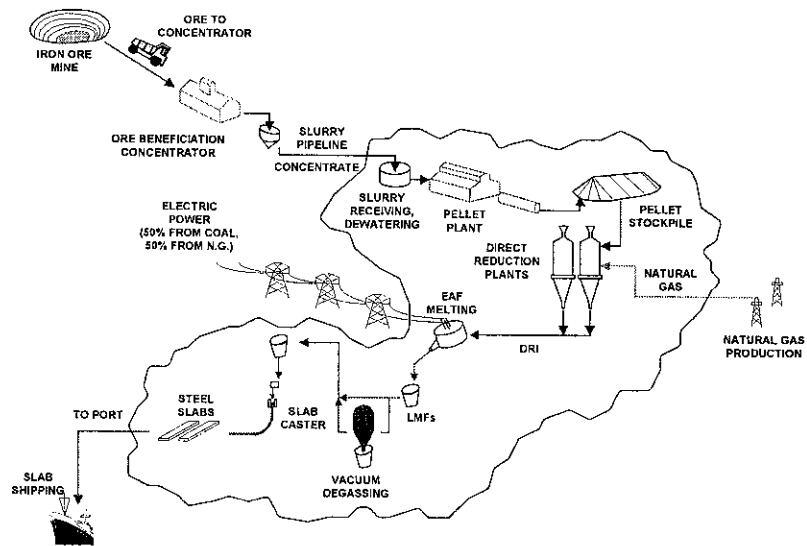




# Ironmaking Process Alternatives Screening Study

## Volume II: Appendix



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**LOCKWOOD GREENE**

**IRONMAKING PROCESS  
ALTERNATIVES  
SCREENING STUDY**

**VOLUME II: APPENDIX**

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# APPENDIX A

## IRONMAKING PROCESS DESCRIPTIONS & BACKGROUND

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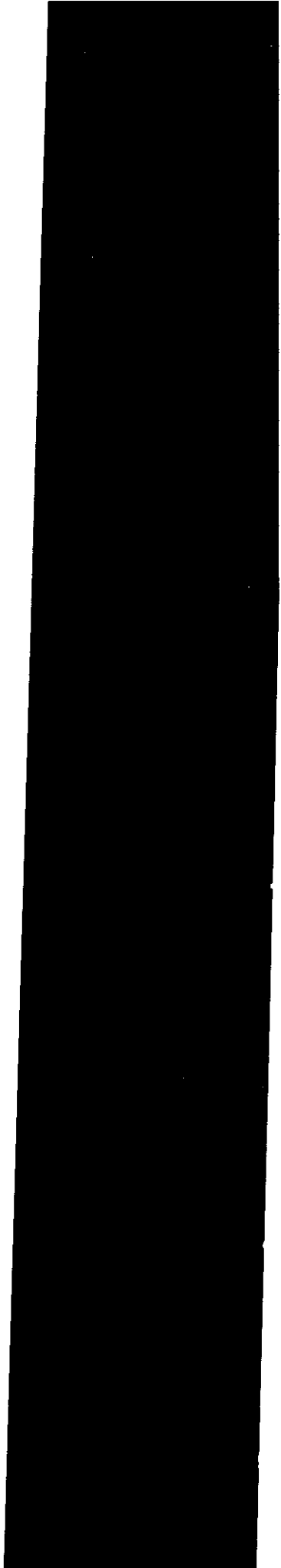
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**PROCESS DESCRIPTIONS**

# **SHAFT FURNACE PROCESSES**

# IRONMAKING PROCESS DESCRIPTION

## MIDREX® SHAFT FURNACE

### PROCESS BACKGROUND:

The Midrex™ Direct Reduction process is based upon a low pressure, moving bed shaft furnace where the reducing gas moves counter-current to the lump iron oxide ore or iron oxide pellet solids in the bed. The reducing gas (from 10-20% CO and 80-90% H<sub>2</sub>) is produced from natural gas using Midrex's CO<sub>2</sub> reforming process and their proprietary catalyst (instead of steam reforming).

A single reformer is utilized instead of a reformer/heater combination. The reformed gas does not need to be cooled before introduction to the process. There is also no need for a separate CO<sub>2</sub> removal system.

The process can produce cold or hot DRI as well as HBI for subsequent use as a scrap substitute feed to a steelmaking melting furnace (SAF, EAF or oxygen steelmaking process).

Over 50 Midrex™ Modules have been built worldwide since 1969. They have supplied over 60% of the worlds DRI since 1989.

### Standard sizes:

MIDREX™ MINIMOD Plant	(0.25-0.5 MM mt/year)
MIDREX™ Series 500 Module	(0.5-0.8 MM mt/year)
MIDREX™ Series 750 Module	(0.8-1.0 MM mt/year)
MIDREX MEGAMOD™	(1.0-1.6 MM mt/year)
MIDREX SUPER MEGAMOD™	(1.6-2.7 MM mt/year)

### PROCESS DESCRIPTION:

The iron oxide feed to a Midrex® shaft furnace can be in the form of pellets, lump ore or a mixture of the two (in 0 to 100% proportions). The solid feed is discharged into a feed hopper on top of a proportioning hopper that evenly distributes the solids into the shaft furnace.

A dynamic seal leg keeps the reducing gas inside the furnace. The shaft furnace operates at low pressure, under 1 bar gauge, which allows dynamic seals to be used on the furnace inlet and discharge. The iron ore burden in the shaft furnace is first heated, then reduced by the upward flowing, counter-current reducing gas that is injected through tuyeres located in a bustle distributor at the bottom



of the cylindrical section of the shaft. The ore is reduced to a metallization typically in the range of 93% to 94% by the time it reaches the bustle area.

Below the bustle area, it goes through a transition zone (with design to reduce agglomeration or lumping) and then reaches the lower conical section of the furnace. Lower carbon reduced iron (<1.5% C) is cooled using a circulating stream of cooled exhaust gas that is introduced in the conical section for cold DRI discharge. Higher carbon DRI (up to 4.0% C) can be produced by introduction of natural gas into this cooling gas. It readily reacts (and cracks) with the highly reactive metallic DRI.

For hot discharge of DRI to be used for hot charging of EAF's (i.e. Midrex's Hotlink™ Process) or for feed to hot briquetting presses (to produce HBI), the lower part of the furnace is modified to allow handling of hot burden.

The Midrex gas generation system consists of a CO<sub>2</sub> reformer using their own catalyst. The feed to the reformer is a mixture of process gas recycled from the furnace and makeup natural gas. The top gas leaving the shaft furnace at a temperature of 400 to 450C is cooled and dust is removed in a top gas scrubber. About two-thirds of the gas is recycled back to the process (process gas) and the rest is used as a fuel. The process gas is compressed, mixed with natural gas and is preheated in the reformer recuperator before entering the tubes of the reformer.

The reformed gas comprising of mostly CO and H<sub>2</sub> exits the reformer at about 850 °C and passes through collection headers to the reformed gas line. The ratio of H<sub>2</sub> to CO is controlled at about 1.5 to 1.8, and reducing quality at 11 to 12 for best operation.

#### PROCESS ADVANTAGES:

World-wide commercial use

Proven performance

“Relatively-forgiving” operation

Raw material flexibility

CO<sub>2</sub> reformer eliminates need for steam system, reformed gas quench, reducing gas heating and CO<sub>2</sub> removal system.

## **HYLSA PROCESS (HYL III)**

### **PROCESS BACKGROUND:**

The HYL process uses reducing gases within a moving bed shaft furnace reactor to remove the oxygen from iron ore pellets and lump ore. In comparison to other similar technologies, it operates at slightly higher reduction temperatures (about 50 °C higher) and intermediate reduction pressures (up to 6 bars). The process can produce cold/hot DRI as well as HBI.

The HYL process can utilize higher-sulfur ore and gas feeds since it is equipped with a sulfur removal step (prior to the conventional steam reformer). A more-positive control is obtained for the reducing gas (CO to H<sub>2</sub> ratio) is obtained by utilizing a selective CO<sub>2</sub> removal circuit (typically PSA) in the circulating gas systems. This allows a wide range of CO to H<sub>2</sub> ratios (from 0.1 to 0.3) to be utilized depending on the required degree of metallization and/or carbon content of the final product.

### **PROCESS DESCRIPTION:**

The iron oxide feed to a HYL shaft furnace can be pellets, lump, or a mixture of the two. The solids are fed to the top of the shaft furnace by conveyor. An automatic system of bins and pressure locks receives the ore at atmospheric pressure in an open bin, pressurizes in intermediate bins and charges it continuously to the reactor.

Hylsa divides the process into two independent sections: reducing gas generation and iron ore reduction. The natural gas (makeup to the reducing gas stream) is mixed with reducing gases recycled from the CO<sub>2</sub> removal system. The pressurized reducing gas is passed through a gas heater (where it is heated up to 930 °C) and is introduced to the reactor at up to 6 bar gauge. The higher gas pressure system reduces the tendency for bed fluidization, permits higher capacity from a given-diameter shaft furnace and reduces the effective volumetric flow rates of circulating gases. Higher mole ratios of reducing gas to iron oxide solids can be obtained (as compared to other shaft furnace processes).

The exhaust reducing gas from the reactor (at about 400 °C) is cooled in a quenching/scrubbing system that removes most of the water produced during the reduction process from the gas stream. Also most of the dust in the exhaust gas is also removed. The scrubbed gas is compressed, fed to the CO<sub>2</sub> removal system (and optionally to a SO<sub>2</sub> removal system) before being fed back to the lower part of the shaft furnace.

In the reducing gas generation system, natural gas is passed through a section of the reformer recuperator to preheat it, and is then desulfurized to reduce the sulfur content to less than 1 ppm. This is to prevent poisoning of the reformer catalyst with sulfur compounds. The natural gas is mixed with superheated steam from the reformer steam circuit in a steam to carbon ratio of around 2.4 to 1 by volume, and the mixture is further superheated to 620C in the reformer recuperator.

The gas mixture is heated in the tubes by gas-fired burners to a temperature of about 830 °C where the reforming reactions take place. The reformed gas passes through a waste heat boiler and through a boiler feed water preheater to recover heat. It is then quenched to remove water remaining in the gas. The product gas contains around 72% H<sub>2</sub> and 16% H<sub>2</sub>. The reactor has a cylindrical upper section with reducing gas inlets and outlets for top gas and cooling gas. The lower part is conical and has inlets for the cooling gas when cold DRI is produced.

The use of a reformer that does not process gas from the reduction section isolates it from any gas-side changes which might occur in the reactor.

As the solid feed moves down the reactor by gravity flow, it is heated and reduced by reducing gas flowing upwards. The major reductant is H<sub>2</sub> due to its higher concentration in the reducing gas. In the conical lower part of the reactor, the burden is cooled and carburized by a circulating cooling gas that is enriched with natural gas. The product is reduced to a metallization up to 95% and carbon can be controlled in a range of 1.5% to 4.5%. For hot discharge of DRI, Hylsa's HYTEMP™ system is used which links the reactor discharge to the melt shop by way of a pneumatic conveying system.

## PROCESS ADVANTAGES

Proven performance

Raw material flexibility (high S ore and natural gas)

Conventional Steam reforming

Selective elimination of H<sub>2</sub>O and CO<sub>2</sub> from the reducing gas circuit allows maximum recycle of reducing gases to the reduction reactor.

Higher pressure operation reducing circulating gas volumetric flow at high molar

Flexibility to generate electric power by high pressure steam produced in the reformer.

## **HYLSA 4M PROCESS**

### **PROCESS BACKGROUND:**

The Hylsa 4M process is based on a moving bed shaft furnace (similar to HYL III process but without a reformer) which reduces iron ore pellets and lump ore, and operates at typical reduction temperatures and intermediate reduction pressures. This process requires no reformer to generate the reducing gas as the reforming of the natural gas takes place inside the reduction reactor using the metallic iron of the DRI product as the catalyst. The process can produce cold/hot DRI as well as HBI.

### **PROCESS DESCRIPTION:**

As before, the iron oxide feed to a Hylsa 4M furnace can be pellets, lump, or a mixture of the two (from 0 to 100% of either).

HYL divides the process into three primary units: Reduction system, DRI handling system and External cooling system.

The HYL 4M reactor operates at similar conditions to the other Hylsa reactors (e.g. HYL III, etc.). The reactor has a cylindrical upper section where reduction and reforming reactions take place. The lower part is conical with a rotary valve at the end to control the flow of solids discharging the reactor.

The starting point of the reduction circuit is the fresh stream of natural gas that is used as a makeup for the process. This natural gas (desulfurization is not necessary, but is optional) is mixed with recycled gas and fed to a humidifier, where the humidity of the total stream of reducing gas is controlled to adjust the carbon deposition rate on the DRI at the bottom of the reactor.

The reducing gas goes to the top gas heat recuperator, where sensible heat is recovered from the reactor top gas. Then the preheated gas goes to a gas heater where its temperature is increased to above 900 °C. In the transfer line to the reactor, O<sub>2</sub> is injected in order to have some partial combustion of the reducing gas to increase its temperature to above 1020 °C. This gas, upon introduction into the bottom of the HYL reactor, flows upward into the reduction zone countercurrent to the moving bed of solids.

In the lower part of the reduction zone, insitu reforming reactions are carried when this hot gas contacts the metallic DRI product. The metallic iron in the DRI acts as a catalyst for the reforming reactions. In addition, this occurs in parallel with the final stage of reduction of the iron ore. As a result some of the DRI

reacts with the carbon and is carburized (to  $\text{FeC}_3$ ) and there is some excess free carbon.

#### PROCESS ADVANTAGES:

Proven equipment performance (uses HYL II and HYL III reactor technology)

Raw material flexibility

Not sensitive to S in natural gas or ore

No reformer - lower Capital costs

High energy efficiency (87% in comparison to 70% for most efficient other DRI plant).

Hylsa claims lower overall operating costs (to be confirmed)

## **BLAST FURNACE PROCESS**

### **PROCESS BACKGROUND:**

The blast furnace process is based upon a moving bed reduction furnace which reduces iron ore with coke and limestone. Reduction is carried out at typical reduction temperatures. The process produces liquid pig iron.

### **PROCESS DESCRIPTION:**

The blast furnace process consists of weighing of the burden, charging of the blast furnace, hot product dispersal from the blast furnace and offgas cleanup system. The blast furnace is a tall shaft-type furnace with a vertical stack superimposed over a crucible-like hearth. Iron bearing materials (iron ore, sinter, pellets, mill scale, steelmaking slag, scrap, etc.), coke and flux (limestone and dolomite) are charged into the top of the shaft. A blast of heated air and also, in most cases, a gaseous, liquid or powdered fuel are introduced through openings at the bottom of the shaft just above the hearth crucible. The heated air burns the injected fuel and most of the coke charged in from the top to produce the heat required by the process and to provide reducing gas that removes oxygen from the ore. The reduced iron melts and runs down to the bottom of the hearth. The flux combines with the impurities in the ore to produce a slag which also melts and accumulates on top of the liquid iron in the hearth. The total furnace residence time is about 6 to 8 hours. The hot metal produced is sent to a steelmaking shop or a pig-casting machine. The slag goes to a water-spray granulator, a cry slag pit or a slag dump. The gas from the top of the furnace goes through the gas cleaning system, and then a portion goes to fire the hot blast stoves with the balance being used in other parts of the plant. The dust is removed from the gas in the cleaning system and goes to the sinter plant to be agglomerated for recycling back into the blast furnace.

### **PROCESS ADVANTAGES**

Proven performance  
Raw material flexibility

## TECNORED PROCESS

### PROCESS BACKGROUND:

The Tecnored process is based upon a low pressure moving bed reduction furnace which reduces pellets made out of iron ore fines with cement and coke fines. Reduction is carried out at typical reduction temperatures. The process produces liquid pig iron.

### PROCESS DESCRIPTION:

The Technored process consists of pelletizing of the iron ore fines with cement and coke fines. The pellet size is controlled for the optimum reaction in the reduction furnace. The pellets are cured and dried at 200C and fed to the top of the furnace. The furnace internal pressure is about 3.5 to 5.2 psig. The total furnace residence time is 30 to 40 minutes against 6 to 8 hours in blast furnace.

Lump coke is fed into side feeders in the furnace below the hot pellet area. Hot blast air at about 1550C is blown in through tuyeres located in the side of the furnace to provide combustion air for the coke. A small amount of furnace gas is allowed to flow through the side feeders to use for pet coke drying and preheating. Cold blast air is blown in at a higher point to promote post combustion of CO in the upper shaft. The use of coke with sulfur (pet coke) necessitates an elaborate furnace clean-up system in order to meet environmental regulations.

The pig iron produced is tapped into a ladle on a ladle car, which can tilt the ladle for deslagging. The liquid iron is desulfurized in the ladle, and slag raked into a slag pot.

### PROCESS ADVANTAGES

Low cost raw materials

Low metling costs using low cost fuels to reduce electric power and electrode cost.

High productivity and energy efficiency in the furnace

Full metallization (upto 99%)

## COREX PROCESS

### PROCESS BACKGROUND:

The Corex process is based upon a reduction shaft for iron ore reduction and a melter gasifier for the coal gasification and iron melting. Comparing the Corex process with the blast furnace, if a blast furnace is cut into half along the cohesive zone, the same reactions that take place in the upper part of the blast furnace take place in the Corex reduction shaft. Similarly, the reduced iron is melted in the melter gasifier like the region along or underneath the cohesive zone in a blast furnace.

### PROCESS DESCRIPTION:

The iron oxide feed to a Corex reduction shaft is in the form of lump ore or pellets. Non-coking coal is used in the Corex process as the strength of coke needed in the cohesive zone of the blast furnace to provide sufficient permeability to the bed is not required. All other coke functions such as fuel supply, basis for the reduction gas generation and carburization of the hot metal can be fulfilled as well by non-coking coal. Similar to the blast furnace process, the reduction gas moves in counterflow to the descending burden in the reduction shaft. Then, the reduced iron is discharged from the reduction shaft by screw conveyors and transported via feed legs into the melter gasifier. The gas containing mainly of CO and H<sub>2</sub>, which is produced by the gasification of coal with pure O<sub>2</sub> leaves the melter gasifier at temperatures between 1000 and 1050C.

Undesirable products of the coal gasification such as tar, phenols, etc. are destroyed and not released to the atmosphere. The gas is cooled to 800-850C and cleaned from dust particles. After reduction of the iron ore in the reduction shaft, the top gas is cooled and cleaned to obtain high caloric export gas. The main product, the hot metal can be further treated in either EAF or BOF or can be cast and sold as pig iron.

### PROCESS ADVANTAGES

Use of low cost non-coking coal



# **ROTARY KILN PROCESSES**

## SL/RN PROCESS

### PROCESS BACKGROUND:

The SL/RN process is a kiln based process that uses lump ore, pellets, beach sand or ilmenite ore and solid carbon to produce hot or cold DRI. The process operates at high temperature and atmospheric pressure. This is the most widely used coal based direct reduction process.

### PROCESS DESCRIPTION:

The iron oxide feed to a SL/RN kiln is in the form of lump or pellet iron ore, reductant (low-cost non-coking coal) and limestone or dolomite (to absorb sulfur from high sulfur reductant). The rotary kiln is inclined downward from the feed (elevated end) to the discharge end. The discharge end is provided with a burner to be used for startup or to inject reductant. Typical retention times are around 10 hours. The kiln is divided into two process regions; preheat and reduction. In the preheat section, the charge is heated to about 1000C, free moisture is first driven off and reduction to FeO occurs. As the reductant is heated, volatile components are released and part of the gases are burned in the freeboard above the bed by the air injected into the kiln. This combustion transfers heat to the charge directly by radiation, and also by conductive heat transfer from the kiln lining, which is first exposed to the flame and heated before contacting the charge. The charge then passes into the metallization or reduction zone where the temperature is maintained at about 1000C to 1100C, depending upon the type of charge used. The final metallization is about 93% and carbon content about 0.1 to 0.2%. The product DRI can be discharged hot or cold.

