Alternative routes of Iron making

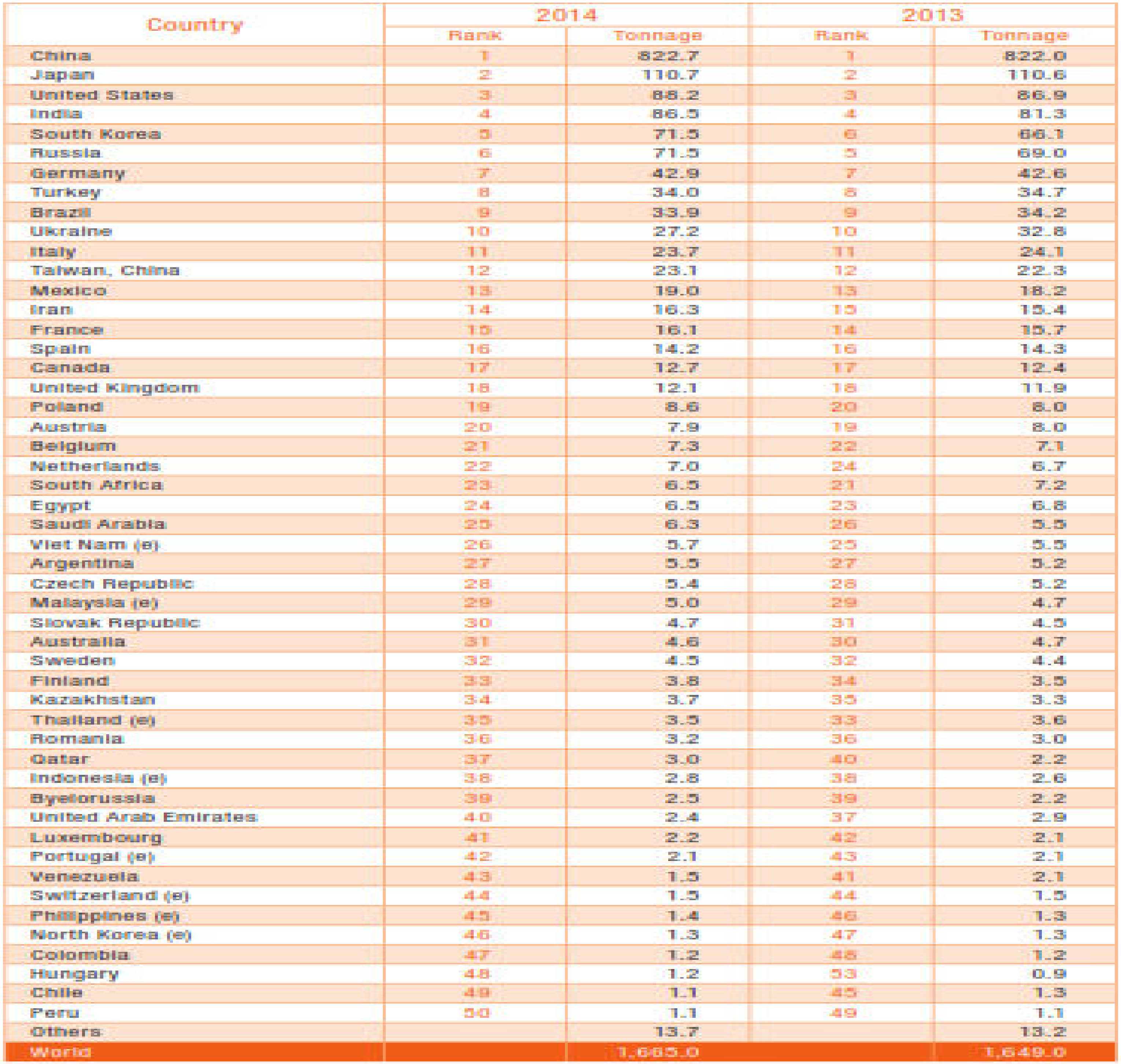
World crude steel production since 1950 in mtpa

Years	World
1950	189
1955	270
1960	347
1965	456
1970	595
1975	644
1980	717
1985	719
1990	770
1995	753

Years	World
2000	850
2001	852
2002	905
2003	971
2004	1,063
2005	1,148
2006	1,250
2007	1,348
2008	1,343
2009	1,238

Years	World
2010	1,433
2011	1,537
2012	1,559
2013	1,649
2014	1,665

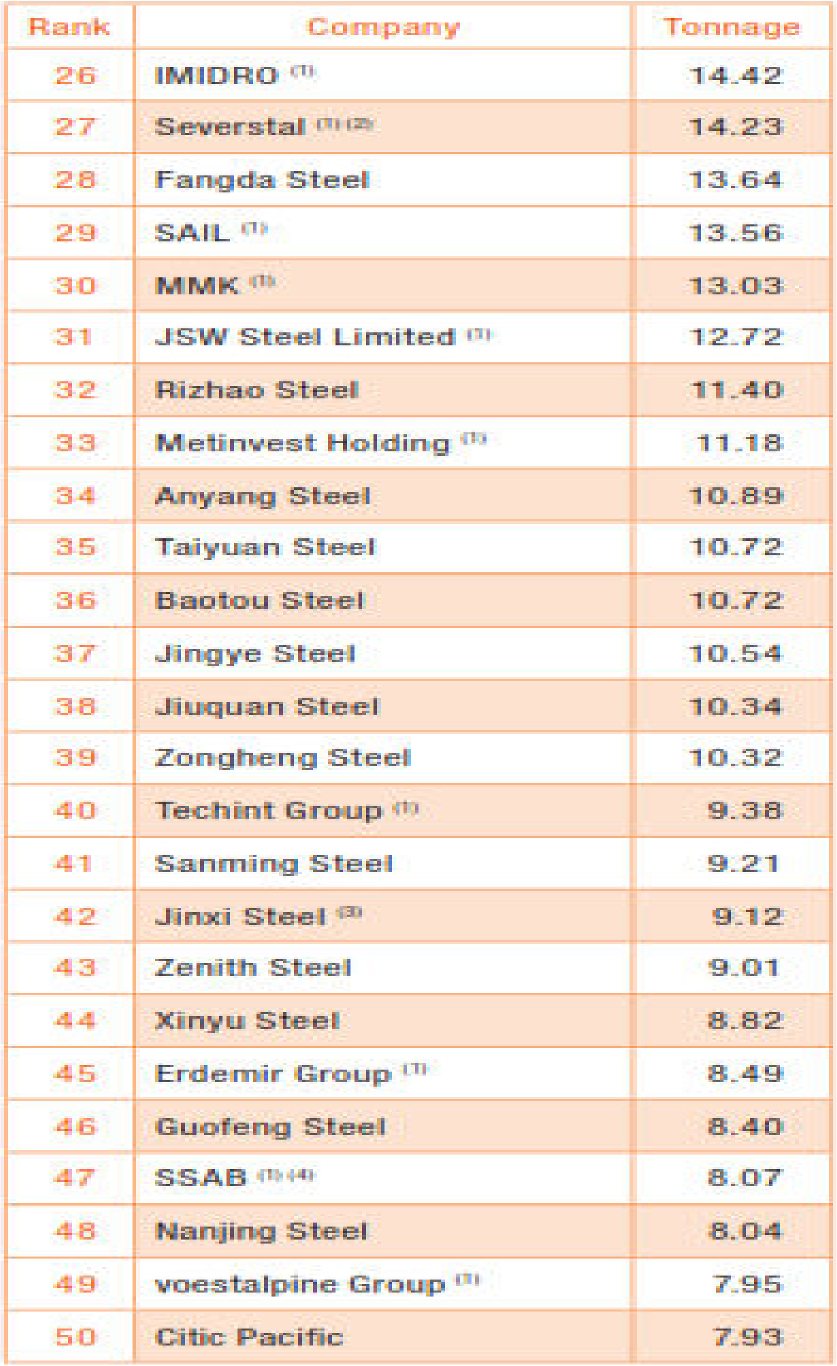
Country wise crude steel production 2014 in mtpa



Country	2014		2013	
	Rank	Tonnage	Rank	Tonnage
China	1	822.7	1	822.0
Japan	2	110.7	2	110.6
United States	3	88.2	3	86.9
India	4	86.5	4	81.3
South Korea	5	71.5	6	66.1
Russia	6	71.5	5	69.0
Germany	7	42.9	7	42.6
Turkey	8	34.0	8	34.7
Brazil	9	33.9	9	34.2
Ukraine	10	27.2	10	32.8
Italy	11	23.7	11	24.1
Taiwan, China	12	23.1	12	22.3
Mexico	13	19.0	13	18.2
Iran	14	16.3	15	15.4
France	15	16.1	14	15.7
Spain	16	14.2	16	14.3
Canada	17	12.7	17	12.4
United Kingdom	18	12.1	18	11.9
Poland	19	8.6	20	8.0
Austria	20	7.9	19	8.0
Belgium	21	7.3	22	7.1
Netherlands	22	7.0	24	6.7
South Africa	23	6.5	21	7.2
Egypt	24	6.5	23	6.8
Saudi Arabia	25	6.3	26	5.5
Viet Nam (e)	26	5.7	25	5.5
Argentina	27	5.5	27	5.2
Czech Republic	28	5.4	28	5.2
Malaysia (e)	29	5.0	29	4.7
Slovak Republic	30	4.7	31	4.5
Australia	31	4.6	30	4.7
Sweden	32	4.5	32	4.4
Finland	33	3.8	34	3.5
Kazakhstan	34	3.7	35	3.3
Thailand (e)	35	3.5	33	3.6
Romania	36	3.2	36	3.0
Qatar	37	3.0	40	2.2
Indonesia (e)	38	2.8	38	2.6
Byelorussia	39	2.5	39	2.2
United Arab Emirates	40	2.4	37	2.9
Luxembourg	41	2.2	42	2.1
Portugal (e)	42	2.1	43	2.1
Venezuela	43	1.5	41	2.1
Switzerland (e)	44	1.5	44	1.5
Philippines (e)	45	1.4	46	1.3
North Korea (e)	46	1.3	47	1.3
Colombia	47	1.2	48	1.2
Hungary	48	1.2	53	0.9
Chile	49	1.1	45	1.3
Peru	50	1.1	49	1.1
Others		13.7		13.2
World		1,665.0		1,649.0

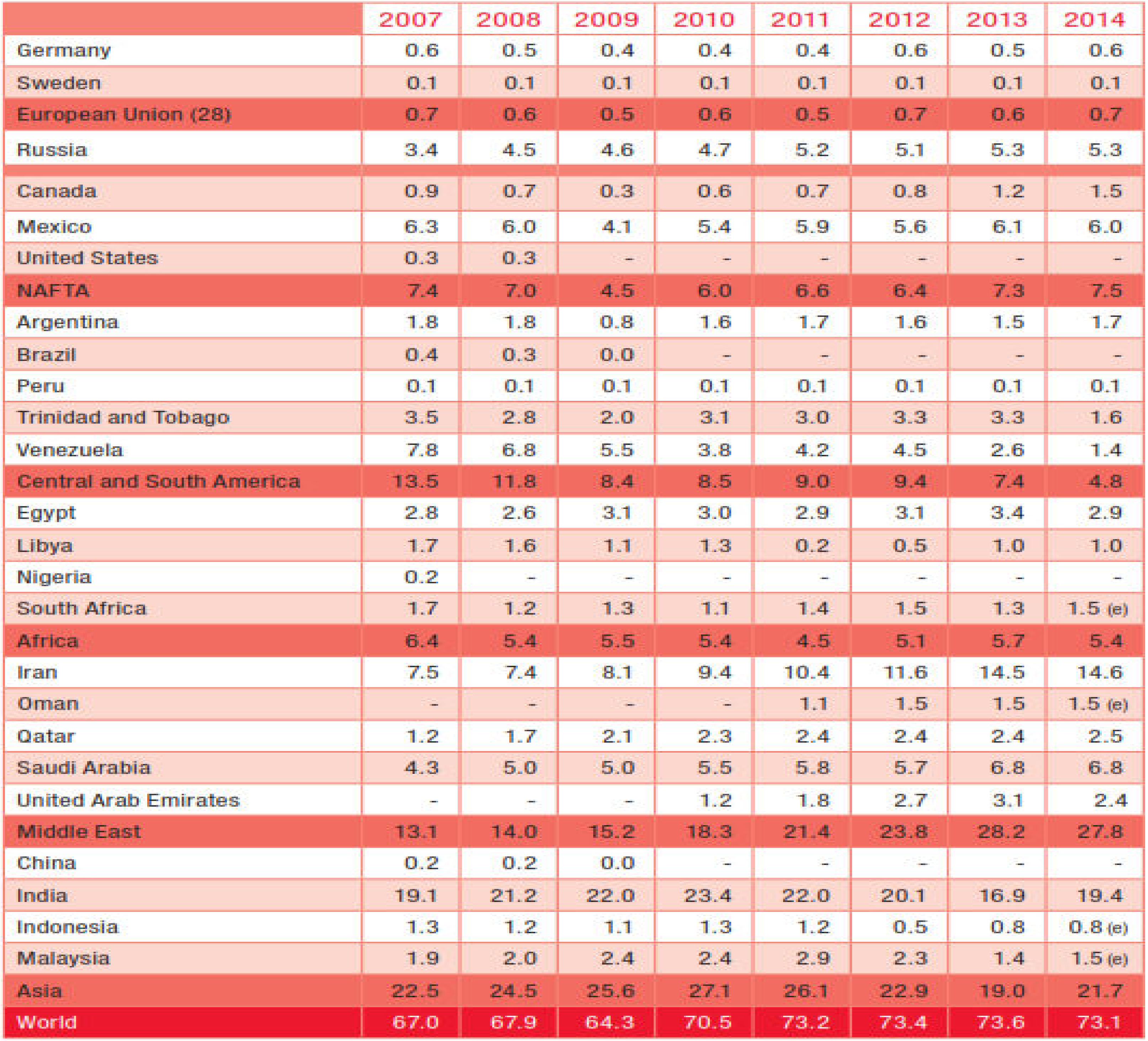
Company wise crude steel production 2014 in mtpa

Rank	Company	Tonnage
1	ArcelorMittal (1)	98.09
2	NSSMC (1)	49.30
3	Hebei Steel Group (1)	47.09
4	Baosteel Group (1)	43.35
5	POSCO (1)	41.43
6	Shagang Group	35.33
7	Ansteel Group (1)	34.35
8	Wuhan Steel Group (1)	33.05
9	JFE (1)	31.41
10	Shougang Group (1)	30.78
11	Tata Steel Group (1)	26.20
12	Shandong Steel Group	23.34
13	Nucor Corporation (1)	21.41
14	Hyundai Steel Company (1)	20.58
15	U. S. Steel Corporation (1)	19.73
16	Gerdau (1)	19.00
17	Maanshan Steel (1)	18.90
18	Tianjin Bohai Steel	18.49
19	ThyssenKrupp (1)	16.27
20	Benxi Steel	16.26
21	NLMK (1)	16.11
22	Evraz Group (1)	15.54
23	China Steel Corporation (1)	15.40
24	Valin Group	15.38
25	Jianlong Group	15.26



Rank	Company	Tonnage
26	IMIDRO (1)	14.42
27	Severstal (1)(2)	14.23
28	Fangda Steel	13.64
29	SAIL (1)	13.56
30	MMK (1)	13.03
31	JSW Steel Limited (1)	12.72
32	Rizhao Steel	11.40
33	Metinvest Holding (1)	11.18
34	Anyang Steel	10.89
35	Taiyuan Steel	10.72
36	Baotou Steel	10.72
37	Jingye Steel	10.54
38	Jiuquan Steel	10.34
39	Zongheng Steel	10.32
40	Techint Group (1)	9.38
41	Sanming Steel	9.21
42	Jinxi Steel (3)	9.12
43	Zenith Steel	9.01
44	Xinyu Steel	8.82
45	Erdemir Group (1)	8.49
46	Guofeng Steel	8.40
47	SSAB (1)(4)	8.07
48	Nanjing Steel	8.04
49	voestalpine Group (1)	7.95
50	Citic Pacific	7.93

Countries wise DRI production 2007 to 2014 in mtpa



	2007	2008	2009	2010	2011	2012	2013	2014
Germany	0.6	0.5	0.4	0.4	0.4	0.6	0.5	0.6
Sweden	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
European Union (28)	0.7	0.6	0.5	0.6	0.5	0.7	0.6	0.7
Russia	3.4	4.5	4.6	4.7	5.2	5.1	5.3	5.3
Canada	0.9	0.7	0.3	0.6	0.7	0.8	1.2	1.5
Mexico	6.3	6.0	4.1	5.4	5.9	5.6	6.1	6.0
United States	0.3	0.3	-	-	-	-	-	-
NAFTA	7.4	7.0	4.5	6.0	6.6	6.4	7.3	7.5
Argentina	1.8	1.8	0.8	1.6	1.7	1.6	1.5	1.7
Brazil	0.4	0.3	0.0	-	-	-	-	-
Peru	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Trinidad and Tobago	3.5	2.8	2.0	3.1	3.0	3.3	3.3	1.6
Venezuela	7.8	6.8	5.5	3.8	4.2	4.5	2.6	1.4
Central and South America	13.5	11.8	8.4	8.5	9.0	9.4	7.4	4.8
Egypt	2.8	2.6	3.1	3.0	2.9	3.1	3.4	2.9
Libya	1.7	1.6	1.1	1.3	0.2	0.5	1.0	1.0
Nigeria	0.2	-	-	-	-	-	-	-
South Africa	1.7	1.2	1.3	1.1	1.4	1.5	1.3	1.5 (e)
Africa	6.4	5.4	5.5	5.4	4.5	5.1	5.7	5.4
Iran	7.5	7.4	8.1	9.4	10.4	11.6	14.5	14.6
Oman	-	-	-	-	1.1	1.5	1.5	1.5 (e)
Qatar	1.2	1.7	2.1	2.3	2.4	2.4	2.4	2.5
Saudi Arabia	4.3	5.0	5.0	5.5	5.8	5.7	6.8	6.8
United Arab Emirates	-	-	-	1.2	1.8	2.7	3.1	2.4
Middle East	13.1	14.0	15.2	18.3	21.4	23.8	28.2	27.8
China	0.2	0.2	0.0	-	-	-	-	-
India	19.1	21.2	22.0	23.4	22.0	20.1	16.9	19.4
Indonesia	1.3	1.2	1.1	1.3	1.2	0.5	0.8	0.8 (e)
Malaysia	1.9	2.0	2.4	2.4	2.9	2.3	1.4	1.5 (e)
Asia	22.5	24.5	25.6	27.1	26.1	22.9	19.0	21.7
World	67.0	67.9	64.3	70.5	73.2	73.4	73.6	73.1

Alternative routes of Iron Making

- More than 90% of world iron production is through Blast furnace technology route
- Driving forces for development of Alternative Ironmaking technologies
  - Costly and scarce coking coal:
    - Need to look beyond coking coal
  - possibility to use iron ore fines directly
  - Land-constraint
  - Environmental considerations
    - Eliminate pollution-intensive sintering and coke-making processes
  - Water scarcity
  - Large scale of economy
    - High capital cost
  - Scientific/ engineering knowledge
    - To think/ design alternative processes

