in the world, boosting the profitability of this route in countries outside of the traditional production areas such as MENA where large reserves of NG are available.

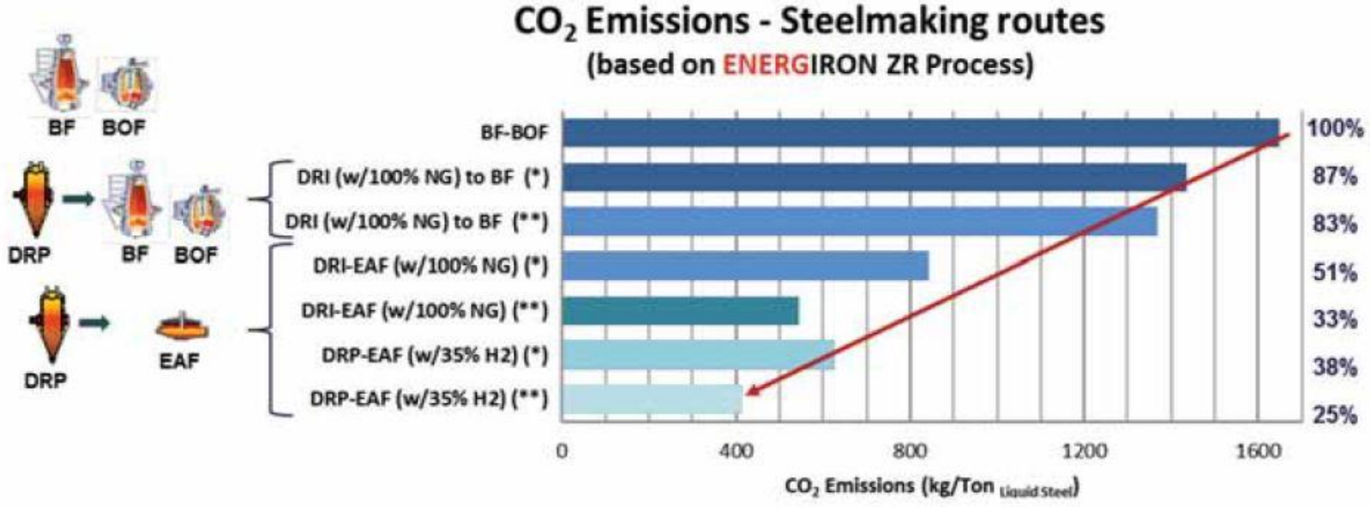
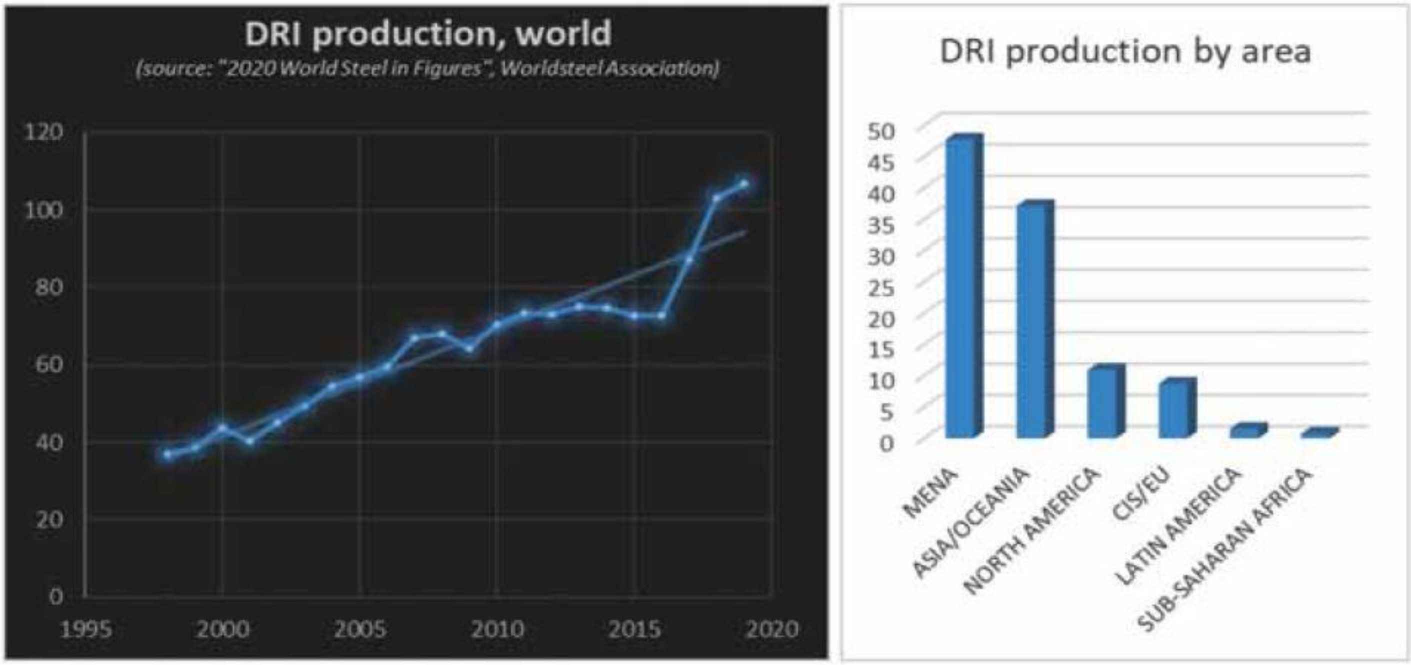


Fig. 3: Notes:(*) Without CO_2 off-taking/commercialization(**) With CO_2 off-taking/commercialization, H_2% as energy input


DRI production, world

(source: "2020 World Steel in Figures", Worldsteel Association)

DRI production by area

Fig. 4: Production of DRI worldwide

Conversion from BF-BOF to DRI-EAF: Challenges and Constraints

Beyond the obvious consideration of capital expenditures, the transformation of existing integrated cycle facilities into DRI-based operations poses several challenges, the first being the availability of a power distribution grid with sufficient capacity to sustain the load of a large electric arc furnace and to tolerate the disturbances induced by this machine.

Let's consider a DRI-EAF line worth producing 2.5 Mt per year of DRI. The size of the transformer required to feed such a productive machine is 200-250MVA (depending on the chemistry of the pellets and feeding temperature), with a peak load of about

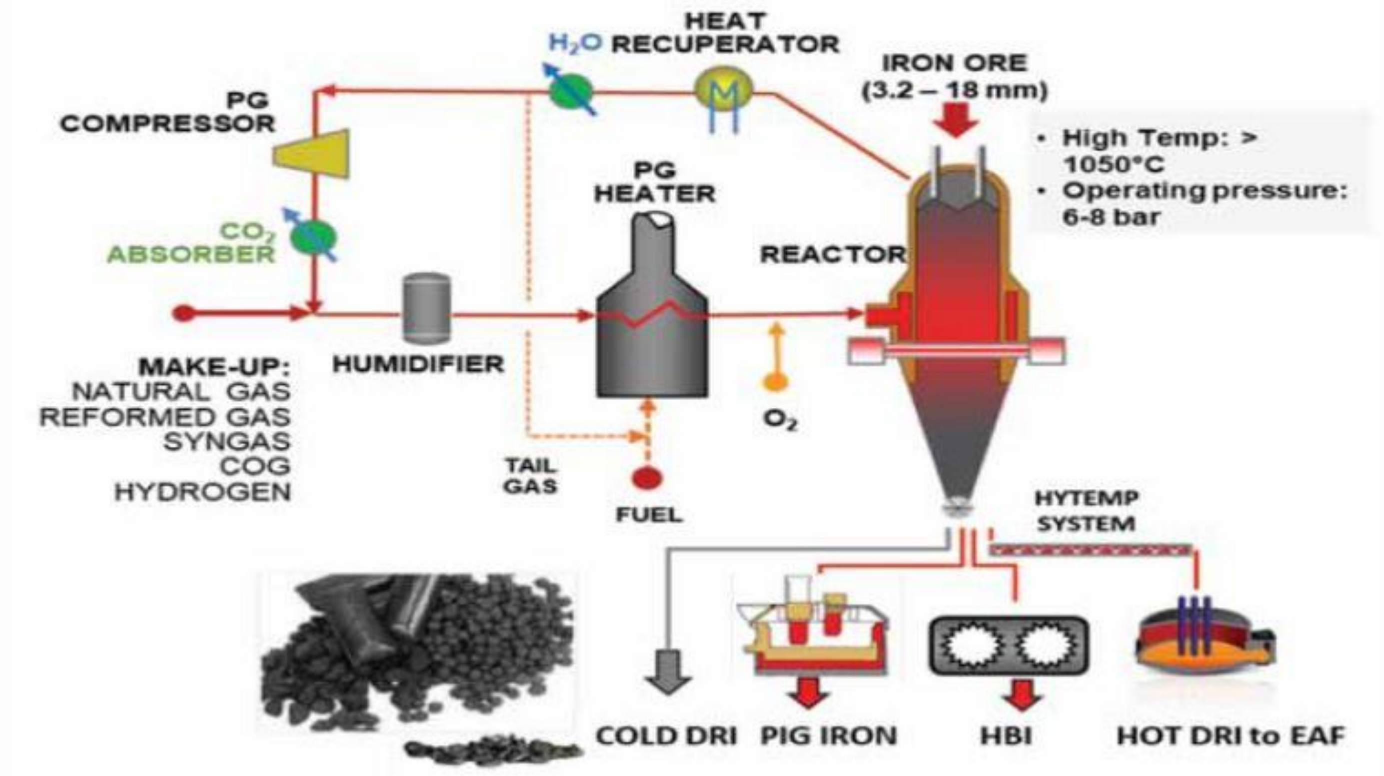


Fig. 5: The ENERGIRON® process - Pig Iron production via Direct Reduction

180MW. Besides the sheer availability of such an amount of power, the operation of the EAF generates disturbances (flicker) that reverberate on the upstream grid in inverse proportion to the short-circuit power of the same, causing high-frequency fluctuations of the active power. Even considering state-of-the-art flicker compensation equipment, able to reduce the flicker by a factor up to 4, the areas where such a machine can be installed are still quite limited. Power requirements of even the largest BF-BOF plant are not comparable, and large infrastructural investments are required to increase significantly the tolerable load of the power grid.

In addition to the infrastructural concerns, fitting a DRI-EAF route into an existing BF-BOF plant poses also logistic issues. Should a plant be willing to consider a gradual transition, progressively weaning the plant from the dependence of liquid hot metal but keeping the de-gassing and casting lines as they are, the operation team would have to integrate within the existing liquid steel stream a source characterized by a different pace (about 45 minutes' cycle time against around 30 for typical BOF), with a different tapping size and producing a liquid steel slightly different than the one produced in the preexisting facilities (even though DRI-EAF lines can be used to produce any kind of known steel grades).

Successful conversion to DRI-EAF route also requires changes in the choices of raw materials. The so-called DRI-grade pellets are formed by high-grade iron ore concentrates, typically with iron content in excess of 65%, and in the best ones the gangue is mostly basic (CaO and MgO). EAF operation requires the slag to respond to certain minimum criteria to allow for Phosphor removal, keep an adequate viscosity throughout the whole process and prevent chemical erosion of the refractory lining of the crucible, typically built with MgO-C bricks. If the pellets charged in the EAF contain significant quantities of Silica and/or Alumina, theprocess will require more than equal addition of basic fluxes to keep the slag within acceptable parameters, and since the fluxes require twice as much energy as the iron to melt, this results in an increase of the electric energy required by the process.

Moreover, as oxygen is blown to achieve the desired composition endpoint, the slag-steel equilibrium causes the concentration of FeO in the slag to be almost fixed for a certain required %C, so the more slag needed, the more Iron gets lost to the slag.High quantity of gangue implies high-energy consumption and low yield. Currently, low-grade pellets are used in DRI-EAF plants only in areas where the energy cost is almost negligible.

