

THE SEARCH FOR A NEW IRONMAKING PROCESS TOWARDS SUSTAINABLE DEVELOPMENT

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CONTENT

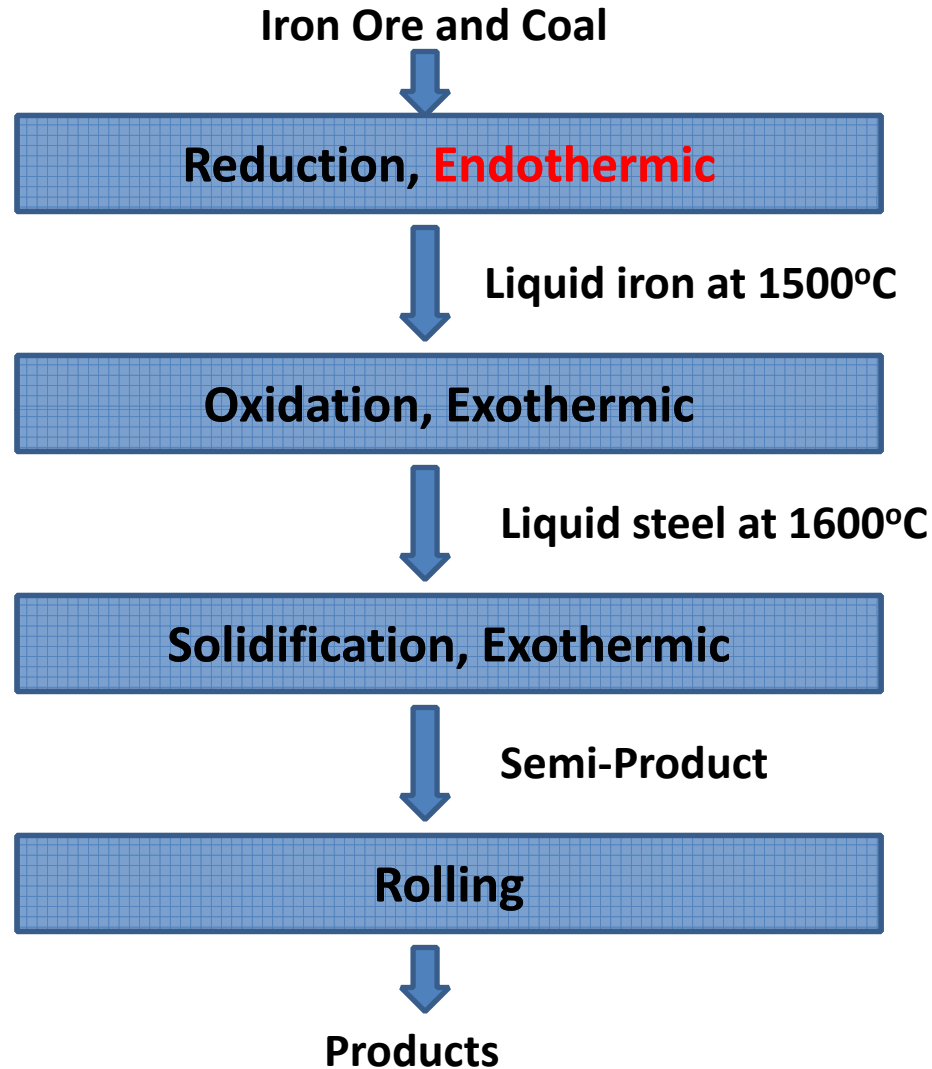
Background

1. Do we need carbon for making virgin iron.
2. The role of carbon.

New Processes for making liquid iron

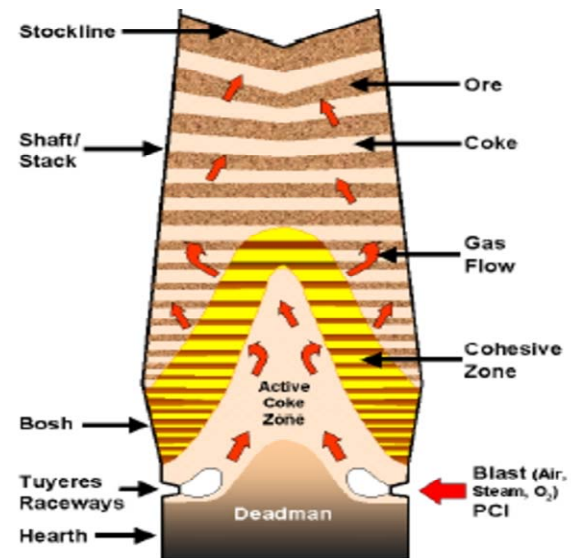
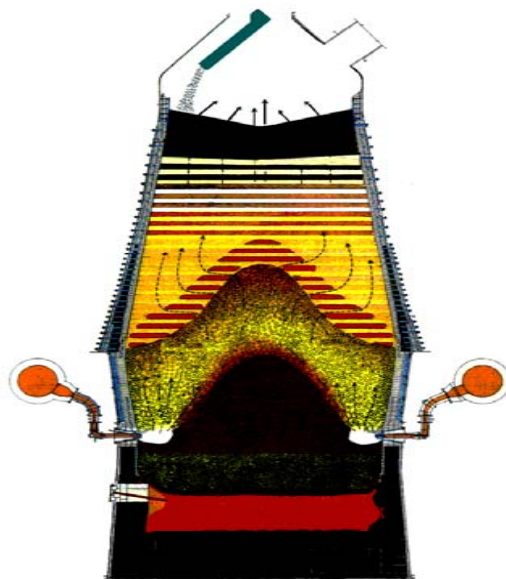
3. Single Reactor process.
4. Two-Reactor system with coupling.
5. De-coupled Two-Reactor system

MAJOR STEPS IN AN INTERGRATED PLANT



BLAST FURNACE IRONMAKING

It is vertical shaft furnace with counter-current solid (ore and coke)-hot reducing gas flows



CAN CARBON BE REPLACED IN IRONMAKING ?

Theoretically, **carbon, hydrogen and electrons** can all be the reducing agent; and electricity can also be the source of energy.