Possible Solutions: Alternatives for Ironmaking

1] Production of Non-Liquid Iron (DRI)

- Direct Reduced Iron (DRI) has emerged as an excellent substitute for scrap for electric furnaces.
- That's why, DRI production has zoomed throughout the world (`~73 mt in 2015)
- *SL/RN, MIDREX, HyL, ITmk3 etc.*

2] Alternative method for Liquid Iron (Hot Metal)

- Smelting Reduction (SR) processes:
- *COREX, FINEX, Hismelt etc*.
  - using non-coking coal
  - obviating the need for coke oven batteries and sinter plants
    - needing smaller land/ area
    - Iron ore fines can be used directly (except COREX)
    - Lesser pollution

DRI Production Technologies

- **DR processes have overcome many of theirs conceptual & engineering problems, and hence have been commercialized throughout the world in a big way.**

- ***Two major production technologies:***
  - **Coal Based DR processes**
  - **Coal based rotary kiln process**
  - **Coal based rotary hearth process**
  - **~20% of world DRI production**

  - **Gas Based Shaft Reduction processes**
  - **~80% of world DRI production**
  - **MIDREX (~60% among all DRI processes),**
  - **HyL (~20% among all DRI processes)**

DRI Technologies

Both gas-based & coal-based DRI technology readily available

Scale of operation

- Gas based : 0.8 –2.0 mtpa/module
- Coal based : 0.03 -0.15 mtpa/module

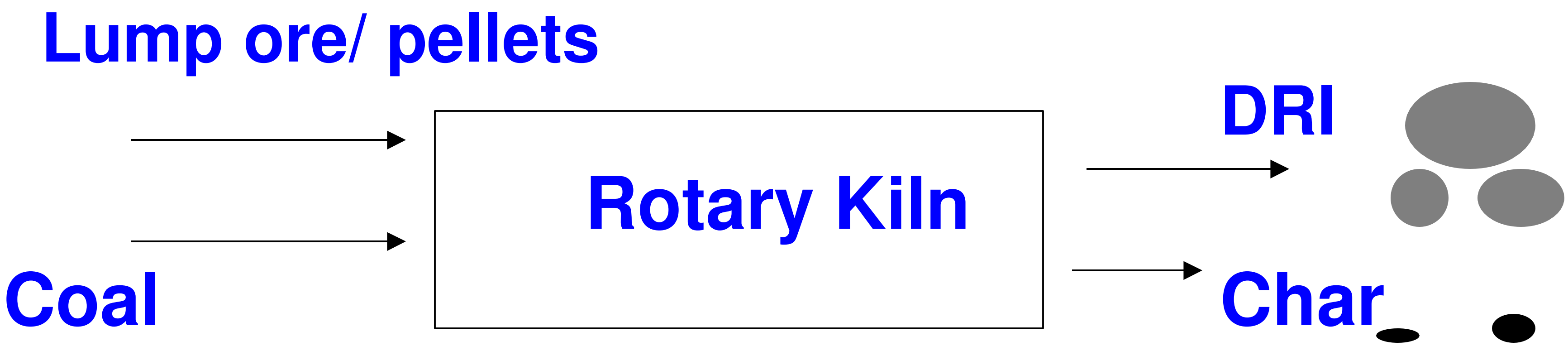
Feed stock :

- Gas based processes
  - Pellet (8-15mm): 33 -100 %; Iron ore (6-30mm): 0 -67%
  - Natural gas / Coal gas (not practiced yet)
- Coal Based Processes (rotary kiln)
  - Iron Ore/Pellet (6- 20 mm): 100%,
  - Non-coking Coal

- Any of these can be adopted based on techno-economics
- India : World Leader: ~ 20 mtpy: 27% of world production
- India: Pollution specially rotary Kiln processes

Production Technologies

- **Coal Based Rotary Kiln process**



Lump ore/ pellets

Coal

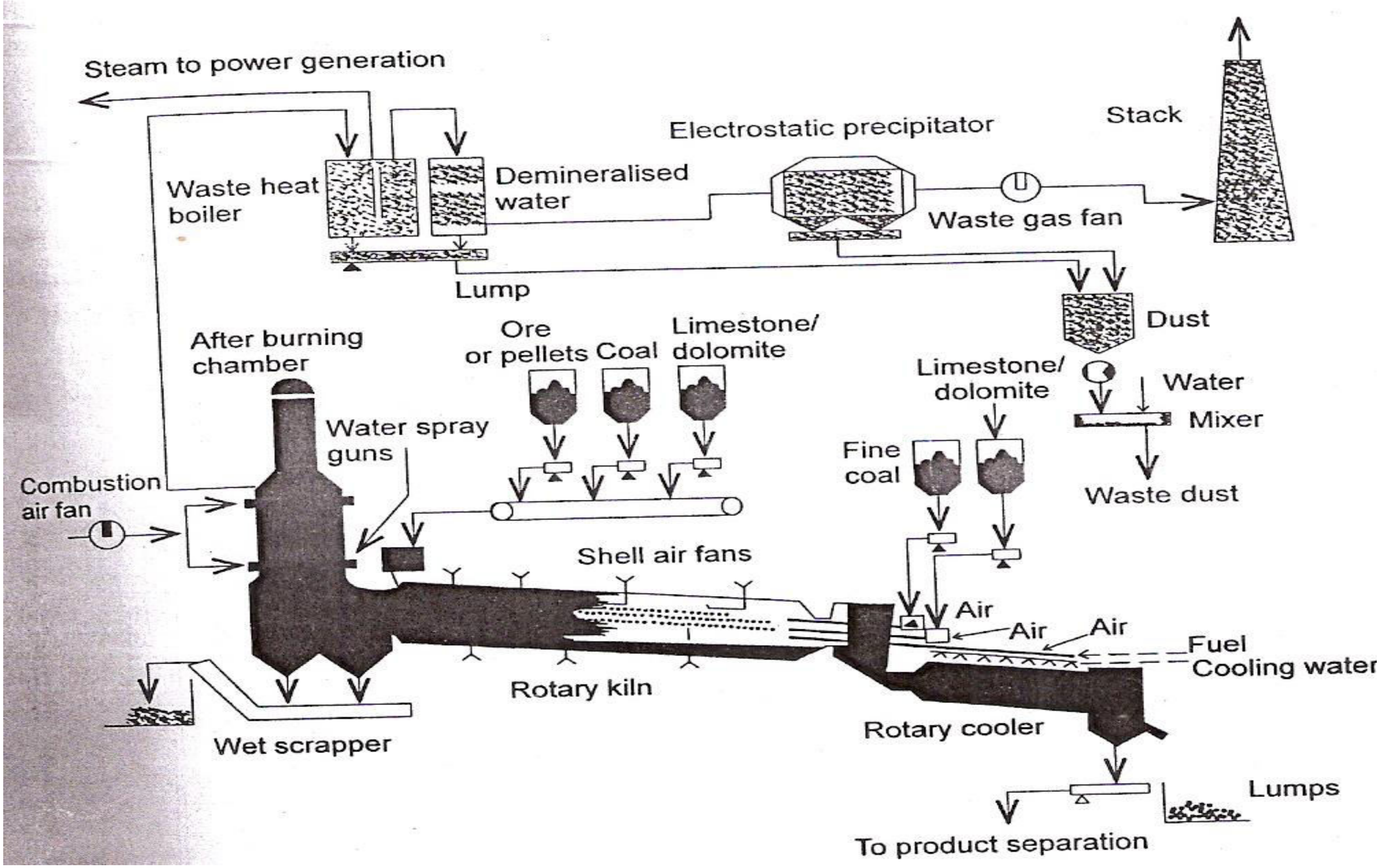
Rotary Kiln

DRI

Char

Scheme for DRI Production in Rotary Kiln

Flow sheet of SL/RN Process



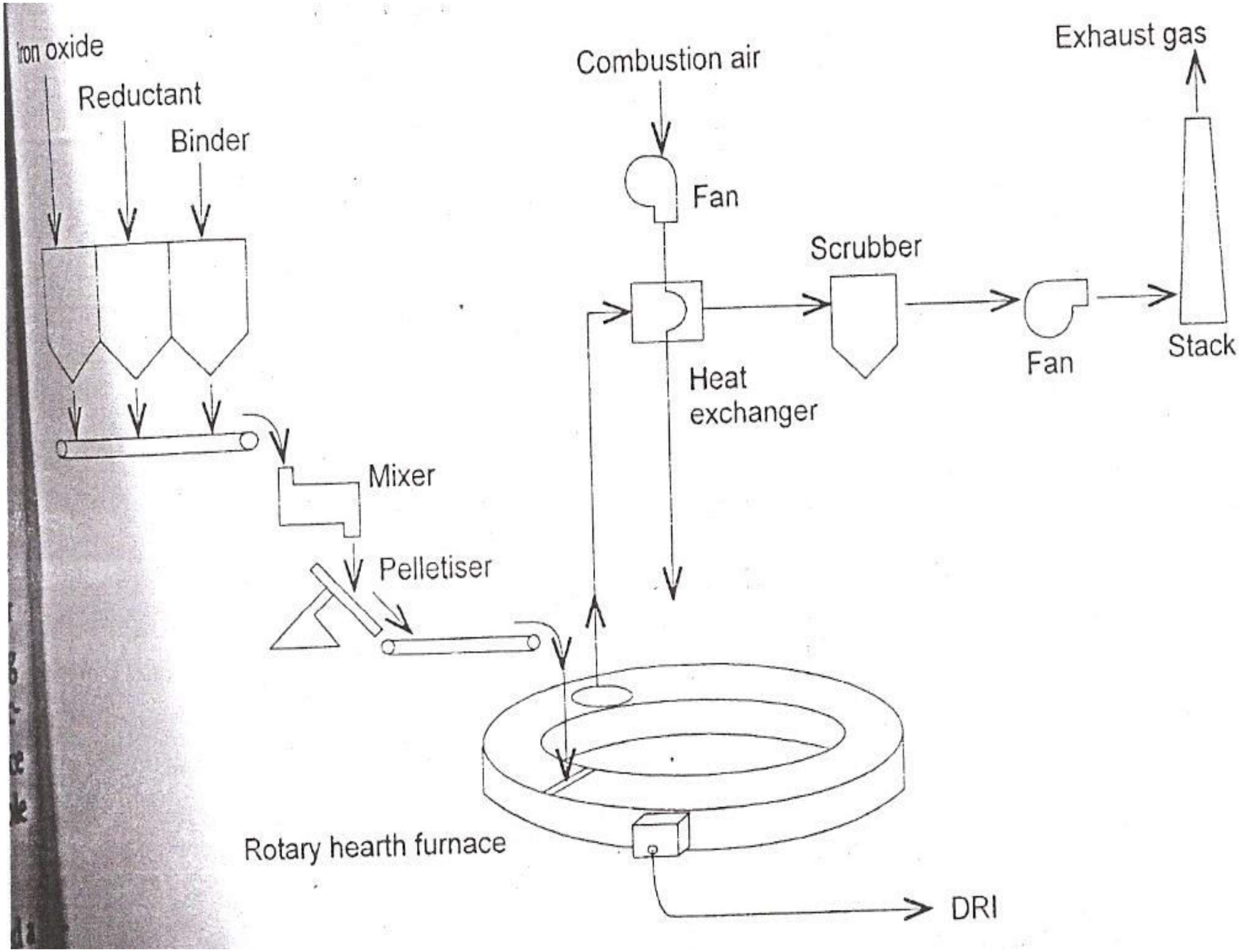
Rotary Hearth Furnace Based DR Processes

- **INMETCO Process**
  - International Nickel Company, Canada developed the thermal reduction process in 1970 for reduction of various metallic wastes in the plant
  - Input of wastes 150 tpd or 45,000 tpa producing alloy required iron 20,000 tpa
  - In 1983 SMS Demag signed a worldwide license agreement with Inmetco for development & marketing
  - Process has the following three basic steps
    - Feed preparation, blending & pelletising
    - Reduction
    - Smelting & casting

Rotary Hearth Furnace Based DR Processes

- **INMETCO Process**
  - The ground oxide materials, ground coal and binder are mixed and palletized
  - The green pellets are charged on a moving rotary hearth in layer thickness of 20 mm
  - Pellets are heated in counter current flow of gases
  - The burners are arranged in the heating & the reduction zone
  - In the heating zone pellets are heated to the reduction temperature by means of radiation from the off gas and the walls
  - CO generated in the reduction zone is totally combusted along with volatiles of the coal
  - Off gas leaves the furnace at 1100°C

Flowsheet of Inmetco process



Rotary Hearth Furnace Based DR Processes

- **INMETCO Process**
- DRI is extracted at about 900°C and charged into air tight refractory lined transportation hoppers. In hot condition it is charged into downstream melting furnace
- Metallization achieved in about 90%
- Depending upon the quantity of carbon & lime in the charge, the chemistry of hot metal can be as following

  C: 0.1 – 3.5%
  Si: 0.1 – 0.6%
  S: 0.05 – 0.15%
  P: 0.01 – 0.05%
- ELLWOOD City Plant
- Pelletiser – 47, 000 tpy
- Rotary Hearth Furnace - 60,000 tpy
- Melting Furnace - 25,000 tpy

Rotary Hearth Furnace Based DR Processes

- **INMETCO Process**
  - Typical operating figures for a 300,000tpa plant production

	Requirement/t
Iron ore fines	1.55 t
Coal fines	0.70 t
Electric power	950 kWh
Carburizer	40 kg
Lime	50 kg
Binder	15 kg
Electrode paste	8 kg

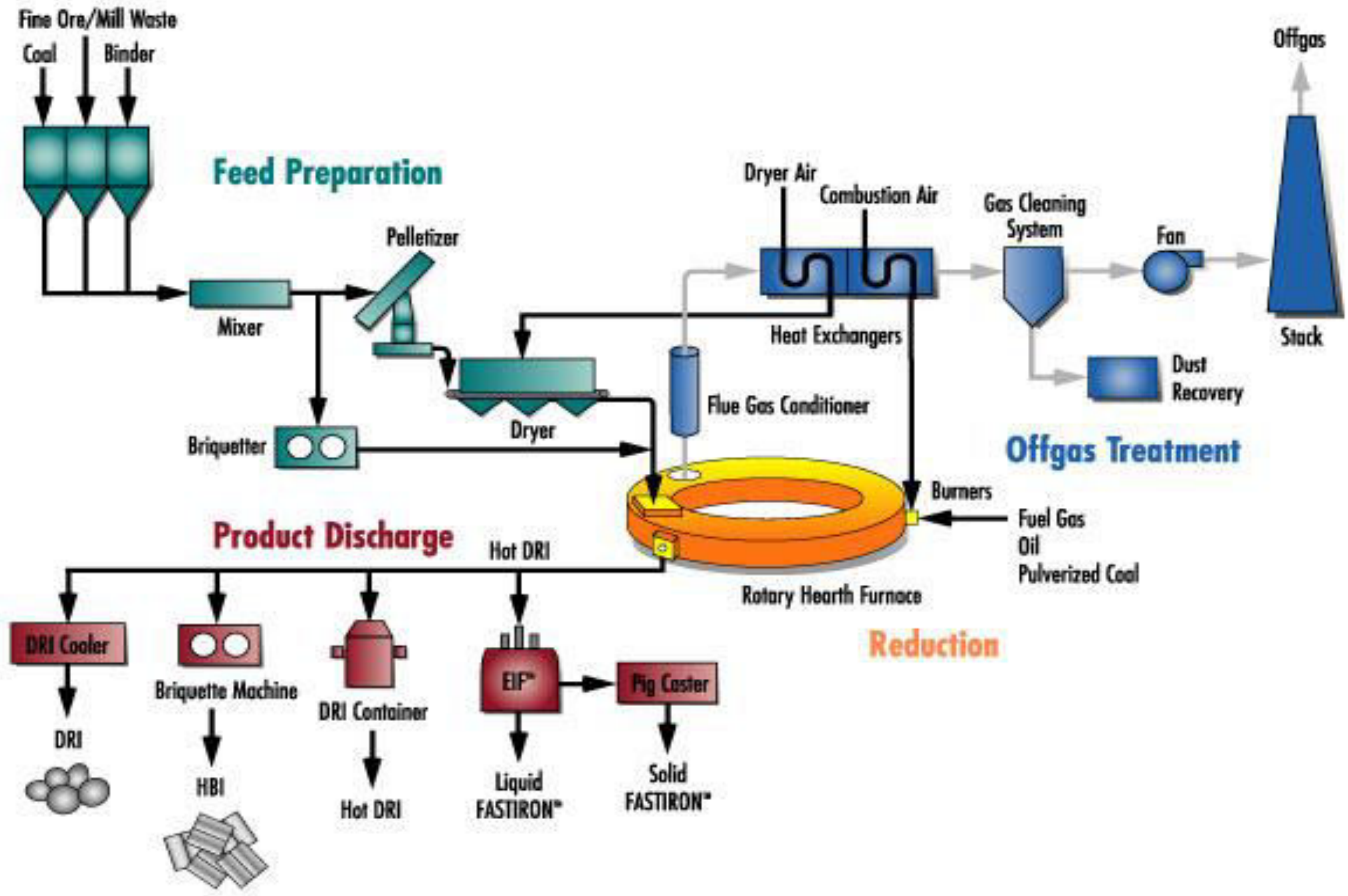
Rotary Hearth Furnace Based DR Processes

- **FASTMET Process**
- This process is being developed by Midrex Corporation.
- In 1991 – 2.5m dia rotary hearth was installed at Midrex
- Technical Centre to simulate the reduction process.
- In 1994 – Midrex & Kobe steel constructed 2.5 tph Fastmet plant at Kobe steels Kakagawa works in Japan
- Iron ore concentrate, pulverized coal and binder are mixed and pelletized
- Green pellets are either fed to a drier or charged directly to RHF
- The pellet layers on rotary hearth are one to three pellets depth
- Burners & post combustion of CO provides the heat to raise the pellets to reduction temperature

Rotary Hearth Furnace Based DR Processes

- **FASTMET Process**
  - Burners are fired with NG, FO, COG or pulverized coal
  - Pellets are heated to 1250-1400 ‘C when the iron oxides are reduced to metallic iron
  - Reduction time on hearth is 10-12 minutes
  - DRI is continuously discharged at around 1000°C from the furnace easily into the refractory lined vessels for hot transfer to melt shop or into briquetting machines for production of hot briquettes (HBI)
  - C in the product can be controlled between 1-6%
  - Off gas from the plant is used in heat exchanger to preheat the combustion air and dry the green pellets
  - Additional heat can be recovered to produce power