Last but not least, many BF-BOF plants are used to sell the BF slag to the concrete industry as an aggregate while the EAF slags, having high content of Iron oxide (20-40% depending on process) and being strongly basic, are not suitable for this purpose.

A New Approach to Ironmaking: The HDRI-to-Hot Metal Route

Urged by several steelmakers, TENOVA began some years ago investigating a minimally impacting transitional solution to allow a gradual conversion of existing integral steelmaking plant. The purpose of the research was to find a production line mimicking a blast furnace but with significantly lower emissions. The objective was toeliminate the dependence from the coke while remaining able to process low-grade iron ore to produce an intermediate material compatible with the existing downstream processes, while tackling all logistic concerns related to the introduction of a DRI-EAF line into an existing BF-BOF plant.

The first item of this innovative production line is the ENERGIRON® Zero Reformer module. This direct reduction technology, developed by TENOVA and now managed within the ENERGIRON® consortium, uses a pressurized vessel to reduce iron ore pellets to DRI. Within the ENERGIRON® ZR module the same iron pellets in the module act as a catalyst for the cracking of the methane and of the other hydrocarbons contained in the feeding gas.The ZR operates at high pressureachieving metallization rates between 94 and 95%. It can produce DRI with Carbon content up to 5% (High-C DRI). The pellets can be charged directly inthe downstream melting unit at a temperature in excess of 600°C reducing significantly the required.

The solution proposed by TENOVA uses an OSBF to complete the reduction of the iron oxide remaining in the pellets through a reaction with a portion of the carbon contained in the same and melt the pellets, separate the gangue from the iron and bring the liquid to the desired temperature. A portion of the Silica contained in the gangue is also reduced to metallic silicon in the bath, achieving a composition of the liquid that is very close to the hot metal produced by blast furnaces, while the Sulphur content remains dramatically lower as natural gas (or hydrogen, or a mix of the two) is used to reduce the iron instead of Coke (which brings Sulphur to the hot metal produced via the traditional blast furnace route).

OSBFsfeature a large static vesselwith semi-permanent refractory lining, designed forlife cycles of severalyears.

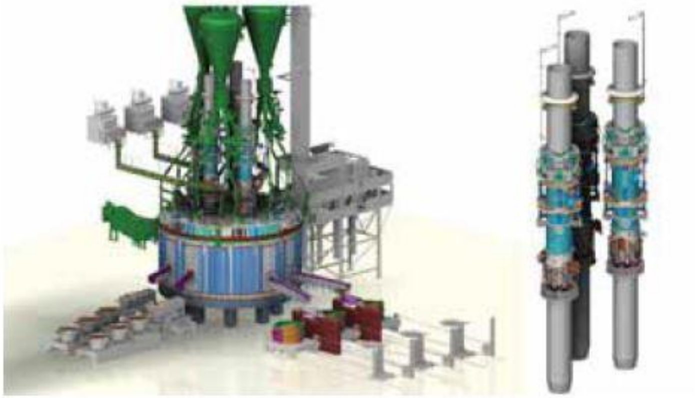


Fig. 6: TENOVA PYROMET Open Slag Bath Furnace. On the right: Soederberg type electrodes (TENOVA, 2019)

The feed, generally constituted by different ores, fluxes and reductants, is charged by gravity in the vessel and heated by means of resistive arcsthat spark through the slag layer. The OSBF ispowered by three independent single-phase AC transformers feeding Soderberg electrodes, independently regulated by means of hydraulic systems.

Periodically, the slag and metals are evacuated through tapholes and launders placed at different heights in the vessel (higher for the slag and lower for the metal). The tapping temperature can be adjusted by providing more or less electric energy to the bath, whilethe carbon content can be trimmed by adding carburizing agents to the feed. At the end of tapping, the holes are plugged with a clay gun and the cycle is repeated. The process maintains a large metal heel in the furnace sothe furnace always operates in liquid bath steady operation. This process generates an amount of electrical disturbances (flicker) that is almost negligible if compared with the noise generated in the power grid by an EAF of similar productivity.

OSBFs have a significantly lower power density (MW/ m_2) than EAFs and do not operate with open, radiating arcs as the EAFs do. Thanks to this feature, the slag requirements are dramatically less stringent as the protection of the sidewall refractories is achieved by a sheer temperature gradient, keeping the slag next to the wall below its solidifyingtemperature.

As the steady and static operation of an OSBF implies vastly lower mechanical stresses, the unit uses Söderberg electrodes. With this system, the gradual consumption of the electrodes near the tip is compensated by adding a paste composed by anthracite, pet coke and graphite that graphitizes with the process temperature as the electrode slips down. This material costs significantly less than standard graphite electrodes used in EAFs.

Logistic-wise, for the plants where the assembly needs to be installed away from the BOF shop (a configuration quite common in the integrated cycle plants) the liquid produced can be tapped into ladles ortorpedo cars and transported with a modest temperature drop at a significant distance, same as it is done in blast furnaces.

DR module and OSBF are integrated in an organic automation package controlling the operating

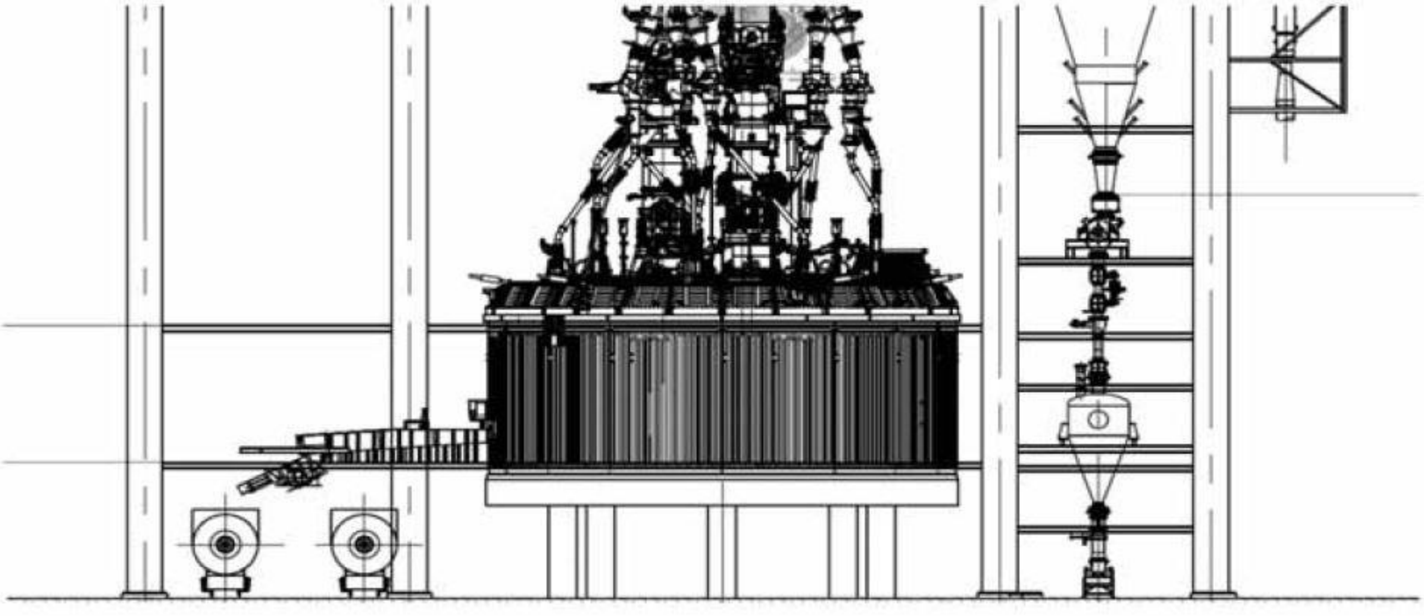


Fig. 7: OSBF tapping in hot metal torpedo cars. On the right: DRI cooler for cold DRI discharge

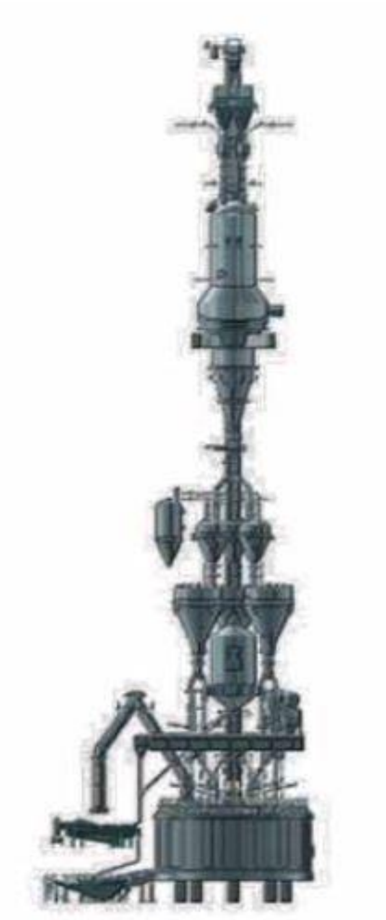


Fig. 8: Pig iron/vanadium slag production plant in Canada, basic engineering

parameters of both units,keeping under watch the process from the raw materials feed to the tapping into the receiving vessels in a fully automated way.

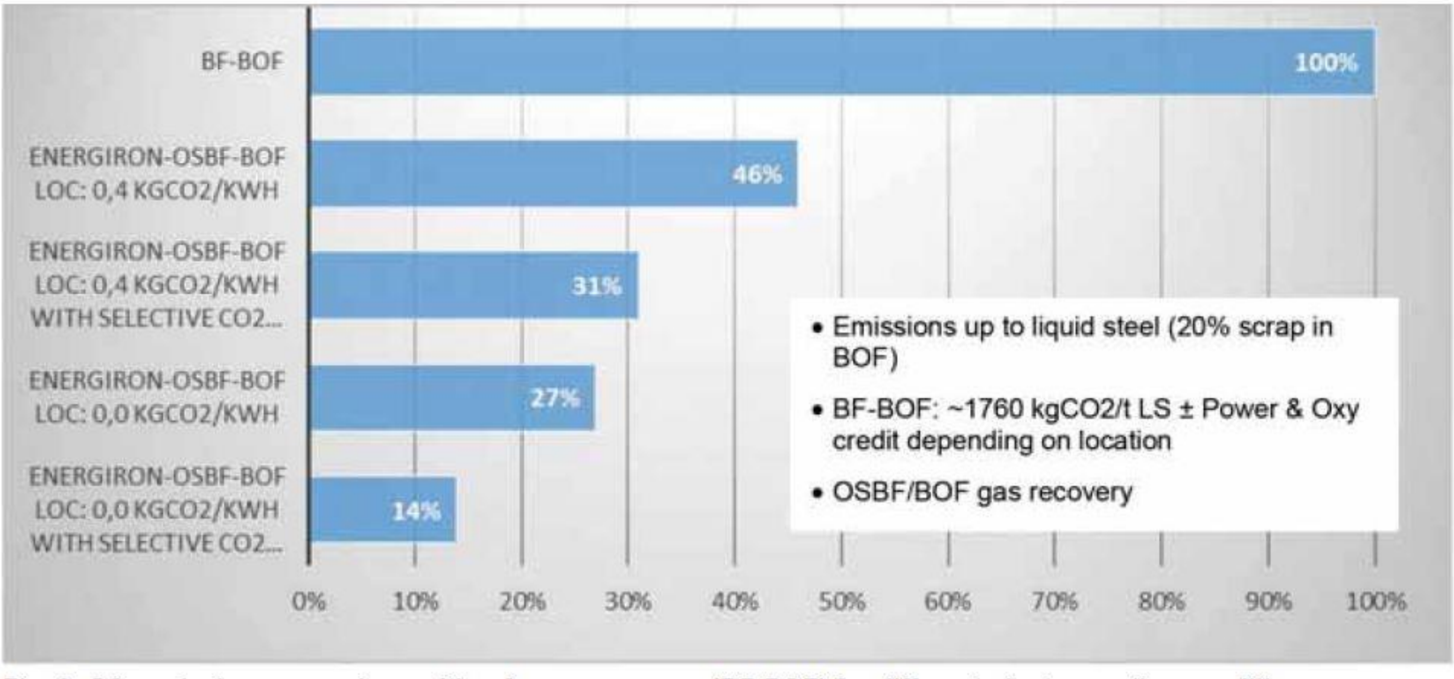
CONCLUSION

TENOVA, through productive interaction with European and Eastern steelmakers, developed an innovative process route based on industrially proven, referenced units. This fully integrated line can produce hot metal with adjustable Carbon (up to 5%)and Silicon (0,2-0,4%) content from low-grade iron ore pellets, while producing BF-like slag that can be granulated and sold as a byproduct.