The combustion off-gases from the kiln contain char particles and combustible gases. These are burned off in a afterburner and the offgas then passes through an evaporative cooler and an electrostatic precipitator and vented to the atmosphere.

### PROCESS ADVANTAGES

- Use of any iron bearing material
- Wide variety of reductants
- Proven DRI technology
- Economic production of DRI

# **ROTARY HEARTH PROCESSES**

## REDSMELT PROCESS

### PROCESS BACKGROUND:

The Redsmelt process is based upon a rotary hearth furnace which reduces green pellets made out of iron ore, reductant fines and binders to produce hot, metallized DRI (similar to blast furnace pig iron) that is directly charged to an electric melter or HBI. The process operates at high temperature and atmospheric pressure.

### PROCESS DESCRIPTION:

The iron oxide feed to a Redsmelt furnace is in the form of green pellets made of fine iron ore, reductant and binders. Binders are to give to the green pellets sufficient mechanical strength to support the handling shocks downstream. Pellets are screened on a roller-type screen to a size between 8 to 16 mm. Under and oversize materials are recirculated to feed the pelletizing disks. Pellets are then distributed onto the RHF in a layer up to 30 kg/m<sup>2</sup>. While travelling throughout the furnace in 12 to 18 minutes, pellets are heated up to 1200-1300C. Drying of the pellets, coal devolatilization and iron oxide reduction takes place during the heating process. The intimate contact between iron oxide and carbon at a very high temperature results in a very fast reaction rate. To prevent reoxidation of metallized iron the final zones of the furnace are operated in sub-stoichiometric atmosphere. The hot DRI product is then fed to the submerged arc furnace (SAF) for smelting into Hot metal and slag.

### PROCESS ADVANTAGES

- Iron ore fines as raw material
- Wide variety of solid reductants
- Less reduction time (12 to 18 minutes)
- Proven equipment usage

## FASTMET/ FASTMELT PROCESS

### PROCESS BACKGROUND:

The FastMet process is based upon a rotary hearth furnace which reduces briquettes made out of iron ore fines, waste iron bearing materials and pulverized coal to produce hot, metallized DRI that can be directly charged to a specially designed electric melter (FASTMELT) or HBI.

### PROCESS DESCRIPTION:

The iron oxide feed to a FastMet furnace is in the form of dried greenballs made of iron ore and coal. They are continuously fed to the RHF by means of a loss-in-weight vibrating pan feed system. After introduction, the greenballs are heated in 3 burner/ reaction zones; all fired by side-wall mounted burners. Zone 1 has three burners, Zone 2 has five burners and Zone 3 has two burners. All burners are designed for air/natural gas or oxygen enriched air/natural gas combustion. A water cooled chill plate is positioned after Zone 3 for cooling of the hot DRI product to 1000-1200C prior to discharge from the RHF. The hot DRI product can either be collected in N2 purged transfer cans, or directly fed to the electric furnace for melting. The RHF operates under a slight negative pressure, and sealed by a water seal trough.

The DRI melter is a custom design single phase AC electric arc furnace type melter that has a stationary hearth and a water cooling roof. It produces carbon containing molten iron (FASTIRON) from a charge of 100% hot DRI continuously fed from the RHF.

### PROCESS ADVANTAGES

- Iron ore fines as raw material
- Wide variety of solid reductants
- Less reduction time (6-12 minutes)
- Lower capital investment costs than NG based DR processes
- Proven equipment usage

## IRON DYNAMICS PROCESS

### PROCESS BACKGROUND:

The Iron Dynamics process is based upon a rotary hearth furnace which reduces a carbonaceous iron oxide charge to metallic iron solids that are charged to a SAF to complete the reduction and to melt and desulfurize the reduced iron. Melting the DRI also allows for a phase separation of the resulting liquid slag and iron.

### PROCESS DESCRIPTION:

The IDI process is composed of five process areas: raw material receiving, ore and reductant (coal) grinding and preparation, pelletizing, rotary hearth reduction and submerged arc furnace smelting. After the ore is received, it is dried to the moisture content less than 0.5% using offgas from the rotary hearth furnace. Ore is also beneficiated using magnetic separators and screens to reduce the amount of silica. It is then ground to 50% minus 200 mesh. Coal is conveyed to a coal/fluxstone pulverizer for sizing to 80% minus 200 mesh. Ground ore and coal are intensively mixed with binders and water in a mixer and fed onto disc pelletizers. Wet pellets are dried to less than 1% moisture and preheated to 150C in a circular grate dryer. The pellet charger receives the dried green balls and layers them onto the furnace hearth in 1 1/2 - 1 in. thick layers. The natural gas fired rotary hearth furnace has eight reaction zones. Temperature, gas flow and gas composition are controlled to provide the required conditions in each zone to properly heat, reduce and protect the pellets. The DRI at the discharge of the furnace has about 85% metallization. An additive facility introduces flux, coke, silica or other materials to the DRI transport bottles to control slag chemistry in the submerged arc furnace. The offgas system removes heat, dust, sulfur dioxide and nitrous dioxides from the flue gas. An afterburner combusts any remaining CO in the offgas water-cooled duct. The gas is cooled and the Nox removed in the primary cooler. Offgas is used to preheat combustion air and supply heat to the ore, coal and pellet dryers. After the pellet dryer, the gas is filtered and Sox removed prior to discharge from the stack. The DRI and the additives fall into the slag layer of the Submerged Arc Furnace by gravity where smelting takes place. Average metallization here is about 95.8%. Slag is tapped from the furnace into slag pots and transferred to a slag processing facility.

### PROCESS ADVANTAGES

- Iron ore fines as raw material
- Wide variety of solid reductants
- Less reduction time
- Lower capital investment costs than NG based DR processes
- Proven equipment usage

## INMETCO PROCESS

### PROCESS BACKGROUND:

The InMetCo process is based upon a rotary hearth furnace which reduces briquettes made out of iron ore fines, waste iron bearing materials and pulverized coal to produce hot, metallized DRI that can be directly charged to an electric melter or HBI. The process operates at high temperature and atmospheric pressure.

### PROCESS DESCRIPTION:

The iron oxide feed to a Inmetco furnace is in the form of disk pellets made of fine iron ore under 250um in size and fine coal or coke or char with less than 25% volatiles. They are distributed onto the RHF in a layer about 3 pellets deep by means of a pivoting belt conveyor. The process uses a quick acting binder which allows the pellets to be transported to the hearth without significant degradation. The hearth rotates continuously and the pellets are heated by burners located around the periphery of the hearth to 1250C to 1300C during a period of 10 to 15 minutes. The burners are arranged in groups, and form heating and reduction zones. The heating zone makes about 1/3 of the hearth area and the reduction zone about 2/3. The burners are located on the inner and outer circumference

The hot DRI product can either be collected in N<sub>2</sub> purged transfer cans, or directly fed to the electric furnace for melting. The RHF operates under a slight negative pressure, and sealed by a water seal trough.

### PROCESS ADVANTAGES

- Iron ore fines as raw material
- Wide variety of solid reductants
- Less reduction time (6-12 minutes)
- Proven equipment usage

## MAUMEE PROCESS

### PROCESS BACKGROUND:

The Maumee process is based upon a rotary hearth furnace which reduces green pellets made out of waste iron oxide materials and pulverized non-metallurgical coal to produce hot, metallized (>90%) DRI. The process operates at high temperature and atmospheric pressure, features a short residence time and can be used to recycle revert materials.

### PROCESS DESCRIPTION:

The iron oxide feed to a Maumee furnace is in the form of green pellets/ briquettes made of fine iron oxides and coal or coke that eliminates the pre-drying of the pellets. Under ideal high-temperature (2350°F) theoretical conditions, iron oxide will react with fixed carbon to form metallic iron in the briquette with the release of CO<sub>2</sub>. The theoretical ratio of fixed carbon to iron oxide is 1.5:1. Maumee process has been formulated to produce metallic iron using a carbon-to-oxide ratio of 6:1, which results in the evolution of both CO and CO<sub>2</sub> and leaves a residual carbon level of about 4%. The key to this process is controlling the CO-to-CO<sub>2</sub> ratio to minimize reoxidation, carbon consumption and furnace residence time. While travelling throughout the furnace, pellets are heated up to 2350F. Drying of the pellets, coal devolatilization and iron oxide reduction takes place during the heating process. The intimate contact between iron oxide and carbon at a very high temperature results in a very fast reaction rate. The hot DRI product can then be supplied to the steel mill by a number of different options.

### PROCESS ADVANTAGES

- Iron ore fines or waste iron units as raw material
- Wide variety of solid reductants
- Less reduction time
- Proven equipment usage



## ITmk3 PROCESS

### PROCESS BACKGROUND:

The ITmk3 process is based upon a rotary hearth furnace similar to a FASTMET furnace which reduces dried green pellets made out of iron ore, reductant fines and binders to produce hot, metallized DRI that is charged to a Melter which separates liquid metal from liquid slag in a short time. The process operates at high temperature and atmospheric pressure.

### PROCESS DESCRIPTION:

The iron oxide feed to a ITmk3 furnace is in the form of dried green pellets made of fine iron ore, reductant and binders. Binders are to give to the pellets sufficient mechanical strength to support the handling shocks downstream. Pellets are dried and screened for 17 to 19 mm greenball diameter. Undersize and oversize materials are recirculated to feed the pelletizing disks. Pellets are then distributed onto the RHF. While travelling throughout the furnace, pellets are heated up to 1350C. Drying of the pellets, coal devolatilization and iron oxide reduction takes place during the heating process. The intimate contact between iron oxide and carbon at a very high temperature results in a very fast reaction rate. Heating of the gangue and ash components also occurs and leads to softening and subsequent initiation of slag droplet coalescence. Often a hollow, highly metallized iron shell is formed, and at the bottom of the hollow is a bead of melted slag. The hot product is then fed to the Melter for complete separation of Hot metal or the cold iron shots (iron nuggets) from slag. Further heating in the melter results in the formation of molten iron droplets, collapse of the iron shell structure followed by coalescence of iron droplets into a nugget of molten iron which is completely separated from the slag.

### PROCESS ADVANTAGES

- Iron ore fines as raw material
- Wide variety of solid reductants
- Less reduction time
- Complete separation of hot metal from slag

# **FLUIDIZED BED PROCESSES**

## FINMET PROCESS

### PROCESS BACKGROUND:

The Finmet process is a multiple fluidized bed process which utilizes a H<sub>2</sub> rich reducing gas produced by steam reforming. Reduction is carried out at intermediate reduction temperatures, but at a higher operating pressure than most DR processes. The process produces hot briquetted iron, HBI.

### PROCESS DESCRIPTION:

The iron oxide feed to the Finmet process is in the form of iron fines under 12 mm in size. The fines are first dried to 0.2% moisture in a fluid bed drier at about 100C and stored in a hopper close to the reactors. In the first reactor, the oxide fines are preheated to about 550C. Then they pass through the other reducing reactors in series, where they are heated and reduced by the reducing gas. The reactor system operates at high pressure, about 11-13 bars gauge, in order to increase the productivity.

The fresh reducing gas required for the process is produced in a steam reformer with a steam to natural gas ratio of 3 to 4. The reformed gas consisting of CO and H<sub>2</sub> passes through a waste heat boiler to produce steam required for the reforming reaction. The reducing gas entering the bottommost reactor is distributed by the grid, passes through the fluid bed where reduction occurs, then exits the reactor via the cyclones, located inside the reactor vessel. Reduction temperatures range from 550C in the top reactor to about 800C in the lower one. The reduced ore exits the last reactor with a metallization of 93% and carbon in the range of 1 to 3%. The reduced fines are compacted to a density of 5 g/cc in a briquetting press.

### PROCESS ADVANTAGES

Direct use of low cost iron ore fines

Proven fluid bed technology

High process and plant flexibility through separate gas production, fines reduction and briquetting.

## CIRCORED PROCESS

### PROCESS BACKGROUND:

The Circored process is a two stage fluidized bed process that operates at low reducing temperatures and uses natural gas to produce reducing gas by means of reforming. The process uses ore fines that have a particle size between 1mm and 0.03mm and produces HBI.

### PROCESS DESCRIPTION:

The iron ore fines are first dried and heated to about 800C in a fluid bed preheater system. The dried fines are then charged to a circulating fluidized bed (CFB). The heat required is generated by the combustion of natural gas and air that is introduced into the CFB. The fines are reduced to about 70% metallization in CFB. The process reactions are endothermic and the required energy is introduced in the form of preheated iron ore fines and process gases. The pressure in the CFB is about 4 bars and the reaction temperature is about 630C. This temperature is lower than that used for other reduction processes, and hence avoids the sticking problems that occur with high temperature fines-based processes. The fluidizing gas in the CFB is a mixture of heated process gas which enters the lower part of the CFB, and the off-gas from the second stage conventional fluidized bed reactor, Stage II Reactor, FB. The retention time in the CFB is relatively short, of the order of 15 to 20 minutes.

A portion of the partially metallized fines are withdrawn from CFB and enter the FB reactor. The FB reactor is compartmentalized into several sections, and has gas velocities in the range of 0.5 to 0.6 m/s. The fines reach a final metallization of 92 to 93% in the FB reactor. The off-gas leaving the top of the FB passes on to the CFB. The product leaves the FB reactor at about 630C, is then heated to about 680C, and briquetted.

### PROCESS ADVANTAGES

- Ability to process directly low cost fine ore
- Excellent heat and mass transfer conditions in CFB
- Low investment costs
- Low operating cost

## CIRCOFER PROCESS

### PROCESS BACKGROUND:

The Circofer process is a two stage fluidized bed process that uses iron ore fines and a solid carbon source such as coal to produce reducing gas. Reduction is carried out at high reduction temperatures. The process produces hot briquetted iron, HBI.

### PROCESS DESCRIPTION:

The iron oxide feed to the Circofer process is in the form of iron fines between 1mm and 0.03mm in size. The coal to be used as the energy source and reductant must have an ash softening temperature above 1500C due to operating temperature of the gasifying process. The fines, lime and char are first preheated by the hot exhaust gases. These then enter the gasifier, where O<sub>2</sub> is injected and coal is fed in from the charge hopper. The gasifier operates at about 1000C and at these conditions, the O<sub>2</sub> partially combusts the carbon contained in the coal, producing heat and a CO/CO<sub>2</sub> gas mixture. The heat produced in the gasifier heats the ore and char to process temperatures. In the CFB, the ore fines are reduced to about 70% metallization. The fluidizing gas in the CFB is a mixture of heated recycle gas which enters the lower part of the CFB, and the offgas from the second reducer (FB) which enters further up in the CFB. The fines and char are carried out of the CFB due to the high gas velocity in the reactor, are captured by the cyclone, and returned to the CFB via the gasifier. Thus a circulation pattern is set up which allows the heat to be transferred to the CFB reactor.

Reduced solids from the CFB enter the FB reactor, which is a conventional bubbling bed. In this second reduction stage, the fines reach a final metallization of 92 to 93%. The gas leaving the top of the FB passes on to the CFB. The product from the second reducer is partially cooled, the char and ash are removed by magnetic separation, and the product is briquetted and cooled.

### PROCESS ADVANTAGES

- Direct use of low cost iron ore fines
- Proven fluid bed technology
- High quality product

## IRON CARBIDE PROCESS

### PROCESS BACKGROUND:

Iron carbide ( $\text{Fe}_3\text{C}$ ) is a chemical compound of 93% iron and 7% carbon in pure form. It can be used as the only feed for BOFs and EAFs. In that role it eliminates the need for coke ovens and the blast furnace, and all the ancillary equipment for coal and lime. The Iron Carbide process is a two stage fluidized bed process that operates at a lower temperature than other DR processes. It operates at low pressures and uses steam reforming to produce the  $\text{H}_2$  which is mixed with  $\text{CH}_4$  to make the carburizing gas. It produces  $\text{Fe}_3\text{C}$  powder which contains about 6% carbon.

### PROCESS DESCRIPTION:

The iron oxide feed to the iron carbide process is in the form of iron ore fines in the range of 1mm to 0.1 mm. Iron ore fines are preheated in a series of cyclones and then pressurized to reactor pressure in lockhoppers, and fed to the reactor by a screw feeder.

The fluidized bed reactors have the upward moving stream of 600C gas composed of  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{H}_2$ ,  $\text{CH}_4$  and  $\text{H}_2\text{O}$ . The hydrogen reacts with the iron ore, combining with its oxygen to form water (the only process by-product). Carbon from the carbonaceous gases combines with the elemental iron to form iron carbide. The methane provides the gas system equilibrium. After the reactions in the fluid bed reactors, the off gases are condensed to get rid of water vapor, reconstituted with  $\text{H}_2$  and carbonaceous gases, raised to reactor working pressure to 1.8 atm, heated to 600C, and reintroduced in the windbox of the reactor.

An indication of the inherent thermal efficiency of the process is gained from the fact that the temperature of formation of iron carbide in the fluid bed reactor is only 600C as against around 1000C for reduction of iron in DRI processes and 1500C to produce hot metal in the blast furnace.

### PROCESS ADVANTAGES

- Lower operating temperature
- Lower production costs
- No storage costs as the product does not oxidise
- Steelmaking cheaper with  $\text{Fe}_3\text{C}$

# **OTHER PROCESSES**

## HISMELT PROCESS

### PROCESS BACKGROUND:

The HIsmelt process was initially developed as an air-blown, bottom-injected, refractory-lined process. But due to excessive refractory wear, the initial horizontal design was abandoned and a new Vertical smelt reduction vessel (SRV) was proposed.

### PROCESS DESCRIPTION:

In this process, the iron ore is preheated (and optionally prereduced as far as magnetite) in a lean-phase cyclone preheat system similar to that on many cement kilns. It is then injected into the SRV, along with coal and flux materials through two water-cooled solids injection lances such that the mixture is carried predominantly into the metal phase. Rapid dissolution and smelting occur in the metal and the resulting product gases (mainly hydrogen and carbon monoxide) rise under buoyancy to generate the large liquid fountain, a characteristic of HIsmelt. The result is strong mixing within the metal and slag phases with effective elimination of any significant thermal gradients.

Hot offgas from the SRV is enriched with a small quantity of natural gas, the resulting mixture being roughly equivalent to blast furnace gas. This gas is cooled to around 1000C and split into roughly equal proportions. One portion is used (hot) in the preheater, whilst the other is scrubbed and subsequently burned as fuel in the hot blast stoves.

### PROCESS ADVANTAGES

Direct smelting



## ROMELT PROCESS

### PROCESS BACKGROUND:

The Romelt process is a bath smelting technology for converting iron oxides (either virgin iron ores or iron bearing waste materials) to blast furnace – grade pig iron using non-coking grades of coal as a fuel and reductant. Liquid, granulated, or cast pig iron have the highest “value-in-use” of all scrap substitutes, as they contain no gangue, have low residuals, and a high carbon content, and hence enable the EAF to produce high quality steel grades while simultaneously increasing furnace productivity.