FAST MET process flowsheet



Rotary Hearth Furnace Based DR Processes

- **FASTMET Process**

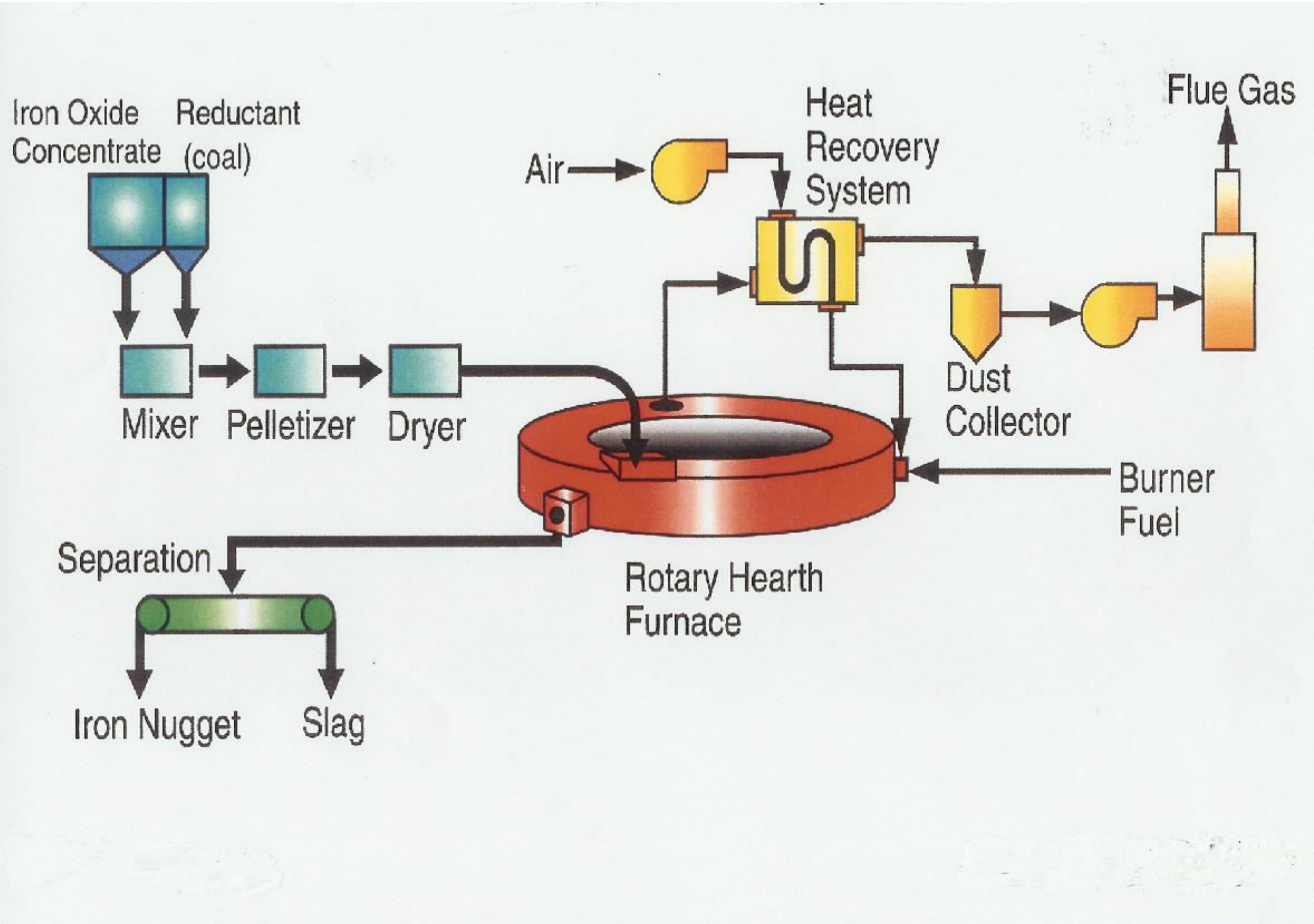
	Unit consumption
Iron ore (67% Fe), t	1.2-1.35
Coal, t	0.3-0.4
Aux fuel, G cal	0.7
Power kWh	100
Water, m3	2

- Midrex & Kobe steel have also developed the molten iron production process (FAST MELT) by charging the hot DRI into a submerged arc furnace

Rotary Hearth Furnace Based DR Processes

- **ITmk3 Process**
  - In ITmk3, the iron ore fines & pulverized coal are formed into green pellets
  - The pellets are fed to a rotary hearth furnace and heated to 1300 -1450°C
  - At this temp. range, the pellets are reduced and melted
  - Iron making process takes only 10 minutes against BF(10 hrs), Rotary Kiln (8hrs)
  - Iron & slag get separated & product is called nuggets
  - Iron nuggets can be fed directly into BOF or EAF as pure iron source and substitute of scrap
  - By substituting scrap, it can dilute tramp elements like Cu, Pb, Sn & Cr

ITmk3 process flowsheet



Rotary Hearth Furnace Based DR Processes

- **ITmk3 Process**

Quality of iron nuggets

Fe met %	97
Carbon %	2-2.5
S %	0.07-0.1
P %	0.01-0.02

GAS BASED DR PROCESSES

1. Retort processes
2. Fluidized bed processes
3. Shaft reactor processes

1. Retort processes

HYL-I:

- Developed in Mexico by HYL Technologies
- First plant in Monterrey Mexico in 1957
- Uses lump iron ore / pellets
- Natural Gas is reformed by steam
- Batch type process, carried out in 4 reactors

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Consumption of energy 15 GJ/t

HYL-II:

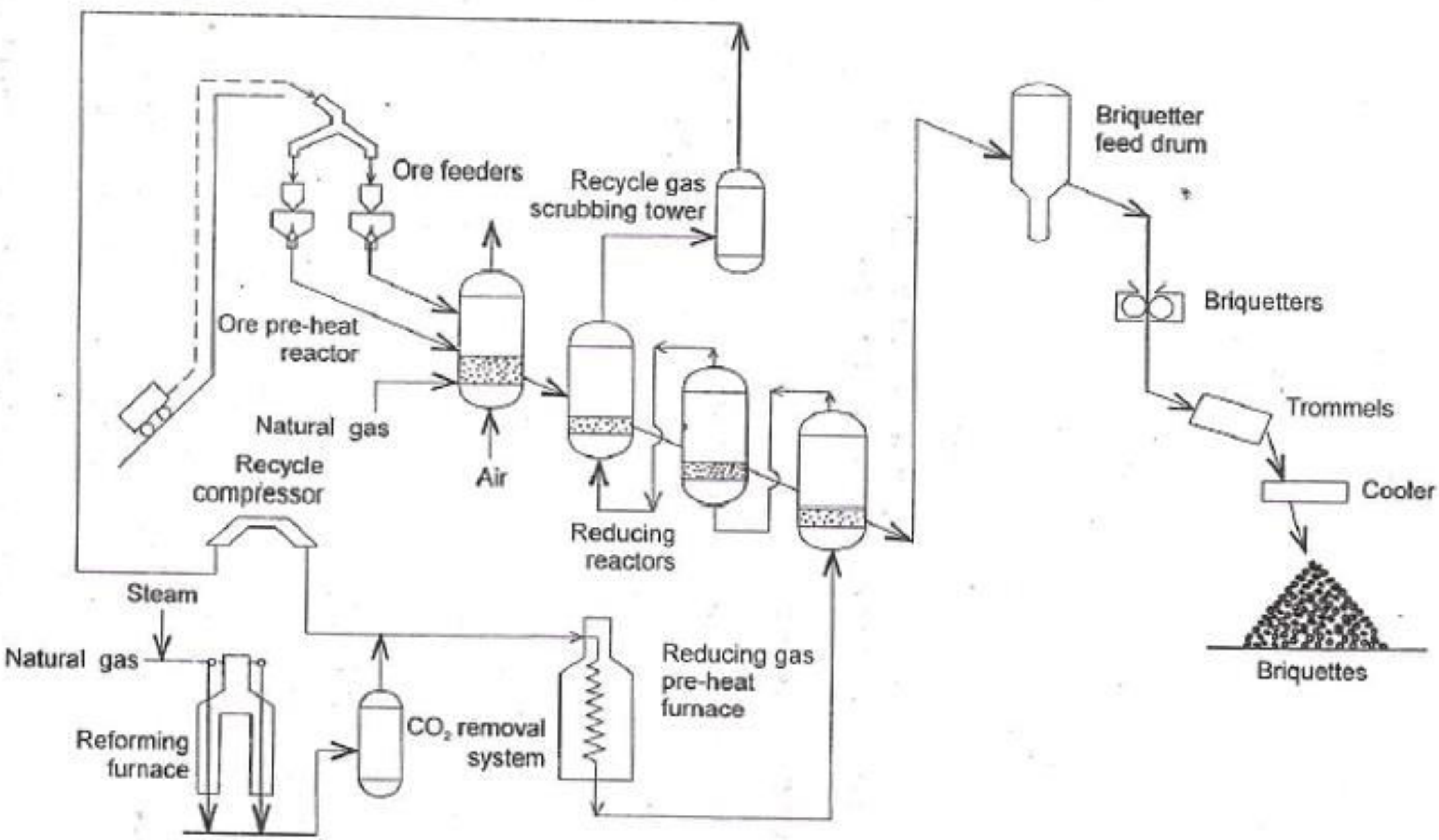
Similar to HYL-I.
It is the second plant installed in Sidor, Venezuela

2. Fluidized bed processes

Fior:

- Fluidized iron ore reduction process
- Developed by ESSO Research & Engg Co, USA
- Uses iron ore fines (-12mesh)
- Reduction takes place in series of 4 fluidized bed reactors
- Reaction pressure 10 atm
- Reducing gas NG is reformed by steam
- Temperature of reduction 800°C
- NG consumption is 5 Gcal/t
- Compacted hot (650°C) in briquettes
- First plant built in Motanzas, Venezuela in 1976 – 0.4Mtpa

Fior process flowsheet



Fluidized bed processes

Finmet:

- Also a fluidized iron ore reduction process
- Developed jointly by Fior de Venezuela & Voist Alphine, Austria (VAI)
- There are four heating and reduction reactors
- Temperature for reduction in final reactor is 800°C
- Reactor pressure 11 to 13 bar
- Hot reduced fines are briquetted
- Gas after reduction is recirculated after scrubbing of H2O & CO2

Fluidized bed processes

Finmet:

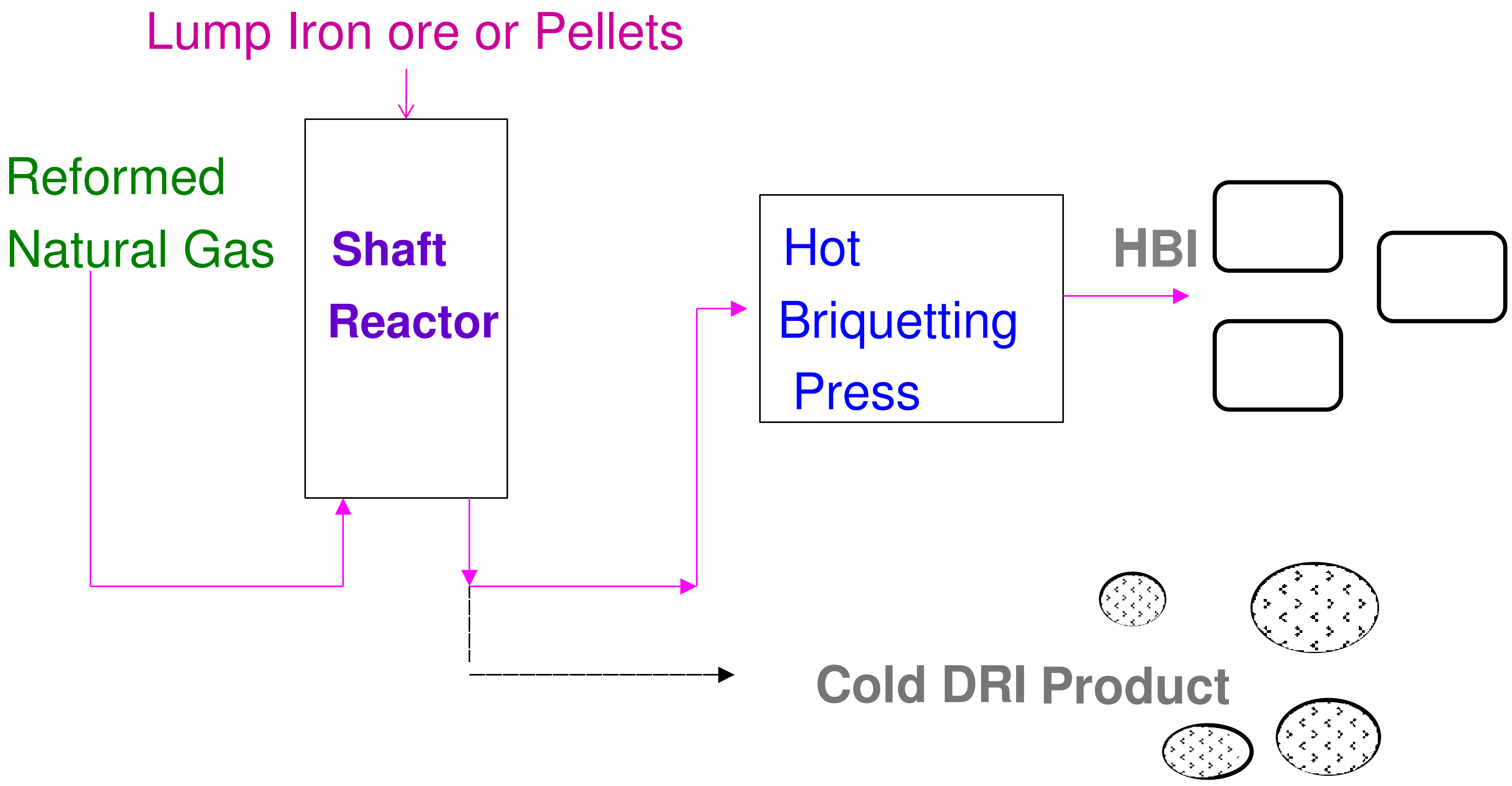
- Making up gas (NG) is reformed by steam
- NG consumption is 3 Gcal/t
- One plant built in Matanzas, 1999
- Capacity 2Mtpa, 4 reactors each of 0.5Mtpa
- Capital cost USD 800 million
- Ownership BHP + Sivensa
- Production cost is cheaper than Midrex & HYL (20%)
- Capital cost is higher than Midrex & HYL (20%)

The other processes in this category are circored and spinex

3. Shaft reactor processes

- Counter current flow moving bed system
- Important processes –
    - HYL-III
    - Midrex
    - Purofer
    - Plasmared
    - Armco
    - NSC
    - Arex
    - Ghaem

Production Technologies of Gas based Reactor Processes



Lump Iron ore or Pellets

Reformed Natural Gas

Shaft Reactor

Hot Briquetting Press

HBI

Cold DRI Product

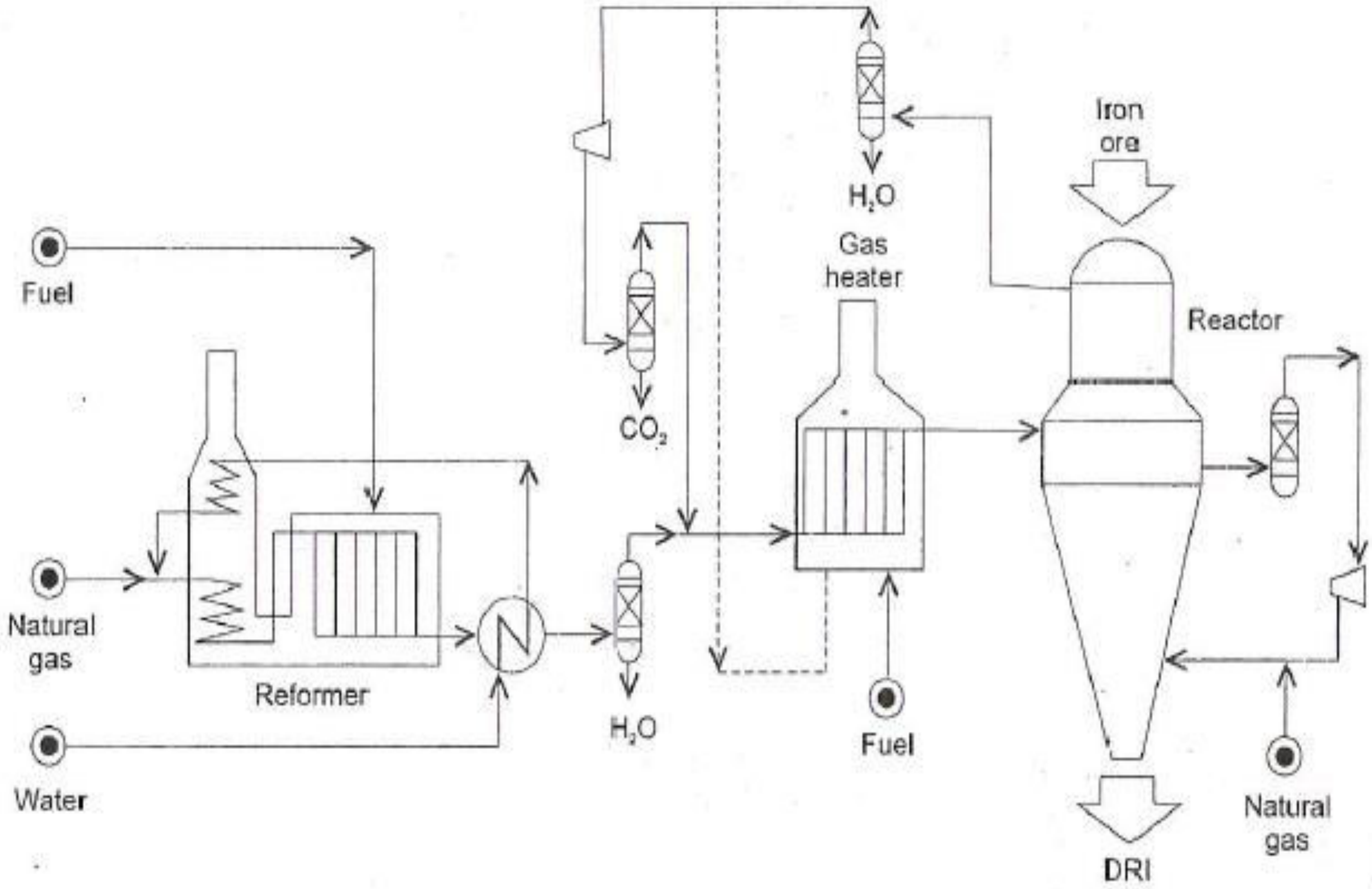
Scheme for HBI Production in Shaft Reactor

Shaft reactor processes

HYL-III

- Lump ore / pellets charge descends by gravity
- Hot reducing gas move upward in the reactor
- Gases are heated in a gas heater to 900°C
- Natural gas is reformed by steam in a gas reformer
- $CH_4 + H_2O \rightarrow CO + 3H_2$
- Top gas after scrubbing of H_2O and CO_2 is mixed with make-up reducing gas
- Cooling zone in lower part of reactor is supplied with cooling gas which is recycled by a cooling gas compressor
- Energy consumption: 9-10GJ/t
- HYL plants are available in capacities between 0.2Mtpa and 2Mtpa
- Welspun plant capacity is 0.8 mtpa (In Maharastra)