In order to overcome the constraints inherent in the DRI-EAF routeTENOVA leveraged its experience in ore smelting furnaces, owned by the South African branch of the group (Tenova PYROMET) specialized in the design and supply of Submerged Arc Furnaces (SAF) and Open Slag Bath Furnaces (OSBF) for the production of ferroalloys and base metals.

The proposed solution, for the cases analyzed, will allow a reduction of CO_2 emissions by roughly 70% (85% if using carbon-neutral electricity)and enables existing ironmaking plants to plan a gradual reconversion during which the operation of the downstream units (BOFs) will remain substantially unchanged.

At the moment of publication of the present article two projects involving this route are active as well as several negotiations with various international players.



- Emissions up to liquid steel (20% scrap in BOF)
- BF-BOF: ~1760 kgCO2/t LS ± Power & Oxy credit depending on location
- OSBF/BOF gas recovery

Fig. 9: CO_2 emission comparison with reference process (BF-BOF) for different plant operating conditions

~~~~~~~~~~~xxxxx~~~~~~~~~~~
~~~~~~~~~~~

The Global HBI/DRI Market: Outlook for Seaborne DR Grade Pellet Supply

(John Atherton, Secretary General,(IIMA) and Chris Barrington, Chief Adviser,(IIMA)

MARCH 1ST 2021

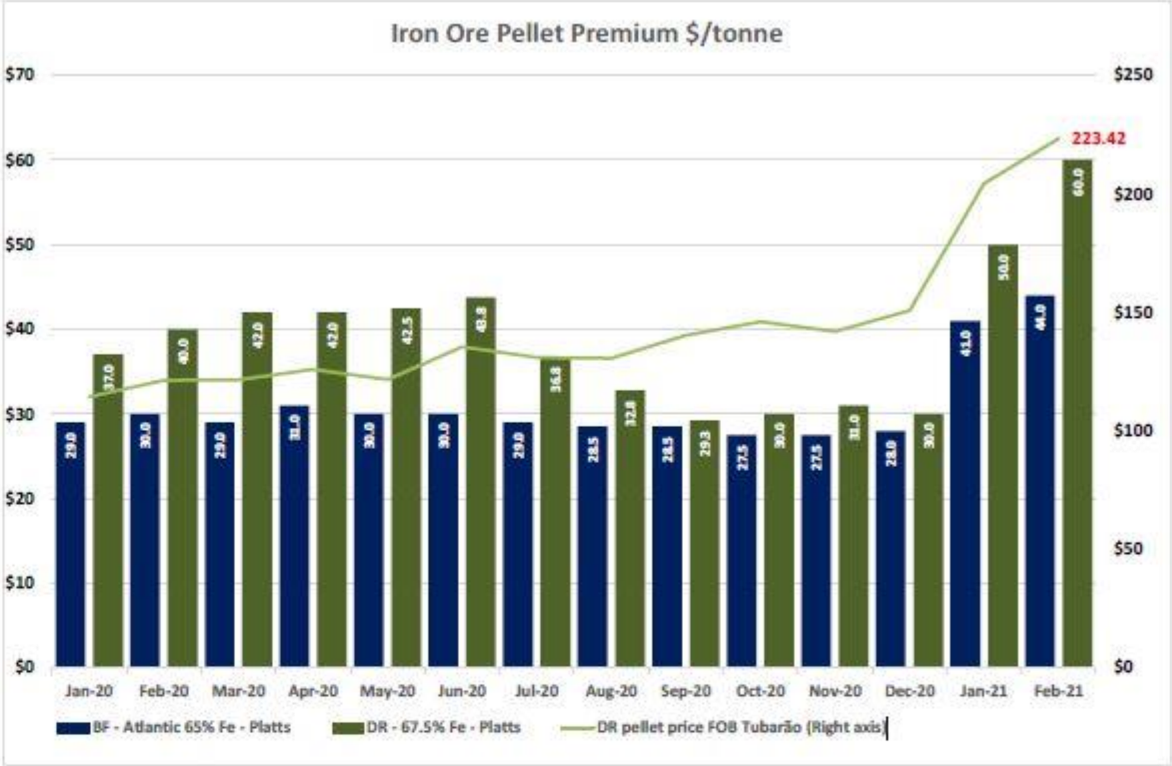
Disclaimer

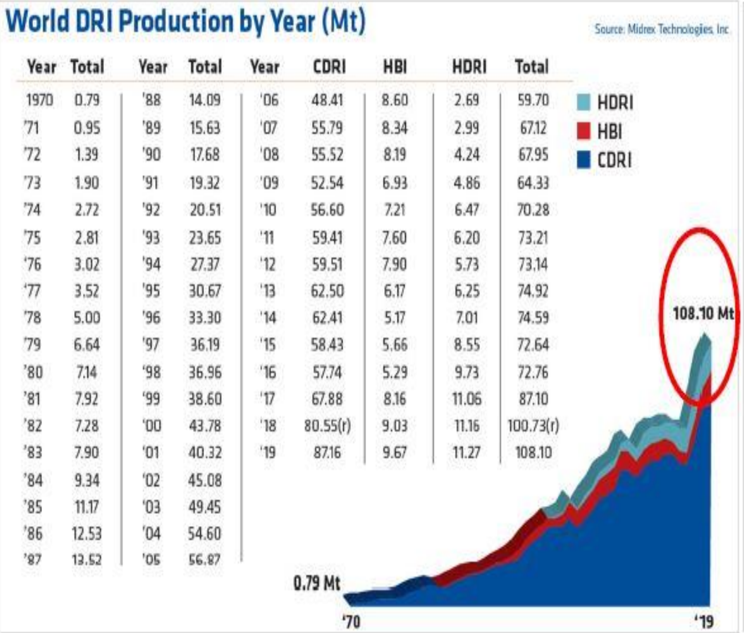
This presentation is intended for information purposes only and is not intended as commercial material in any respect. The material is not intended as an offer or solicitation for the purposes of any financial instrument, is not intended to provide an investment recommendation and should not be relied upon for such. The material is derived from published sources, together with personal research. No responsibility or liability is accepted by the author or International Iron Metallics Association or any of its members for any such information or opinions or for any errors, omissions, misstatements, and negligence or otherwise for any further communication, written or otherwise.

Presentation Overview

- Setting the scene
- Outlook for DR grade pellet supply out to 2030
- DRI and the pathway to carbon-neutral steelmaking

Setting the Scene

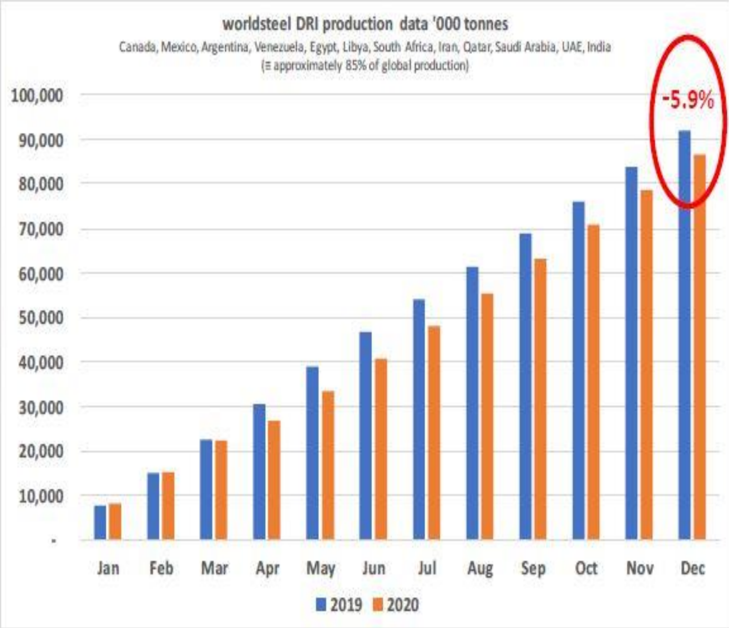




World DRI Production by Year (Mt)

Source: Midrex Technologies, Inc

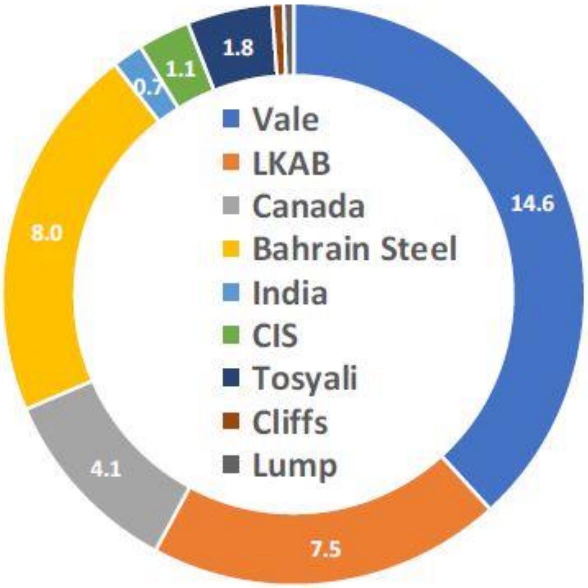
Year	Total	Year	Total	Year	CDRI	HBI	HDRI	Total
1970	0.79	'88	14.09	'06	48.41	8.60	2.69	59.70
'71	0.95	'89	15.63	'07	55.79	8.34	2.99	67.12
'72	1.39	'90	17.68	'08	55.52	8.19	4.24	67.95
'73	1.90	'91	19.32	'09	52.54	6.93	4.86	64.33
'74	2.72	'92	20.51	'10	56.60	7.21	6.47	70.28
'75	2.81	'93	23.65	'11	59.41	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	80.55(r)	9.03	11.16	100.73(r)
'83	7.90	'01	40.32	'19	87.16	9.67	11.27	108.10
'84	9.34	'02	45.08					
'85	11.17	'03	49.45					
'86	12.53	'04	54.60					
'87	13.52	'05	56.87					