### PROCESS DESCRIPTION:

The iron oxide feed to a Romelt furnace can be any iron containing material, e.g. iron ore fines and concentrates, blast furnace and BOF dusts and sludges, mill scale, iron bearing slags from non-ferrous smelting operations, swarfs and turnings, iron dusts, etc. The non-coking coals of 15-20% volatile matter and approx. 8% ash have been used in past. The solid feeds (coal, iron oxides, and fluxes) are charged by gravity in the furnace. A row of lower blast tuyeres on each side of the furnace introduce oxygen to agitate the bath and gasify some coal, while upper tuyeres blow oxygen for postcombustion. The furnace operates under a slight pressure, with an induced draft fan drawing the waste gases out of the furnace and through the off-gas system. Hot metal and slag are removed periodically through separate tapholes in either end of the furnace. The hearth and lower walls of the furnace are refractory lined, and the upper walls of the furnace are made up of a series of water-cooled panels. The furnace consists of four zones: Quiescent metal zone, Quiescent slag zone, Agitated slag zone and Gas combustion zone. The bulk of the reduction process takes place in the agitated slag zone. Interaction between the metal and slag in both the agitated and quiescent zones allows partitioning of minor elements between these two phases to take place. Gases generated in the bath (predominantly CO and H<sub>2</sub>, with some N<sub>2</sub>) enter the combustion zone where they react with the oxygen from the upper blast, liberating energy.

### PROCESS ADVANTAGES

Wide variety of raw material  
Solid waste disposal

## **DIOS PROCESS**

### **PROCESS BACKGROUND:**

The Dios process is a bath smelting process, intensively investigated in Japan. For testing program, 100t smelters are constructed from remodelled BOF converters. Successful operational procedures have been established and an output rate of 40t/hr of hot metal is reported.

### **PROCESS DESCRIPTION:**

Lump iron ore, coal and fluxes are charged from overhead storage hoppers, and ore and coal fines have been injected into the smelter through tuyeres. The oxygen required is introduced through the BOF top lance and a side tuyere provides oxygen for post-combustion. Dios also introduces a prereduction operation which reuses its own energy. It is claimed that the high thermal efficiency has the potential for using less expensive coal and lower consumption compared with BF route.

### **PROCESS ADVANTAGES**

Direct smelting process

## **AISI PROCESS**

### **PROCESS BACKGROUND:**

The AISI direct steelmaking project was a collaborative research programme heavily supported by the US DOE, by the Steel industry and by academic institutions. But now it has been discontinued largely. Hoogovens has continued some work in this area as a source of semi-reduced feedstock for their other project, the cyclone converter furnace.

### **PROCESS DESCRIPTION:**

The AISI process directly uses fine ores and coals to produce molten iron in a two stage process. In the first stage, ore is prereduced and melted in a melting cyclone. Directly connected to the melting cyclone is a converter type vessel where prereduced and melted ore undergoes final reduction. Post-combustion of gases takes place which improves energy efficiency, and the waste gases are used for prereduction of the pellets. A vertical smelter was used initially, but a change to a horizontal reactor has been made which is expected to improve productivity and flexibility.

### **PROCESS ADVANTAGES**

Direct smelting process

## GRIDSMELTER PROCESS

### PROCESS BACKGROUND:

The Gridsmelter process is based upon a melter gasifier which melts efficiently prereduced fine ore (60% to 80%) with some coke and coal in a grid smelter. Reduction is carried out at typical reduction temperatures. The process produces liquid pig iron.

### PROCESS DESCRIPTION:

The Gridsmelter process consists of a melter gasifier for using iron containing fines as feed stock. It is a pressure vessel with internal refractory lining of walls. The high temperature wall area and roof, where fine coal, natural gas or oil burns with preheated air or oxygen are water cooled. The grid that supports a coke/refractory filter bed is also water cooled. The region above the grid (high temperature zone) is very similar to the raceway of a Blast furnace. In this high temperature zone, the final reduction and liquification take place. The liquified materials pass through the filter bed in cocurrent with the gases. FeO droplets formed are reduced, carburized and separated from the leaving gases, falling down into the furnace hearth. The furnace hearth contains liquid pig iron, slag and a bubbling fluidized coal/coke bed. The offgas leaves the vessel in the middle of the vessel height. The gas is hot cleaned by cyclone and used for prereduction and preheating of the feedstock and blast preheating.

### PROCESS ADVANTAGES

Wide variety of raw materials like sponge iron, iron ore fines, mill scale, etc.  
Takes advantage of 'sticking effect'

## COMET PROCESS

### PROCESS BACKGROUND:

The Comet process, developed by the Centre de Recherches Metallurgiques (CRM), is a coal-based system that produces sponge iron from ore fines and limestone in a rotary hearth furnace.<sup>7</sup> A laboratory, 100-kg/hr installation was brought on-stream in Nov. 1996. (Cockerill Sambre, Profil Arbed, Sidmar and Hoogovens have acquired the CRM license for the process.) Based on the successful results obtained, a pilot 1.5-tonne/hour plant has been built at Sidmar, Ghent, Belgium. Metallization results confirm those obtained from the laboratory unit. Productivity, cost, price, energy consumption and environmental impact are being established.

### PROCESS DESCRIPTION:

### PROCESS ADVANTAGES

Direct use of low cost iron ore fines

Low cost reductant

## FINEX PROCESS

### PROCESS BACKGROUND:

The FINEX process produces liquid iron (hot metal) using fine iron ore and non-coking coal directly without any pre-treatment process for raw materials and fuel such as sintering process for raw materials and coking process for coal in the blast furnace ironmaking process.

### PROCESS DESCRIPTION:

**FINEX Development Project in POSCO in Sanghoon Joo RIST, Republic of Korea** The detailed objectives are as follows:

Finex, a coal-based smelting reduction process, continues to be jointly developed by Posco, RIST and Voest-Alpine. This process is reported to be a more advanced smelting reduction technology than Corex. A 150-tonne/day pilot plant is under construction at the Posco Pohang Works based on the success achieved with a smaller 15-tonne/day unit: completion is scheduled for March 1999. It is reported that advantages include the use of fine ore and noncoking coal together with lower construction costs, reduced emissions and lower manpower and production costs than the Corex process.

### PROCESS ADVANTAGES:

- Direct use of ore fines (-8 mm) without sintering
- Direct use of non-coking coal without the coke oven for ironmaking
- Reduced hot metal production cost
- An environment-friendly ironmaking process
- Operational flexibility in ironmaking process.

Contact : Ernst Worrell

## PLASMA PROCESS

### PROCESS BACKGROUND:

In plasma smelting for direct reduction, gases and solids are passed through an arc, much like a welding arc, and are heated. This electric heating replaces oxygen in conventional systems that use oxy-fuel burners.

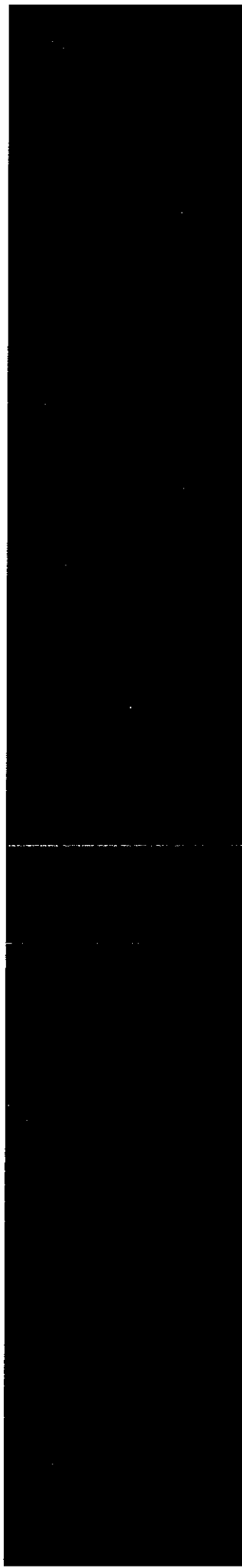
The Plasmasmelt process produces molten iron from prereduced iron ore. A plasma torch consisting of a pair of tubular, water-cooled copper electrodes discharges an electric arc which is magnetically rotated at very high speeds. The electrodes are spaced closely together and during operation, a process gas is injected through the narrow gap between the electrodes. The arc current can be varied independent of gas flow rate and thus, process temperatures can be controlled.

### PROCESS DESCRIPTION:

In this process, the shaft is completely filled with coke. The reactions take place in the shaft furnace with tuyeres spaced symmetrically around the lower part of the furnace. Plasma generators and equipment for injection of metal oxides mixed with slagforming material and possibly reductants are attached to the tuyeres. In front of each tuyere a cavity is formed inside the coke column where reduction and smelting take place. At regular intervals the produced slag and metal are tapped from the bottom of the shaft furnace. During iron ore smelting, the off-gas from the furnace, consisting mainly of carbon-monoxide and hydrogen, are used for prereduction of the ore.

In case the ore contains metals with high vapor pressures, for example zinc and lead, these metals leave the furnace with the off-gas which is then passed through a condenser where the metals are recovered from the gas.

### PROCESS ADVANTAGES:

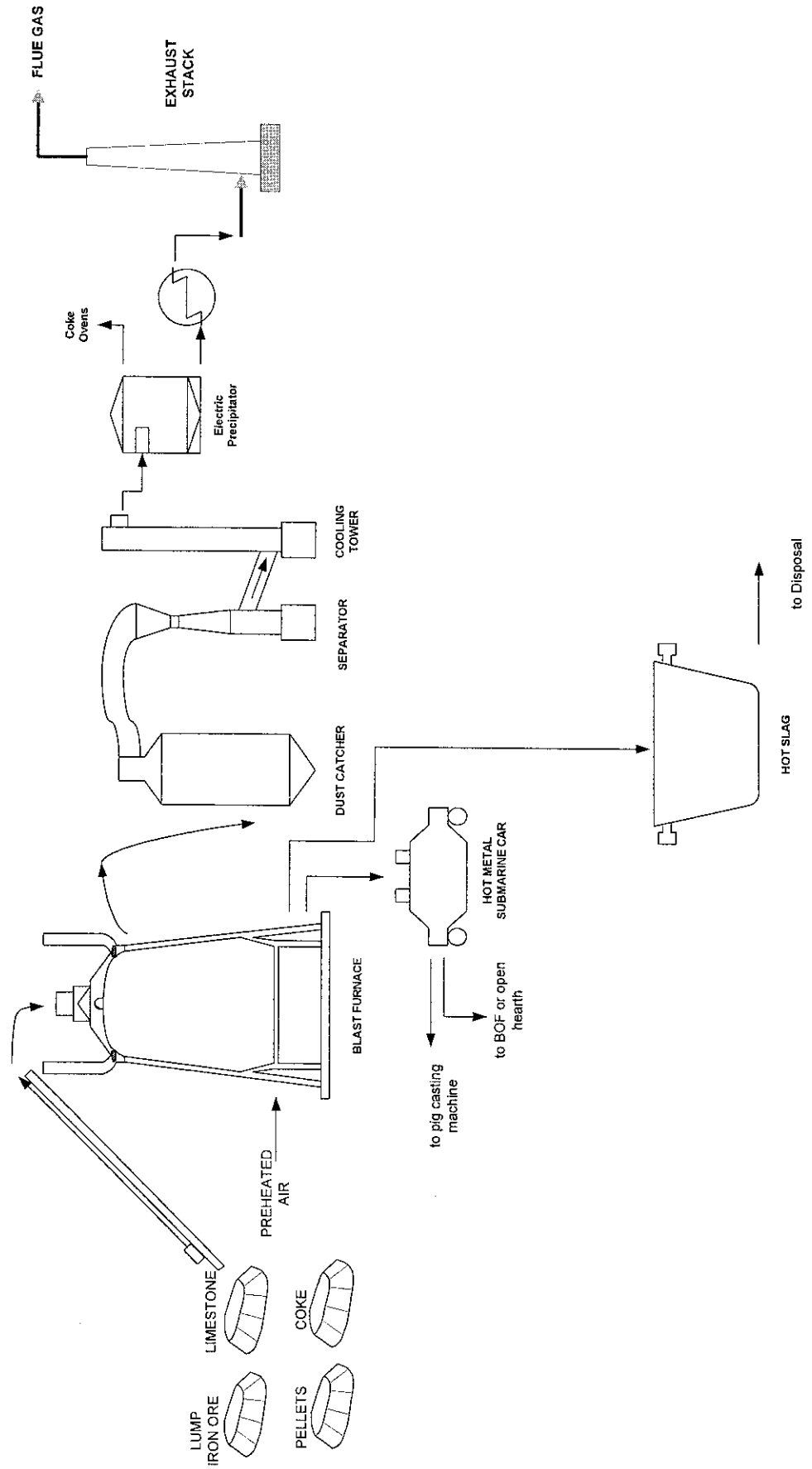




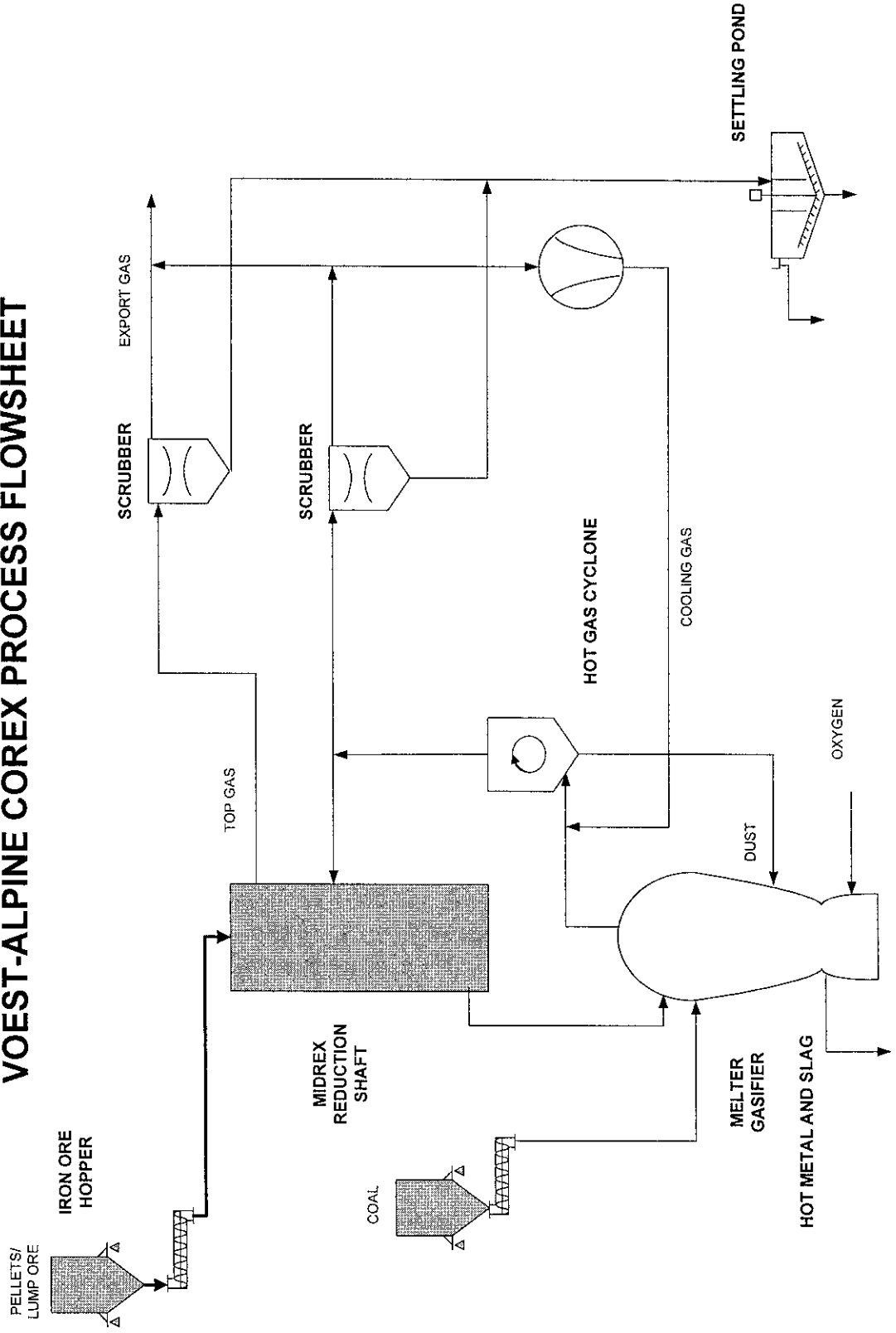
**APPENDIX A-2:**  
**IRONMAKING PROCESS FLOW DIAGRAMS**