HYL III process flowsheet

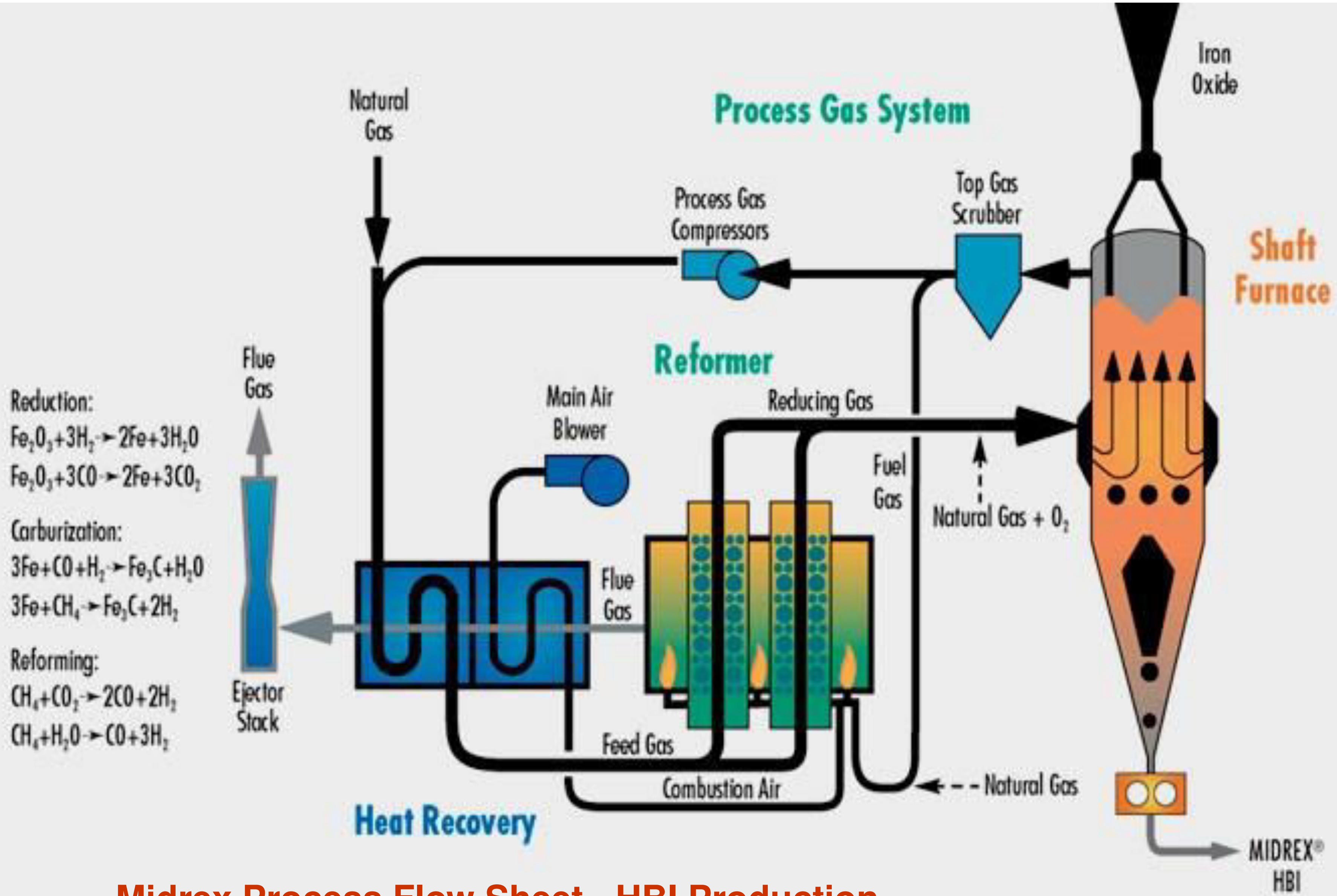


Salient Features of Midrex Process

- Both pellets (8-18 mm) & sized lump ore (6-20 mm) upto 50% can be charged.
- The following reforming reaction takes place in the reformer:

$$CH_4 + CO_2 = 2CO + 2H_2$$

- Reformed Natural Gas: CO=80%, H_2=20% Specially suitable for countries/ locations where natural gas is available in plenty and less expensive
- Indian Scenario:
  - Midrex process plant in Essar Steel, Hazira (Gujarat) Capacity 4 mtpa



Reduction:

$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

Carburization:

$3Fe + CO + H_2 \rightarrow Fe_3C + H_2O$

$3Fe + CH_4 \rightarrow Fe_3C + 2H_2$

Reforming:

$CH_4 + CO_2 \rightarrow 2CO + 2H_2$

$CH_4 + H_2O \rightarrow CO + 3H_2$

Midrex Process Flow Sheet - HBI Production

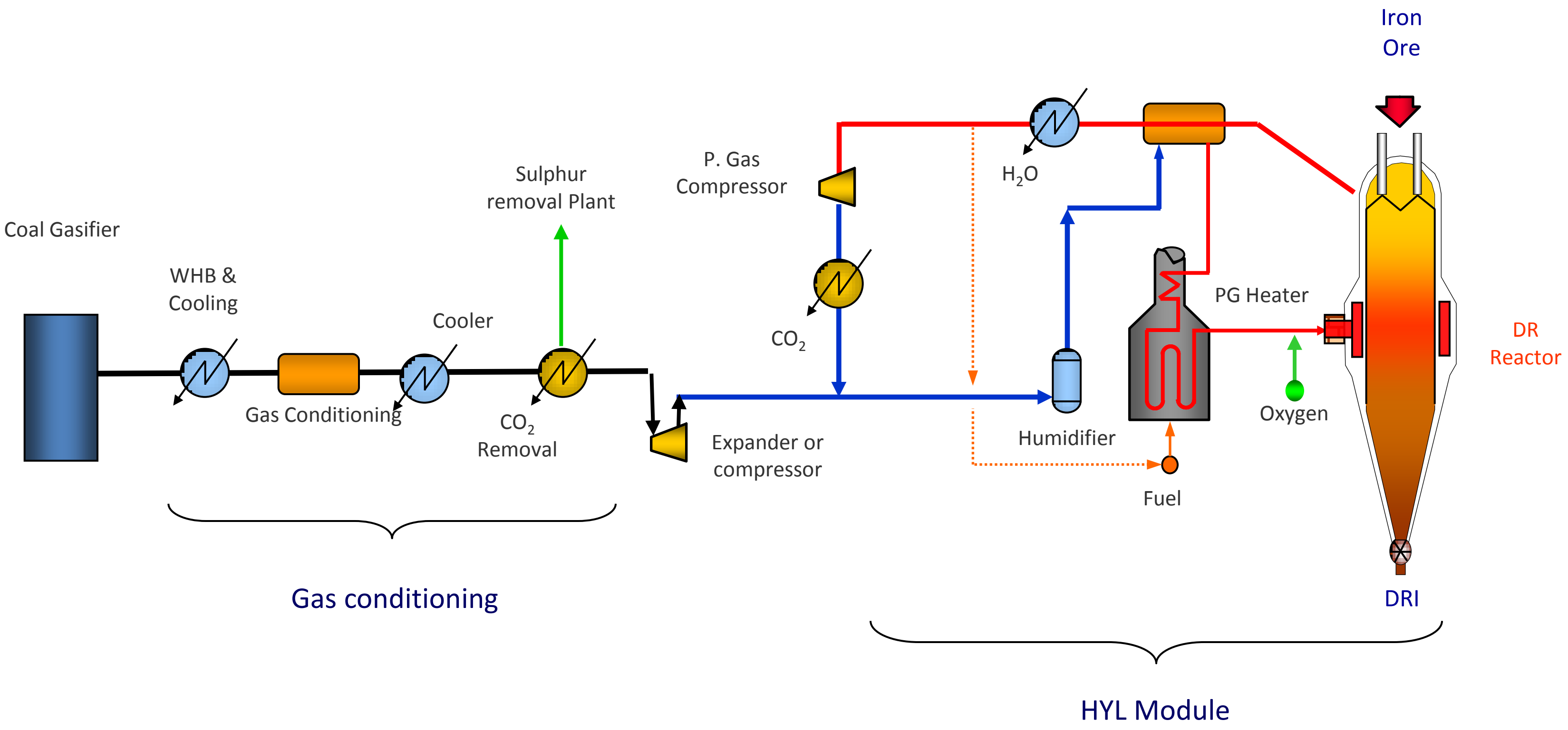
Coal gasification based DRI process

- **Coal gassification based DRI plant (JSPL plant at Angul, Odisha) may open a new trend in India/ world**
- **The <u>DRI-BF-EAF</u> route technology would be adopted for steel production.**
- **The DRI plant (2mt) has a unique feature of using Syn Gas from the coal gasification plant as reductant.**
- ***The DRI-Gasification route: first time in the world: using high ash coal.***
- **JSPL has agreement with Lurgi Sasol Technology Company, South Africa, for coal gasification technology.**

Blast Furnace and DRI can co-exist !

Process flow chart of coal gasification based DRI plant

HYL Process Scheme for Syngas



SMELTING REDUCTION PROCESSES for IRONMAKING

Advantage: Smelting Reduction Processes

- They produce hot metal; hence more relevant to BOF based Integrated Steel Plants
- Direct use of non-coking coal and Iron ore fines
- They need much less land as compared to conventional BF complex

Available Smelting Reduction (SR) Processes

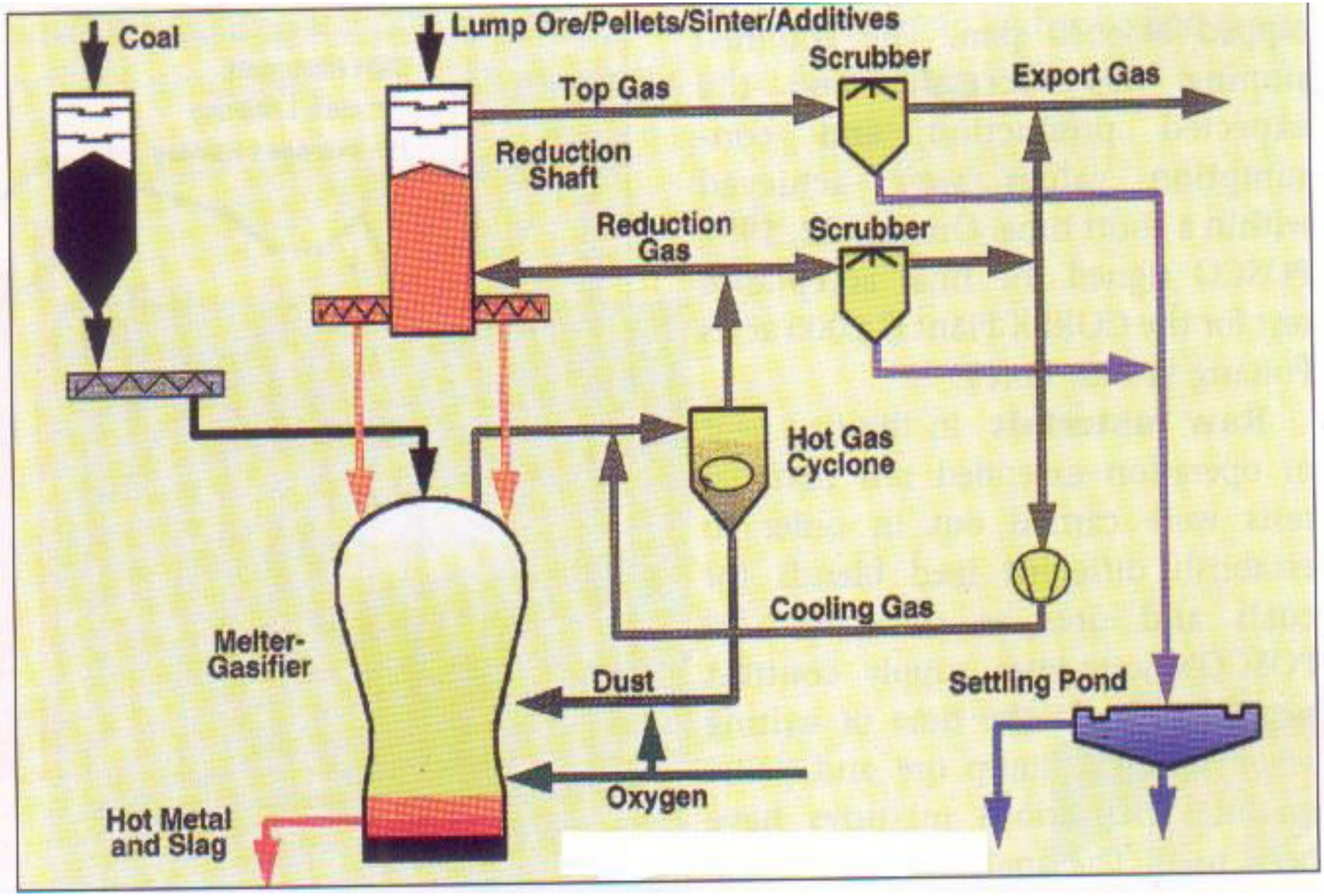
- 4 SR Technologies currently commercially exploited or ready for commercial exploitation

  - **COREX** (Two stage): Operating commercially
  - **FINEX** (Two stage): Operating commercially
  - **HISMELT** (Single stage): Not Operating commercially at present
  - **ROMELT** (Single stage): Not Operating commercially at present

- Single stage: Reduction & melting in the same vessel
- Two stage : Reduction in one vessel; melting in the 2nd vessel

COREX Process
for
Ironmaking

A schematic diagram of COREX process



COREX: Process Features

- Developed by Siemens VAI
- Commercially most successful amongst SR Technologies
- Commercial units in operation
  - **Korea**: POSCO (COREX C-2000 - Capacity: 0.8 Mtpa)
  - **India**: JSW Steel, India (2 Units) (COREX C-2000)
  - **South Africa**: Mittal-SALDANHA, (COREX C-2000)
  - **China**: Baosteel, (COREX C-3000) - Capacity 1.5 mtpa

Experience of COREX at JSW

- Total fuel rate requirement = 950 kg/thm. Out of which ~200 kg coke is required.
- All the non-coking coal is imported. NCC of very high VM or very low FC cannot be used.
- ~ 100% pellets are charged.
- Oxygen requirement = 550 Nm3/thm (very high!)
- Corex HM:
  - Typical HM Composition: C~ 4%, Si=0.5-0.9%, S=0.025-0.07%, P=0.13-0.19%, temp= 1480-1515C

COREX: Process Limitations

- Can't use ore fines directly

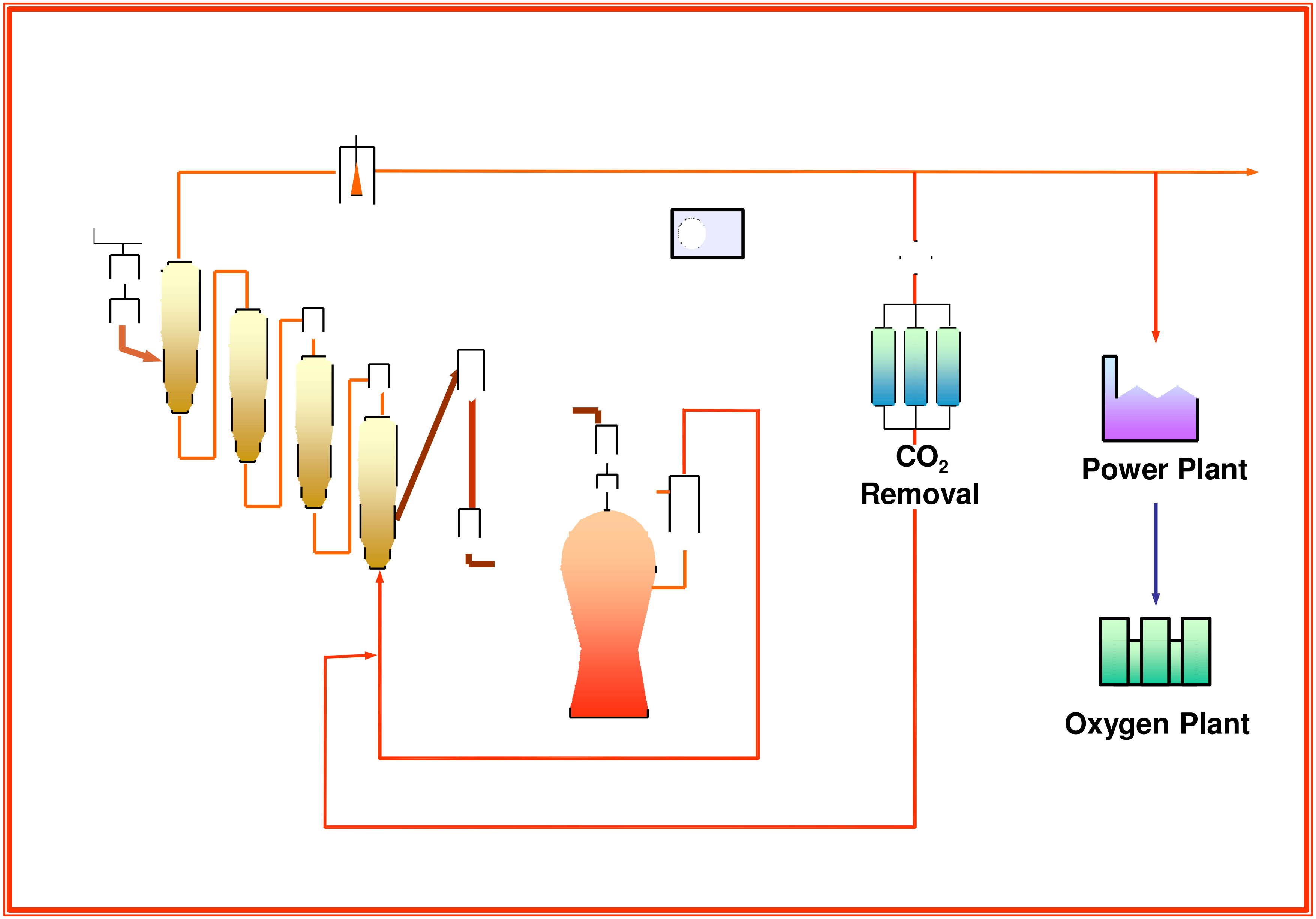
- Restriction on non-coking coal
  - VM of carbonaceous material to be maintained at ~25%.

- Net export gas (1650 nm3/thm; CV:1800 Kcal/Nm^3) to be utilised very economically, the process becomes un-viable.