- Making metallic iron from ore is not difficult chemically.
- Making money by making iron is not easy!
- Making money by making iron with less carbon consumption is one of **“the challenges of our time”**

Geosphere Sinks

Sink	Global (Gt CO ₂)	Capacities -Canada (Mt CO ₂)	Capacities -Alberta (Mt CO ₂)	Retention -Time (Years)	Storage Rates -Alberta (Mt CO ₂ /yr)
EOR	238	330	220	10s	2.2
Coalbeds	300-964	14,680- 28,600	18,350	100,000s- 1,000,000s	18
Deleted Oil & Gas Reservoirs	630	18,350	12,850	100,000s- 1,000,000s	13
Deep Aquifers	183- 51,333	No Estimate	19,800	100,000s- 1,000,000s	20

Worldwide Experience with Geological Storage of CO₂ in 2004

76 **Enhanced oil recovery** operations (67 in the U.S., 2 in Canada), since the 60's

60 **Acid gas storage** operations (45 in Canada, 15 in the U.S.), since 1989

1 CO₂ storage operation **into an aquifer** (Sleipner in the North Sea), since 1996

1 enhanced **coalbed methane recovery** operation (San Juan basin, U.S.A.)

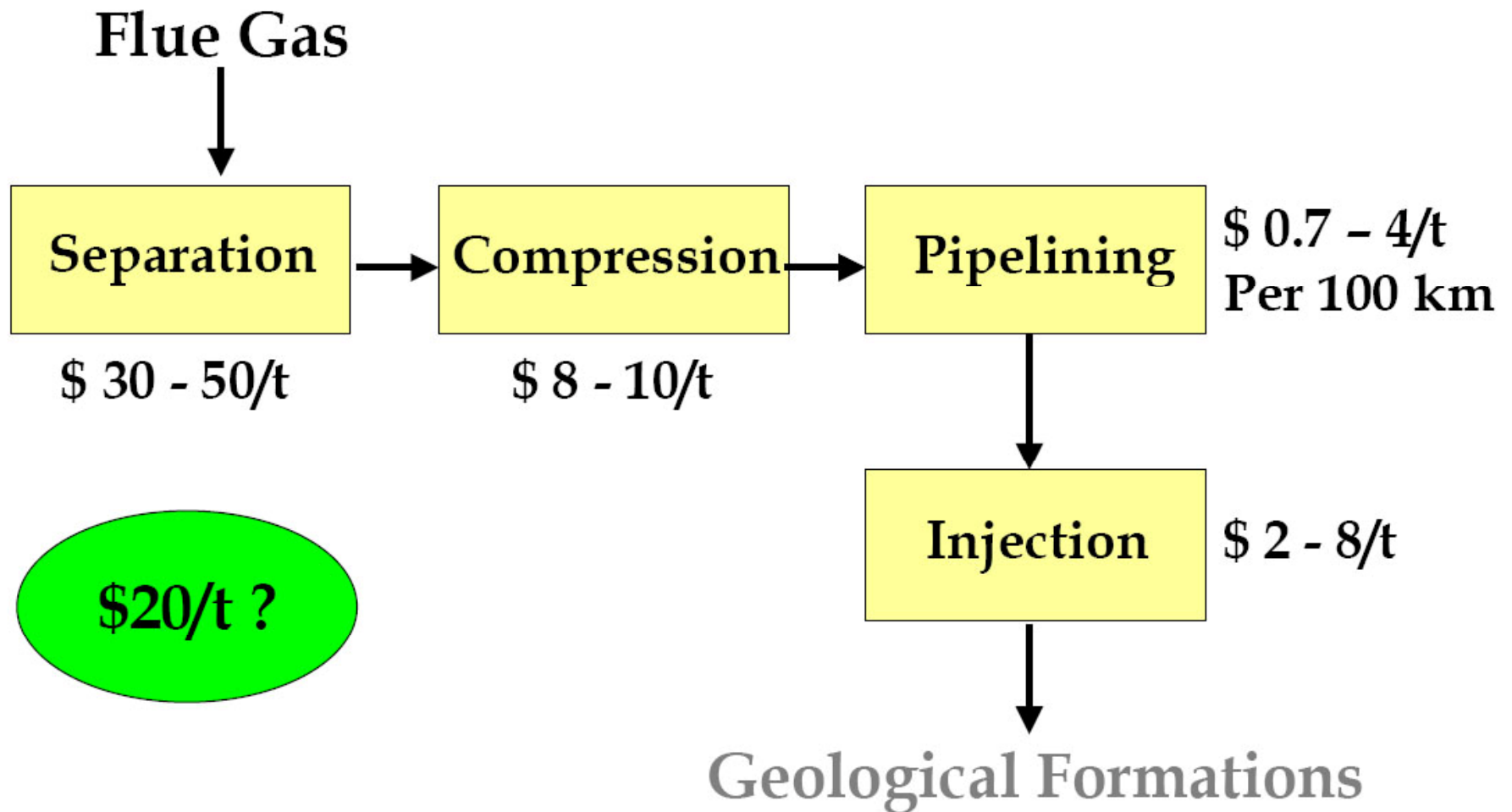
On Thursday, February 28, 2008 reported by the Globe and Mail

Saskatchewan's provincially owned utility "SaskPower" will spend \$758 million (+ \$240 million from Ottawa) to retrofit 100 megawatt plant to capture a million tonnes a year of CO₂, to cut its greenhouse gas emissions of SaskPower by 7.2 % from 2006 level.