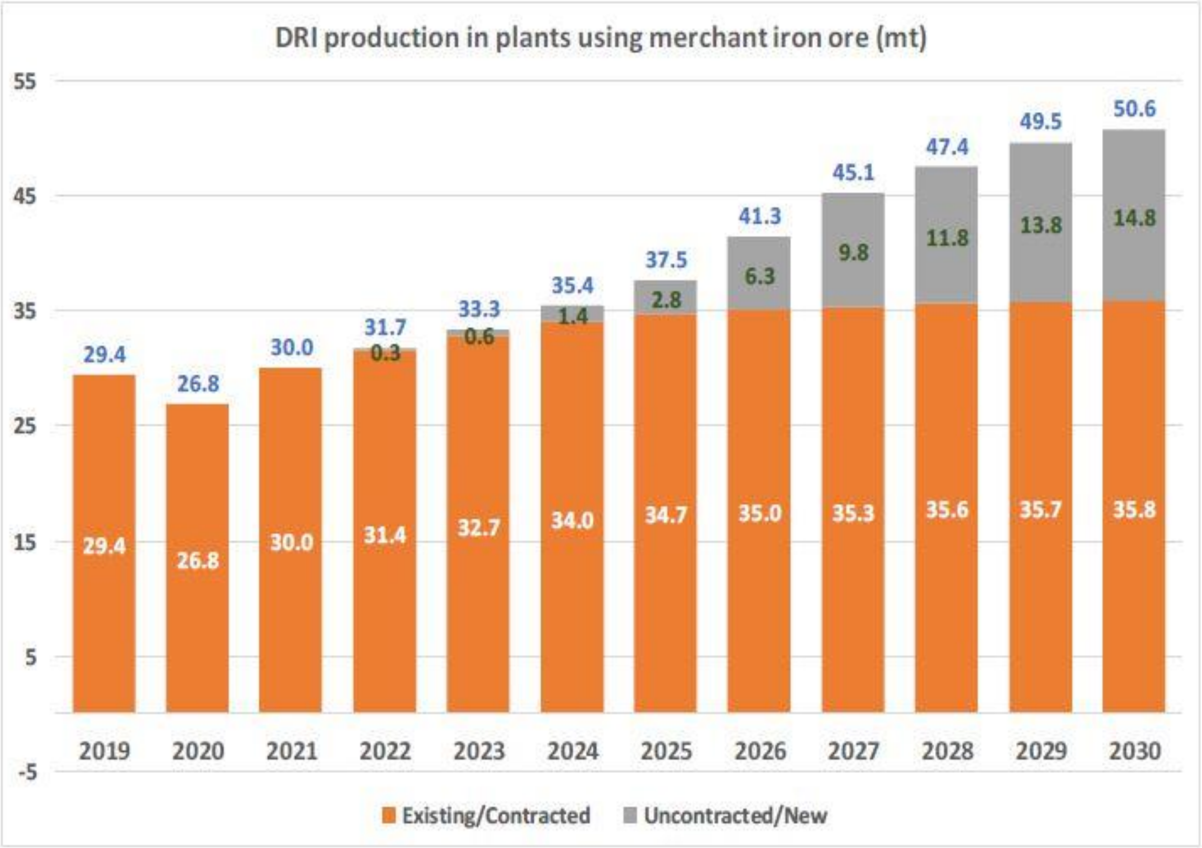
Seaborne Ore Supply to DR plants 2020 (mt) - total 38.2 mt (preliminary estimate)

source: trade statistics and author's estimates

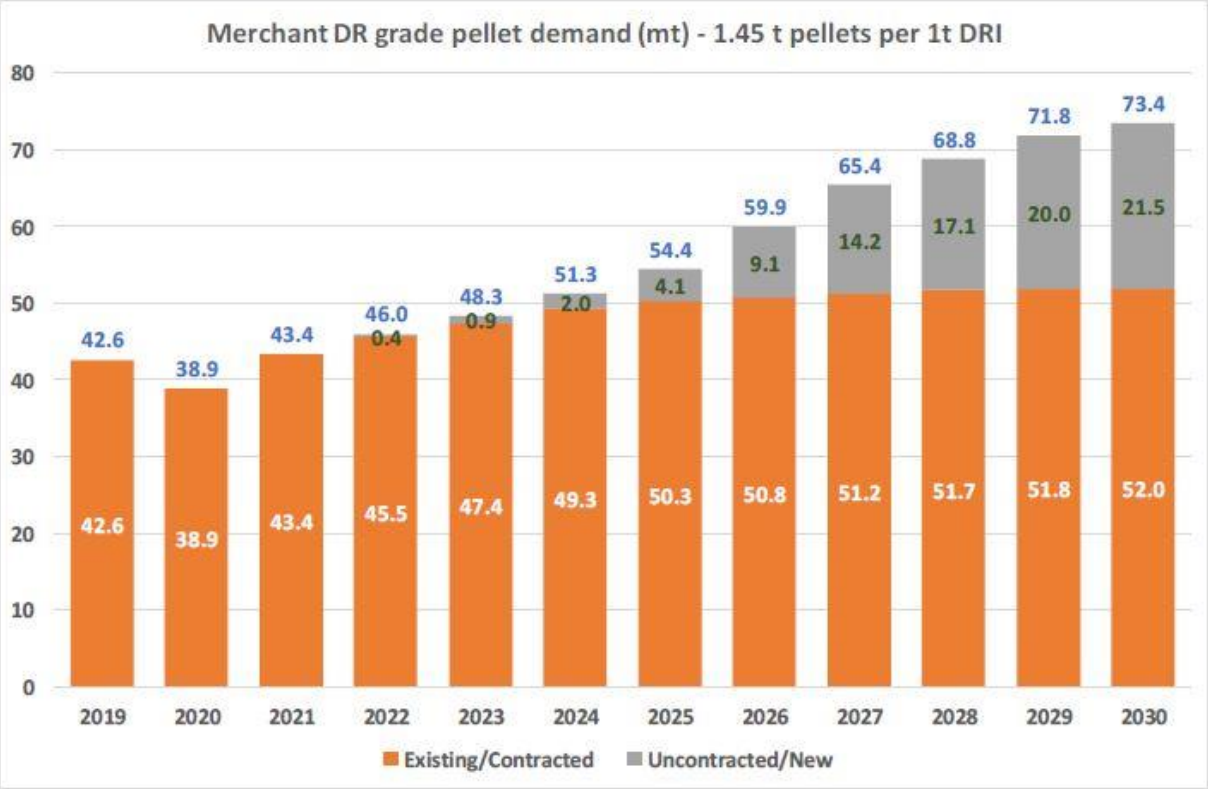
(compares with 38.9 mt derived from DRI production data)

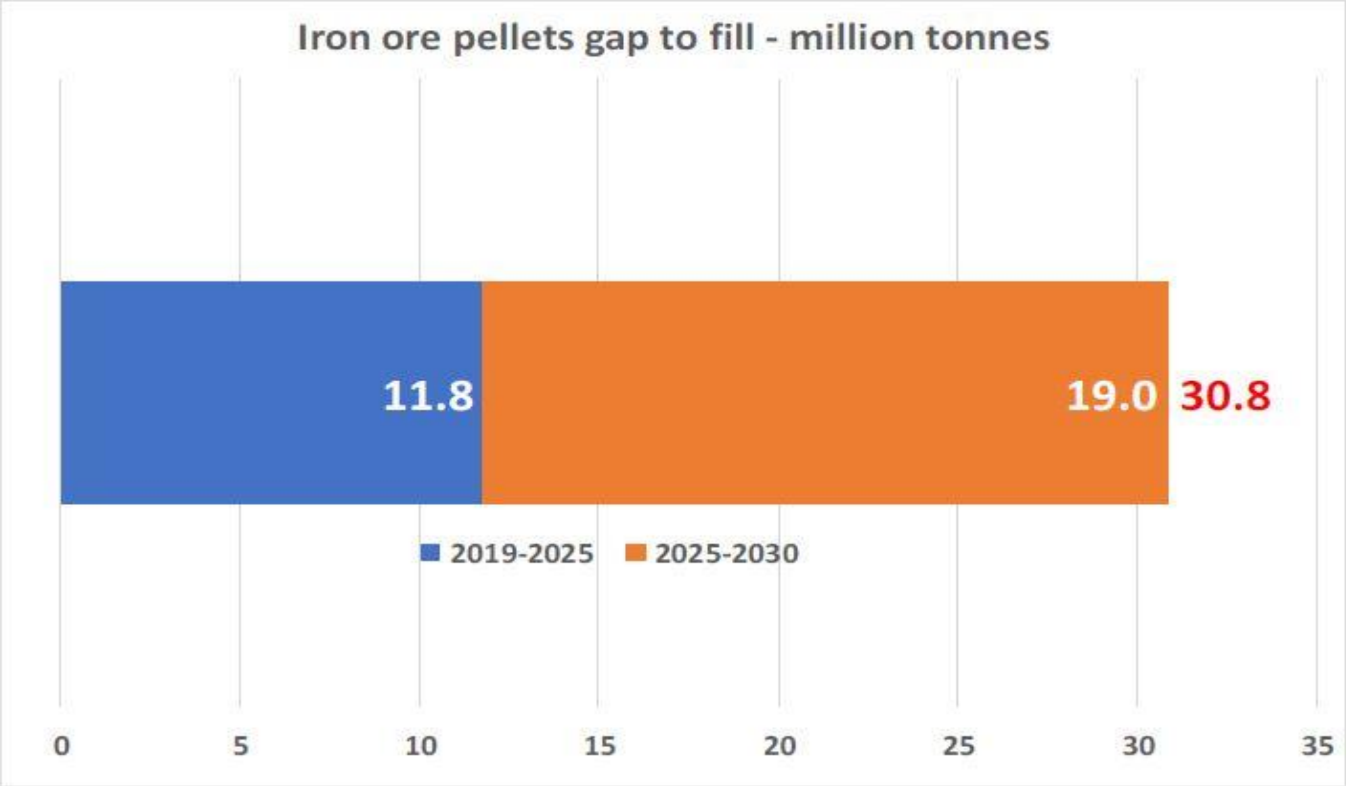


Argentina
Trinidad
USA
Germany
South Africa
Algeria
Libya
Egypt
Saudi Arabia
Qatar
Bahrain
UAE
Oman
Malaysia



Argentina
Trinidad
USA
Germany
South Africa
Algeria
Libya
Egypt
Saudi Arabia
Qatar
Bahrain
UAE
Oman
Malaysia





DRI production from new projects

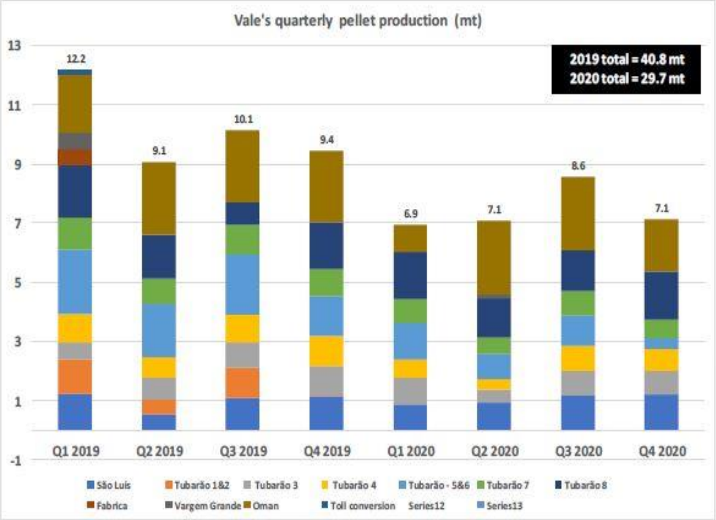
(based on merchant iron ore)

Project	2022	2023	2024	2025	2026	2027	2028	2029	2030	Location
HBIS Group	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	China
Salzgitter			0.8	1.6	2	2.0	2.0	2.0	2.0	Germany
TKS				0.6	1.2	1.2	1.2	1.2	1.2	Germany
Liberty/PW/SHS					1.0	2.0	2.0	2.0	2.0	France
IOC/PW/SHS					0.5	1.0	1.0	1.0	1.0	Canada
MENA 1					1.0	2.0	2.0	2.0	2.0	North Africa
MENA 2						1.0	2.0	2.0	2.0	North Africa
EU							1.0	2.0	2.0	Austria, Italy, Romania….
Asia								1.0	2.0	ASEAN, China
Total	0.3	0.6	1.4	2.8	6.3	9.8	11.8	13.8	14.8	

Author's assumptions

Vale in 2020

source: Q4 2020 production report


Vale's quarterly pellet production (mt)

2019 total = 40.8 mt
2020 total = 29.7 mt

Estimated pellet supply to DR sector in 2020: 13.6 mt


Vale's iron ore sales (mt)

Total	2019	2020
Production	301.972	300.385
Sales	312.505	286.076
Pellet sales	43.199	31.211


Iron ore production - Mt

[1] Excluding the COVID-19 impact (-1 Mt) in Itabira Complex. [2] Excluding the COVID-19 impact (-2.5 Mt) in Serra Norte. [3] Excluding the impact of 6.3 Mt from works postponements due to COVID-19 pandemic. [4] Including ROM production in Fazendão to supply Samarco restart.

outlook Vale

- No formal guidance yet for 2021 pellet production – “slightly more than in 2020” per Vale Q4 earnings call on 26/02. guesstimate: 30-35 mt of which DR grade 14-17 mt.