  Hence, gas is used for production of DRI in MIDREX shaft (SALDANHA) and Power Generation (POSCO, JSW Steel and Bao Steel)

FINEX Process
for
Ironmaking

FINEX Process Flow Sheet: Jointly developed by VAI and research Institute of Industrial Science & Technology, Korea



FINEX: Process Features

- Off-shoot of COREX Process:to use iron ore fines (-8 mm) directly

  Direct use of non-coking coal (-6 mm)

  VM of carbonaceous material to be maintained at ~25%

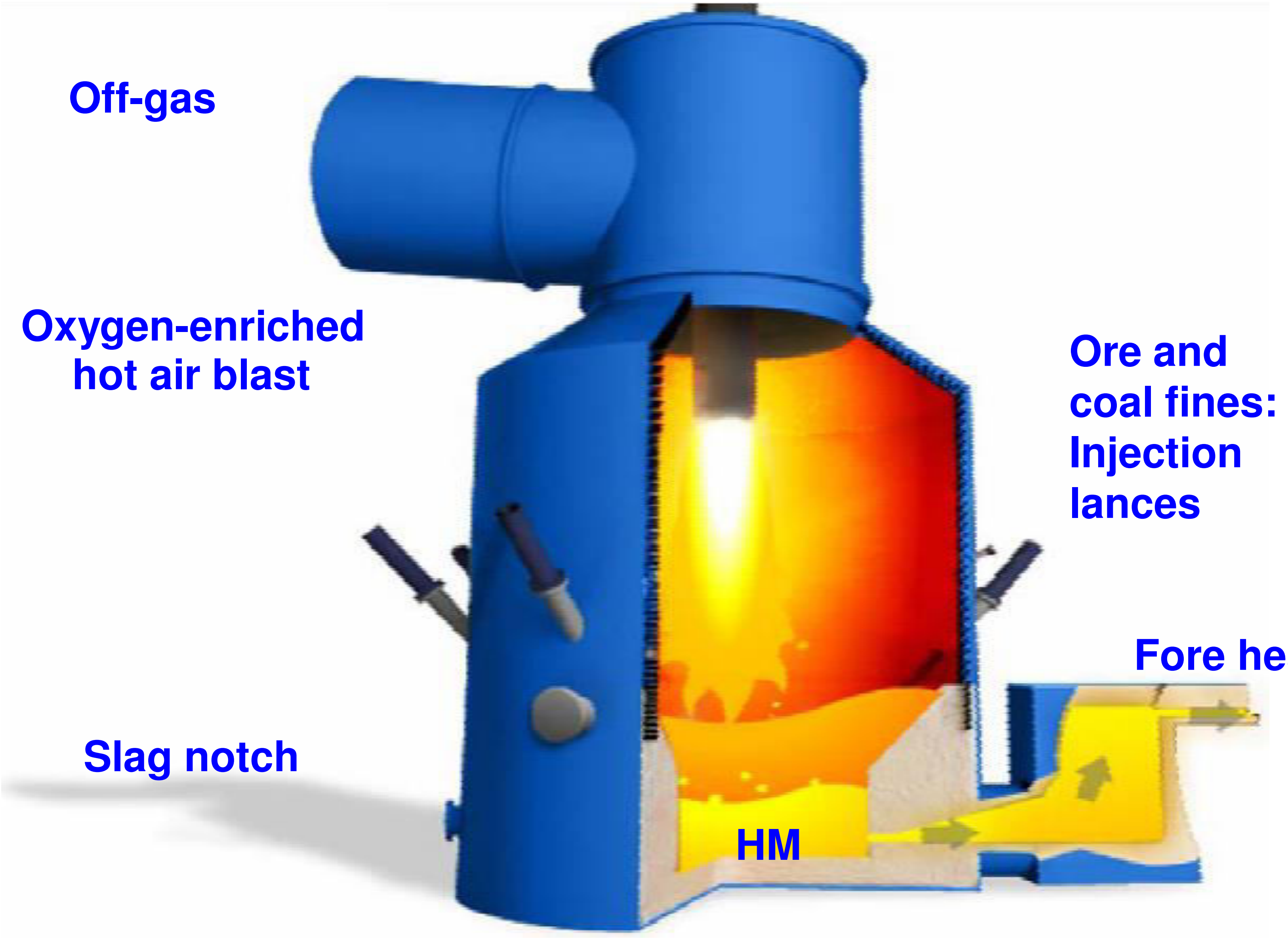
- Fine ore is pre-heated and reduced to DRI in a four stage fluidised bed system. R4 & R3 for preheating. In R2, fine ore is reduced to 30%. In R1, final reduction to 90%. Operational pressure: 4-5 bar.
- The DRI : melted in the COREX like melter- gasifier

FINEX: Process Features

- **FINEX HM** ~ [C= 4.5%, S = 0.03%, Si = 0.60% , Temp= 1520C
- Export gas (CV~2000 Kcal/Nm^3) can be utilised for production of DRI or generation of power
- Coal consumption @ 720 kg/t HM achieved:
  - Pulverised coal injection @ 150 Kg./t HM.
- It is claimed by Finex Technology that Capital cost is lower by 20% and production cost is 15% lower as compared to BF process.
- Commercial unit of 1.5 Mtpa at Pohang, Korea - commissioned in 2007 and in operation since then.
- The FINEX process is being considered for 12.5 mtpa steel plant in Odissa

HISMELT Process
for
Ironmaking

Smelting Reduction Vessel of HIsmelt



Off-gas

Oxygen-enriched hot air blast

Ore and coal fines: Injection lances

Fore hearth

Slag notch

HM

HIsmelt: Features

- Developed by HIsmelt Corporation, Australia
- 1-Stage hot air based Smelting Reduction Process using metal bath as primary reaction medium which is unique:
- Bulk of smelting of ore takes place via dissolved carbon resulting in high reaction rate
- Direct utilisation of ore fines (-0.6 mm) and non-coking coal fines (-0.3 mm): feed martial is directly injected thru water cooled lances into metal bath.
- No oxygen requirement - only preheated air is used

  Variety of coals containing 10 to 38 %VM can be used, Low coal rate (600-620 kg/thm)
- HM: Low P (0.02-0.05% based on ore of 0.12% P) and very very low Si

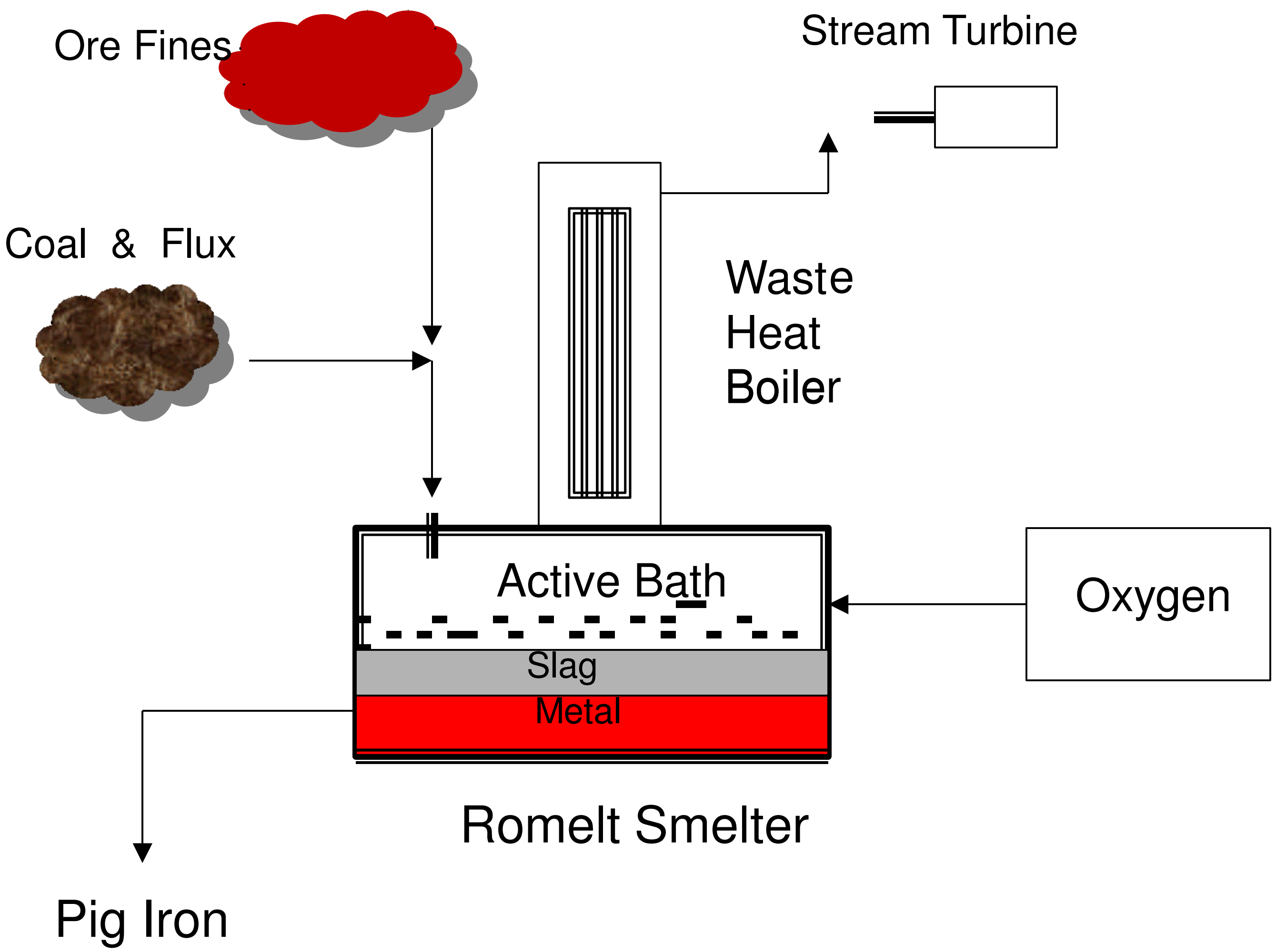
  Off-gas not rich (CV ~700 Kcal/Nm^3) - no need to generate value from off gas

HISMELT: Present Status

- First industrial HIsmelt Plant (capacity 600,000 tpa) commenced operation in Kwinana, Australia in 2005.
- The plant is under maintenance as per their press-release.
- No other plant in the world
- Currently, there are two other licencees in China who have signed a HIsmelt Process Licence. Under the agreements, the groups can replicate the 800,000 tonne per year HIsmelt Plant.
- Process seems to be suitable under Indian conditions, specially for Flat product plant producing API X70/80 products needing low P steel.

ROMELT Process
for
Ironmaking

Schematic Flowsheet of Romelt Process



ROMELT: Process Features

- Developed by Moscow Institute of Steel and Alloys (MISA in mid 1980s)
- Process operates under a slight negative pressure (1-5 mm WC)
- Greater raw material flexibility
  - Accepts iron ore, slimes and other iron bearing materials in a wide range of sizes (0 - 20 mm) without any pre-treatment
  - Non-coking coals of size 0 - 20 mm with moisture content < 10% are acceptable. High VM non-coking coals can be used without any preparation

ROMELT: Process Features

Contd..

- Small scale production of 200,000 to 300,000 tpa HM
- Excellent quality of hot metal (C ~4%, Si ~0.6%, S ~0.040%, Temp. ~1400^0 C). Approx. 40% of input P goes to slag phase & 90% of input S goes to gas phase
- High coal (1.3 - 1.5 t / thm) and high oxygen (900-1100 - Nm^3/thm) consumption
- Fairly high degree of combustion. It produces rich off gas (CV ~1000 Kcal/Nm^3) - has to be utilised efficiently (e.g. power generation to meet the demand of oxygen plant) to make economic production of hot metal.
- **No commercial plant anywhere in the world**

Comparison of Commercially exploited/ Potential SR Processes

	COREX	FINEX	HISMELT
Level of development	Fully Commercially	One 1.5 mtpy commercial plant in operation since 2007	One 0.8 mtpy plant was in operation in 2005, but not now
Ability to use ore fines	No	Yes	Yes
Reductant	Non-coking coal (VM ~ 25 %) (to be imported)	Non-coking coal (VM ~ 25%) (to be imported)	Non-coking coal fines (-0.3mm) (to be imported)
Oxygen (Nm³ / thm) /	~ 550 (High !)	~ 550 (High !)	~ 300
HM Quality	Comparable with BF	Comparable with BF	Very low P & Si
Viability dependent on use of off-gases?	Yes	Yes	No
Ease of obtaining the technology	Commercially available	Uncertain	Available

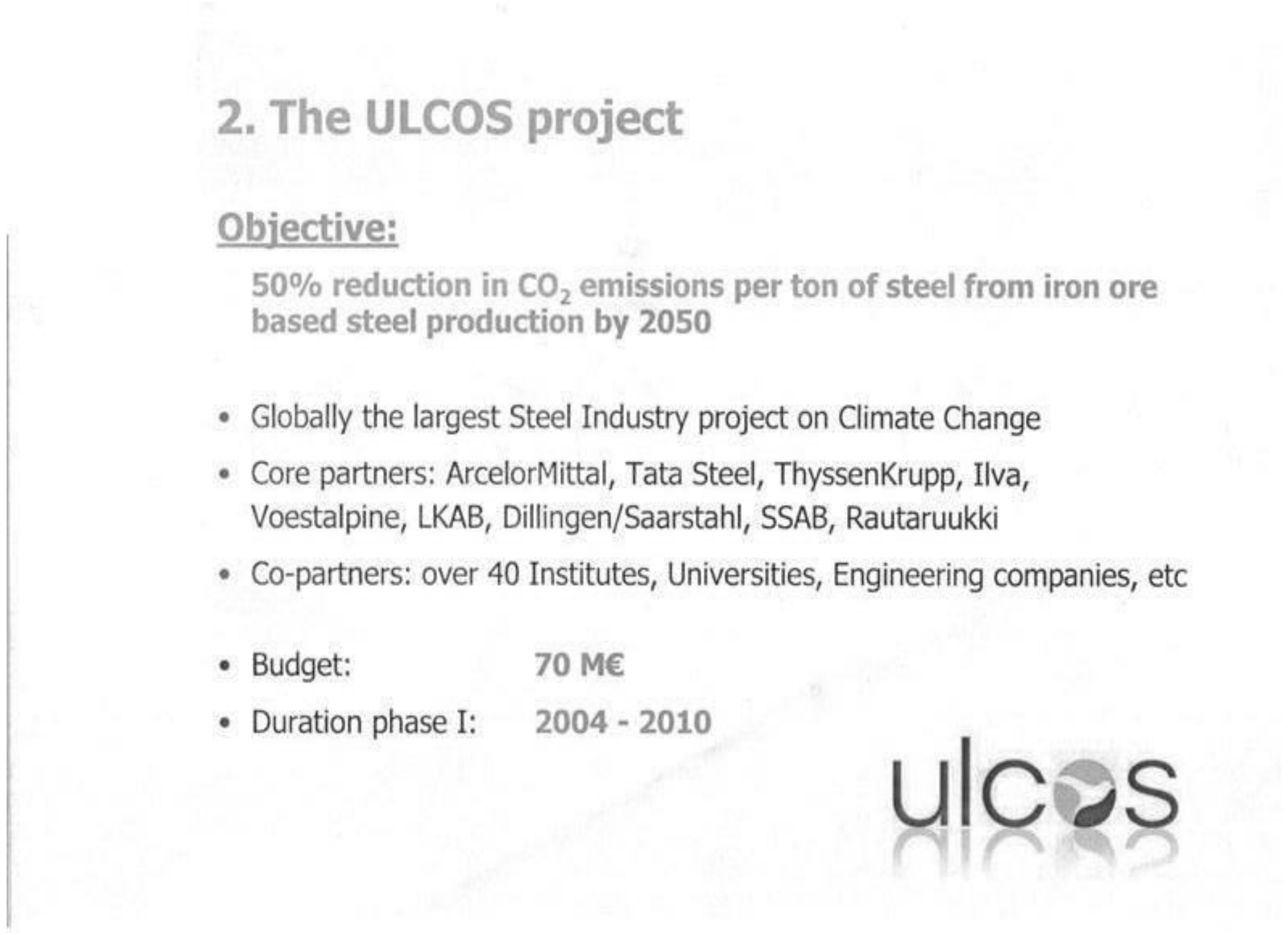
Conclusions: Selection of SR Processes under Indian Conditions

- Out of 3 potential SR processes, only COREX is commercially exploited till date. FINEX is on the verge of commercialisation.
- COREX & FINEX processes: sensitive to quality of input material particularly w.r.t. VM and ash of coal. Type of coal required for these processes is scarcely available in India.
- Experience of COREX at JSW suggest that still ~ 15% coke is required in the process to control VM of the input reductant. Same may be the case for FINEX process.
- Use of pellet atleast partially is a must for COREX process. For FINEX & HISMELT process, iron ore fines can be directly used.
- For COREX & FINEX processes, large amount of oxygen is required.
- For COREX & FINEX processes, rich off gas generated in the process need to be used either for generation of power or for production of DRI.
- HIsmelt is suitable for steel products with low P.