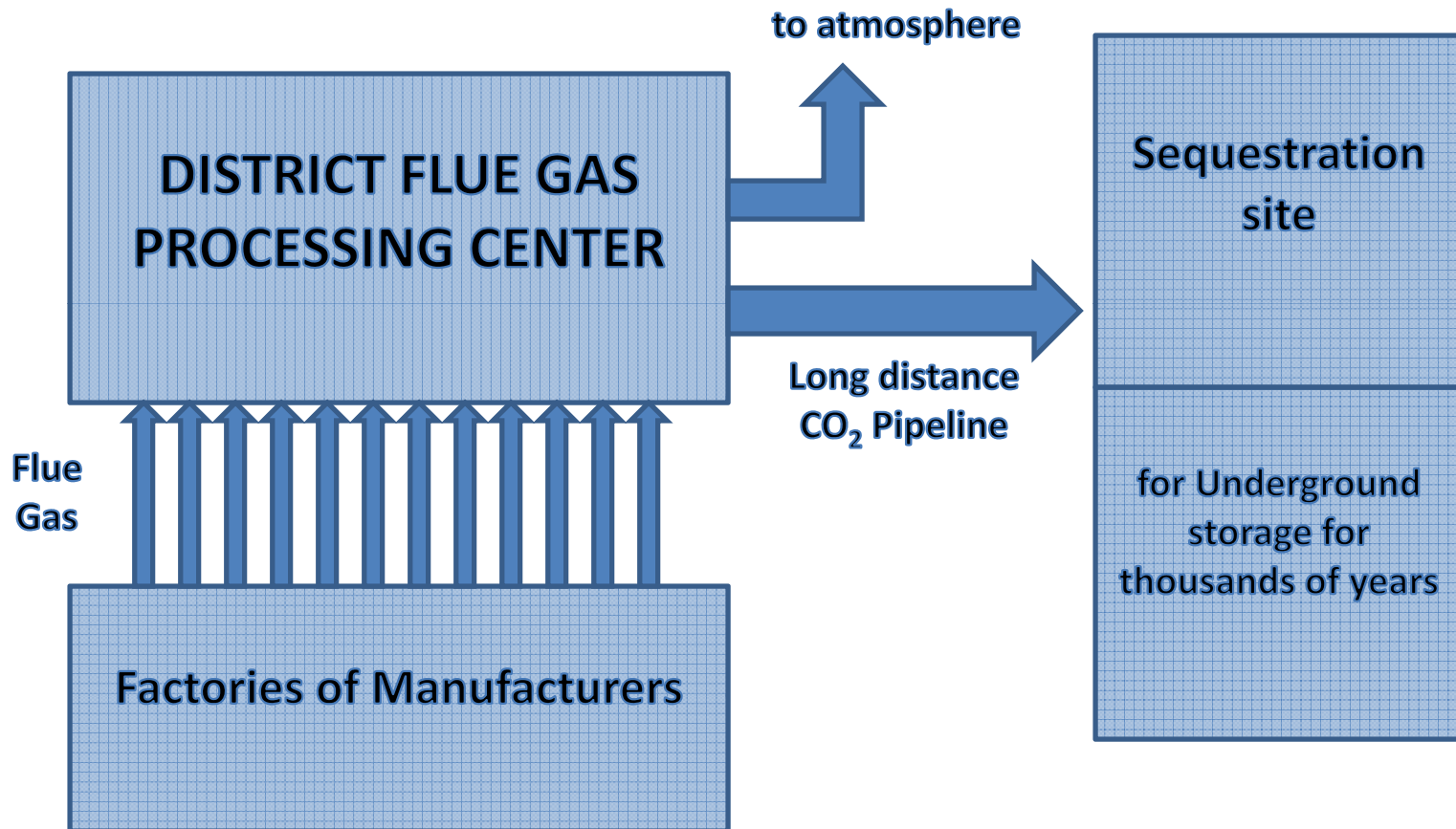
Carbon dioxide will be captured from the flue with a scrubber technology and it will be piped to nearby oil fields, where it will be injected underground to boost the recovery of crude. It is the first plant of this kind in North America, a demonstration project.

This plant is located at Boundary and near an EnCana operation (for seven years) which has been widely studied. It uses carbon dioxide piped from North Dakota in an enhanced oil recovery project, and scientists believed the CO₂ injected there will remain trapped for thousands of years.

Capturing CO₂ from Flue Gas



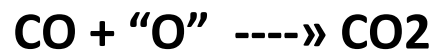
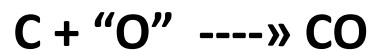
THE CONCEPT OF CENTRAL PROCESSING OF FLUE GAS FOR CARBON MANAGEMENT



The role of carbon in old and new processes

ROLES PLAYED BY CARBON IN IRONMAKING

Carbon can be oxidized in two stages:



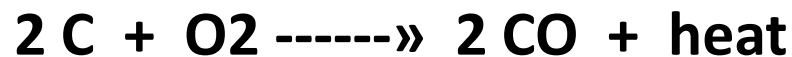
If the oxygen atom "O" is from molecular O₂ , the reaction is combustion to release **heat**.

If the oxygen atom "O" is from iron oxides, the reaction is **reduction of iron ore**.

SIMPLE-MINDED STOICHIOMETRY

Let us mark the oxygen atoms in air black as “O” and oxygen atoms in iron ore red as “O”.

The **Blast Furnace** reactions may be described as follows:



The consequences:

(1) two C atoms for one atom of **oxygen** from the ore.

(2) 50% of carbon oxides leaving the reactor as CO, with its chemical energy un-released.

THE ALTERNATIVE ROUTE OF USING CARBON



The consequences are:

- 1 C atom for 1 "O" from the ore
- Carbon leaves the reactor as dioxide.

- Heat is generated in oxidation region
- Heat is needed in reduction region

Single Reactor Processes

Smelting Reduction

The idea of : SMELTING REDUCTION



In general, a **single reactor**, is a “Bad Idea” Because of high coal rate, due to high CO/CO₂ Ratio and high sensible heat in gases at **high temperature**.