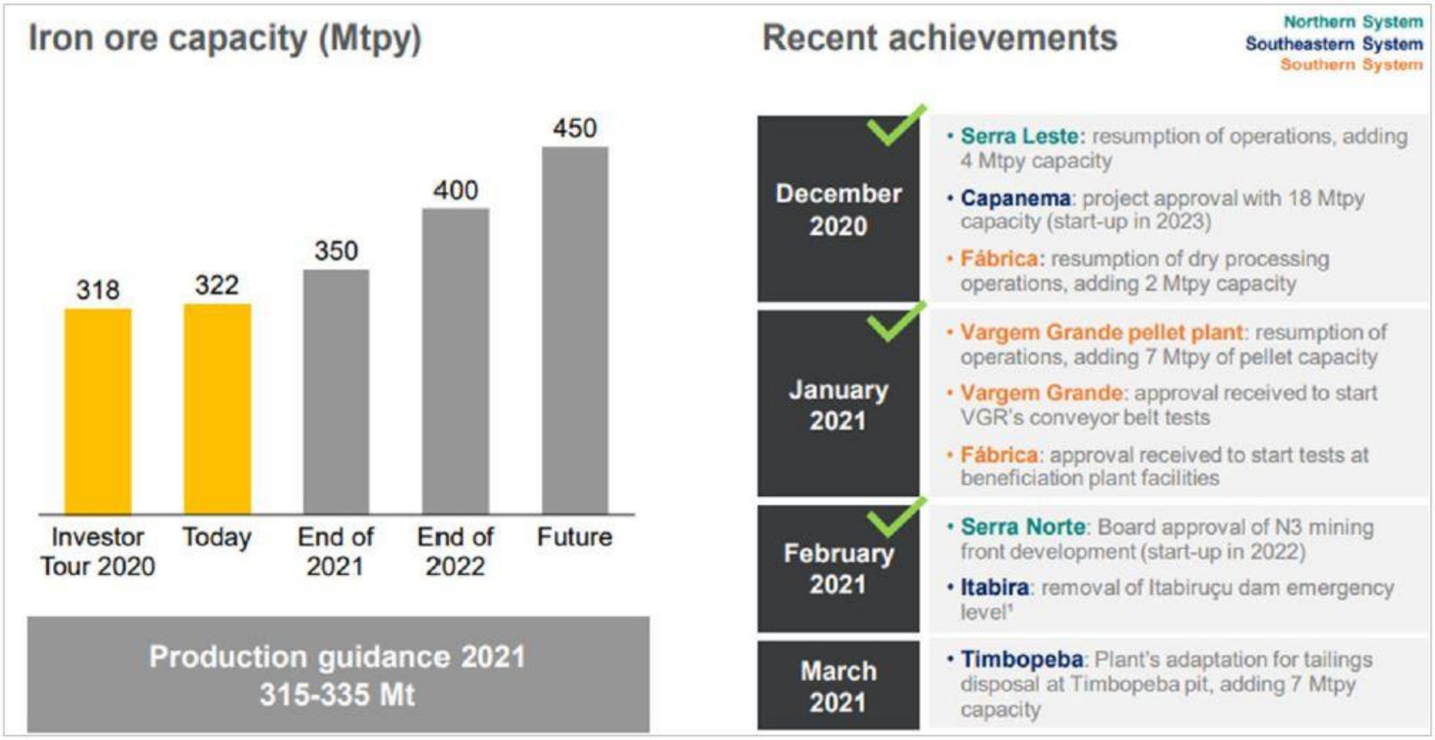
- Vargem Grande pellet plant restarted in January 2021 (7 mt capacity – domestic market focus).

- Fabrica dry processing started 12/2020 with pellet plant restart scheduled in 2022.

- 2021 Tubarão pellet production will be driven market demand and in the case of DR grade pellets by high grade pellet feed availability.

- 2021 Oman pellet production will likely be 9-10 mt, all for DR sector.

- Prior to the Brumadinho dam rupture, we estimated Vale’s pellet supply to DR sector in 2019 and 2020 at ~27 mt (total pellet capacity 60 mt).



Production guidance 2021
315-335 Mt

Recent achievements

December 2020
- **Serra Leste**: resumption of operations, adding 4 Mtpy capacity
- **Capanema**: project approval with 18 Mtpy capacity (start-up in 2023)
- **Fábrica**: resumption of dry processing operations, adding 2 Mtpy capacity

January 2021
- **Vargem Grande pellet plant**: resumption of operations, adding 7 Mtpy of pellet capacity
- **Vargem Grande**: approval received to start VGR’s conveyor belt tests
- **Fábrica**: approval received to start tests at beneficiation plant facilities

February 2021
- **Serra Norte**: Board approval of N3 mining front development (start-up in 2022)
- **Itabira**: removal of Itabiruçu dam emergency level[1]

March 2021
- **Timbopeba**: Plant’s adaptation for tailings disposal at Timbopeba pit, adding 7 Mtpy capacity

Chart source: Vale Q4 2020 earnings call 26/02/2021

outlook - LKAB

- **LKAB has 10 mt capacity at pellet plants with coating capacity (Kiruna KK3 and KK4)**
- **KK3 produces only DR grade, KK4 can switch between BF and DR grades**
- **LKAB’s pellet deliveries in 2020: 23.9 mt (20.7 mt in 2019)**
- **Estimated DR grade pellet supply (basis trade data):**
- **6.9 mt 2020 to November ≡ 7.5 mt on annualised basis (6.7 mt in 2019)**
- **Kiruna still affected by earthquake in May 2020 (4.9 on Richter's scale) and has announced plans to mine 1 mt at mothballed Mertainen mine (near Svappavaara) to provide crude ore buffer for the Kiruna and Svappavaara pellet plants**
- **Based on its contract portfolio, it seems that about 7 mtpy is a maximum level of seaborne DR grade pellet supply for the foreseeable future**
- **From ~2025 HYBRIT project will utilise ~1.5 mt “fossil-free” pellets from Malmberget**

WE TAKE A NEW POSITION ON THE MARKET

A successive change from supplier of iron ore pellets to supplier of sponge iron

THE PACE OF TRANSFORMATION

2020
LKAB produce
the world's first
fossil-free iron
ore pellets

2033
Sponge iron
plant in production
(Malmberget)

2038
Sponge iron
plant in production
(Kiruna)

2045
Sponge iron
plant in production
(Kiruna)

HYDROGEN TECHNOLOGY IS OUR WAY FORWARD / SPONGE IRON

FUTURE PROCESSING

2029
Sponge iron
plant in production
(Malmberget)

2038
Sponge iron
plant in production
(Malmberget)

2042
Sponge iron
plant in production
(Kiruna)

Source: LKAB presentation 23/11/2020

overview - Canada

- **Canada has two pellet producers, Iron Ore Company of Canada (IOC) and ArcelorMittal Canada (AM)**

- **AM supplies DR grade pellets to captive DR plants in Canada and Germany**

- **IOC supplies the wider DR market**

- **AM is considered unlikely to supply DR grade pellets to external DRI producers**

outlook: Iron Ore Company of Canada (IOC)

- **2020 pellet production was 9.6 mt (2019: 10.1 mt).**

- **2020 pellet sales were 10.2 mt of which 3.6 mt was to DR markets (2019: 9.6 mt of which 3.5 mt to DR markets).**

- **Expectation for DR pellet supply in 2021 is about ~4 mt and by the middle of the decade annual supply potential of ~5 mt DR grade pellets.**

- **Most recent news 16/02/2021: Rio Tinto, Paul Wurth and SHS-Stahl-Holding-Saar signed MoU to explore production of low-carbon steel feedstock:**

  a. **transformation of iron ore pellets from IOC to low carbon HBI using green H2 generated from hydro-electricity**

  b. **project to be located in Eastern Canada - understood to be 1 mt HBI plant (≡ 1.45 mt pellets)**

  c. **feasibility study scheduled for completion in late 2021, to be followed by investment decision – earliest start-up probably 2026**

  d. **SHS-Stahl-Holding-Saar is majority shareholder of Dillinger Hüttenwerke (steel plant at Dillingen) and indirect owner of Saarstahl (steel plant at Völklingen) – the two companies each own 50% share of ROGESA Roheisengesellschaft Saar (two blast furnaces at Dillingen, 4.6 mt hot metal)**

outlook - Bahrain Steel

- Bahrain Steel is in effect partly captive to adjacent DR plant SULB which produced 1.5 mt DRI in 2019 (est. 2019 pellet offtake from BS ~2.2 mt).
- Nameplate capacity of the two pellet lines is 11 mt and production at the 12 mt level has been achieved on sustainable basis.
- Ore imports in 2020 are estimated per trade data at about 8 mt (mainly from Brazil, but also Canada and Sweden) with pellet production of about 8.3 mt.
    - of which ~ 2 mt supplied to SULB (now exporting surplus DRI to North African markets) and
    - ~ 6 mt to export markets, mainly in MENA region, but also USA and Trinidad
- Production is now running at full capacity of about 12 mt
- 20 year contract (≥67% Fe / ≤2% gangue) with Anglo American/Minas Rio (annual DR grade pellet feed capacity of which is ~8 mt).

outlook - Tosyali Algerie

- Tosyali Algerie (2.5 mt DR plant) has adjacent 4 mt pellet plant, but no captive supply of pellet feed.
- Supply of suitable pellet feed has been a major constraint, initially due to lack of grinding capacity (now remedied), but also to difficulty in sourcing DR grade pellet feed and port constraints. Latest developments are port improvements and addition of a 4.5 mt ore beneficiation plant, due to commission in 2021.
- DRI production in 2020 was 2.23 mt, requiring ~3.2 mt pellets.
- Based on the previously estimated in-house pellet production of 1.8 mt in 2020, pellet imports would have been ~1.4 mt (trade data for 2020 are so far incomplete).
- Once the ore beneficiation plant is fully operational, dependence on imported pellets should be significantly reduced or eliminated by 2022.
- Tosyali Algerie Phase 4 project beginning 2021 is 4 mt integrated flat steel production facility.

outlook - Samarco

- **Licensing process is complete.**
- **Restarted pellet production in December 2020.**
- **Ramp up will be progressive in three "step-by-step" phases (nominal capacity 7-8 mt pellets each phase):**
  - **Phase 1: starting with concentrator #3/pellet plant #4 with ramp-up Q1 2021**
  - **Phase 2: "official" position is to restart concentrator #2/pellet plant #3 in 2026, but could be sooner, say in 2023 - timing will depend on Phase 1 performance, etc.**
  - **Phase 3: timing is unclear at this point as a tailing solution has still to be determined, but will hopefully be by 2030 - based on 2015 performance, total pellet production of ~28 mt could be achieved**
- **Initial ramp-up will be on BF pellets - best estimate today is that product split in 2021 will be 50-60% BF pellets, 40-50% DR pellets (3.0-3.75 mt DRgrade pellets) - ultimately product split will be market driven (author's estimates).**

"Samarco resumes its operation with a filtration technology whereby 80% of tailings (the coarsest sandy part) will be filtered and dry stacked.
The finer slurry part, representing 20% of tailings, will be disposed of in the "Germano pit" (a totally confined environment)."

outlook - Cleveland Cliffs

- **Cleveland Cliffs produces DR grade pellets (67.3% Fe, 2% SiO2) at its Northshore operation - capacity ~3.0 mt.**
- **Cliffs' 1.9 mt Toledo HBI plant started up in late 2020 and will consume 2.7-2.8 mt pellets at full production.**
- **Thus, ~0.25 mt DR grade pellets is available for sale to third parties (understood to be contracted to Nucor).**