Development of the HIsarna process

An alternative iron-making technology with CO2 capture potential

- HIsarna technology is the combination of HIsmelt (Rio Tinto group) & Isarna (Tata steel group) processes
- This process is being developed under low carbon dioxide steel making (ULCOS) mission
- World steel consumption will double in 2050. The ambition is to cut CO2 emissions by 50% in 2050
- One of the missions of HIsarna process is to reduce CO2 emission by 20% in 2025
- Steel accounts for 5% of total man-made CO2 emissions



2. The ULCOS project

Objective:

50% reduction in CO_2 emissions per ton of steel from iron ore based steel production by 2050

- Globally the largest Steel Industry project on Climate Change
- Core partners: ArcelorMittal, Tata Steel, ThyssenKrupp, Ilva, Voestalpine, LKAB, Dillingen/Saarstahl, SSAB, Rautaruukki
- Co-partners: over 40 Institutes, Universities, Engineering companies, etc

- Budget: **70 M€**
- Duration phase I: **2004 - 2010**

2. The ULCOS project

2.1. ULCOS subjects

1. Efficiency of carbon use

   New and improved processes

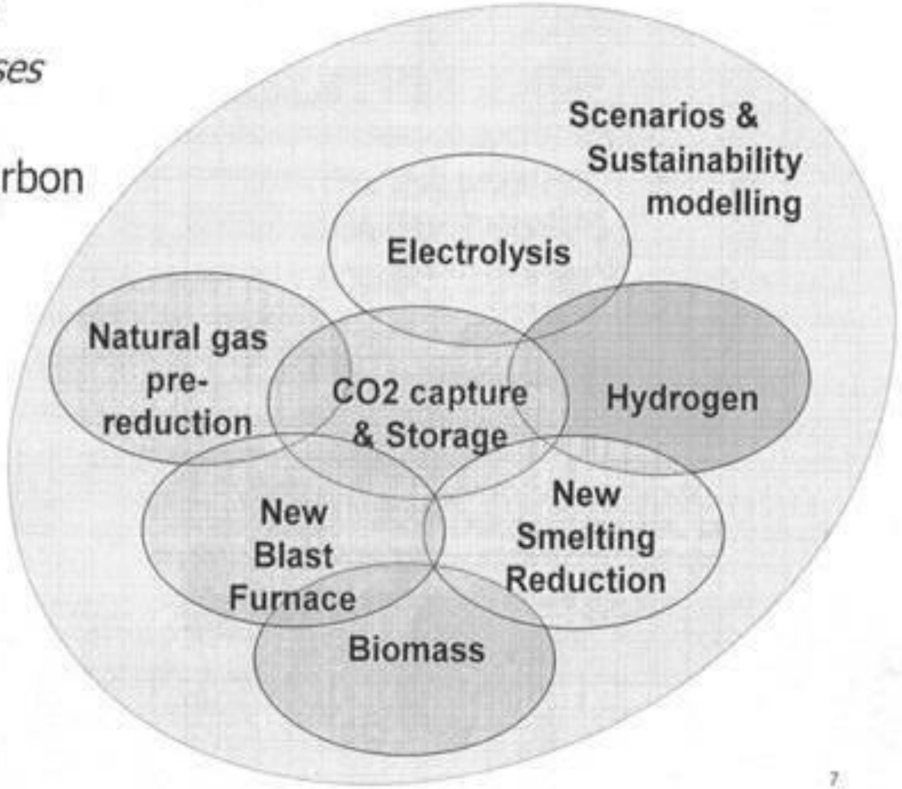
2. Replacement of fossil carbon

   Biomass

   Hydrogen

   Electricity

3. Capture



Scenarios & Sustainability modelling

Electrolysis

Natural gas pre-reduction

CO2 capture & Storage

Hydrogen

New Blast Furnace

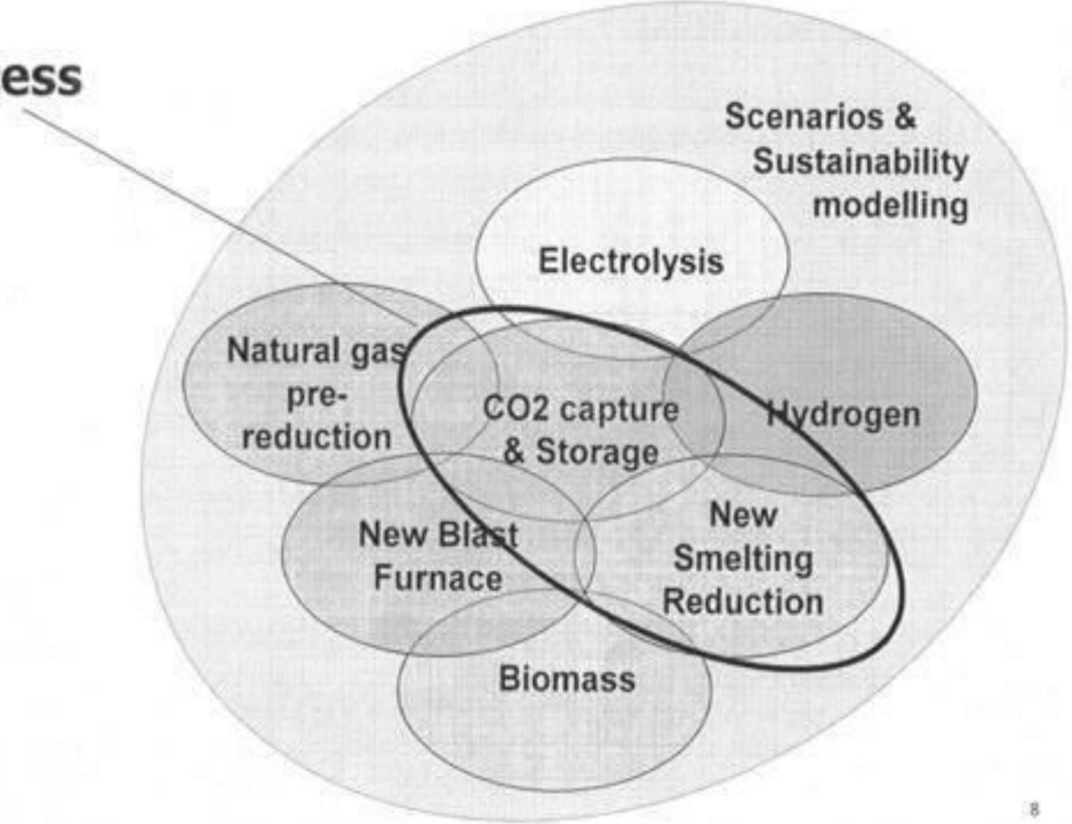
New Smelting Reduction

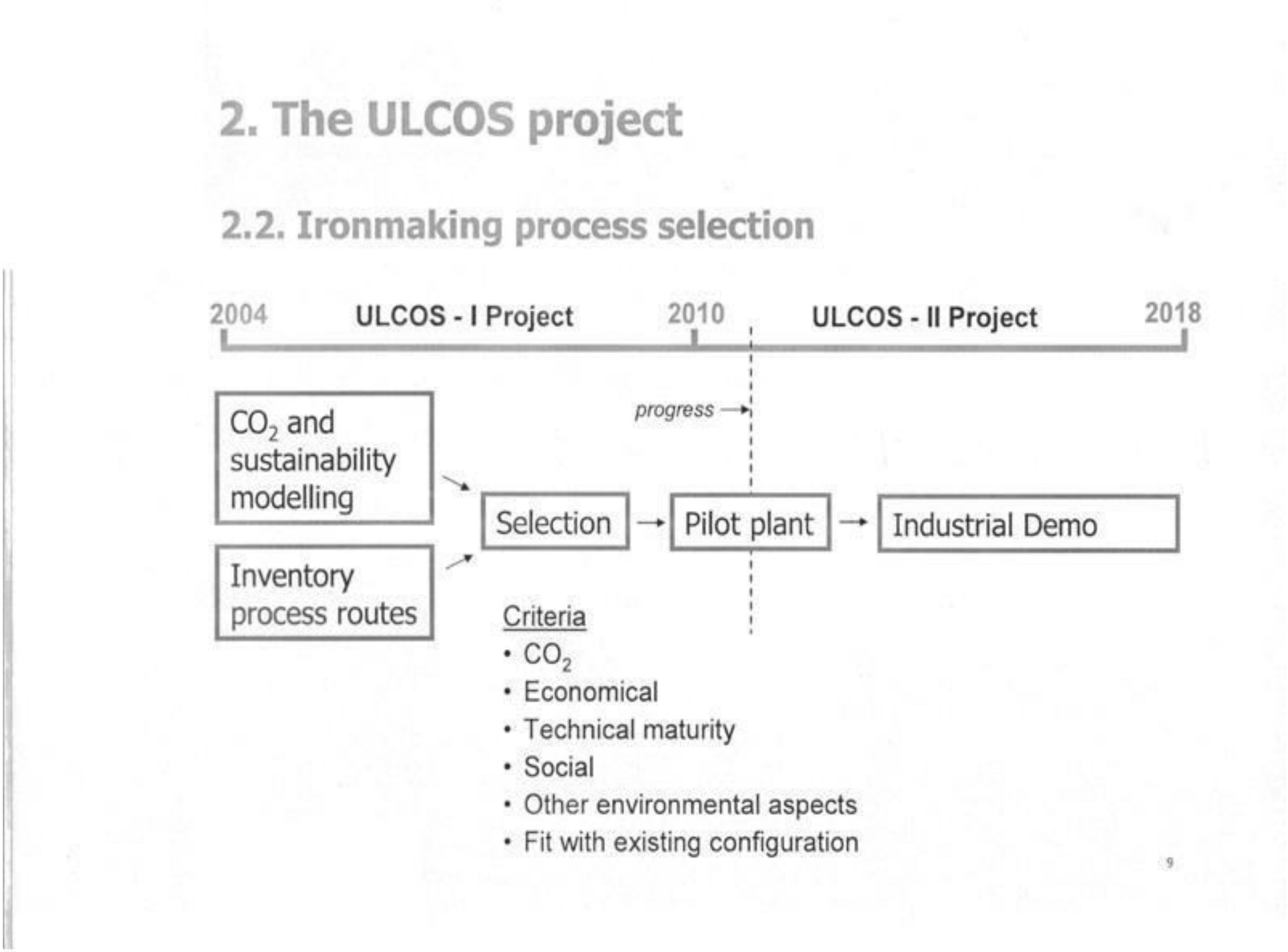
Biomass

2. The ULCOS project

2.1. ULCOS subjects

HIsarna process





2. The ULCOS project

2.2. Ironmaking process selection

2004 **ULCOS - I Project** 2010 **ULCOS - II Project** 2018

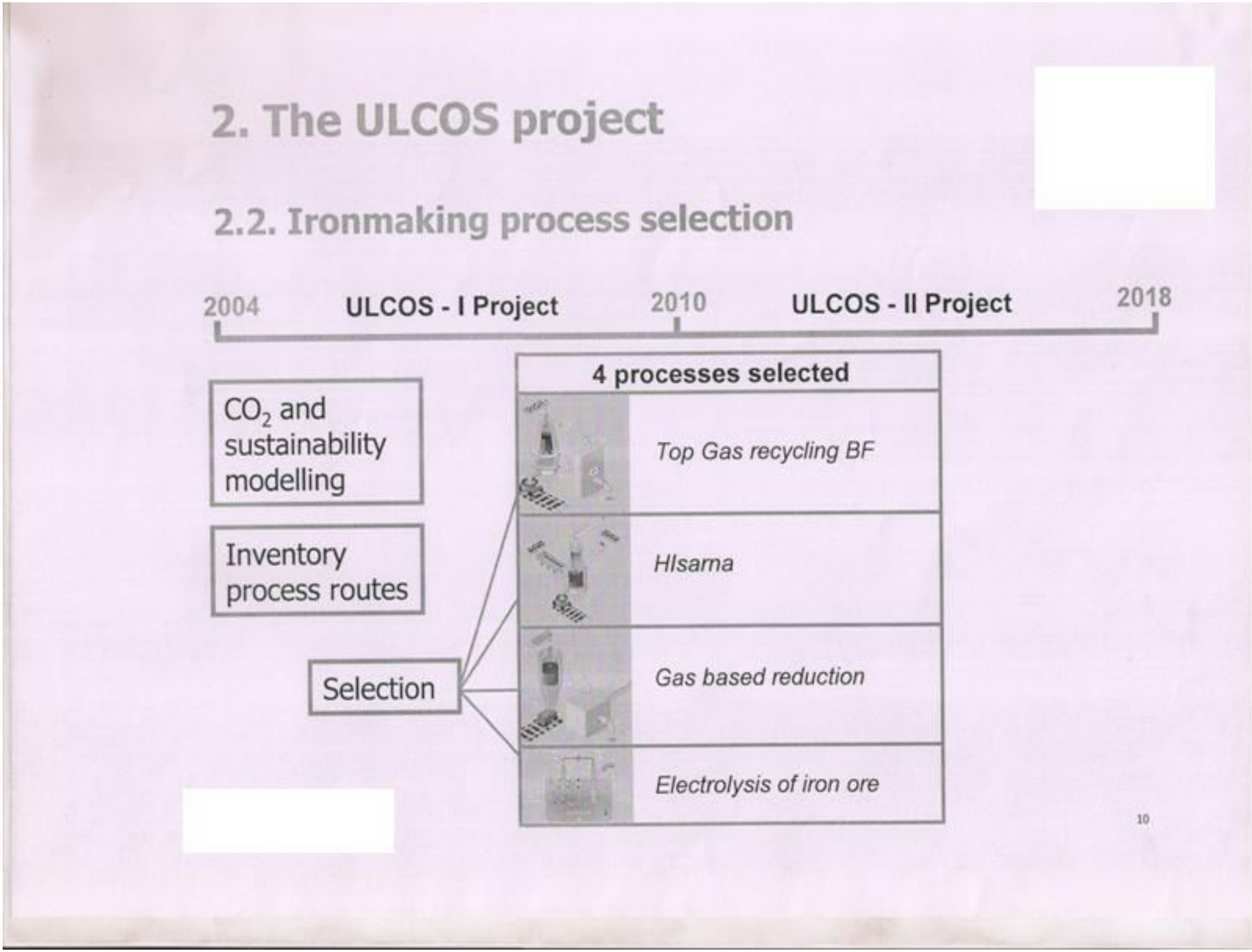
progress →

CO$_2$ and sustainability modelling

Inventory process routes

Selection → Pilot plant → Industrial Demo

Criteria
- CO$_2$
- Economical
- Technical maturity
- Social
- Other environmental aspects
- Fit with existing configuration



2. The ULCOS project

2.2. Ironmaking process selection

2004 **ULCOS - I Project** 2010 **ULCOS - II Project** 2018

CO$_2$ and sustainability modelling

Inventory process routes

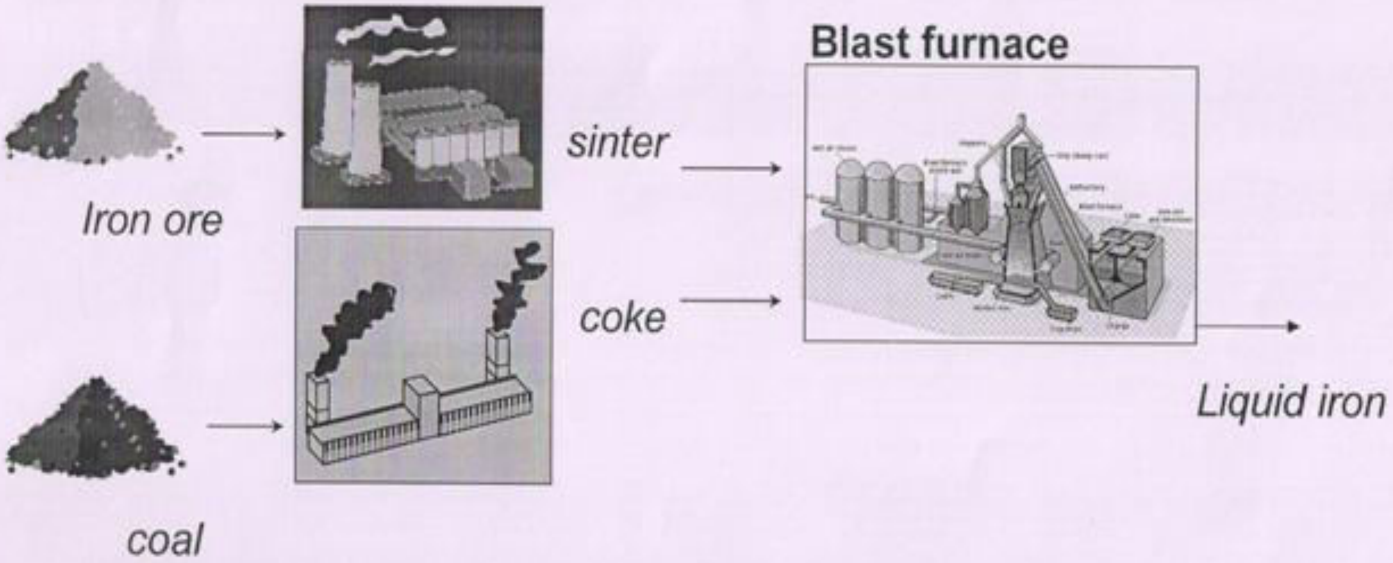
Selection

4 processes selected

- *Top Gas recycling BF*
- *HIsarna*
- *Gas based reduction*
- *Electrolysis of iron ore*