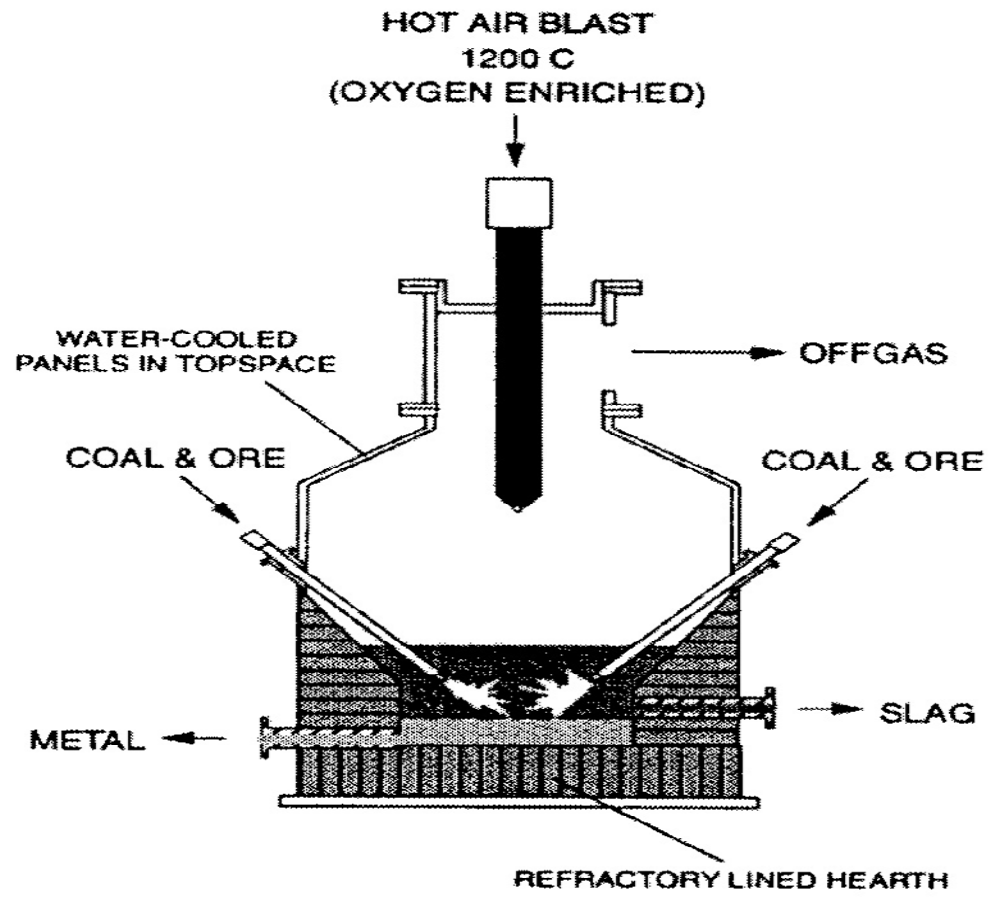


Figure 2 Vertical SRV

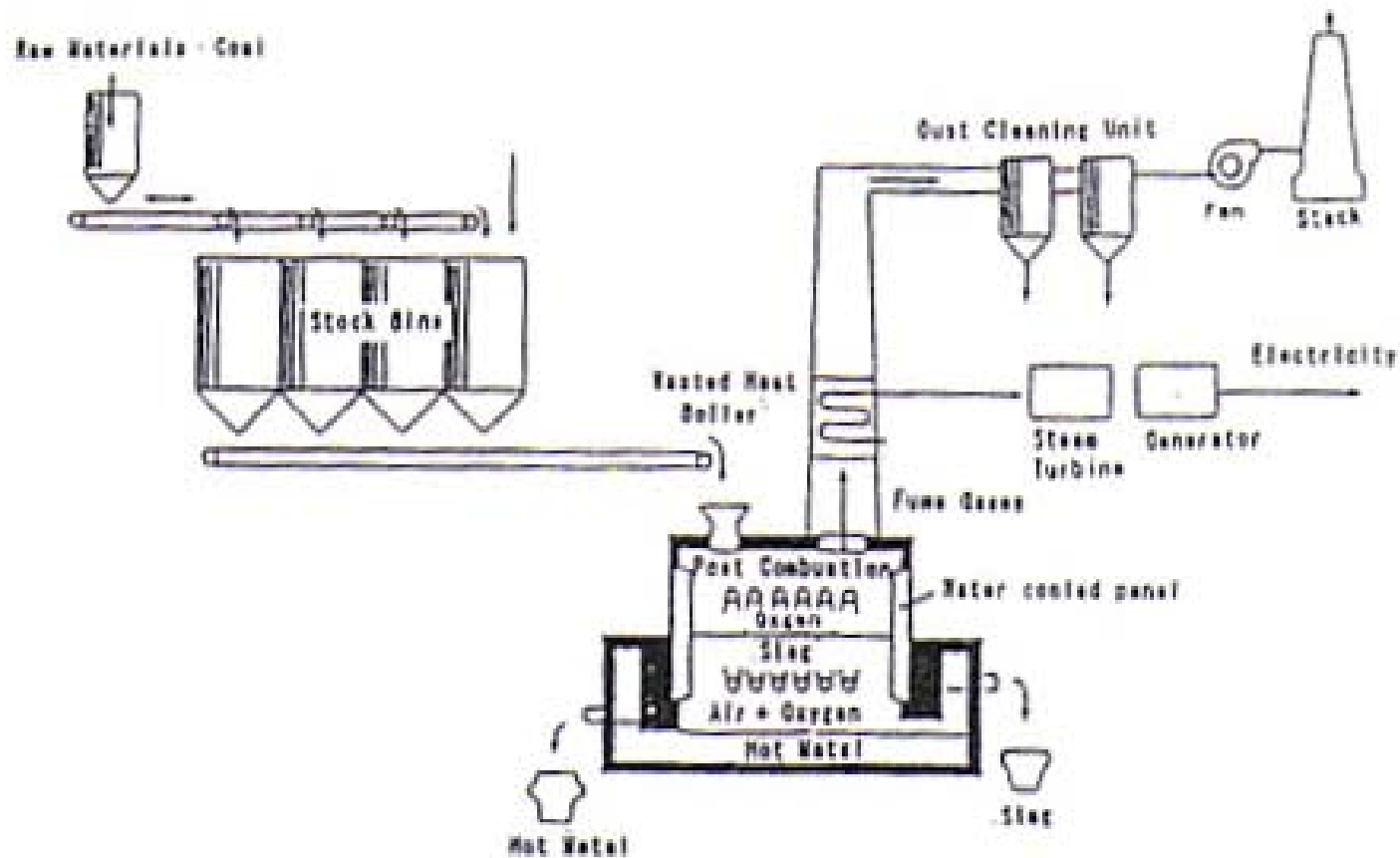


Fig. 6. The Romelt smelting reduction process flow¹⁰⁾.

IN LAST FOUR DECADES

Smelting reduction processes have two fundamental problems to result in **high carbon rate**:

1. Reduction temperature should be lower than melting temperature for thermodynamic advantages.
2. Re-Oxidation can not be eliminated.