CIS - Ukraine

Metinvest – Central GOK

- **Upgrading plan approved in 2018 and now completed:**
- **beneficiation plant: concentrate quality upgraded to 70.5% Fe**
- **pellet plant: addition of double deck screening, new mixer and pelletising disc**
- **full scale operation from Q3/4 2020**
- **Nominal capacity is now 5.5 mt concentrate and 2.2 mt pellets (basis DR grade).**
- **Plan is to produce 2.0-2.2 mt DR grade pellets with target specification of min. 67.6% Fe and max. 2.6% SiO2. DR plants In MENA region are the key target market.**
- **Production of pellets with Fe >67.5% in 2020 was 1.004 mt and deliveries to DR customers have started and are ongoing**

Ferrexpo

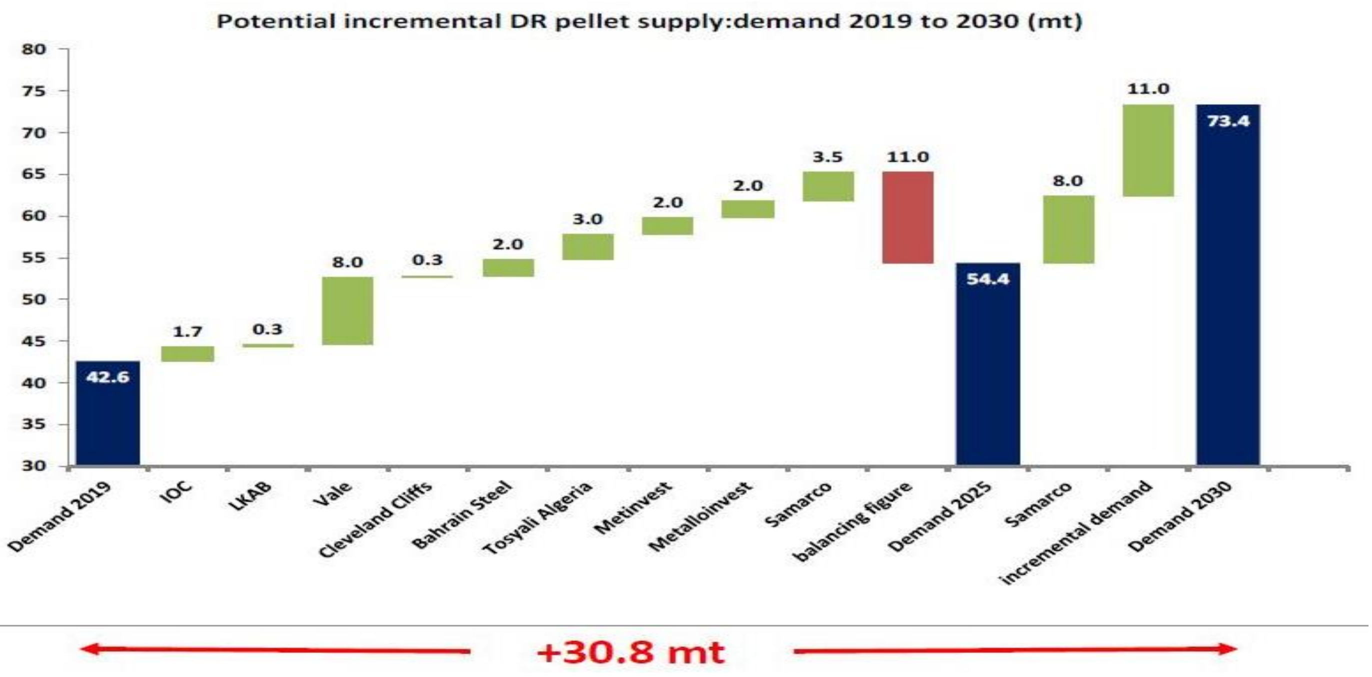
- **Ferrexpo produced 0.339 mt DR grade pellets (67% Fe) in 2020 and plans to increase production of DR grade pellets in the medium term.**

Russia - Metalloinvest

- **Mikhailovsky started pilot scale shipments of DR grade pellets (~68% Fe, 1.4% SiO2) made from Lebedinsky concentrate to OEMK and Lebedinsky in mid-2020. Ore beneficiation is being upgraded to enable production of 16.4 mt high grade concentrate from 2022, including 8.8 mt flotation concentrate grading 70% Fe.**
- **Metalloinvest plans to produce ~0.5 mt DR grade pellets (68% Fe) at Mikhailovsky for trial shipments to the market in 2021 and could supply ~2 mt to the market from 2022 - the decision to produce DR or BF pellets will be market-/margin-driven.**
- **Metalloinvest's 4th HBI plant (capacity 2.08 mt) to be built at Mikhailovsky – production expected to start in H1 2024. DR pellet production will be increased to supply this plant.**
- ***OMK is studying a project to build a 2.5 mt Energiron DR plant at Vyksa Metallurgical Plant (VMP), to be commissioned H2 2024. So far there is no final decision. Company has no iron ore assets.***

Lump ore

- **Main current supplier is Kumba (Anglo American) from Sishen mine:**
  - **Only 0.21 mt DR grade was exported in 2020 (to Egypt).**
  - **Premium grade lump ore (typically 65.2% Fe) is understood to involve selective mining and as the pit gets deeper, scope for increased production is limited.**
- **Potential new supplier is Baffinland Iron Mines' Mary River mine (jointly owned by ArcelorMittal and Nunavut Iron Ore):**
  - **current production 6 mt of which 70% lump with >67% Fe, 1.6% SiO2, 0.9% Al2O3 - could be enriched by selective mining**
  - **proposed Phase 2 Expansion Project would involve constructing a railway from the Mary River Mine Site to the Port Site, adding a second ore dock at the Port and increasing production to 12 Mt per year**
- **Assumes Vale reaches 60mt pellet production of which 45% is DR grade**
- **Assumes 12 mt from Bahrain Steel**
- **Assumes Tosyali Algerie is self-sufficient in pellets by 2025**
- **Assumes start date for Samarco Phases 2 & 3 during second half decade**
- **According to this scenario, potential 2025 DR pellet supply exceeds demand by 20%**
- **To meet the 2030 level of demand, Samarco Phases 2 and 3 and much more will be needed….**



International Energy Agency's "Energy Technology Perspectives 2020" and "Iron & Steel Technology Roadmap"

The IEA considers two scenarios:

- **The Stated Policies Scenario (STEPS) takes into account countries' energy- and climate-related policy commitments, including nationally determined contributions under the Paris Agreement, to provide a baseline against which to assess the additional policy actions and measures needed to achieve the Sustainable Development Scenario.**

- **The Sustainable Development Scenario (SDS) sets out the major changes that would be required to reach the main energy-related goals of the United Nations Sustainable Development Agenda, including an early peak and subsequent rapid reduction in emissions, in line with the Paris Agreement, universal access to modern energy by 2030 and a dramatic reduction in energy-related air pollution. The trajectory for emissions in the Sustainable Development Scenario is consistent with reaching global "net-zero" CO2 emissions for the energy system as a whole by around 2070.**

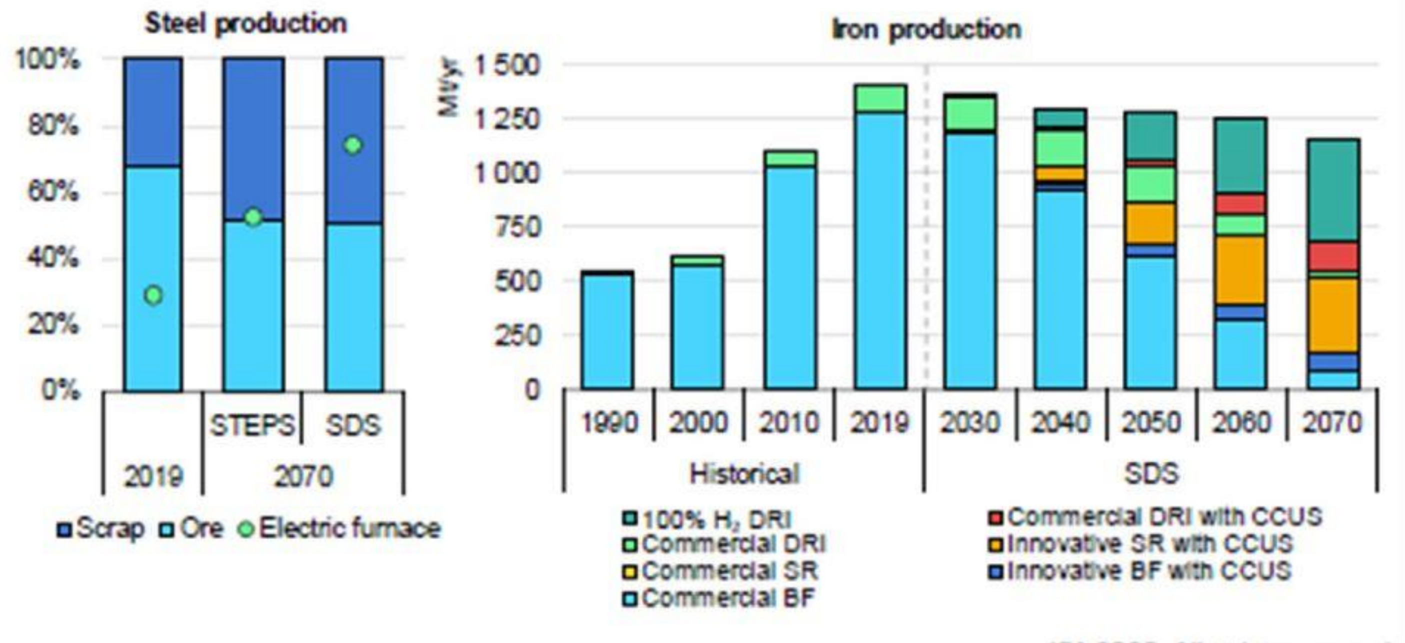


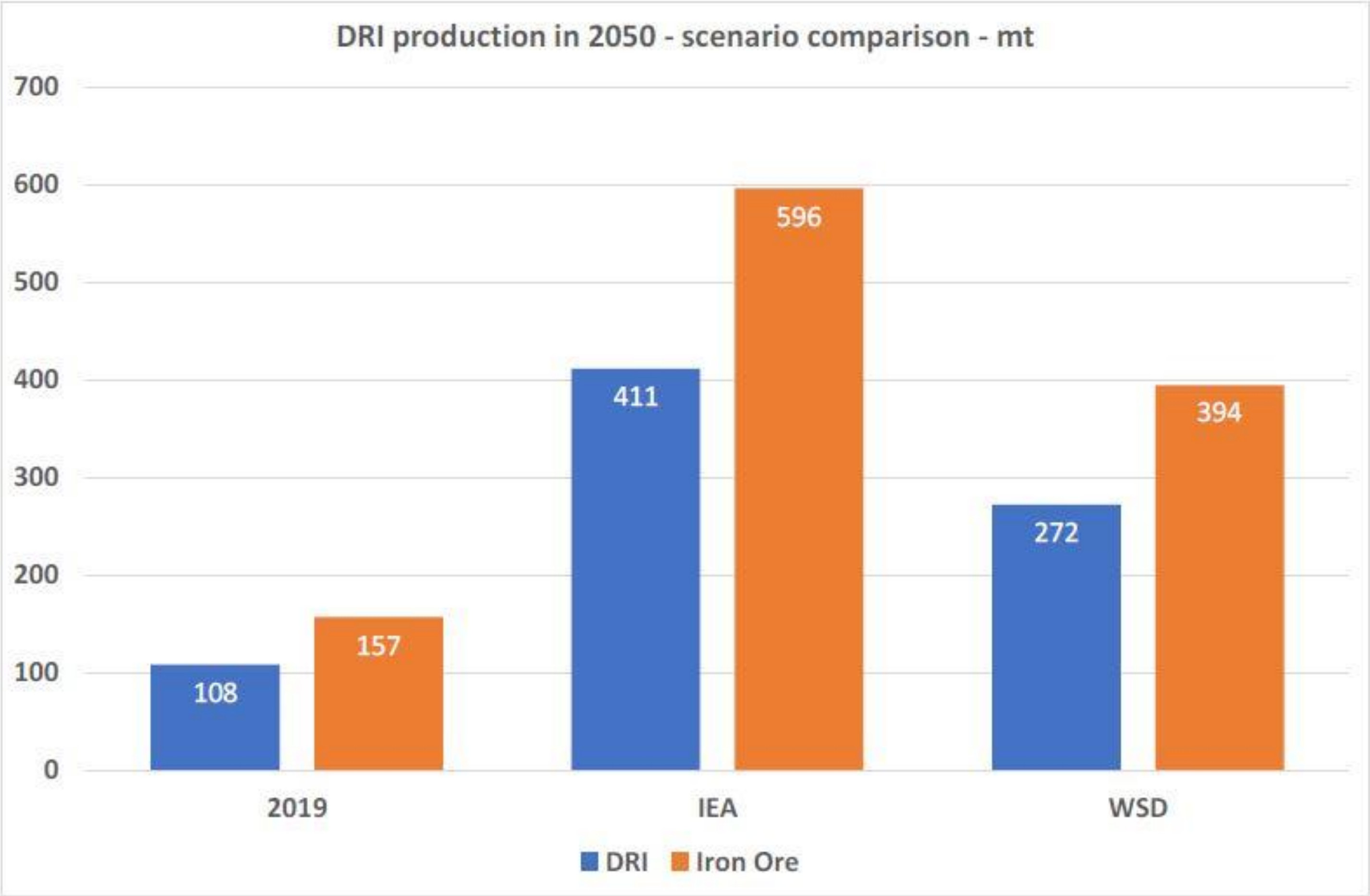
Figure 4.12 Global steel production by route and iron production by technology in the Sustainable Development Scenario, 1990-2070