# **SHAFT FURNACE PROCESSES**

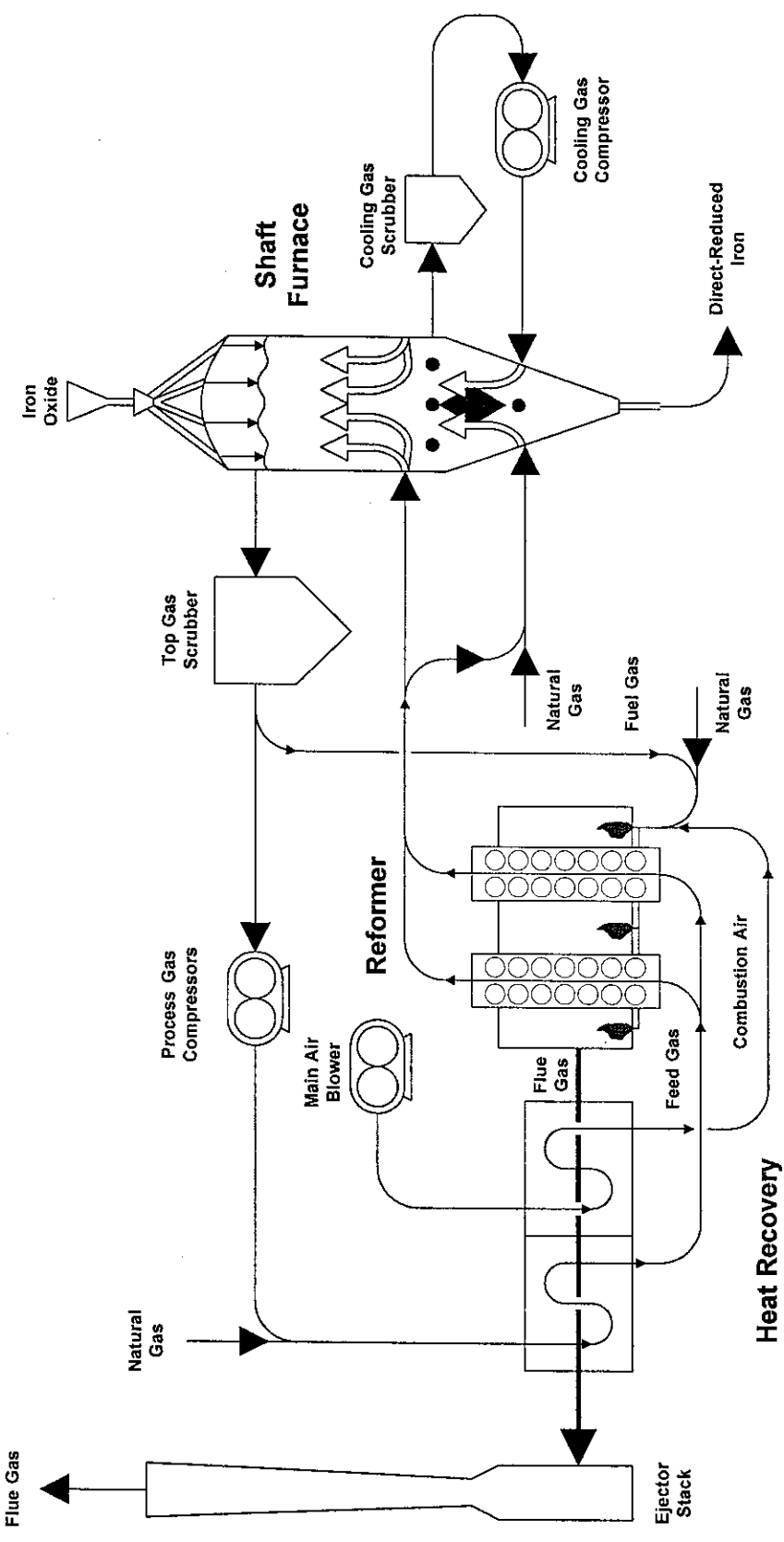
# BLAST FURNACE PLANT FLOWSHEET



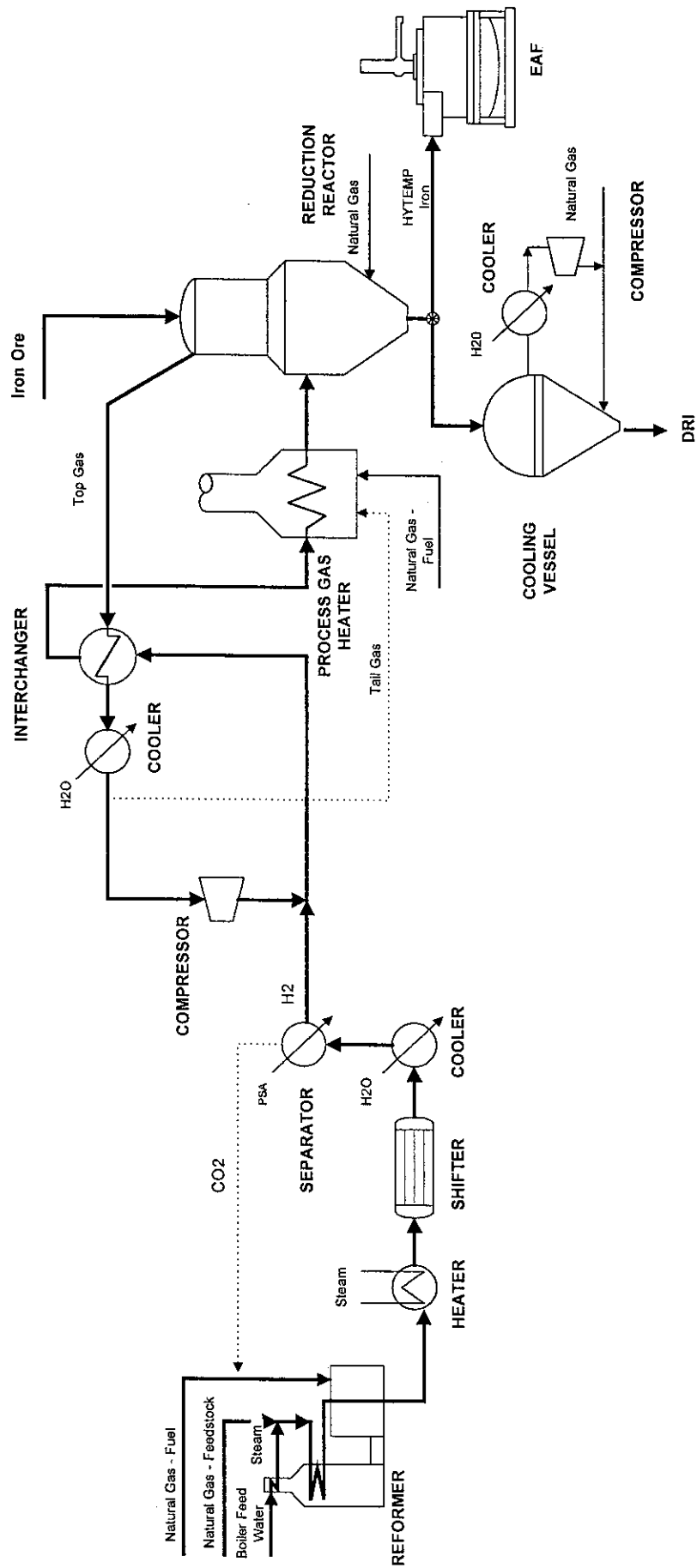
# VOEST-ALPINE COREX PROCESS FLOWSHEET



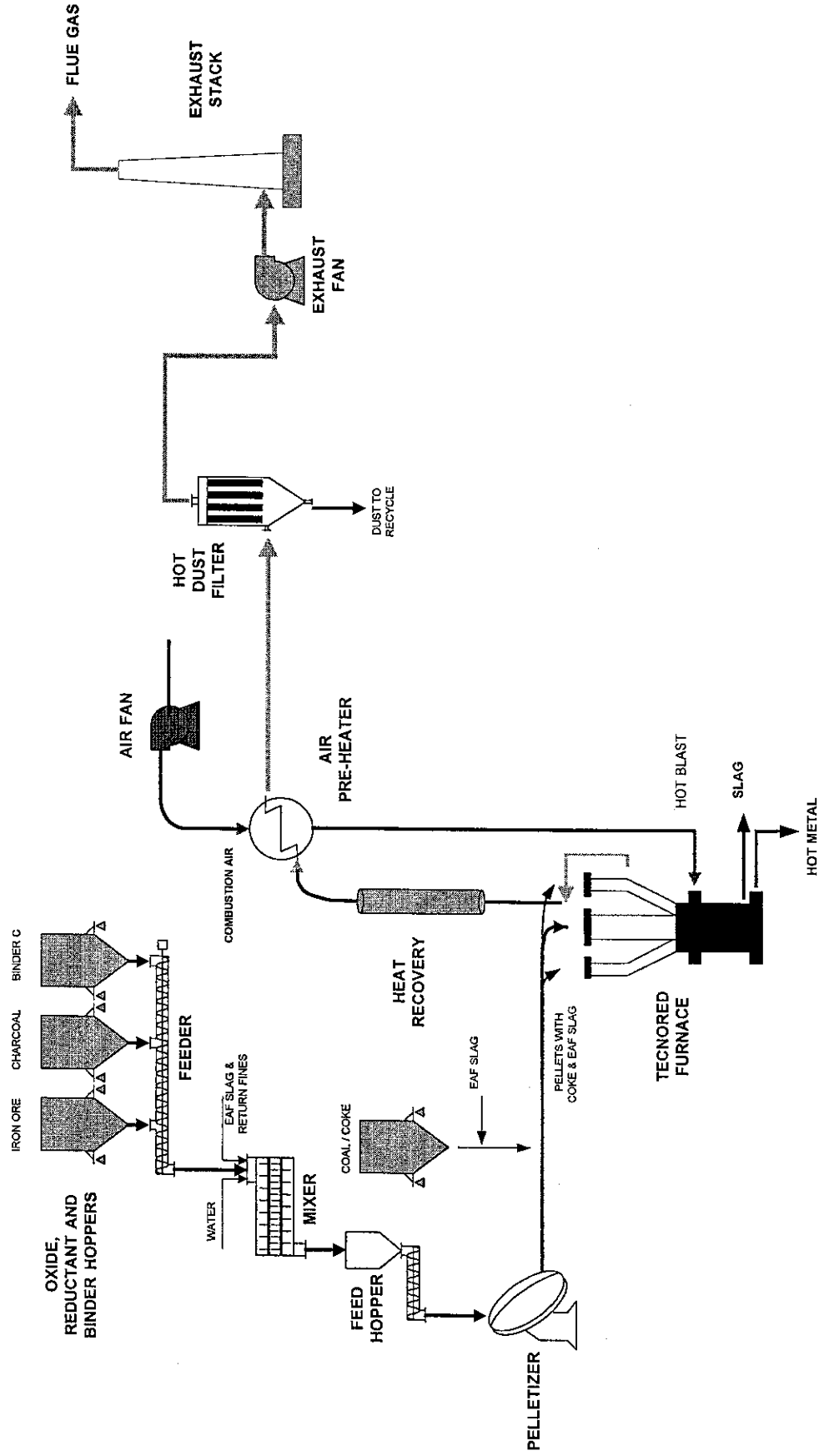
# MIDREX PROCESS FLOWSHEET



# HYLSA PROCESS FLOWSHEET



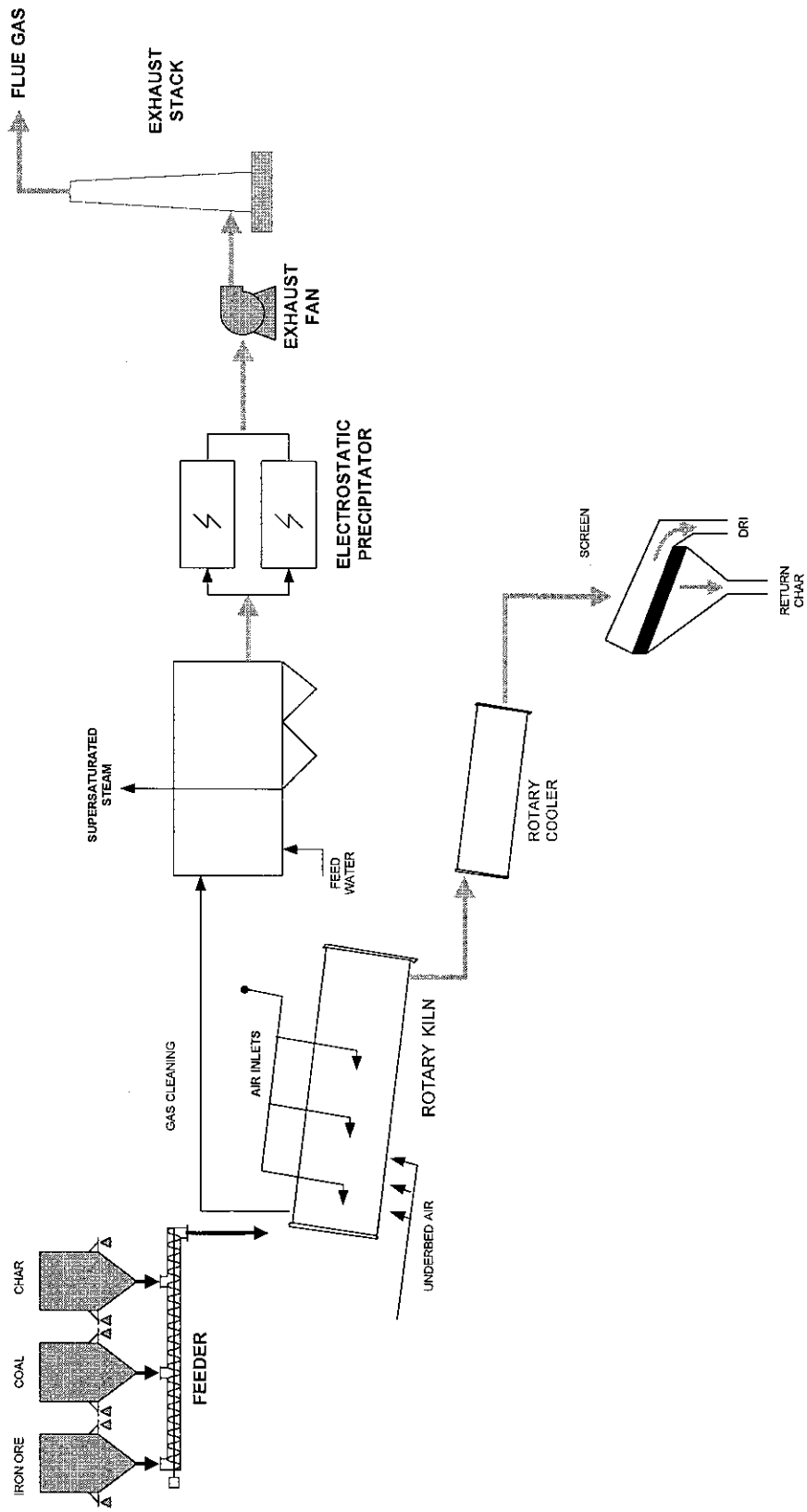
# TECNORED PROCESS FLOWSHEET



# **ROTARY KILN PROCESSES**

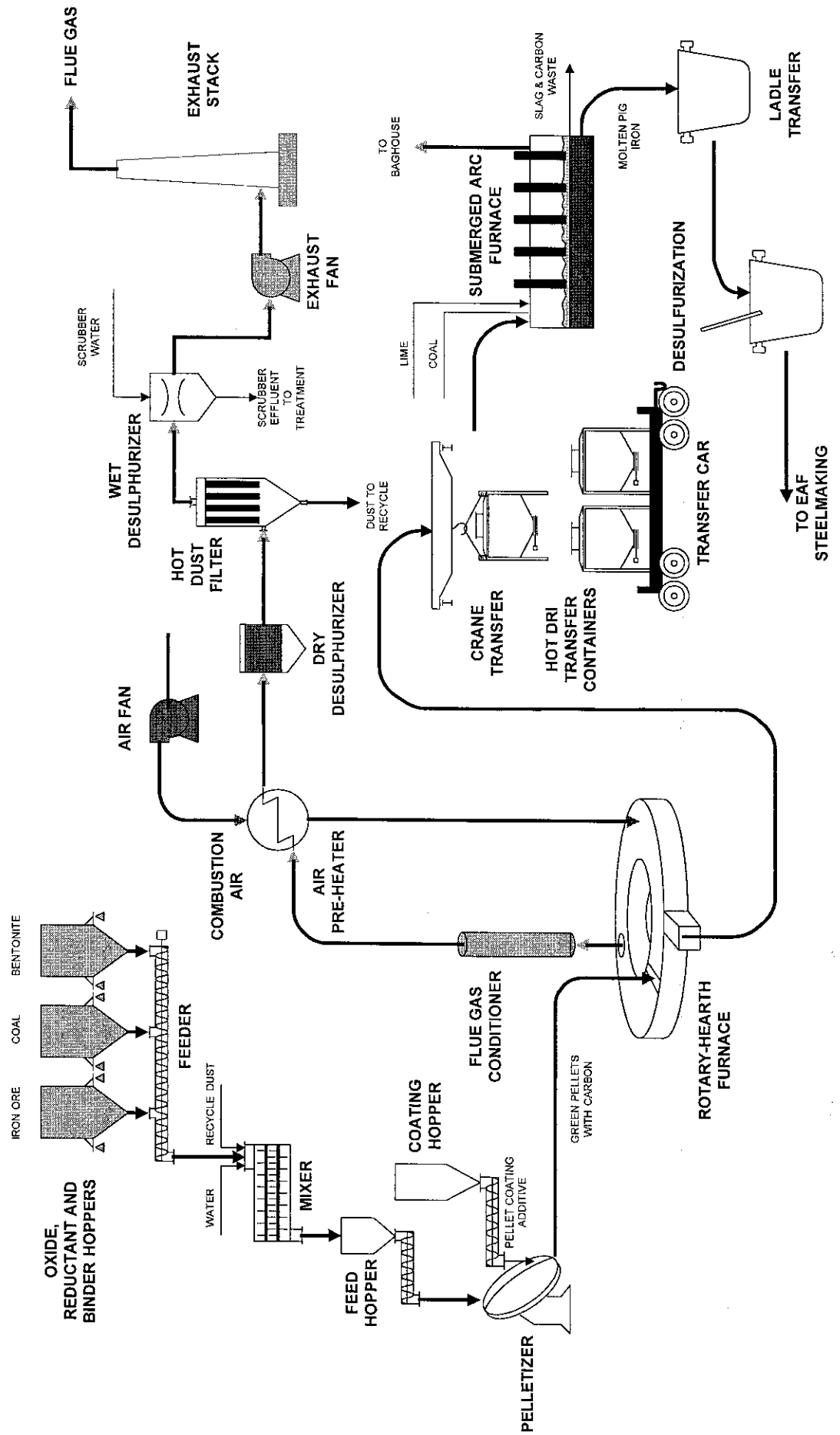


# SL/RN PROCESS FLOWSHEET

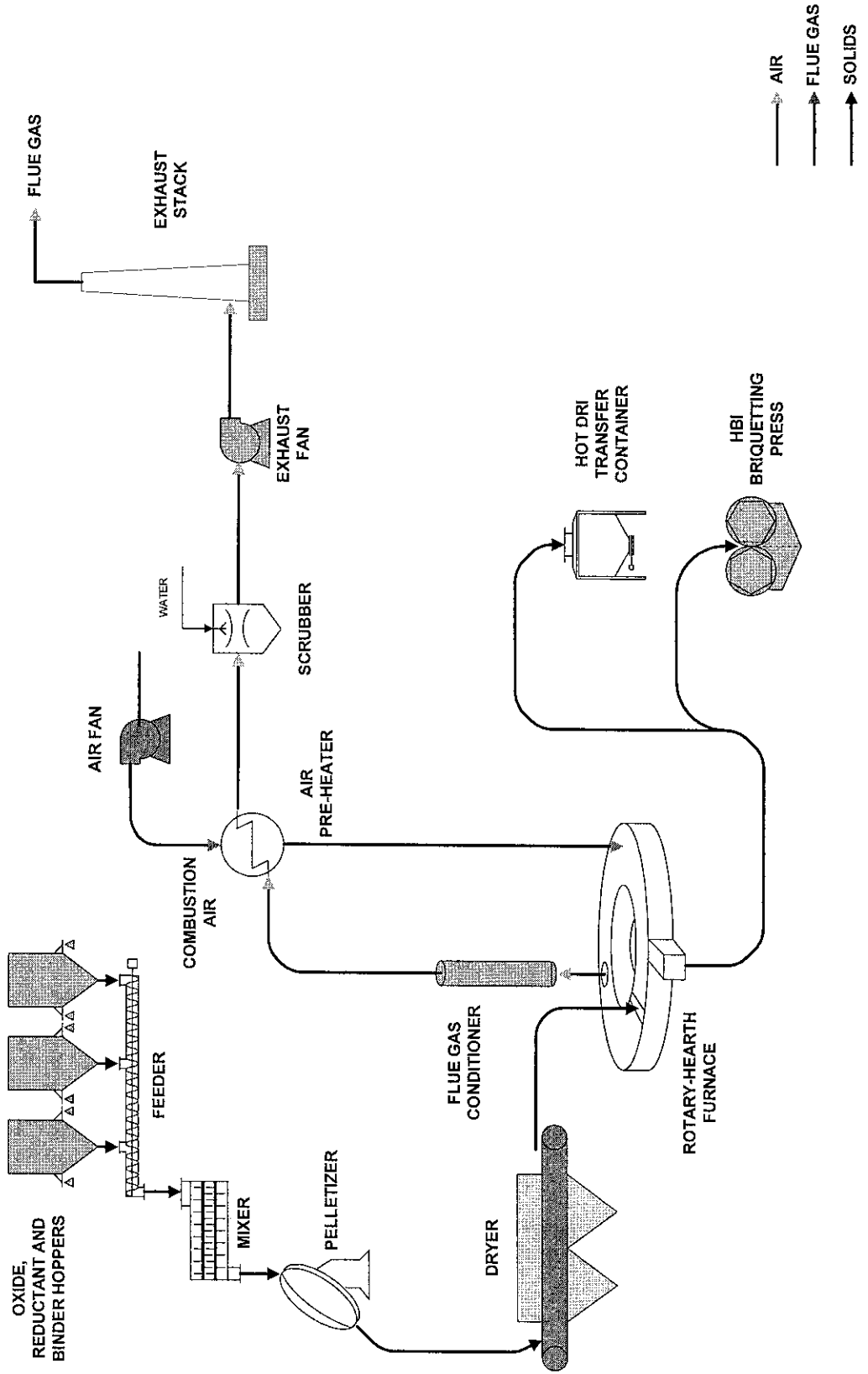


# **ROTARY HEARTH PROCESSES**

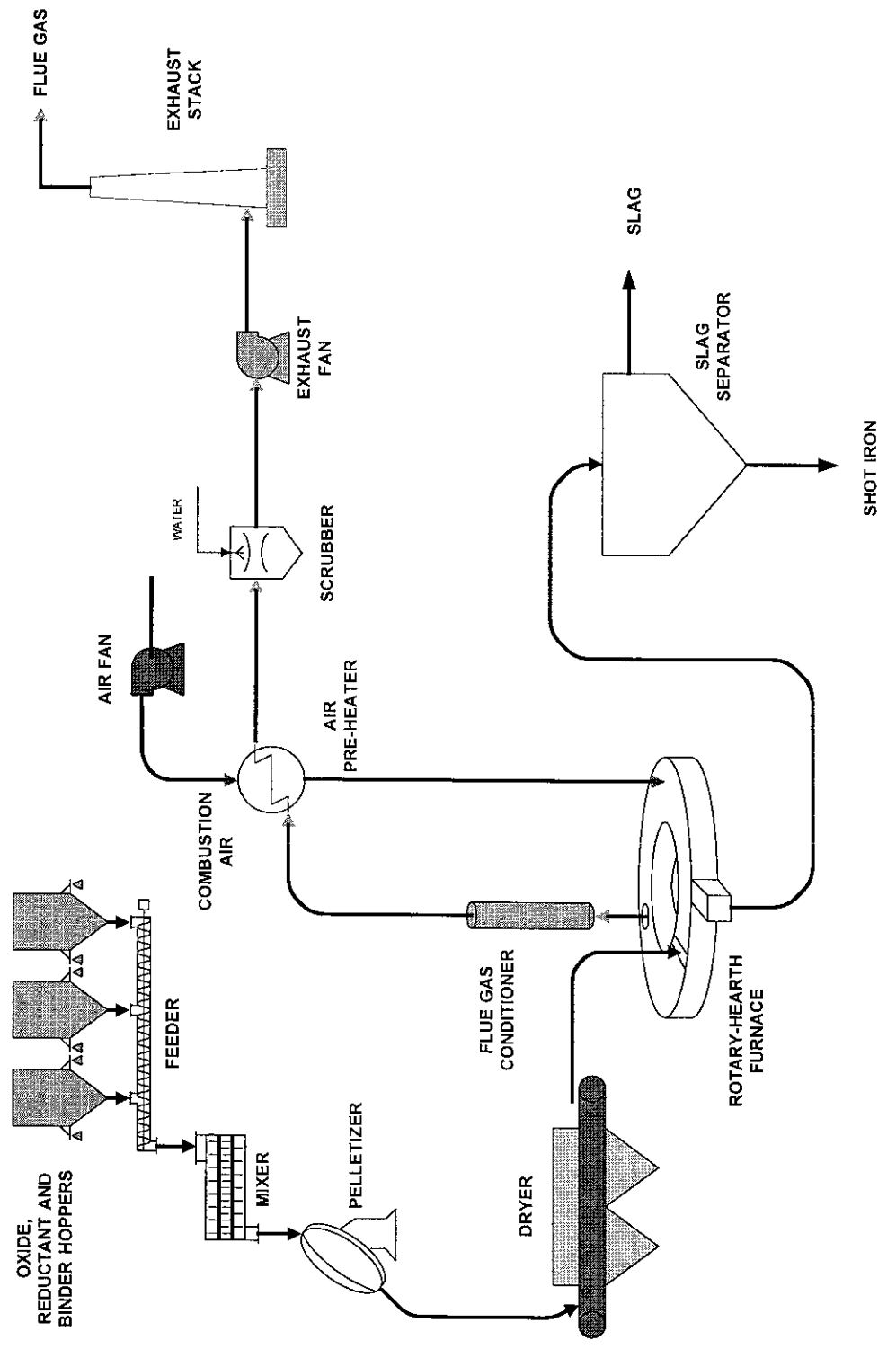
# MANNESMANN DEMAG REDSMELT PROCESS FLOWSHEET