3. HIsarna technology

3.1. Comparison with the BF route



Iron ore

sinter

Blast furnace

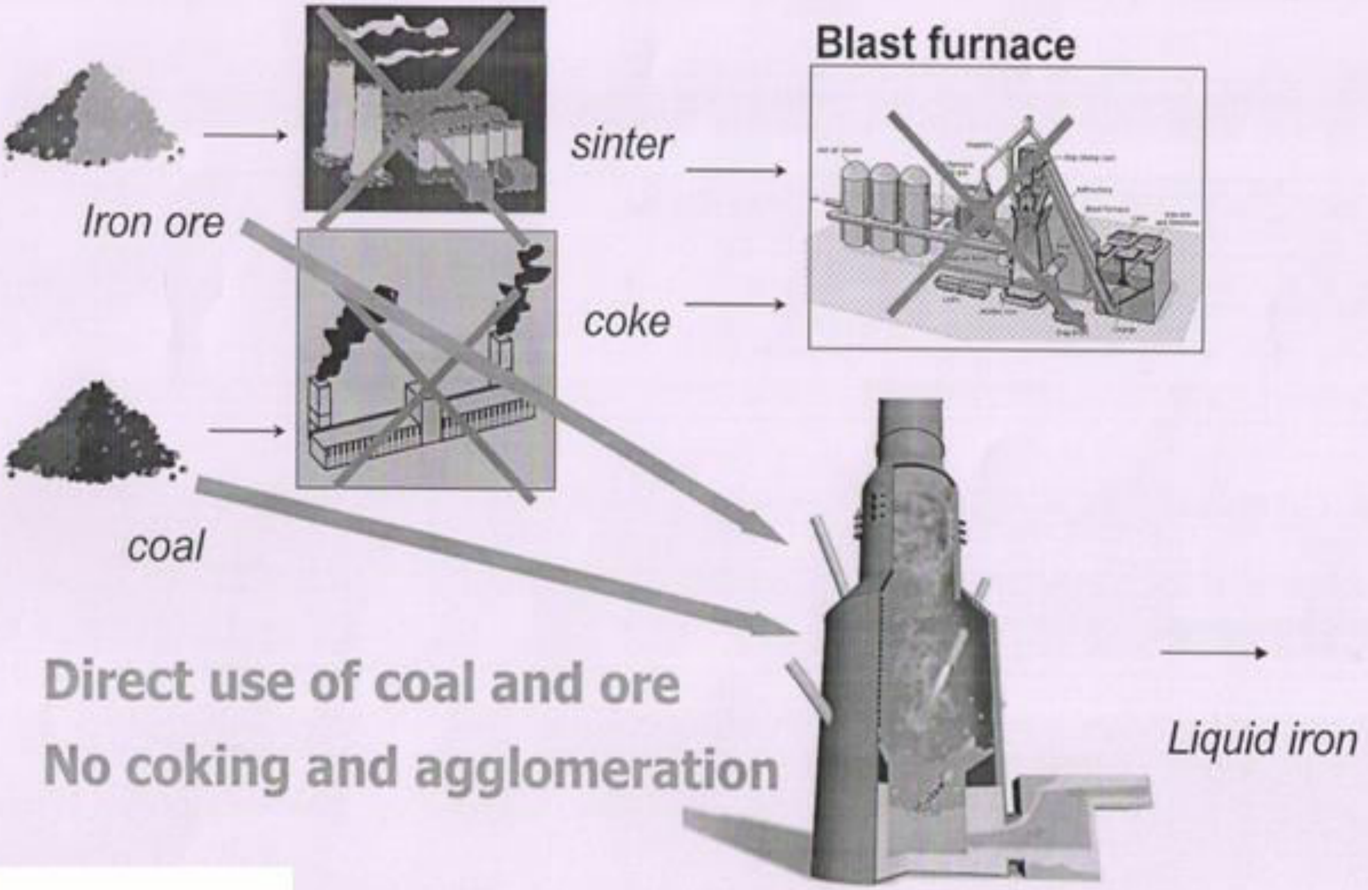
coke

Liquid iron

coal

3. HIsarna technology

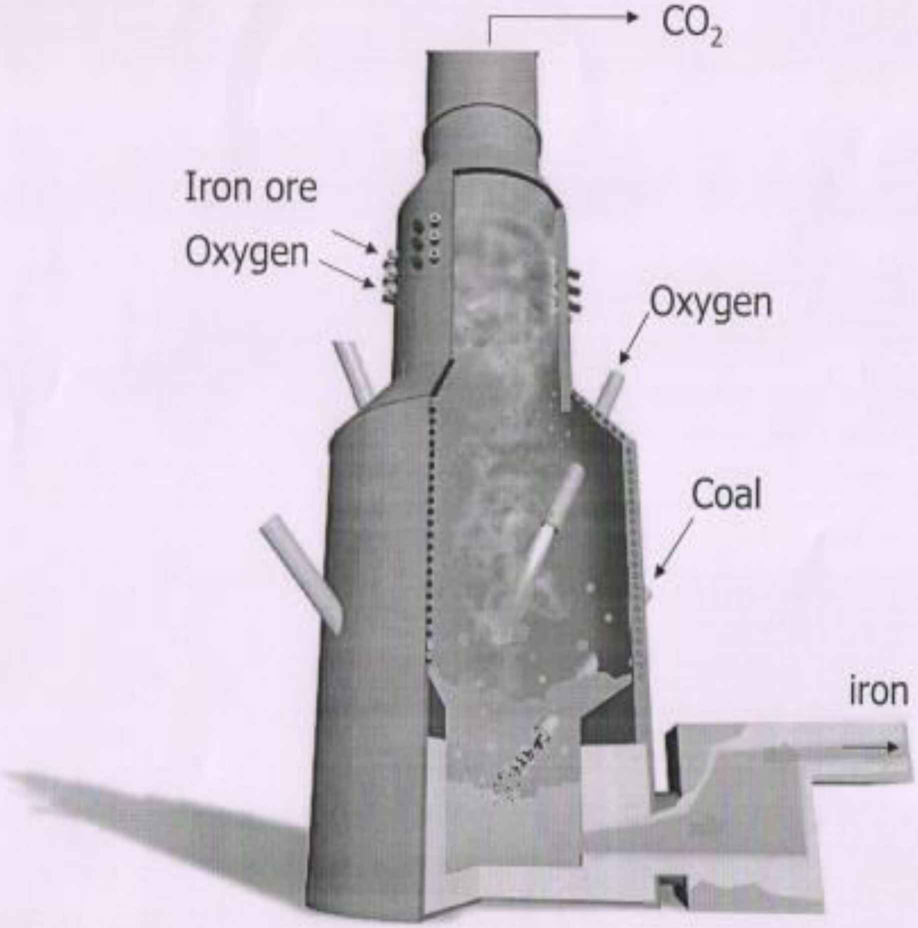
3.1. Comparison with the BF route



Direct use of coal and ore

No coking and agglomeration

3. HIsarna technology

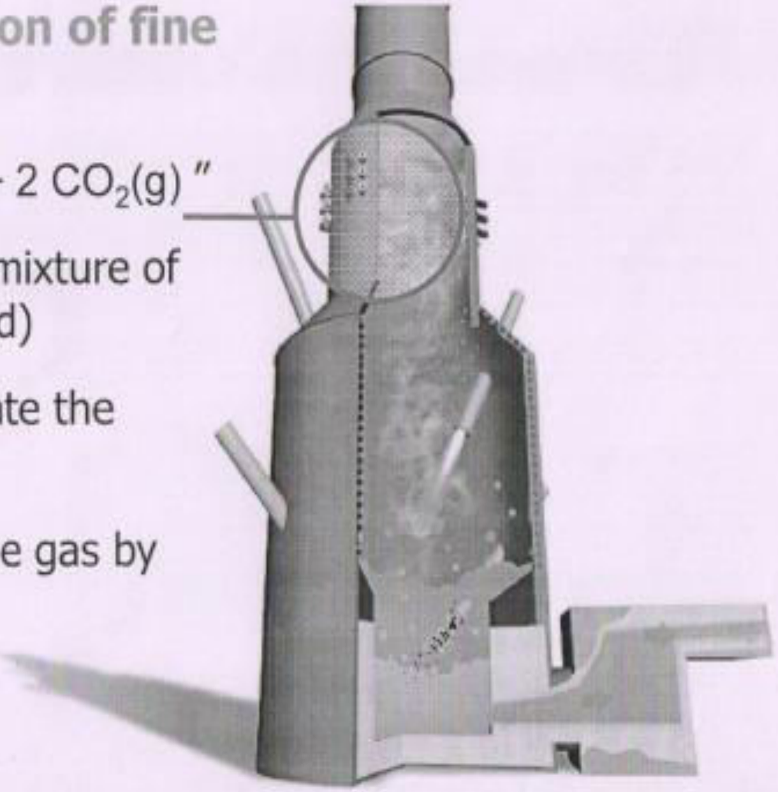


3. HIsarna technology

Melting cyclone technology

Melting and partial reduction of fine iron ores

"$2\ Fe_2O_3(s) + 2\ CO(g) \rightarrow 4\ FeO(l) + 2\ CO_2(g)$"



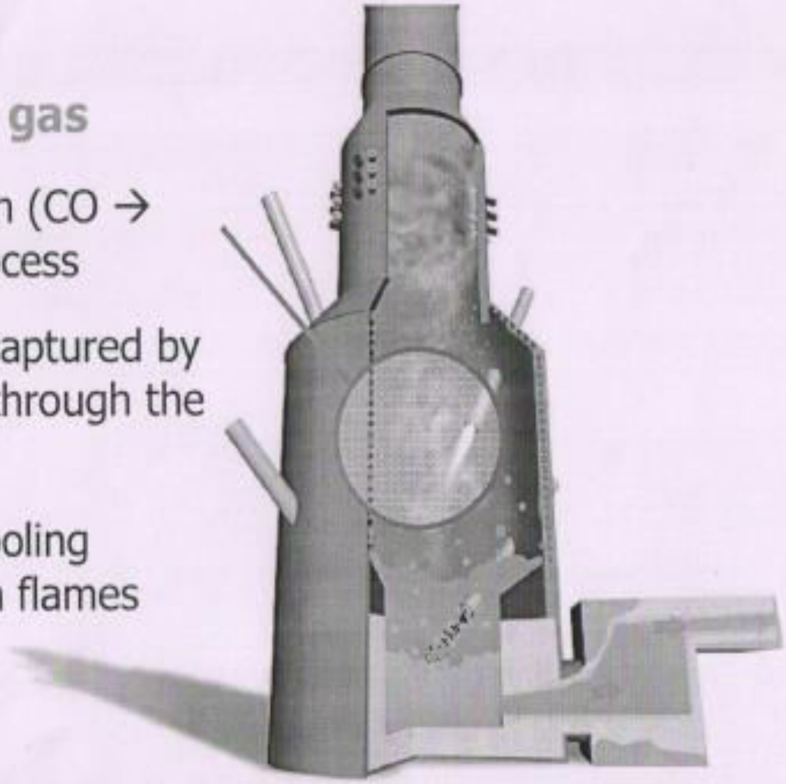
- The cyclone product is a molten mixture of **Fe_3O_4 and FeO** (~ 20 % reduced)
- Pure oxygen is injected to generate the required **melting** temperature
- The fines are **separated** from the gas by centrifugal flow of the gas

3. HIsarna technology

Smelter technology

Post combustion of smelter gas

- Utilisation of the post combustion (CO → CO_2) heat is essential for the process
- The heat of post combustion is captured by the **slag splash** that circulates through the freeboard
- This splash also **protects** the cooling panels from the post combustion flames

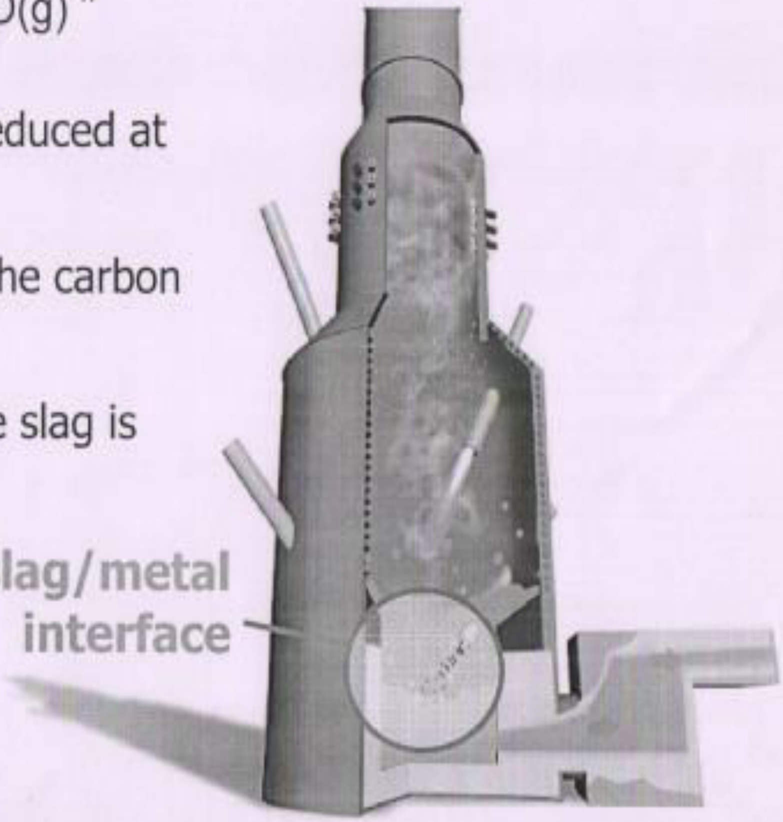


3. HIsarna technology

Smelter technology

"$2\,FeO(l) + 2\,C(s) \rightarrow 2\,Fe(l) + 2\,CO(g)$"

- The iron oxides in the slag are reduced at the slag/metal interface
- Granular coal injection supplies the carbon and creates intense mixing
- Due to this mixing the FeO in the slag is relatively low



Final reduction on slag/metal interface

3. HIsarna technology

Benefits of the HIsarna process

Environmental:

- 20 % reduction of CO_2 per ton steel product
- Well suited for CO_2 storage (nitrogen free off gas)
- 80 % reduction with CO_2 storage
- Substantial reduction of other emissions (dust, NOx, SOx, CO)

Economical:

- Low cost raw material
- Reduced CAPEX

4. HIsarna and CCS

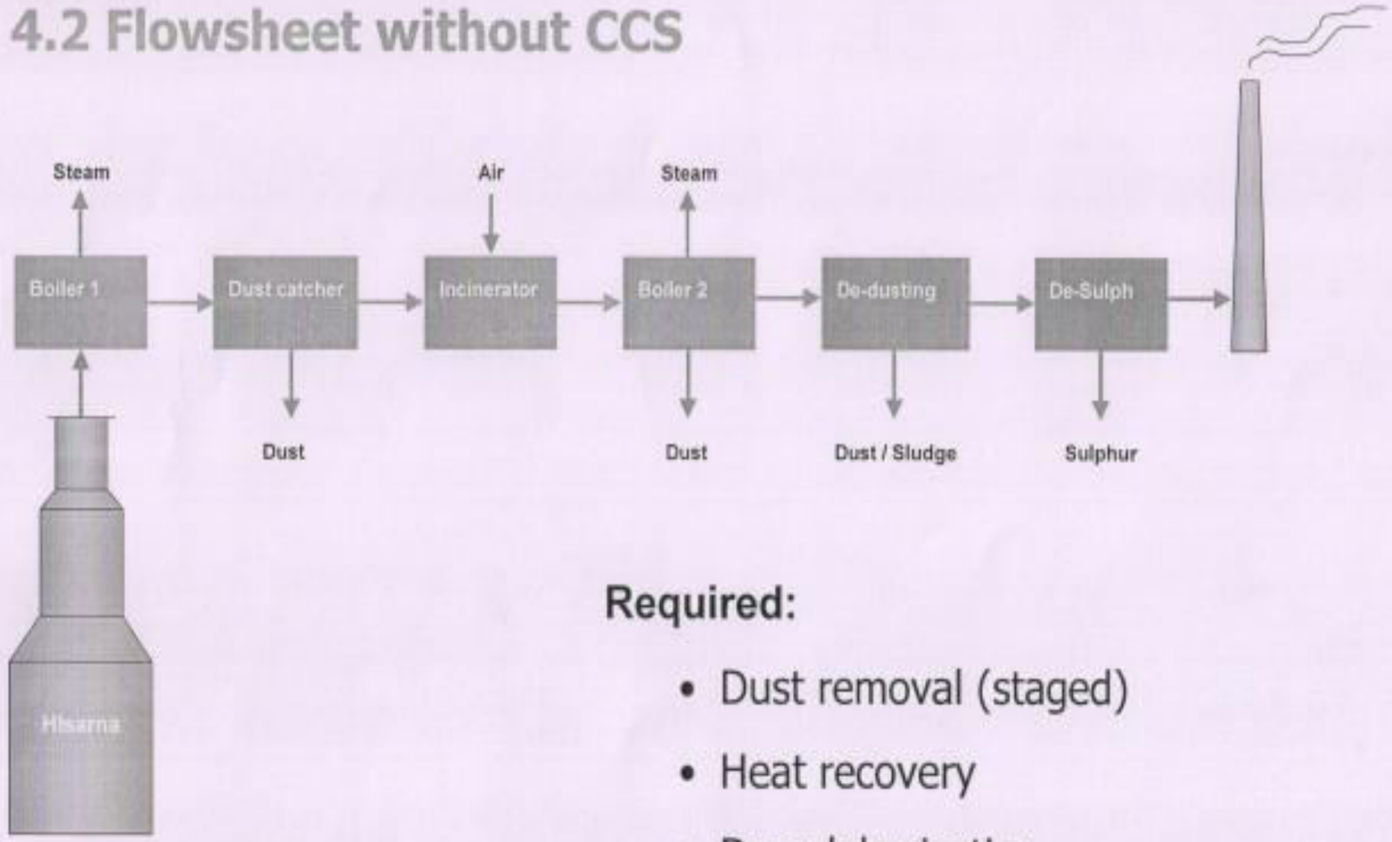
4.1. Why an attractive combination?

HIsarna flue gas:

- Oxygen based process with Nitrogen free flue gas
- All ironmaking flue gases at a single stack (85 % of CO_2 from integrated site)
- Fully utilised gas, (almost) no remaining calorific value

4. HIsarna and CCS

4.2 Flowsheet without CCS



Steam

Air

Steam

Boiler 1

Dust catcher

Incinerator

Boiler 2

De-dusting

De-Sulph

Dust

Dust

Dust / Sludge

Sulphur

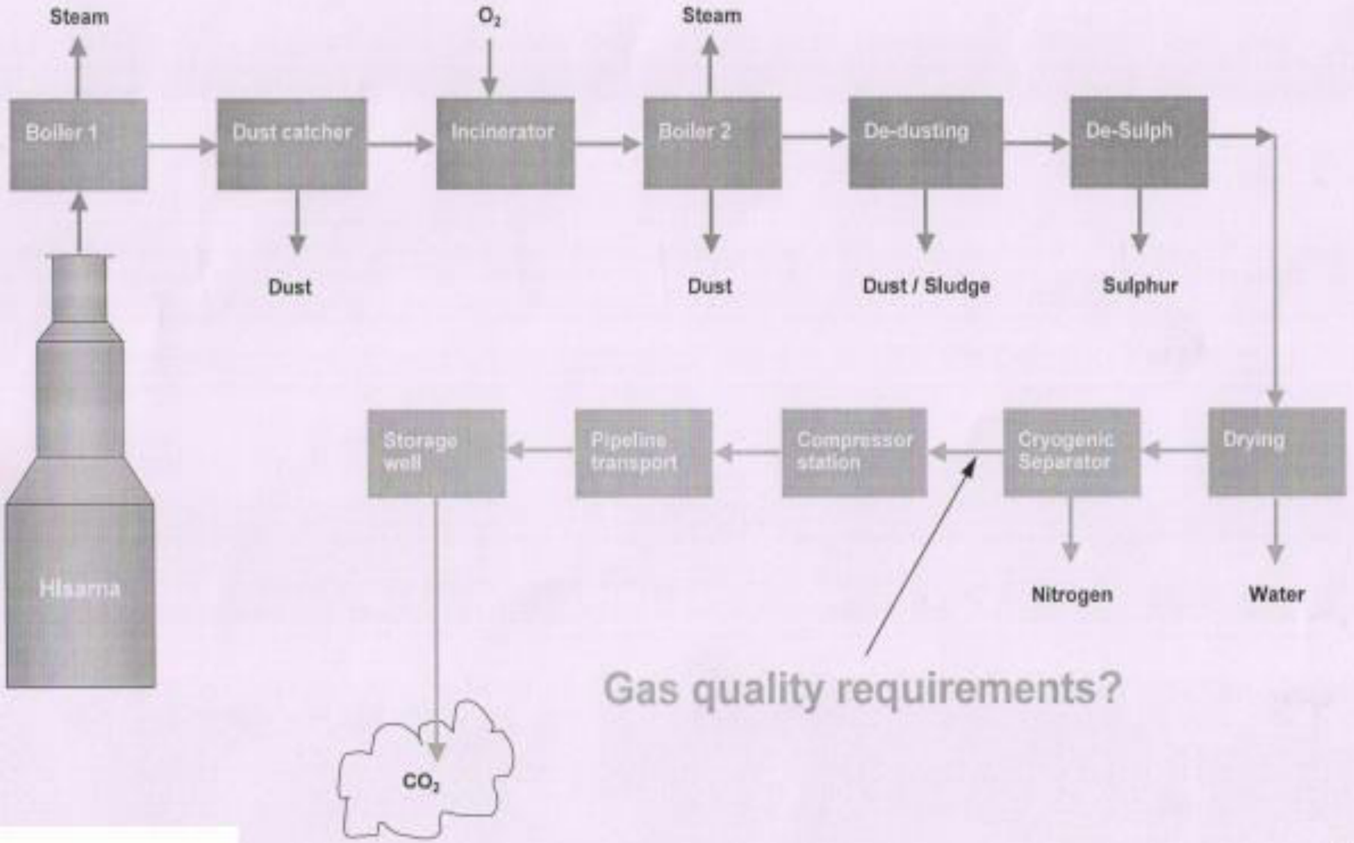
HIsarna

Required:

- Dust removal (staged)
- Heat recovery
- De-sulphurisation

4. HIsarna and CCS

4.3. Flowsheet with CCS



Steam

O_2

Steam

Hisarna

Boiler 1

Dust catcher

Incinerator

Boiler 2

De-dusting

De-Sulph

Dust

Dust

Dust / Sludge

Sulphur

Drying

Cryogenic Separator

Compressor station

Pipeline transport

Storage well

Water

Nitrogen

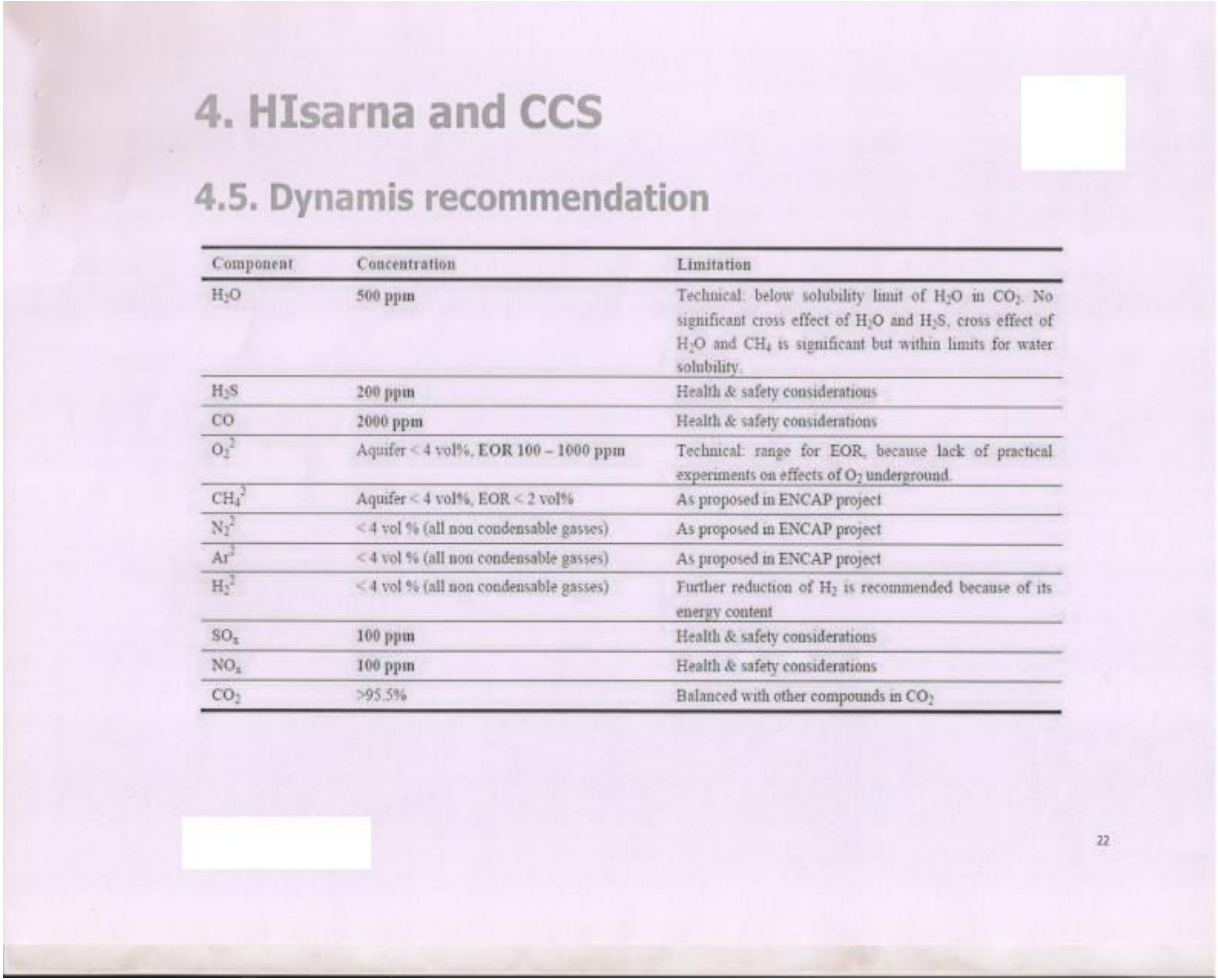
CO_2

Gas quality requirements?

4. HIsarna and CCS

4.4. Gas quality requirements

- Technical requirements
  - Corrosion
  - Hydrate formation
  - Compression energy
- Legal requirements
  - European directive: "*Overwhelmingly CO_2*"
  - Dynamis recommendation: $CO_2 > 95.5$ %
- ***For HIsarna a slightly less strict CO_2 concentration would be very beneficial. According to the directive there is room for negotiation.***

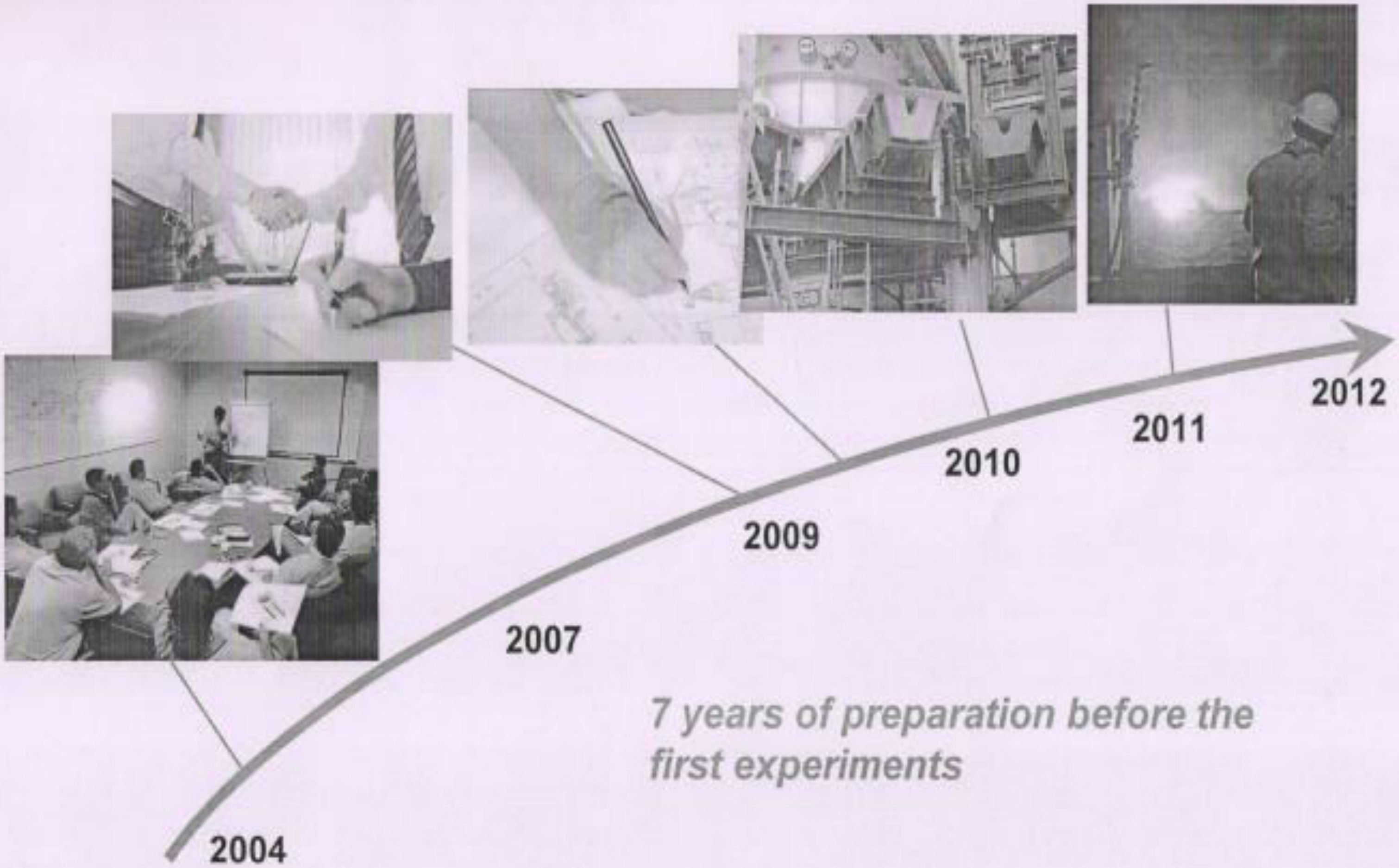


4. HIsarna and CCS

4.5. Dynamis recommendation

Component	Concentration	Limitation
H_2O	**500 ppm**	Technical: below solubility limit of H_2O in CO_2. No significant cross effect of H_2O and H_2S, cross effect of H_2O and CH_4 is significant but within limits for water solubility.
H_2S	**200 ppm**	Health & safety considerations
CO	**2000 ppm**	Health & safety considerations
O_2[2]	Aquifer < 4 vol%, **EOR 100 – 1000 ppm**	Technical: range for EOR, because lack of practical experiments on effects of O_2 underground.
CH_4[2]	Aquifer < 4 vol%, EOR < 2 vol%	As proposed in ENCAP project
N_2[2]	< 4 vol % (all non condensable gasses)	As proposed in ENCAP project
Ar[2]	< 4 vol % (all non condensable gasses)	As proposed in ENCAP project
H_2[2]	< 4 vol % (all non condensable gasses)	Further reduction of H_2 is recommended because of its energy content
SO_x	**100 ppm**	Health & safety considerations
NO_x	**100 ppm**	Health & safety considerations
CO_2	>95.5%	Balanced with other compounds in CO_2

5. Development



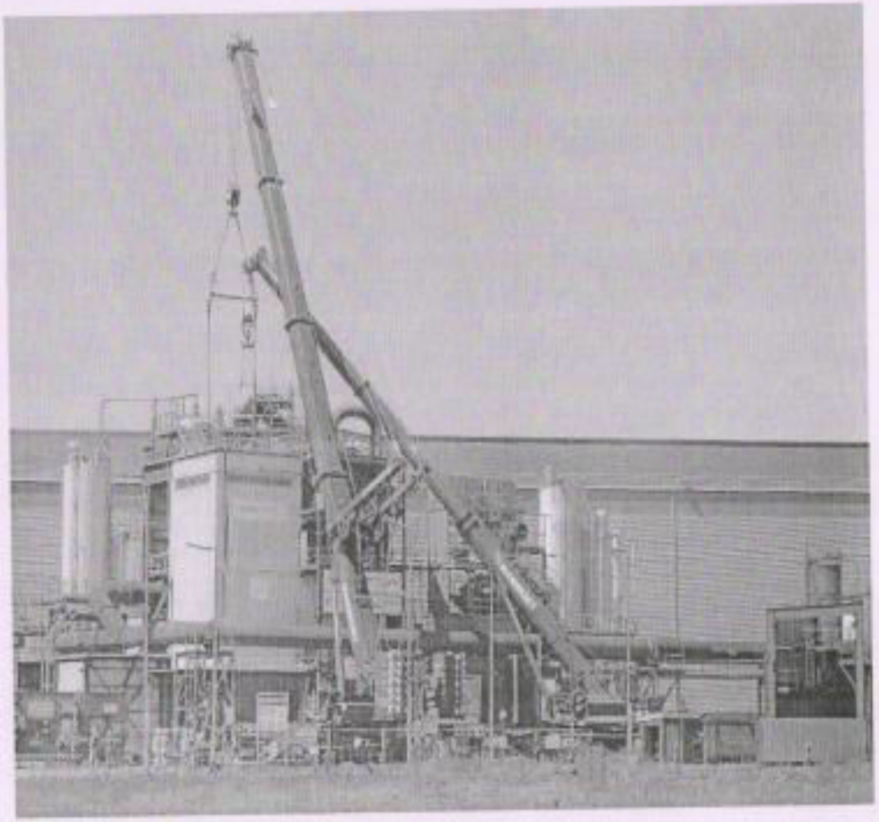
7 years of preparation before the first experiments

5.1. Site construction

- Suitable location (former de-S plant) at Tata Steel IJmuiden
- Project execution:
  - Tata Steel Engineering
  - Tata Steel Research
  - European steelmakers
  - European equipment suppliers
  - Rio Tinto

6. The first campaign (A.)

- The plant was operated from April 18 to June 11
- The team:
  - Tata Steel Operations
  - Tata Steel Research
  - ULCOS partners
  - Rio Tinto
- 4 start-ups took place



6. The first campaign (A.)

	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23
	April-18	April-25	May-2	May-9	May-16	May-23	May-30	June-6
Heat-Up	━	━						
Test A-1			●					
Plant improvements			━	━	━			
Test A-2					●			
Test A-3							●	
Test A-4								●

- First start-up failed
- Various improvements required
- 3 successfull start-ups followed

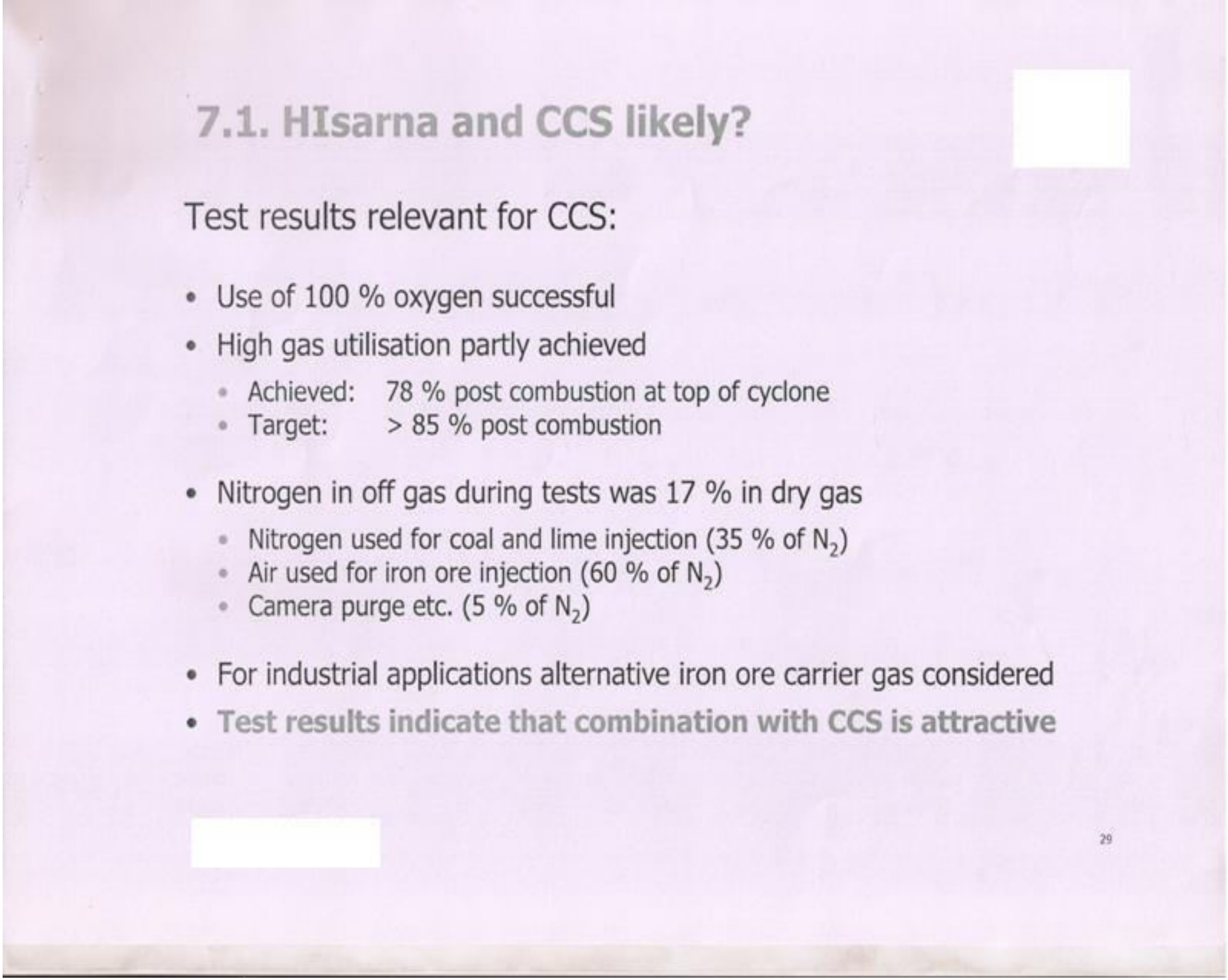
First metal tap at May 20th (test A-2)

[redacted]

[redacted]

7. Results first HIsarna campaign

- After many "teething problems" the plant and all it's support systems were finally operational
- 3 successfull start-ups were carried out
- 60 % of the design capacity was achieved
- Available data indicates that process works as expected but more operating hours are needed to prove this
- The number of operating hours was below expectation



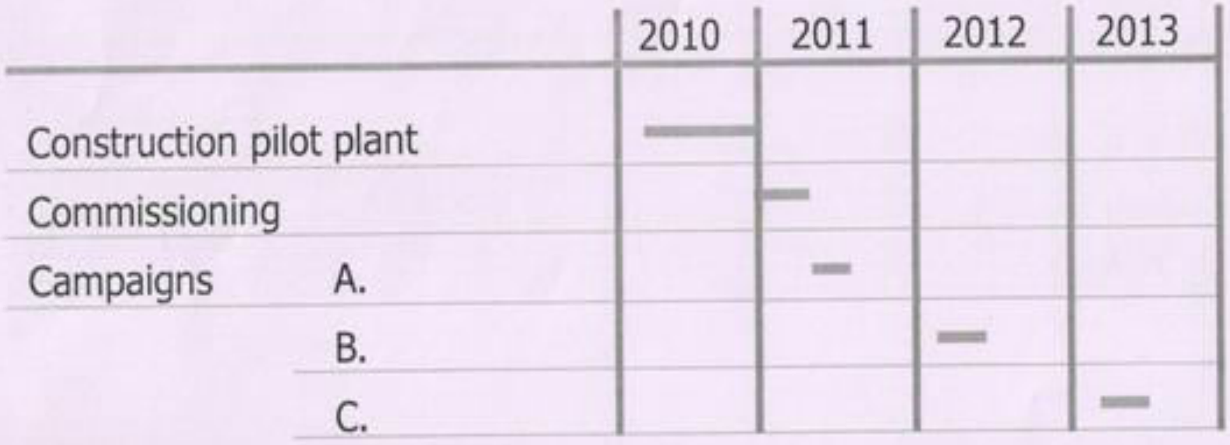
7.1. HIsarna and CCS likely?

Test results relevant for CCS:

- Use of 100 % oxygen successful
- High gas utilisation partly achieved
  - Achieved: 78 % post combustion at top of cyclone
  - Target: > 85 % post combustion
- Nitrogen in off gas during tests was 17 % in dry gas
  - Nitrogen used for coal and lime injection (35 % of N_2)
  - Air used for iron ore injection (60 % of N_2)
  - Camera purge etc. (5 % of N_2)
- For industrial applications alternative iron ore carrier gas considered
- **Test results indicate that combination with CCS is attractive**

8. Further campaigns

Pilot plant experiments



Industrial scale demonstration **2014 - 2018**

Industrial implementation **2020 - …….**

9. Conclusions

- With the ULCOS and HIsarna project the European steel industry is proactively approaching the Climate Change issue
- In the HIsarna project knowledge end experience of steelmakers and equipment suppliers from all over Europe is brought together
- HIsarna is a high risk/high reward innovation that can potentially have a strong **environmental** and **economical** impact on the steel industry
- Environmental impact:
  - Without CO_2 capture and storage **20 %** reduction
  - With CO_2 capture and storage **80 %** reduction
  - Strong reduction of other emission (dust, CO, NOx, SOx)
- No quick fix: HIsarna not ready for industrial implementation before 2020

  CCS available before 2020?

THANK YOU