IEA 2020. All rights reserved.

A head scratcher to conclude

IIMA is preparing a White Paper on the role of and opportunities for ore-based metallics in the world of carbon neutral steelmaking - will be ready in 2021.
Thought starters:

- **Iron ore quality in general is not improving – more beneficiation will be needed**
- **Should future DR plants be somehow integrated with iron ore mines and/or pellet plants?**
- **Is there scope for fines-based DR processes?**



International Iron Metallics Association (IIMA) contact information

Secretary General:	Chief Adviser:	Website:
John Atherton	Chris Barrington	
jatherton@metallics.org	cbarrington@metallics.org	www.metallics.org

Health warning: a forecast (or even a scenario) is not a prophecy!

~~~~~~~~~~xxxxx~~~~~~~~~~
~~~~~~~~~~

Steelmaking through Induction Furnace route – Quality and Energy Conservation

(Dr. Swaren Bedarkar, General Manager (Projects Metallurgy), Electrotherm (India) Limited)

There has been lot of apprehension about the quality steel production through induction furnace (IF) route. This article highlights how quality steel can be produced through IF route - Editor

1 Introduction

Induction furnace is widely used route for producing plain carbon steel and low alloy steel in India. It is normally used for making construction grade long products. Many countries in Middle East Asia, South East Asia, Africa and Eastern Europe, besides Indian Subcontinent have taken up this route for steel making. Steel making through induction furnace (IF) has been one of the most prominent routes in India. India produces about 33% of country's total crude steel production through induction furnace route [1].

About three decades back, induction furnaces were used only in the foundry industry. During mid-80's Electrotherm introduced IFs for steel making despite resistance from other major manufacturers of induction furnaces at that point of time. Gradually, induction furnaces of larger capacities were introduced successfully from 3T to 50T over a period of three decades. Many efforts have been put into effect to make the steel making efficient through induction furnace route. Advancements have been done not only in the induction technology but also in the operation of supporting equipments. As the capacity of steel making increased, scrap became scarcer and eventually direct reduced iron (sponge iron) has become the main raw material for steel making through induction furnace. Higher use of sponge iron in steel making gives rise to high phosphorous content in steel [2]. To tackle this P problem ELdFOS® technology has been developed which uses ladle metallurgy. Once the liquid steel is prepared in induction furnace it is treated in the ladle refining furnace based on needs and then it is cast in the form of billets through continuous casting machine (CCM).

In the present paper efforts have been made to discuss many such developments that have taken place in the induction furnace based steel plants. These developments aim towards efficient steelmaking and save the energy at various stages in induction furnace steelmaking; and ultimately make the process economical to produce quality steel. The work encompasses the use of various raw materials, their impact on quality of steel and the corrective measures taken to produce good quality steel.

2 Induction furnace steelmaking – various practices

As mentioned earlier, steelmaking through induction furnaces is one of the most prominent routes in India. Over the time, various practices have been developed with induction furnace as the main steelmaking equipment. The routes are discussed herewith.

2.1 Use of scrap and sponge iron in induction furnace steelmaking

About three decades back, IFs were using only steel scrap in induction furnace for steelmaking. With time the use of sponge iron in induction furnace became popular. Main driving force to the use of sponge iron in induction furnace is scarcity of scrap in the international market and economics of production of sponge iron. Sponge iron or DRI is the product of direct reduction of iron ore in solid state. The chemical composition of sponge iron is specified in terms of Fe-metallic, FeO, carbon and gangue. Coal based sponge iron has carbon in the range of 0.10%-0.18%; while gas based sponge iron has carbon 1.2-4%. During its melting in induction furnace, unreduced iron oxide reacts with carbon remain in the steel bath and improves its recovery. Thus, yield of sponge iron melting is always greater than its metallic iron. Main advantages of use of sponge iron for steel making are,

- Cheaper compared to steel scrap
- No tramp elements
- Less fume generation during melting compared to steel scrap
- Ease in carbon adjustment

During the melting of sponge iron it is necessary to maintain carbon level in the bath. As a general practice of sponge iron melting, initially high carbon material is melted in the induction furnace. As soon as sponge iron is added in the bath, iron oxide starts its reaction with carbon as follows,

$$FeO_{(s)} + C_{(s)} \rightarrow Fe_{(l)} + CO_{(g)}$$

High carbon liquid bath is formed essentially to improve yield of sponge iron and also to protect acidic refractory lining of the furnace. The high carbon liquid bath may be obtained by melting pig iron, cast iron, high carbon automotive parts, coal addition in the bath, etc. As the sponge iron is added into the bath it starts melting and iron oxide of sponge iron starts reacting with various elements in the bath. Initially silicon reacts with iron oxide. Carbon and manganese react with FeO simultaneously. The result is Si, Mn and C in bath carbon start decreasing gradually. By the time furnace becomes full of liquid metal, the desired carbon level is achieved. In case of gas based sponge iron, the carbon requirement for iron oxide reaction is fulfilled by the carbon in the sponge iron itself. Thus, carbon and iron oxide take care of each other. Whether sponge iron is coal based or gas based, the percentage of sponge iron in the charge mix depends on carbon level and iron oxide content. At the same time, the economics of steel making also impacts the use of sponge iron in induction furnace. At places where the price difference between sponge iron and scrap is large, the induction furnaces are operated mainly with sponge iron. On the other hand, minimal price difference leads to use the medium carbon scrap throughout the heating cycle. In such practices, hardly 10% sponge iron is used at the end of the heat cycle mainly to adjust the final carbon level.

Table 1 depicts the variation of chemistry in the bath. The chemistry mentioned is typical chemistry. It largely depends on yield of sponge iron and input chemistry of scrap. The chemistry mentioned is at the beginning of sponge iron melting and the final chemistry achieved at the end of sponge iron melting.

Table 1

Sr. No.	Wt% of charge mix		%C	%Si	%Mn	%P	%S
1	10%Sponge iron 90% Scrap	Initial chemistry	0.32	0.25	0.50	0.04	0.04
		Final chemistry	0.22	0.1	0.02	0.04	0.04
2	60%Sponge iron 40% Scrap	Initial chemistry	1.00	0.25	0.50	0.04-0.08	0.04-0.08
		Final chemistry	0.22	0.02	0.03	0.04-0.08	0.04-0.08
3	90%Sponge iron 10% Scrap	Initial chemistry	2.0	0.25	0.50	0.04-0.1	0.04-0.1
		Final chemistry	0.22	0.00	0.01	0.04-0.1	0.04-0.1

It is important to note that amount of P in sponge iron solely depends on amount of P in iron ore. If iron ore is high in P, the same is reflected in P of sponge iron about 1.5 times higher than the amount in ore. Low P iron ore results in low P sponge iron. In the same way main source of S in sponge iron is the coal used in rotary kiln to reduce iron ore. Low S coal produces low S sponge iron.

2.2 Use of hot metal along with sponge iron in induction furnace

Increased use of sponge iron in induction furnace requires high carbon bath. Once high carbon bath is prepared, the sponge iron is added in the induction furnace at required feeding rate for steel making.

For steel making, use of sponge iron goes up to as high as 90%. Higher use of sponge iron demands high carbon bath in the initial stage. This requirement is fulfilled by the hot metal available from the blast furnace. A few plants in eastern India have also installed cupola to meet the requirement of high carbon bath by melting pig iron and cast iron. Use of hot metal from the external source reduces the energy consumption of steel production. It also helps increase the production by 10-15%.

Though the scope of application is limited, the route is marginally dependent on the coke prices in the international market, hence not preferred much.

3 ELdFOS® technology

The presence of phosphorous and sulphur in construction grade steel is harmful to its quality, and therefore, they have to be brought down to the specified / acceptable levels. It has become necessary for every steel plant to adopt the technology to reduce P and S from the steel. For induction furnace steel makers this is the big challenge. Electrotherm is one of the leading manufacturers of steel making equipments in India. Through continuous R&D, the company has developed ELdFOS technology (Electrotherm Ladle Dephosphorization and Desulphurization process) where P and S can be reduced to the required limit [3]. Secondary metallurgy is considered as refining of liquid metal in the ladle. ELdFOS technology uses the same concept where steel is refined in the ladle. The refining is carried out using multiple slag practice. Throughout the ladle operation, the liquid metal is purged by inert gas to obtain uniform temperature, composition, inclusion floatation and for good slag-metal reaction.

In this process, the heat is prepared in induction furnace and tapped in the ladle. Prior to tapping, no ferroalloy additions are done in the induction furnace. Tapping temperature is maintained at around 1630°C. During tapping, simultaneous addition of *dephos flux* and liquid metal is done in the ladle. The ladle is then taken to the ELdFOS station and placed on ladle car. If required, *desulph flux* is also added to the bath prior to arcing. The temperature of the bath is raised beyond 1600°C (depending on required temperature at CCM). The ladle trolley has an arrangement for slag removal whenever required. The slag may be removed before arcing or after arcing. Figure 1 depicts ELdFOS process. Once required temperature is achieved by arcing, ferroalloys are added, chemistry is achieved and the ladle is sent to caster. The total process time of ELdFOS is around 40-45 minutes including dephoshphorization, desulphurization and superheating. However, the exact time will largely depend on the extent to which dephosphorization and desulphurization are needed and the required final temperature of the metal. With good practice, the present process is capable of reducing P and S by 70 points each.

LRF is operated by forming basic slags. Ladle lining is also kept basic in nature. Magnesia carbon lining is very popular in LRF operation. During arcing, graphite electrodes are getting consumed due to heat. Other parameters that contribute to the operational cost are various fluxes. Lime, dolomite and fluorspar are the commonly used fluxes which are used to operate LRF. The major elements of the operating cost are electricity consumption, fluxes, electrode consumption and refractory consumption. Considering current prices of various raw materials, the operating cost for dephosphorization and desulphurization with complete LRF operation is about Rs 1500.00 per ton of steel. The operating cost is subjected to change as per the price fluctuation of raw materials used and discontinuous operation.