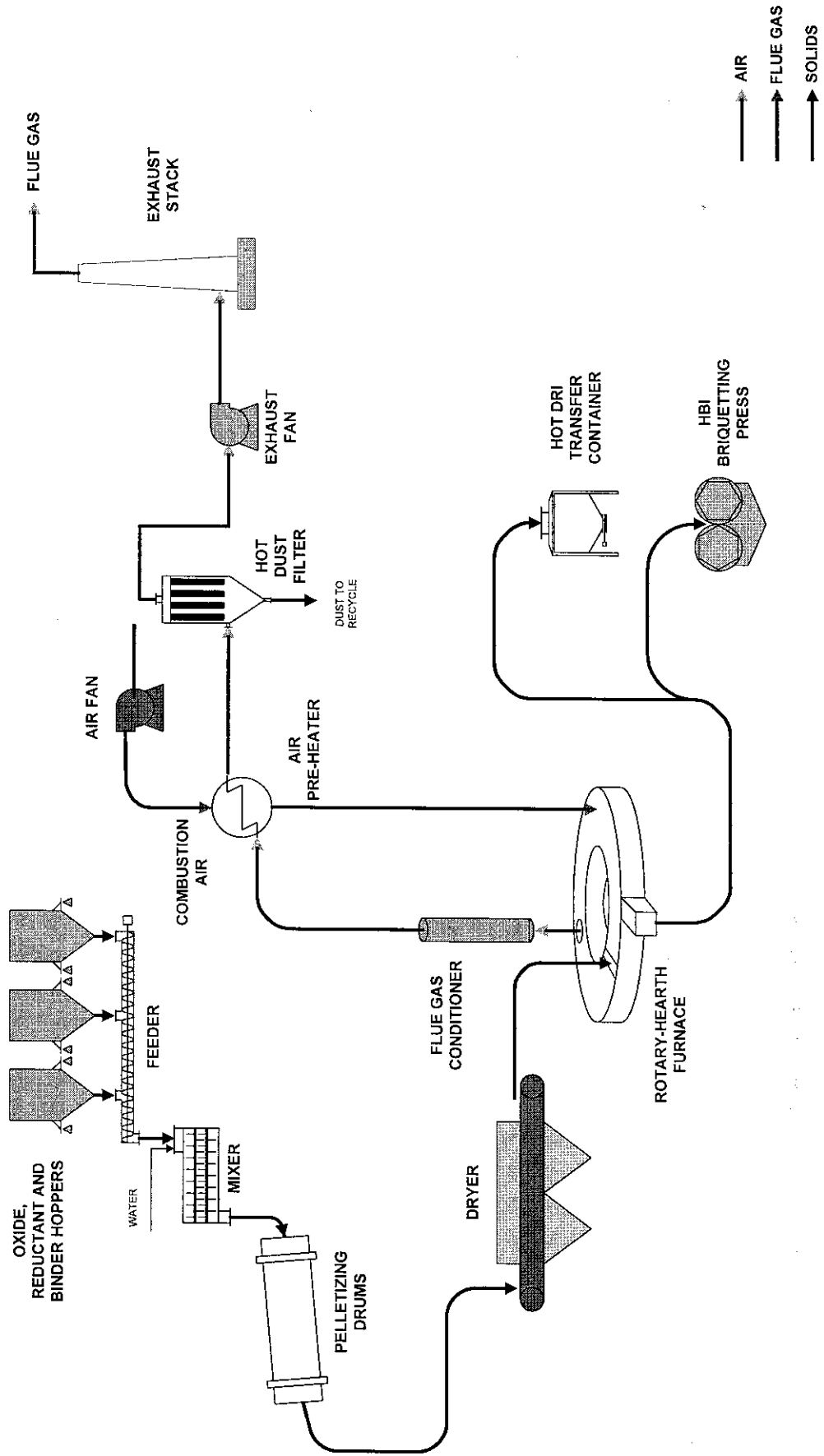
# FASTMET PROCESS FLOWSHEET



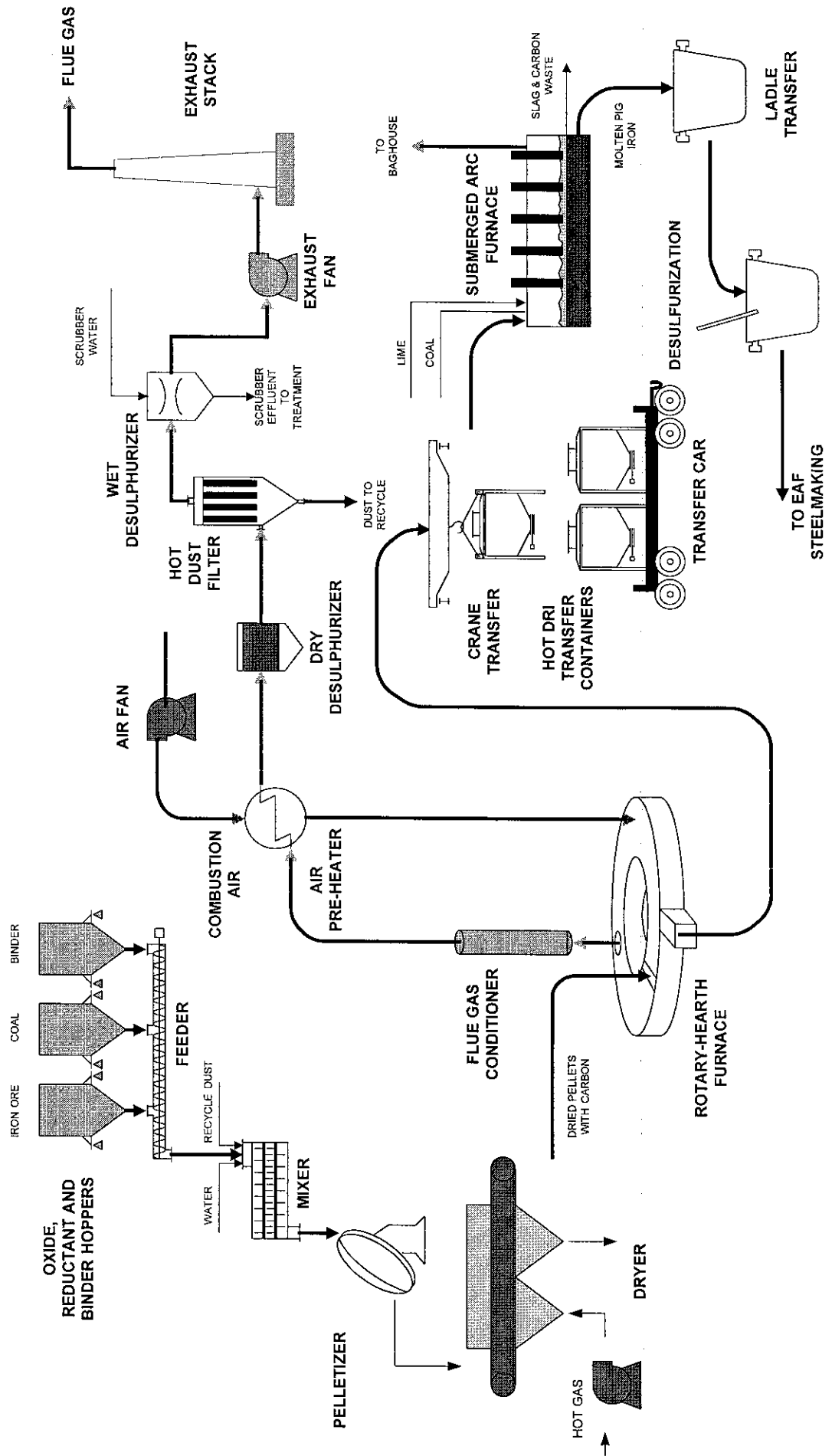
# ITmk3 PROCESS FLOWSHEET



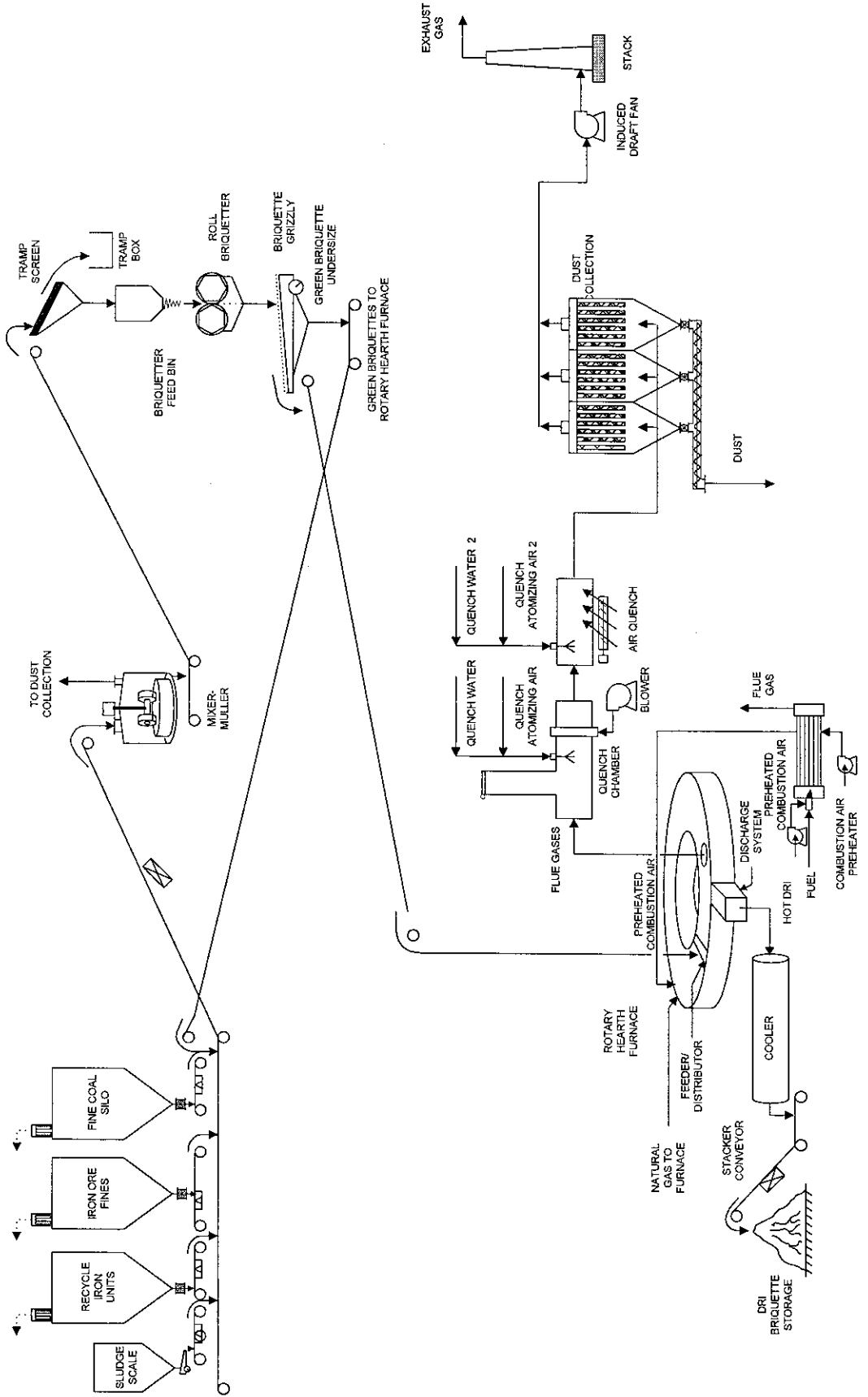
# INMETCO PROCESS FLOWSHEET



# IRON DYNAMICS PROCESS FLOWSHEET



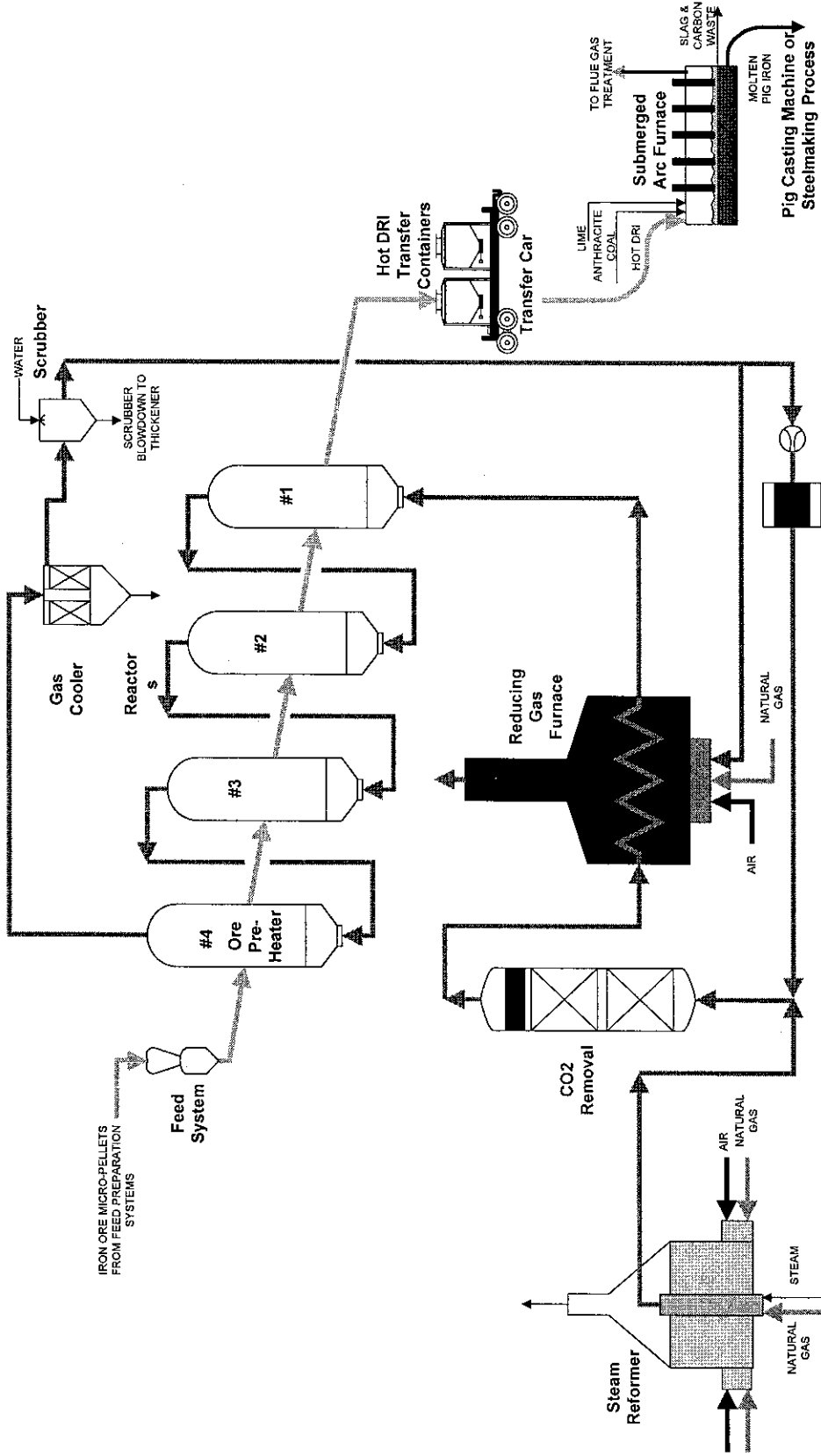
# MAUMEE PROCESS FLOWSHEET



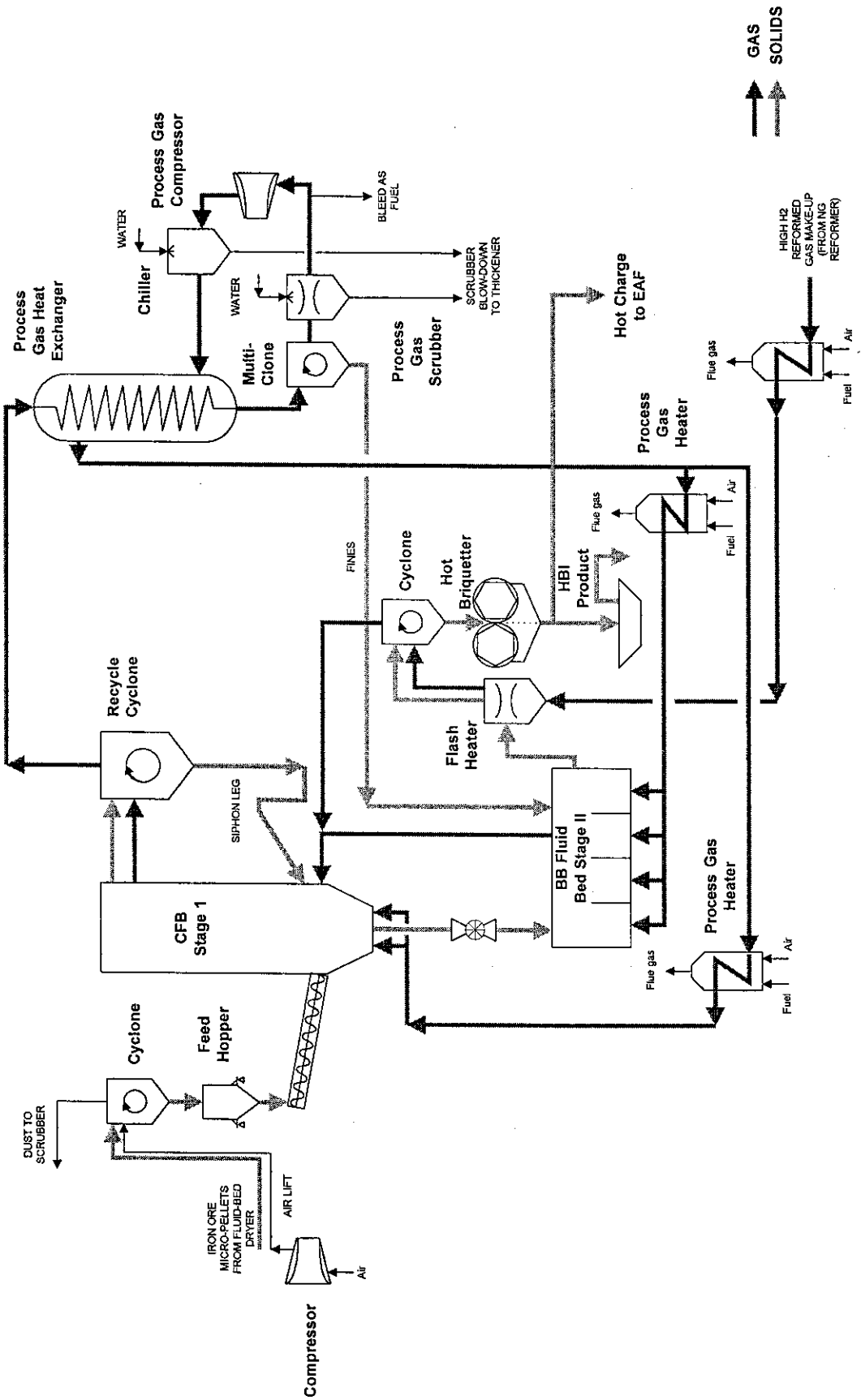


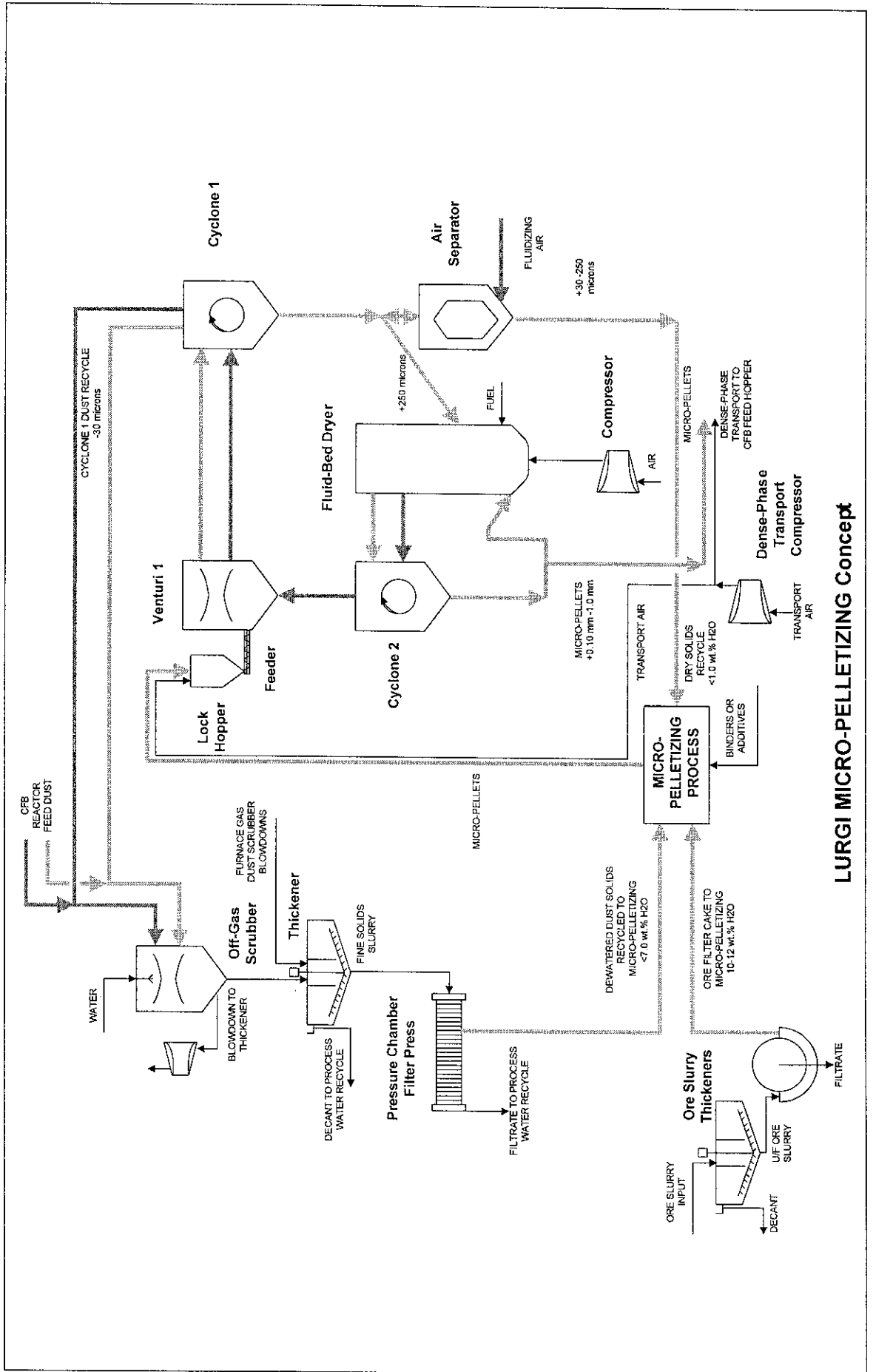
# **FLUIDIZED BED PROCESSES**

# VOEST-ALPINE FINMET PROCESS FLOWSHEET



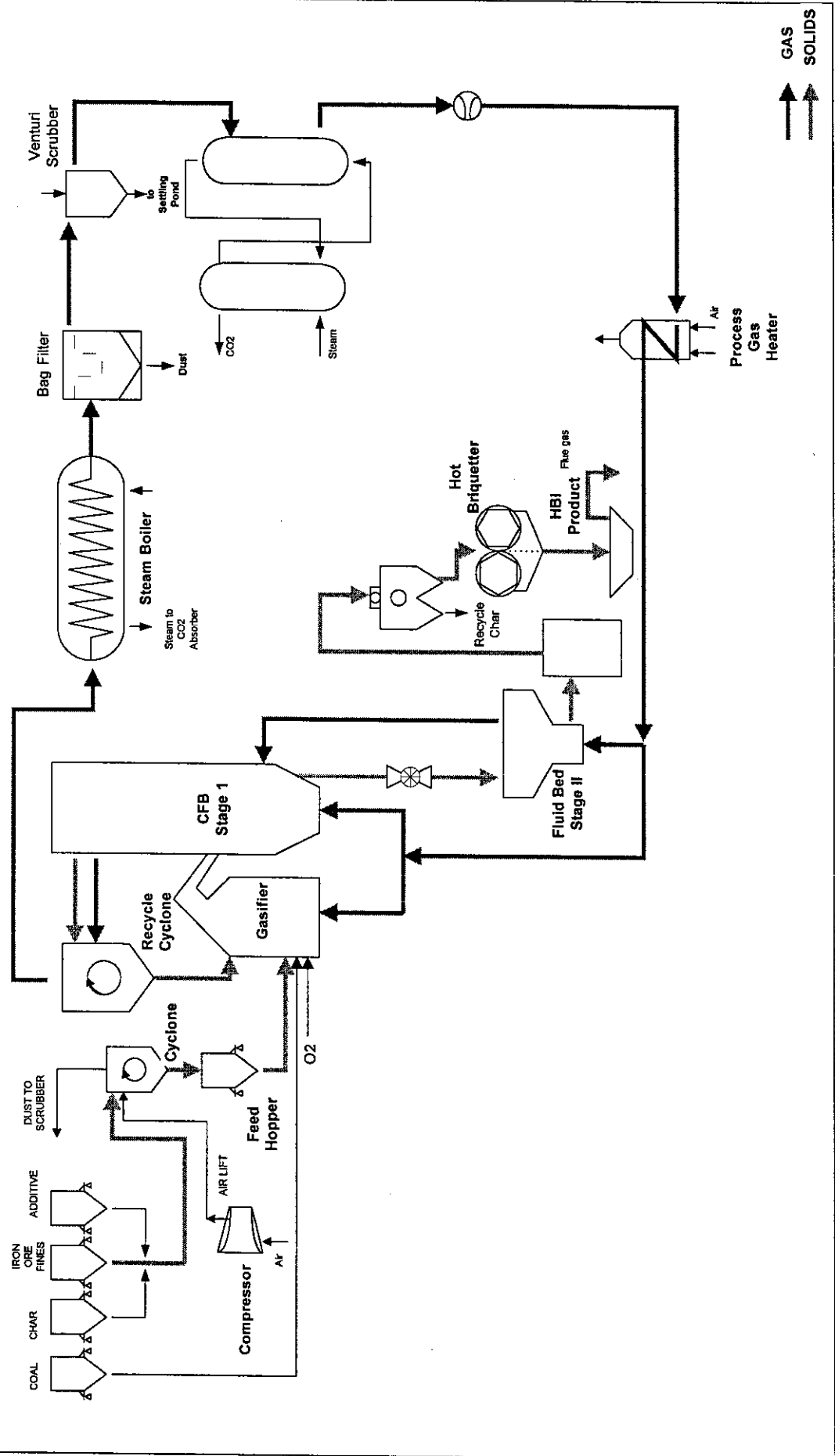