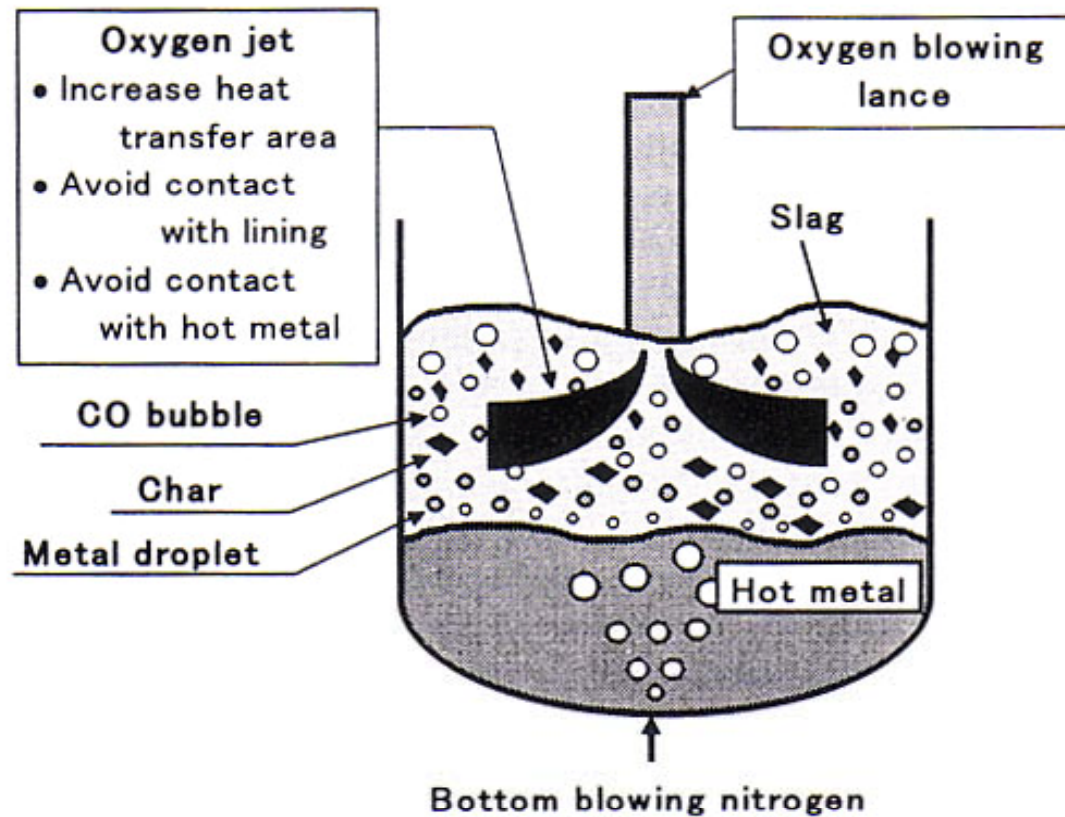


Fig. 3 Physical image in SRF.

O₂ Oxidizes all things in contact, carbon, iron , etc

SOME GENERALLY ACCEPTED CONCLUSION

- An oxy-coal **melting vessel is needed** to produce liquid iron and to separate hot metal from gangue and ash.
- Single reactor system of 100% smelting reduction is **unacceptable** for very high coal rate.
- Two-reactor system (DIOS, AISI, etc.):
 - (1) pre-reduction at lower temperature.
 - (2) less smelting reduction in the vessel.

Two-Reactor system with coupling through gas

COUPLED TWO-REACTOR OPERATION

COUPLING:

GAS from **Melting/Refining Reactor**

to be used

as the reducing reagent in a low temperature

Reducer.