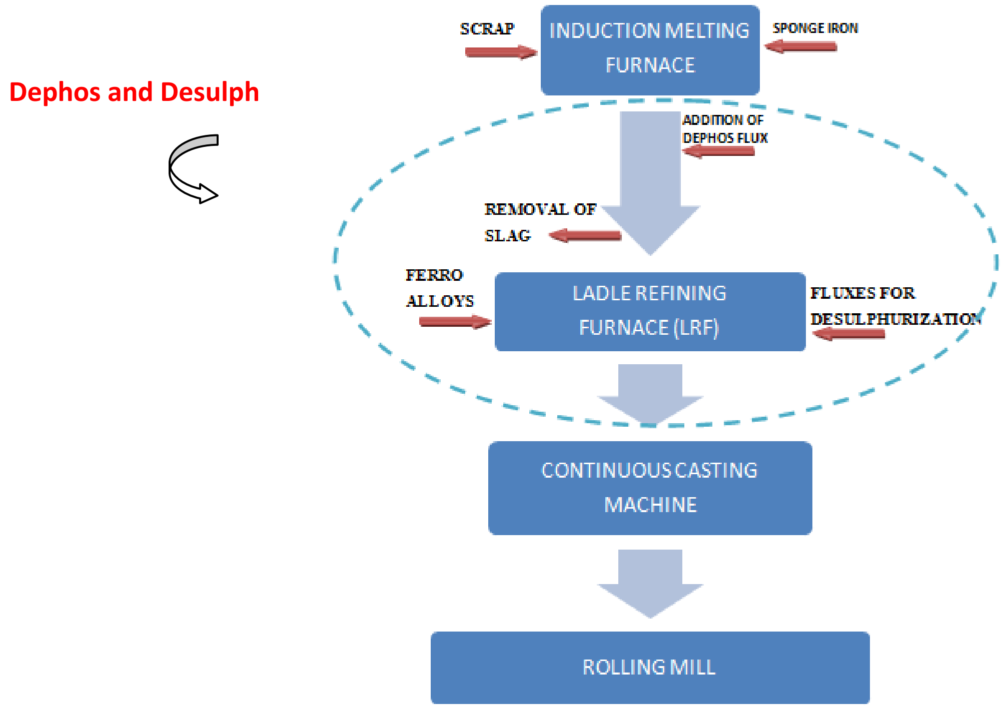


Figure 1 Flow chart of ELdFOS® process

4 Energy conservation

Induction furnace steelmaking has gained popularity because it has been able to melt all kinds of scrap and sponge iron generated by various industries and produce steel that can be well used for construction purposes. At many places, IFs are even used to produce alloy steel. Since, IFs are (electrical) power intensive, their sustainability in present market scenario is very crucial because survival through this route can be possible only when one can produce steel more economically and contain their cost within the market driven pricing. Energy conservation in induction furnace intends to cover many of the productivity improvement equipments that can be adopted by all steel making units and optimize energy usage for sustainability.

4.1 Programmable Dynamic Load Manager

Electrical power is one type of a raw material for induction furnaces.In an ideal situation, the sanctioned power for the plant (kVA) should be utilized completely in operating various steel making equipments or auxiliary loads without any loss. These conditions can be met by installing Programmable Dynamic Load Manager (PDLM) that can manage the entire plant load intelligently under single meter and without any human interference. Other than the induction furnace, there is usually auxiliary load that is variable in steel making plant which comprises of EOT cranes, magnets, cooling towers, pumps, compressors, factory lighting etc. It is very rare to find all these equipment operating at their full capacity during any time in a given cycle. PDLM senses the exact requirement of furnaces and adjusts the power that is fed to each equipment optimally so that production stays uninterrupted and the available load is efficiently managed, thereby reducing the maximum demand recorded. Figure 2 depicts PDLM and its function.

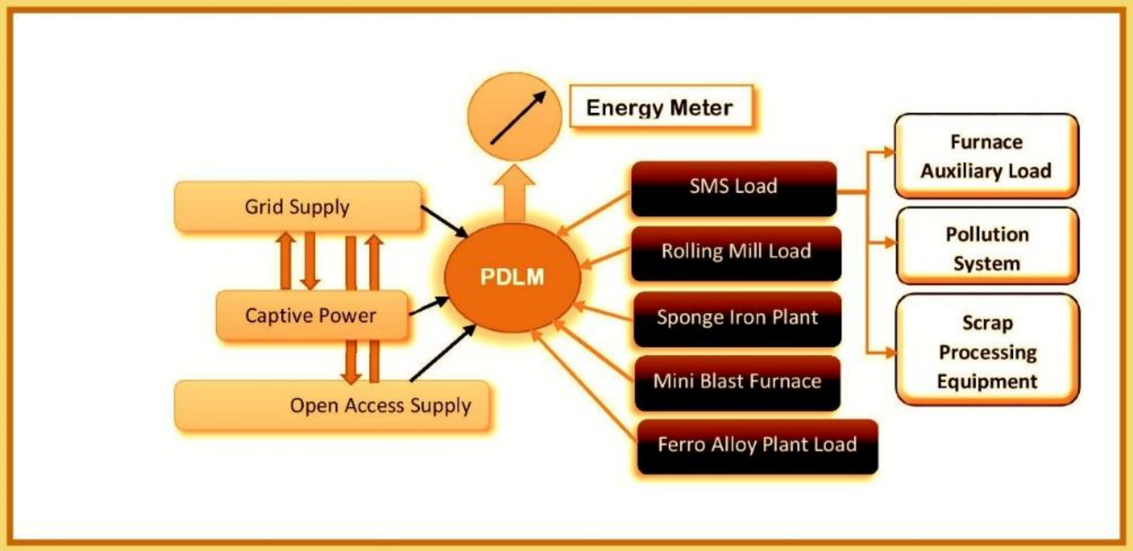


Figure 2 PDLM - Programmable Dynamic Load Manager capabilities

PDLM can also be synchronized with real time grid clock that can take care of peak and off-peak hours. It is also able to work with a variety of inputs like grid power, captive power and power from open access. The overall Load Factor improves because of PDLM and some states have even started offering Load Factor incentives to optimize power usage. PDLM is competent enough to work with any make of induction furnaces and also to handle various other load within a plant like Sponge Iron kilns, Rolling Mills, Mini-Blast Furnaces, and Submerged Arc Furnaces etc. that are connected to a common metering unit.

4.2 *Power optimizers*

Power Optimizers improve overall power factor of furnace by maintaining maximum voltage over the entire melting cycle. They eliminate unwanted delays due to manual operation of adding/removing capacitors and reduce heat time and power consumption by 10-20 Units/Ton, depending upon furnace size.

5 Conclusions

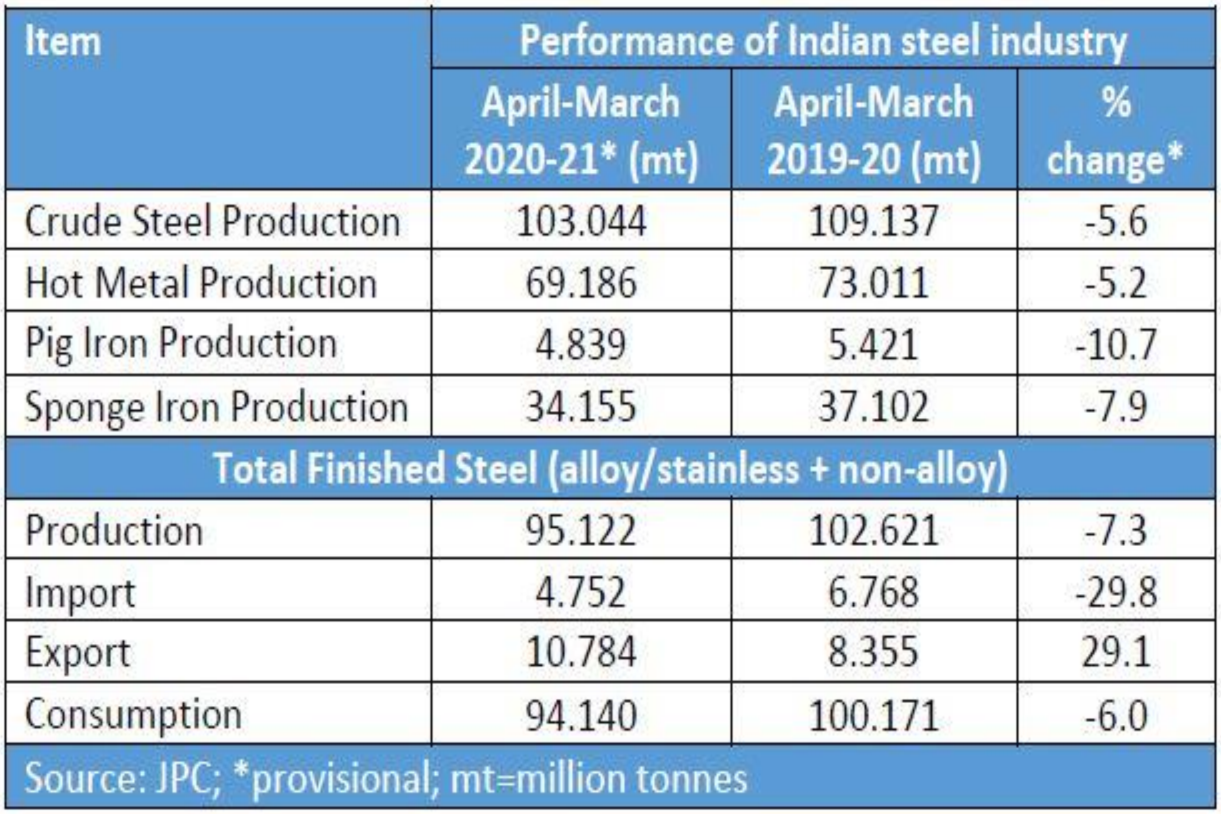
Over last couple of decades, induction furnace steel making has become one of the very important routes. To operate the induction furnace based plants efficiently, power optimizer and PDLM can be effectively used. Use of these equipments reduce overall power demand. In India, sponge iron is very useful raw material. Use of sponge iron in induction furnace helps maintain desired carbon level in the bath, reduce tramp elements and reduce cost of steel production. In order to overcome the limitation of dephosphorization in induction furnace, ELdFOS process has been developed using Ladle Refining Furnace. Ladle refining furnace is very important tool in steel melting shop. Installation of modern LRF in the steel melt shop helps increase productivity. IF–LRF route is absolutely capable of producing steel meeting quality standards required for infrastructure and construction. The route is also capable to produce medium alloy steel, low alloy steel, construction steel, etc. where sulphur and phosphorous are required in the range of 0.02% each. With the effective use of ladle metallurgy, quality of steel produced is less dependent on the primary melting furnace.

References

1. Ministry of steel, Government of India, Annual Report (2019-20)
2. Bedarkar S.S. and Singh R, Removal of Phosphorous from Steel Produced by Melting Sponge Iron in Induction Furnace, Trans Ind Inst Met, 66 (2013), p 207-211.
3. Swaren Bedarkar, Quality steelmaking through induction furnace – LRF route using DRI/sponge iron, Steel Technology, July 2016, vol. 60 (2), p 79 – 81.

~~~~~~~~~~XXXXX~~~~~~~~~~
~~~~~~~~~~

STATISTICS



Item	Performance of Indian steel industry		
	April-March 2020-21* (mt)	April-March 2019-20 (mt)	% change*
Crude Steel Production	103.044	109.137	-5.6
Hot Metal Production	69.186	73.011	-5.2
Pig Iron Production	4.839	5.421	-10.7
Sponge Iron Production	34.155	37.102	-7.9
Total Finished Steel (alloy/stainless + non-alloy)			
Production	95.122	102.621	-7.3
Import	4.752	6.768	-29.8
Export	10.784	8.355	29.1
Consumption	94.140	100.171	-6.0
Source: JPC; *provisional; mt=million tonnes			

~~~~~~~~~~~xxxxx~~~~~~~~~~~
~~~~~~~~~~~