# LURGI CIRCORED PROCESS FLOWSHEET

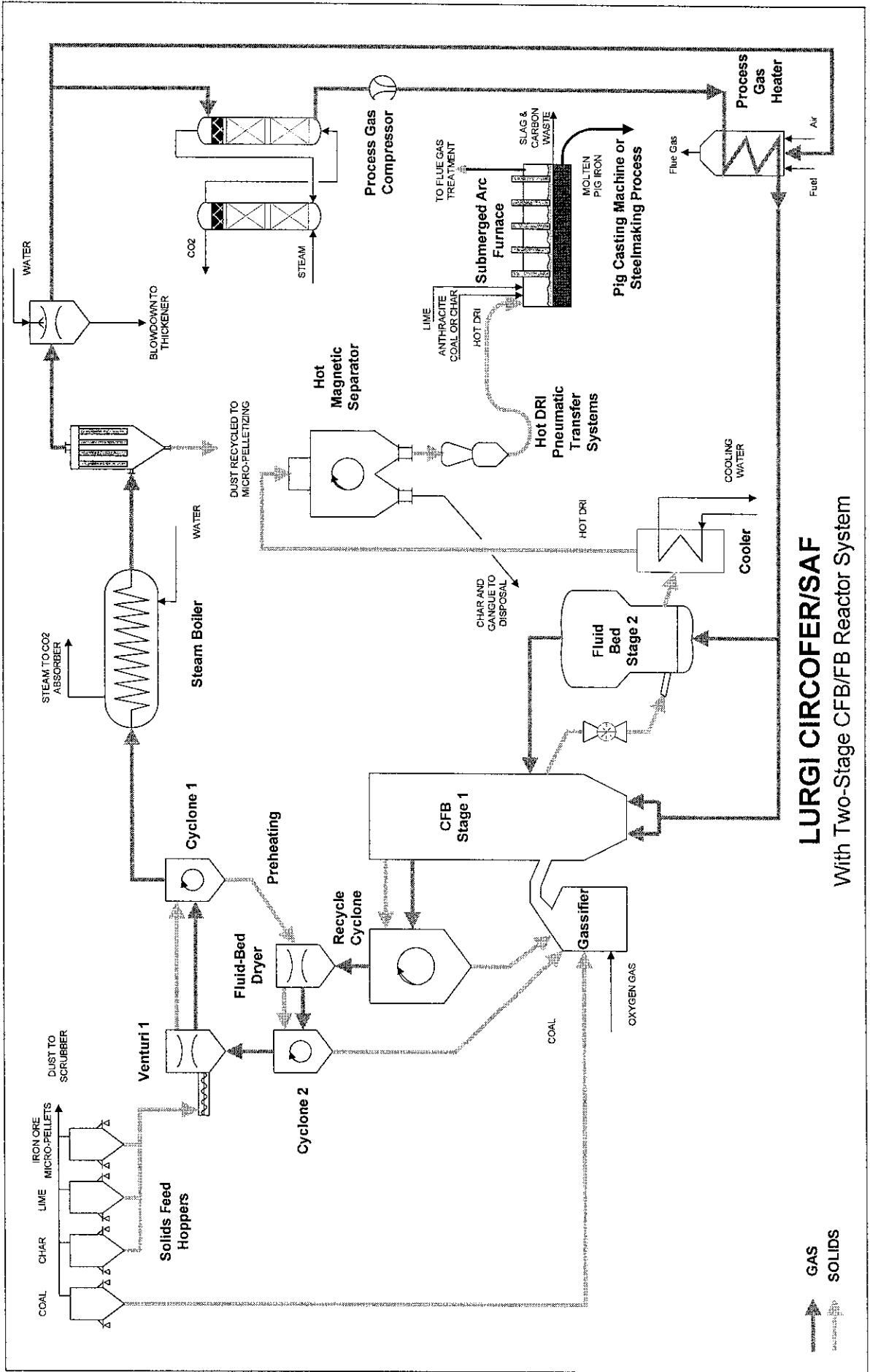




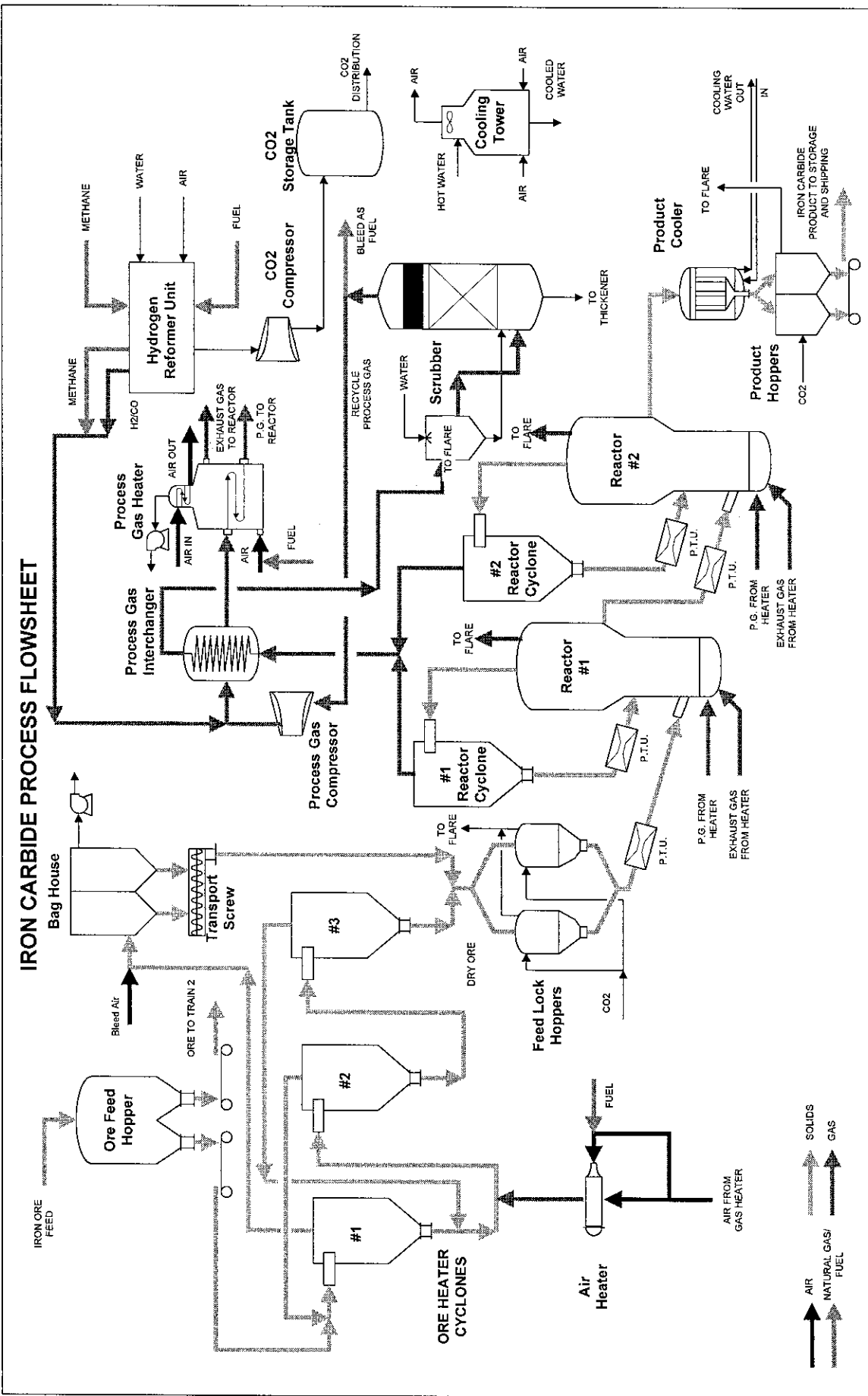
**LURGI MICRO-PELLETIZING CONCEPT**

# LURGI CIRCOFER PROCESS FLOWSHEET

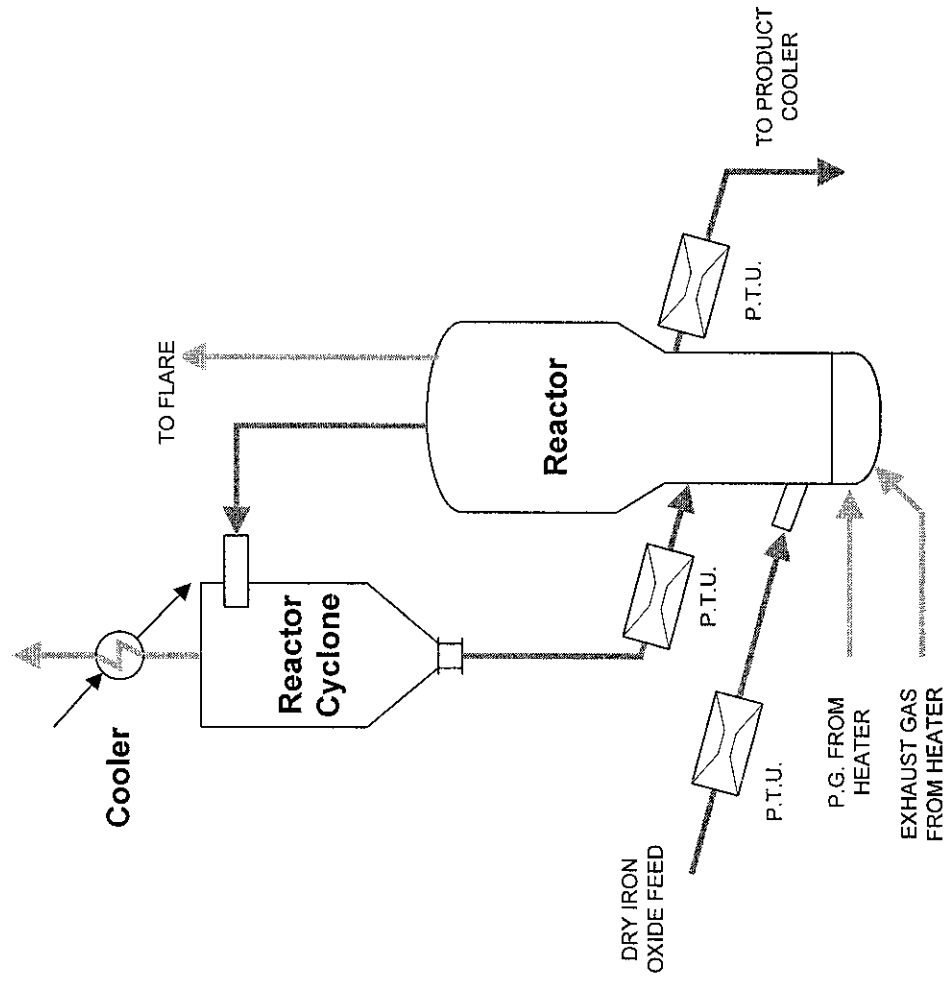




**LURGI CIRCOFER/SAF**  
With Two-Stage CFB/FB Reactor System

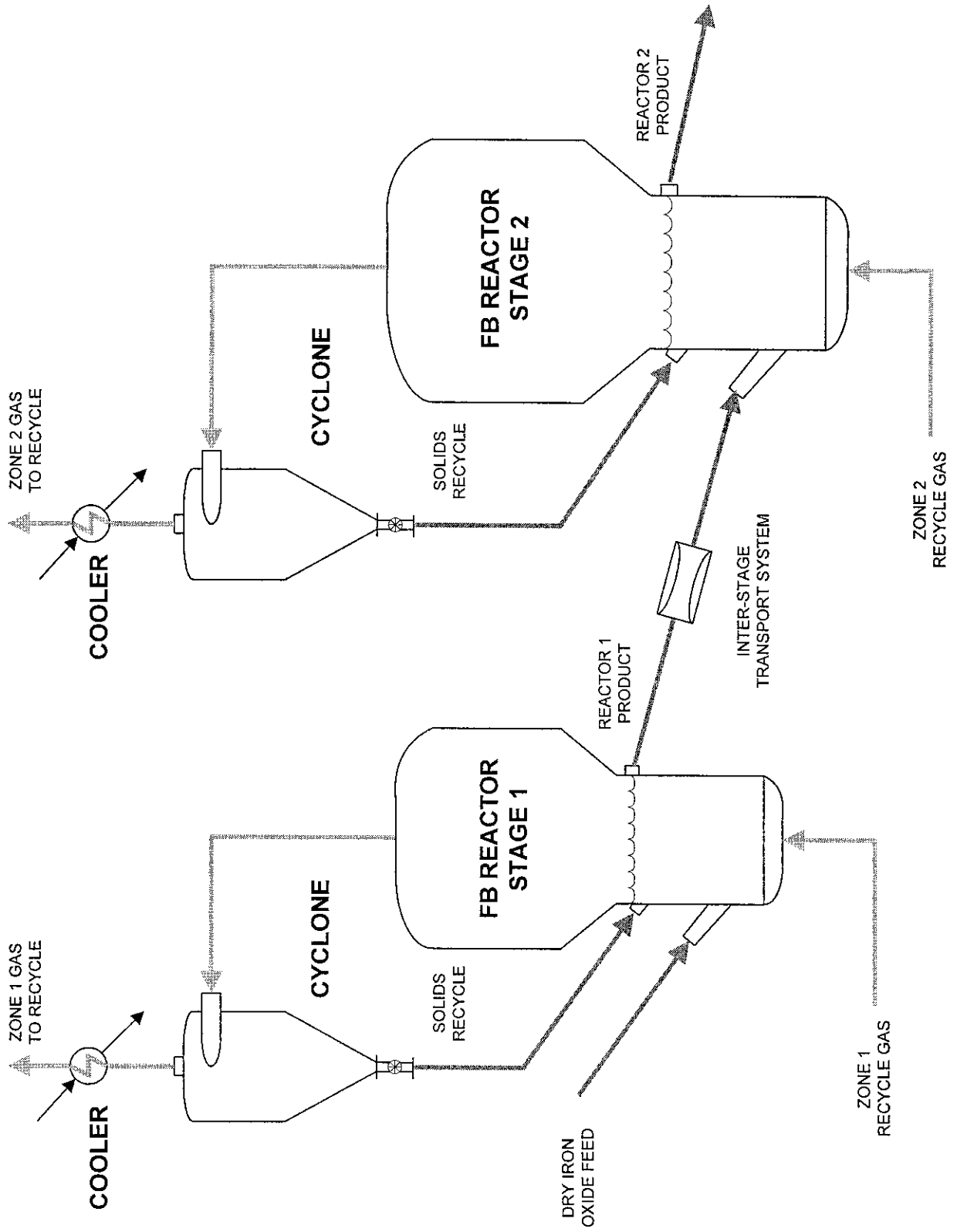


# SINGLE-STAGE IRON CARBIDE REACTOR SYSTEM

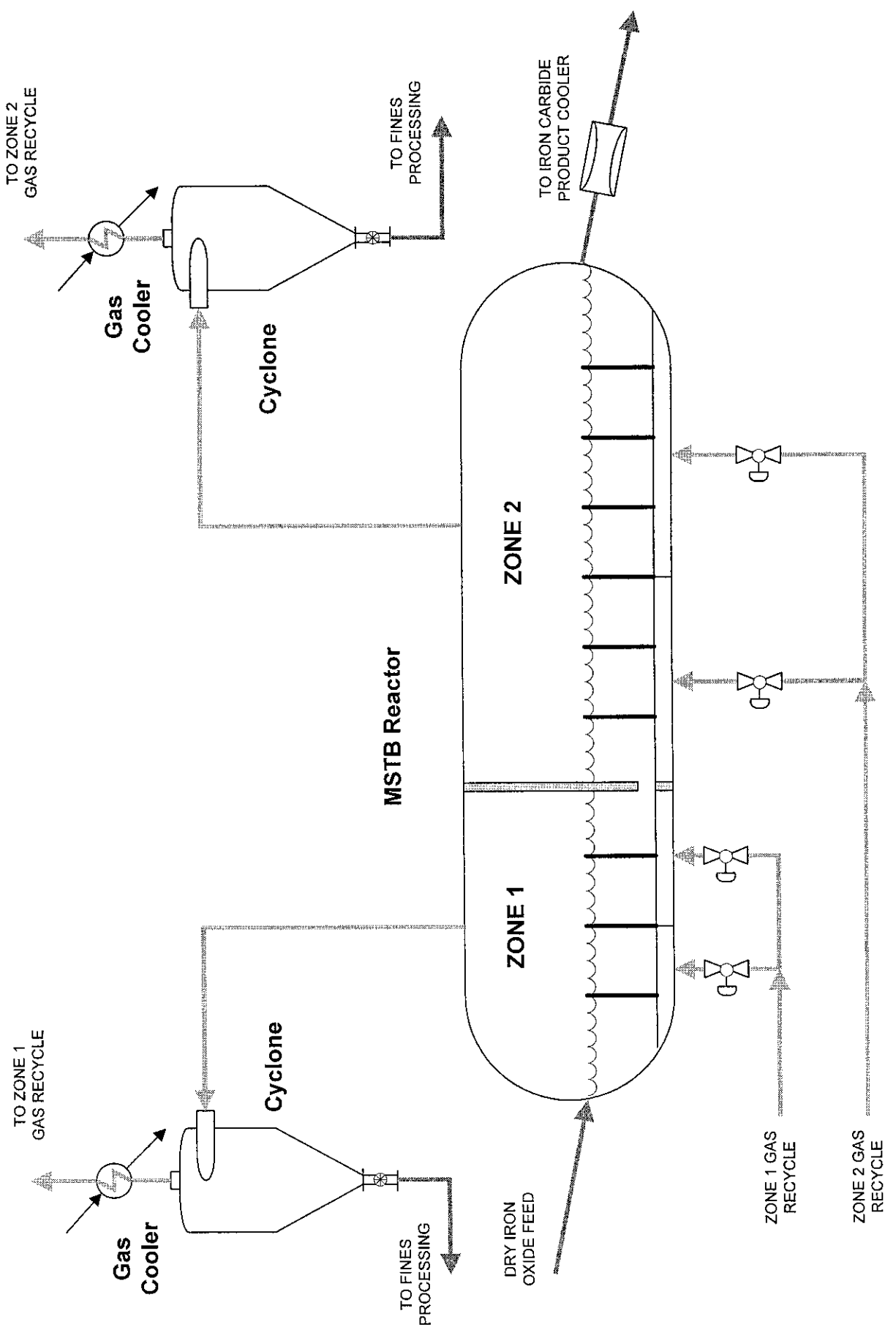




# TWO-STAGE IRON CARBIDE REACTOR SYSTEM

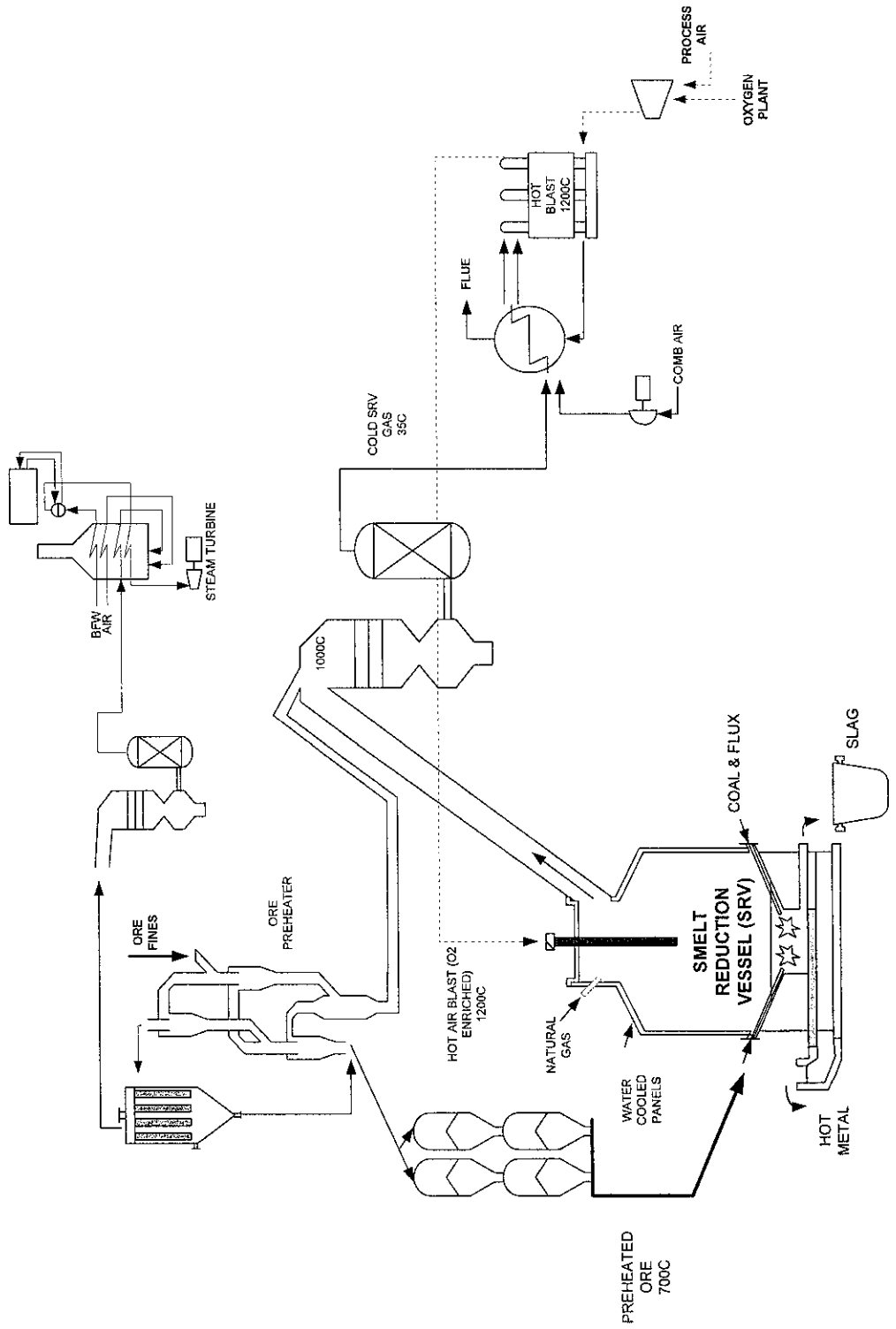