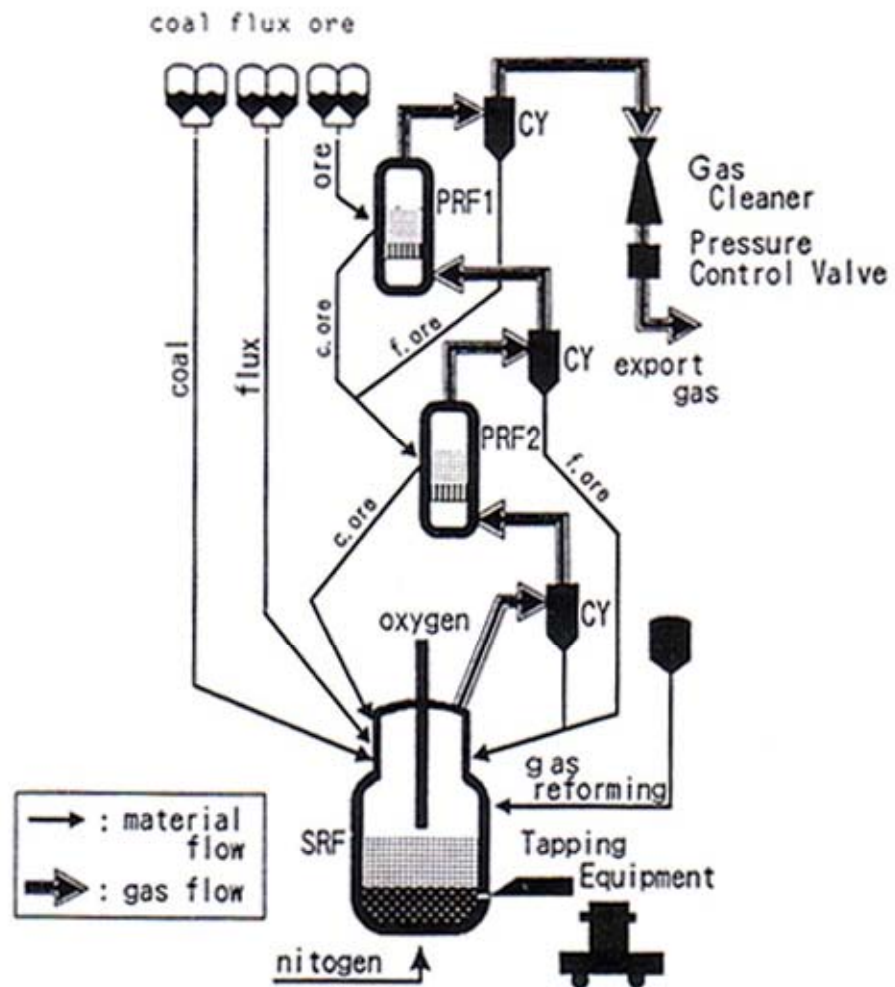
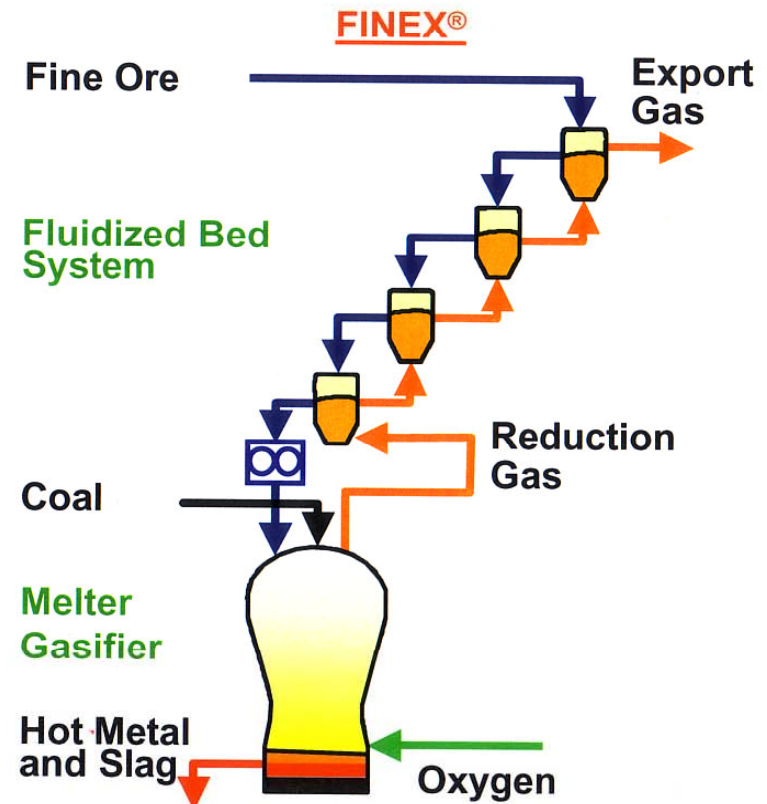
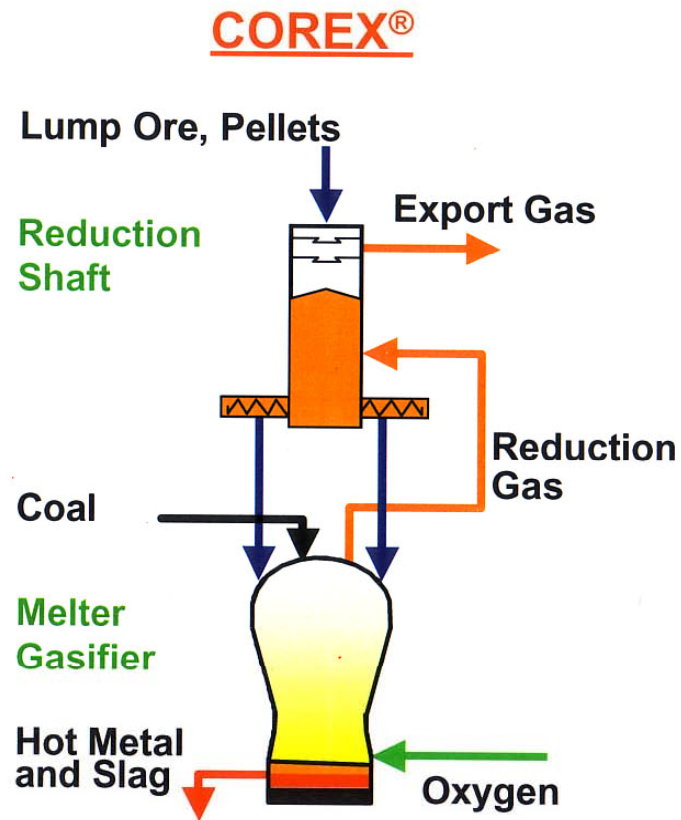


Fig. 1 Process flow sheet of the DIOS pilot plant.
 CY : cyclone, f. ore : fine ore, c. ore : coarse ore

COREX[®] - FINEX[®] Processes



Comparison of the Process Flow Sheets



COUPLING THROUGH “GAS”

The **total coal rate** has been **higher** than
that in blast furnace operation.

De-coupled Two-Reactor system

TWO-REACTOR SYSTEM FOR HOT METAL PRODUCTION

(1)Reduction Reactor

Sized ore and high VM coals are used “directly” to produce highly metallized DRI. It is the challenge!

(2)Melting and refining Reactor

In an oxy-coal vessel, hot DRI is melted for metal/slag separation and hot metal quality control.

NEW DRI UNIT NEEDED

Operating conditions:

- Using ore and coal directly
- Very little hot reducing gas available from the vessel
- **Process temperature** should be high enough for fast carbon gasification and low to keep product in solid stat.

Commercial technology available:

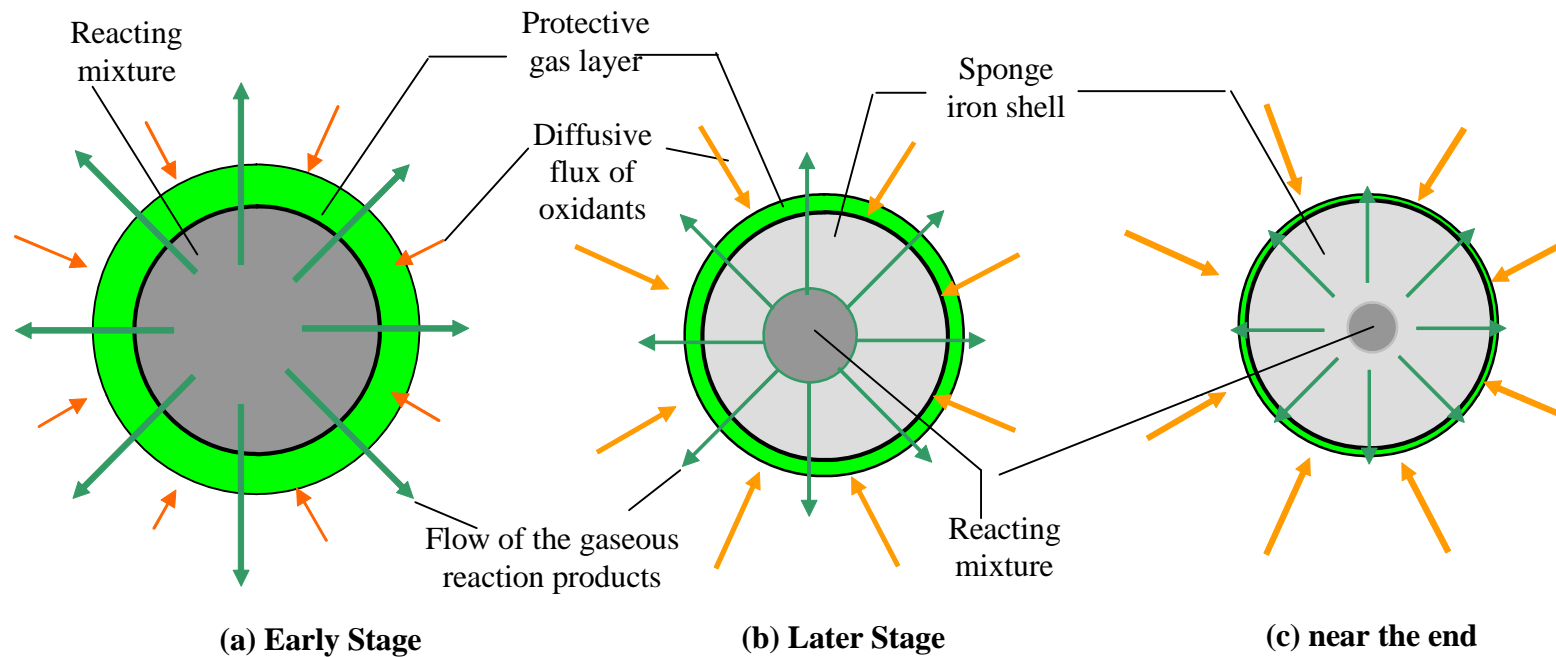
- By heating **ore/coal composite agglomerates** in a Rotary Hearth Furnace (**RHF**)
- **Rotary Kiln** (T?)

ORE/COAL COMPOSITE PELLETS

It is made of mixture of fine ore and coal
And **chemically self-sufficient**,
And needs to be heated to sustain
reduction and metallization.

**The best form of using
renewable carbonaceous material
to replace “coal”.**

MECHANISM OF IRON RE-OXIDATION



The protective gas flow from the interior to repel the oxidizing gases during reduction

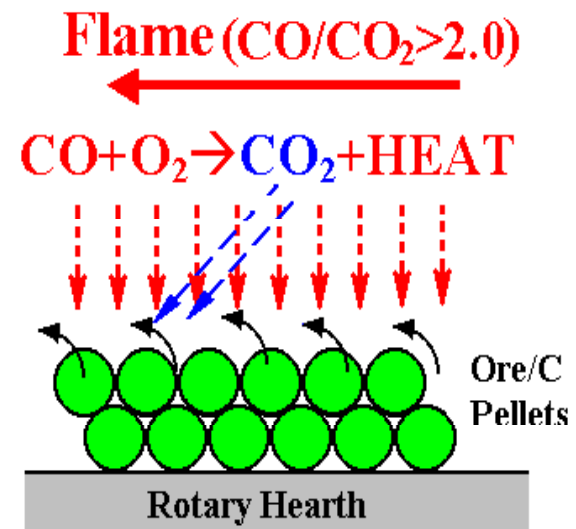
The risk of re-oxidation of sponge iron in a **shallow bed in conventional RHF** increases when the outward flow of gaseous reaction products weakens.

In order to make DRI of high degree of metallization, excessive amounts of coal and burner fuel have to be used.

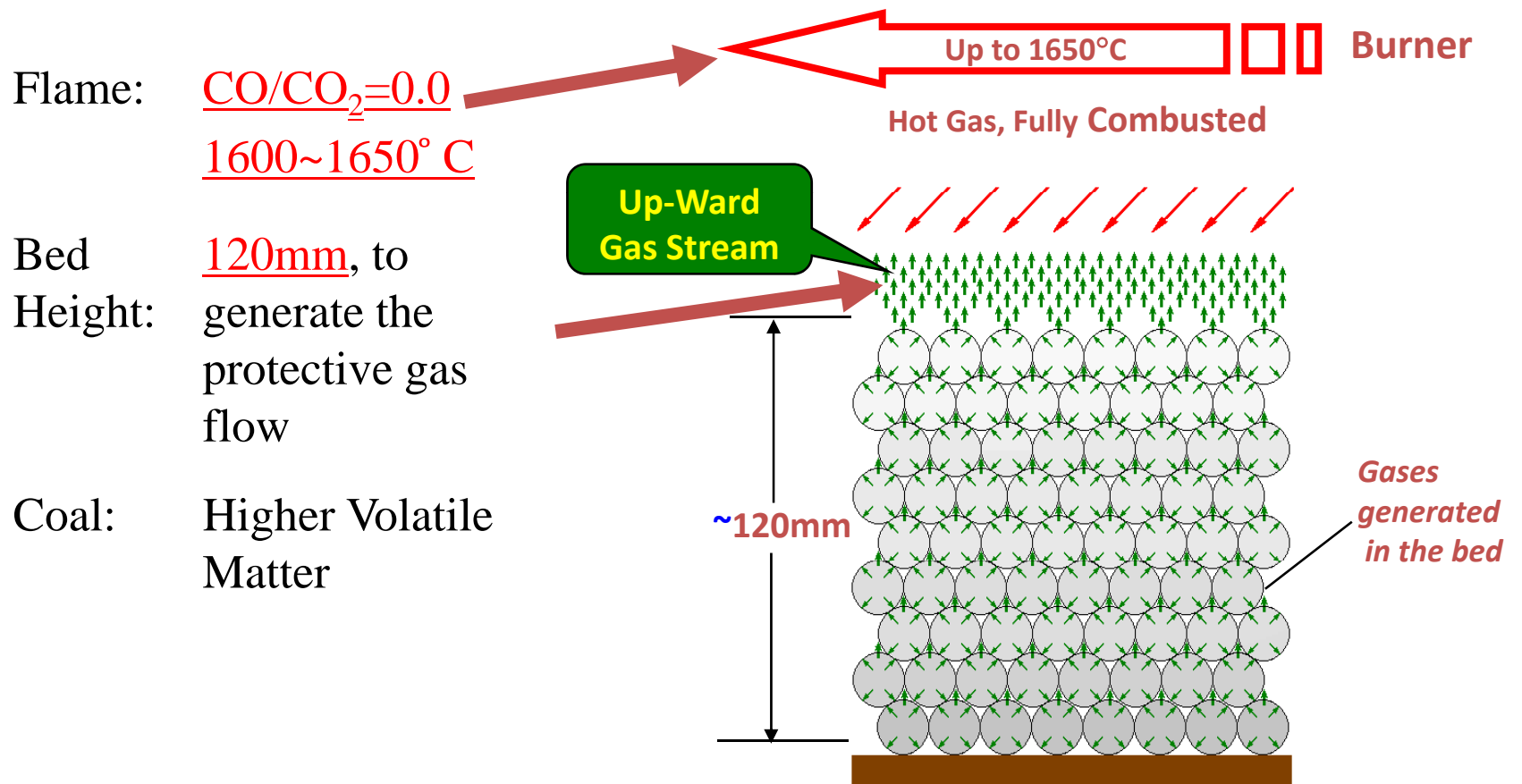
ROTARY HEARTH FURNACE(RHF)

Shallow Bed has contradictory requirements for fuel efficiency and protection of sponge iron

- Lower furnace temperature: 1300~1350C
- Incomplete combustion ($CO/CO_2 > 2.0$) of fuel in reduction zone, more than a half of the total heat of the fuel can not be liberated in reduction area.
- The incomplete combustion atmosphere could only moderate the rate of re-oxidation of sponge iron.
- Re-oxidation of DRI produces slag of high FeO



PAIRED STRAIGHT HEARTH (PSH) FURNACE RE- OXIDATION IS PREVENTED THUS, GAINS IN PRODUCTIVITY AND ENERGY EFFICIENCY



PAIRED STRAIGHT HEARTH (PSH)

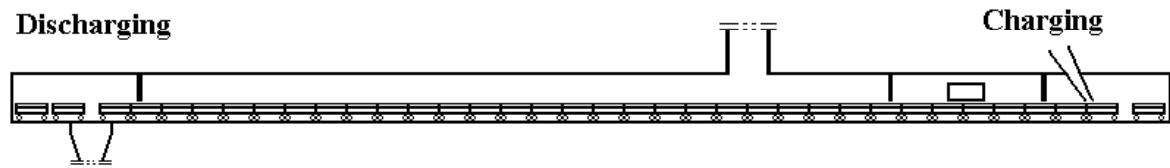
PSH FURNACE and TALL BED TECHNOLOGY

It is originated from **McMaster University** based on fundamental and applied research work sponsored by funding agencies of Canadian and US governments and AISI.

The problem of **re-oxidation of sponge iron** has been solved by the self shrouding with gaseous products due to (1) tall bed, (2) high process temperature, (3) high volatile coal and (4) fully oxidized flame to result in low coal rate and high metallized DRI.

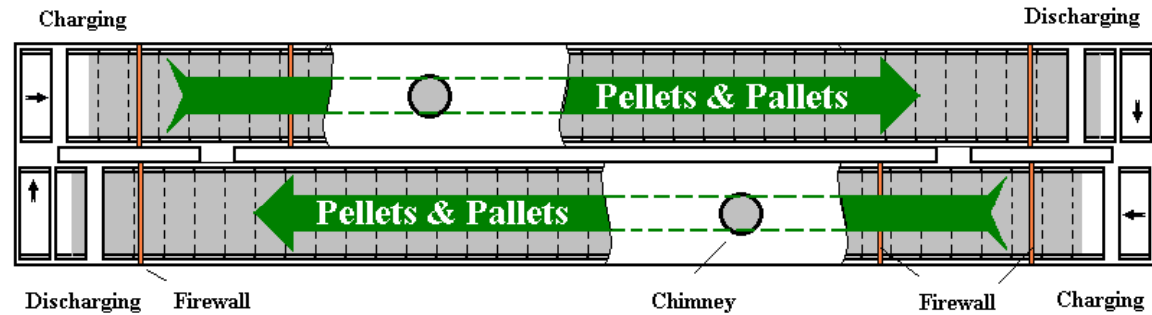
PAIRED STRAIGHT HEARTH (PSH) FURNACE

Side View



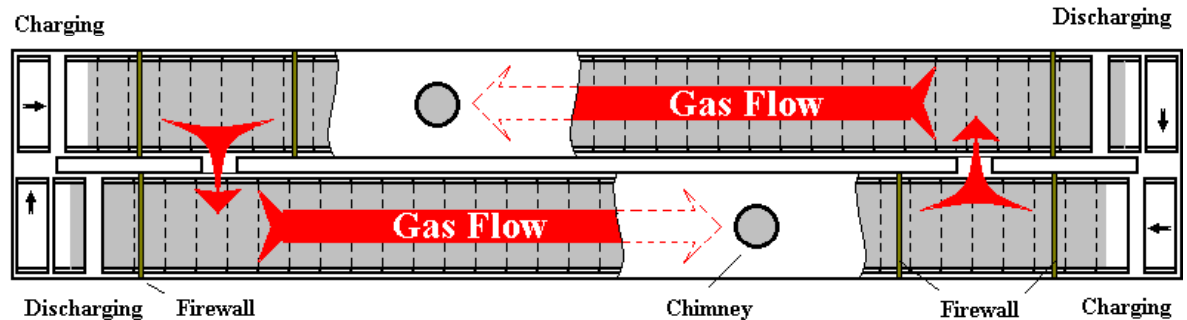
Top View

Pellet Movement



Top View

Gas Movement



Energy Consumption of hot metal production with an oxy-coal melter

Items	Consumption	GJ/THM	
Coal	396 kg	11.47	
Oxygen	96 Nm ³	0.20 (0.61*)	
Lime	95 kg	0.70	
Electricity	60 kwh	0.21(0.66*)	
Gas credit (from hearth furnace)		-1.11	
Total		11.47 (12.33*)	

* including the losses for generation and transmission of electricity, following Stubbles[1]

To be compared with **18 GJ / tonne-HM** for good blast practice in US Steel industry in 1998 according to “Energy Use in the U.S. Steel Industry: A Historical Perspective and Future Opportunities” authored by John Stubbles, Sep. 2000, P8.

Thank you for your attention