# PROCEEDYNE MSTB IRON CARBIDE REACTOR SYSTEM

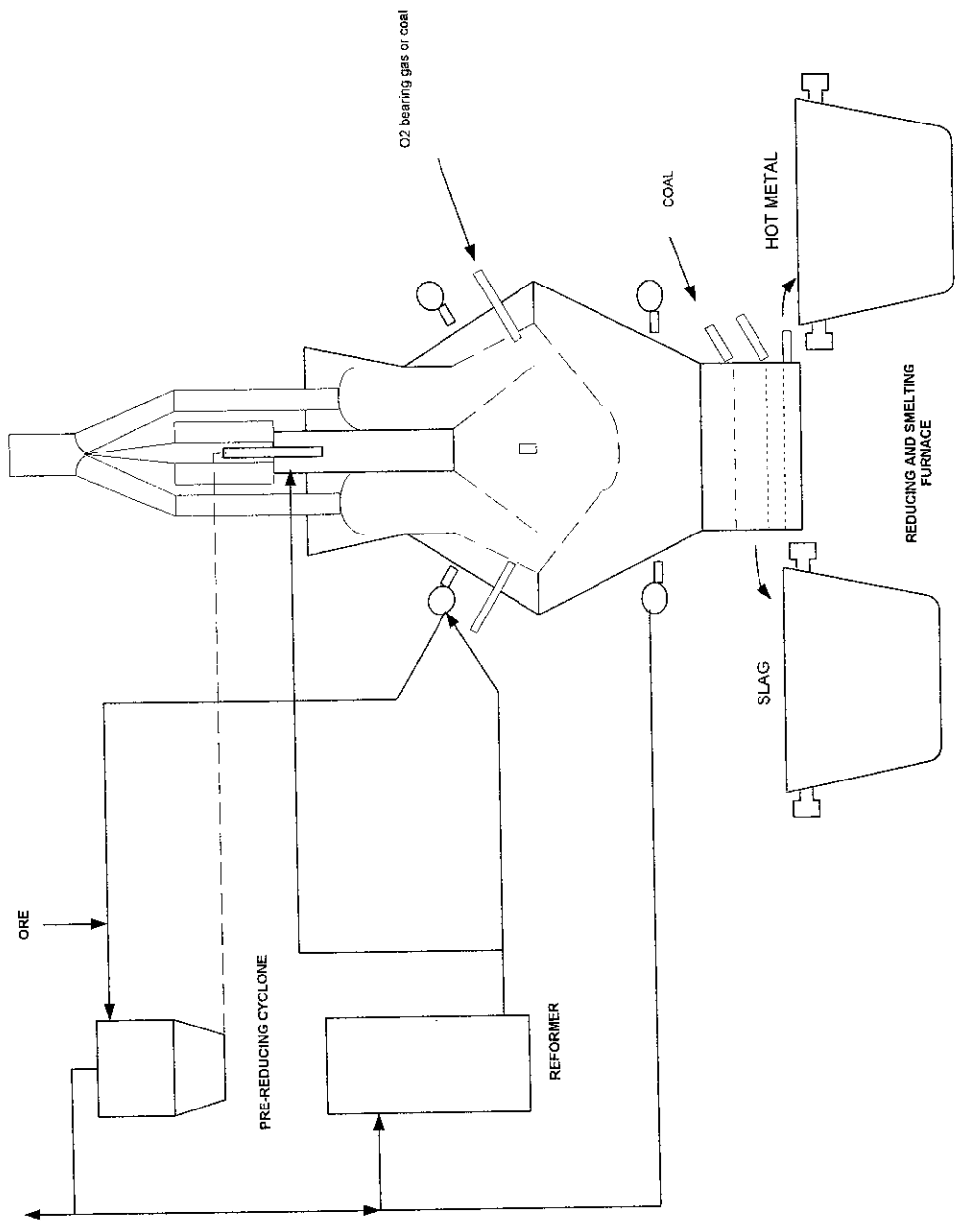


# **OTHER PROCESSES**

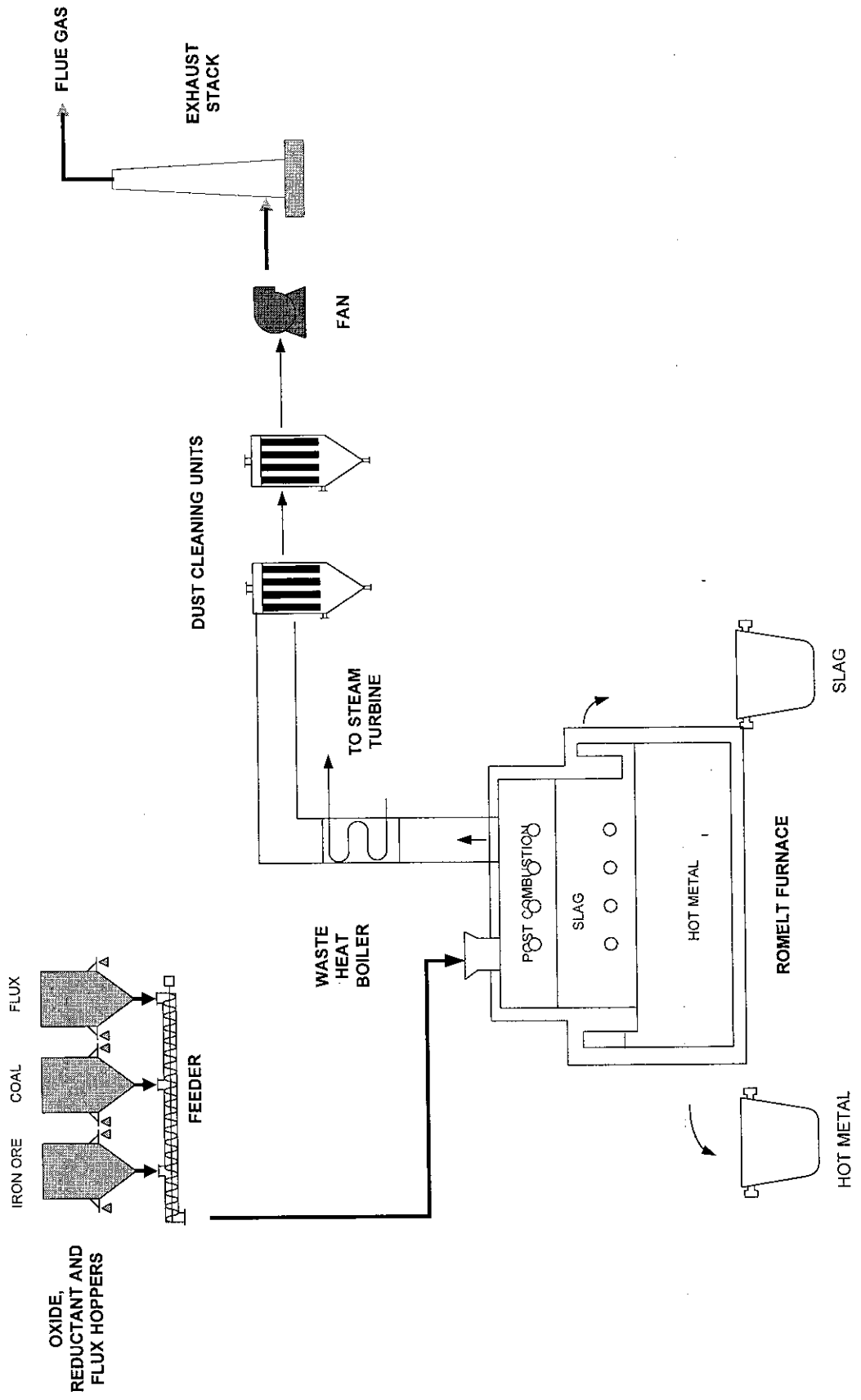
# HISMELT PROCESS FLOWSHEET



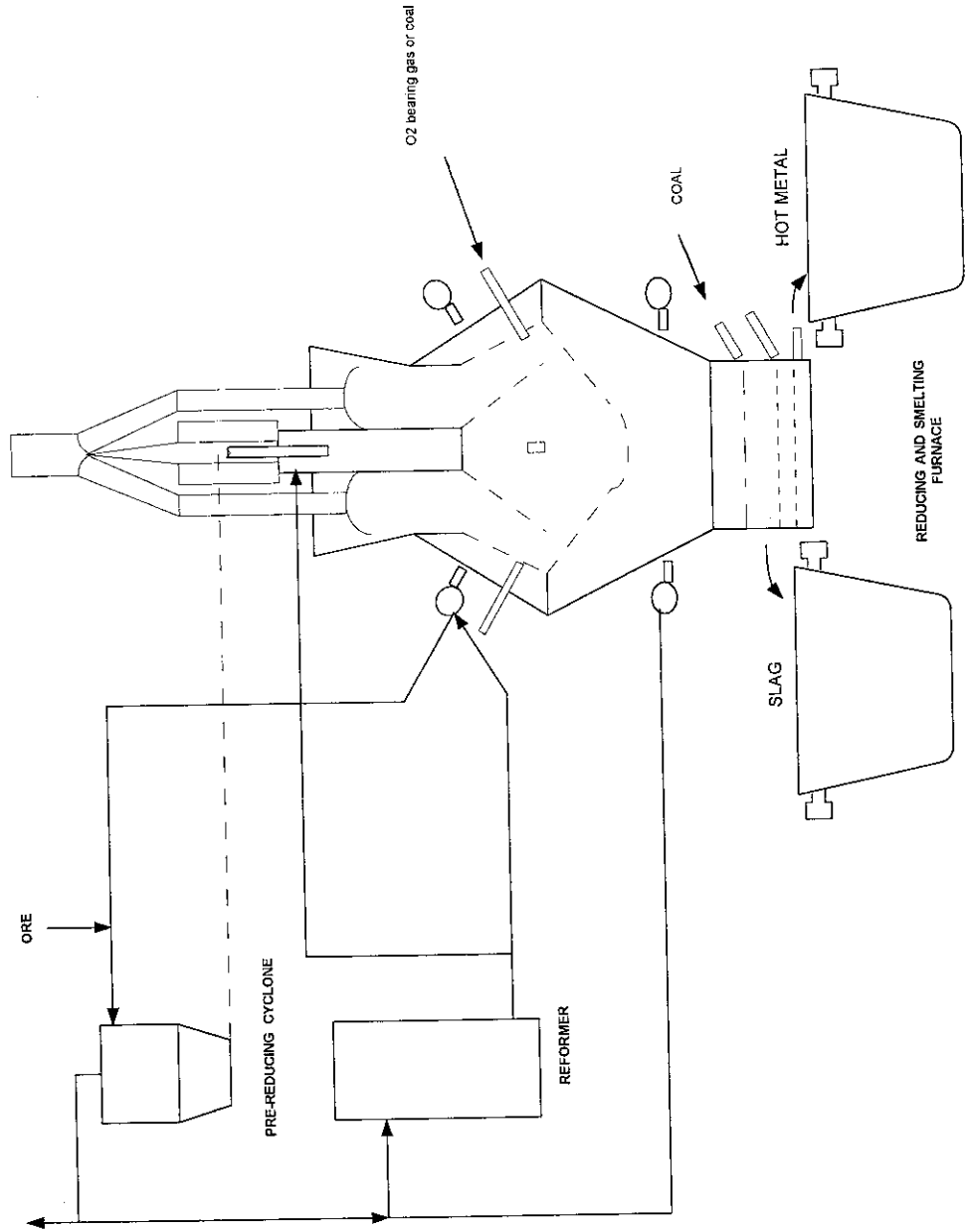
# ISCON GRIDSMELTER PROCESS FLOWSHEET



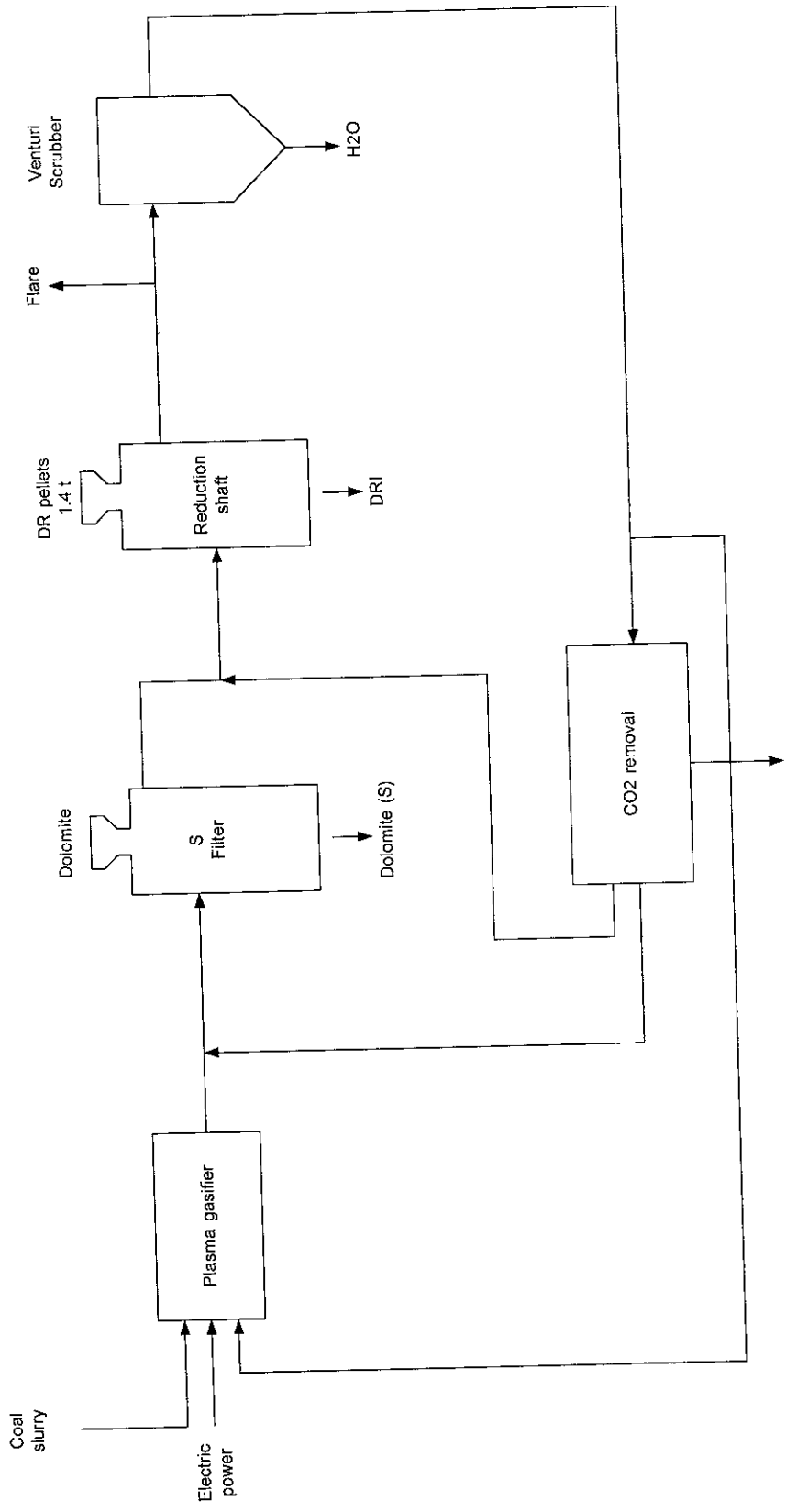
# ICF KAISER / MISA ROMELT PROCESS FLOWSHEET



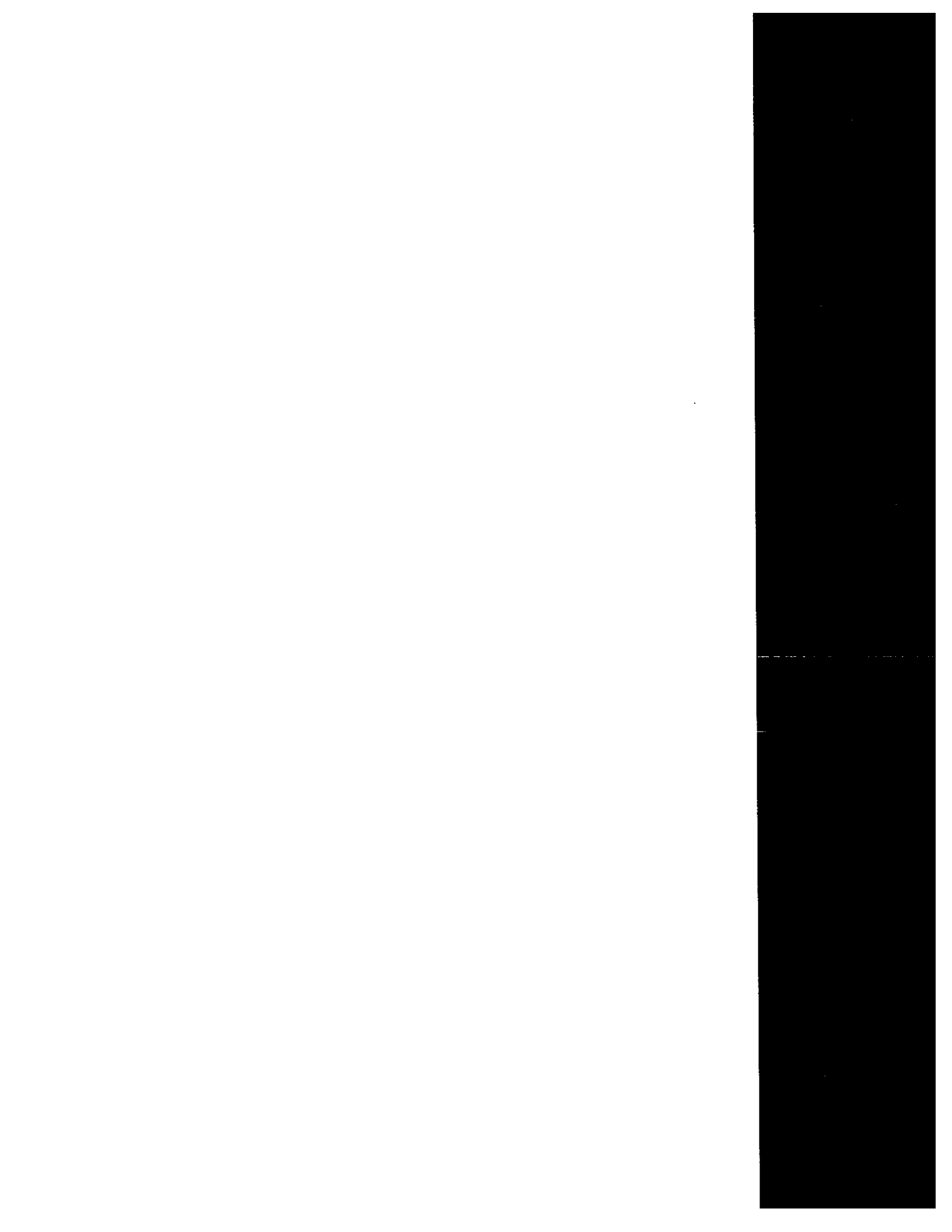
# ISCON GRIDSMELTER PROCESS FLOWSHEET



# PLASMARED PROCESS FLOWSHEET







**APPENDIX A-3:**  
**COMPONENT AND PROCESS BLOCK FLOW**  
**DIAGRAMS**

# **APPENDIX A-3.1**

## **ELECTRIC POWER GENERATION - COAL & NATURAL GAS**

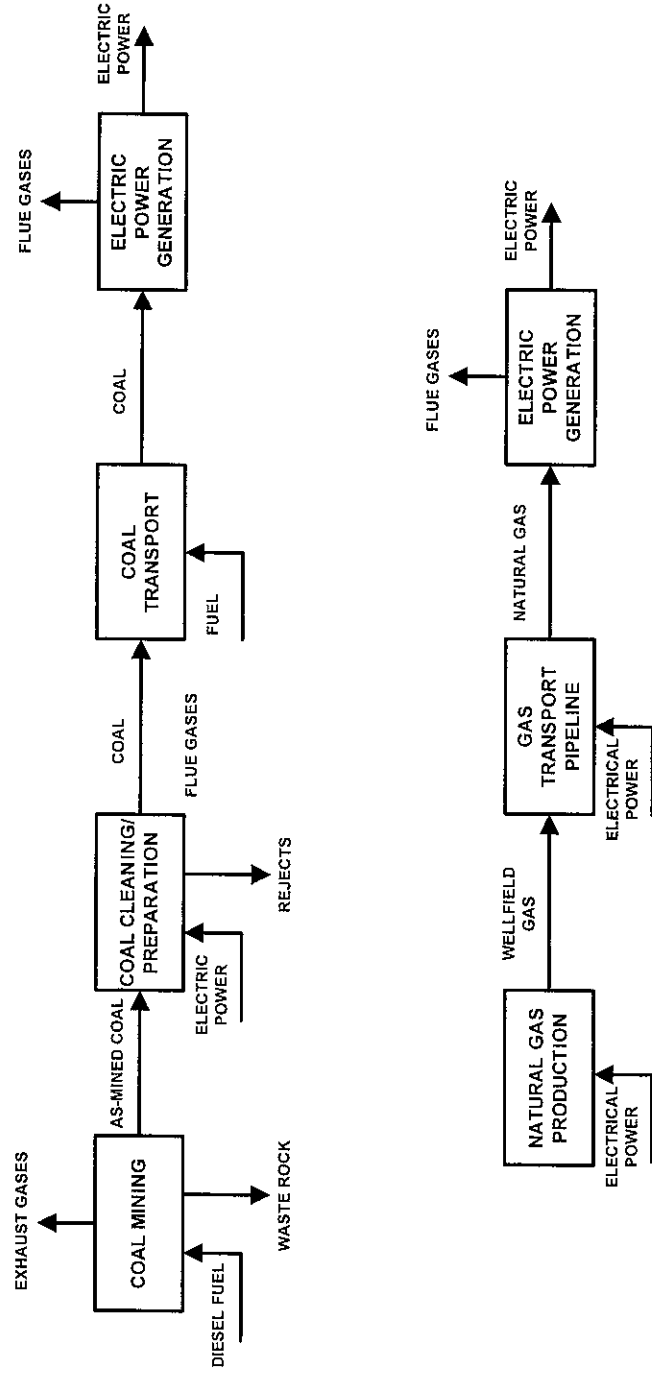


FIGURE A-1  
ELECTRICAL POWER GENERATION -  
COAL AND NATURAL GAS

## **APPENDIX A-3.2**

### **OXYGEN AND CARBON ELECTRODES**

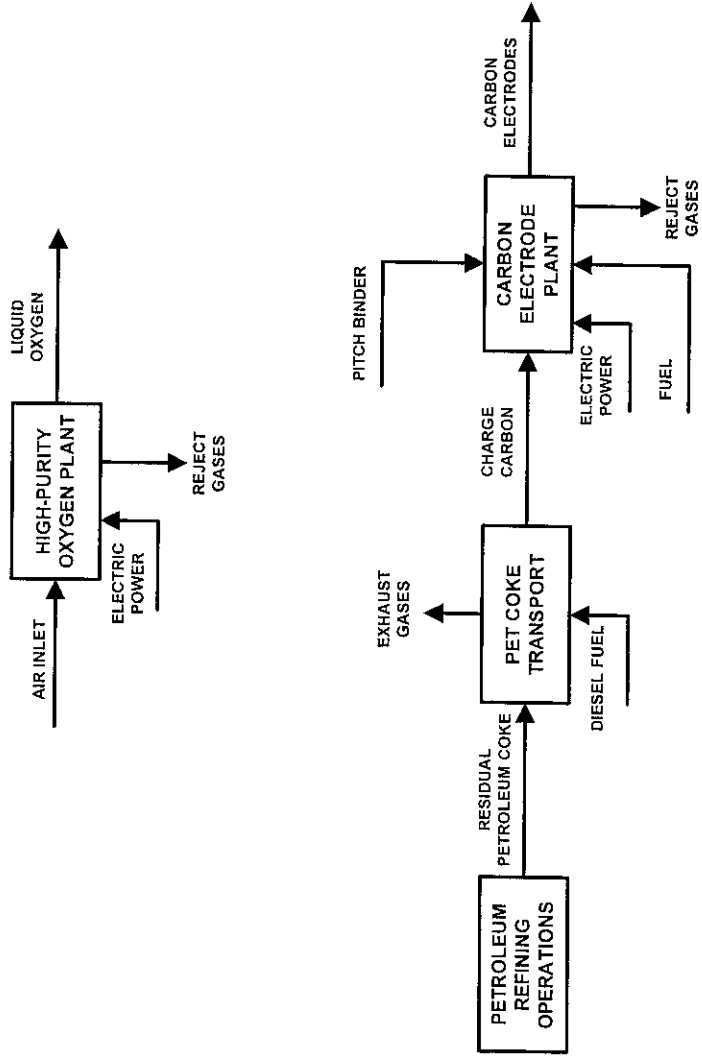


FIGURE A-2  
 COMPONENT BALANCES -  
 LIQUID OXYGEN AND CARBON ELECTRODES

## **APPENDIX A-3.3**

### **BURNT LIME AND PELLETIZING BINDER**

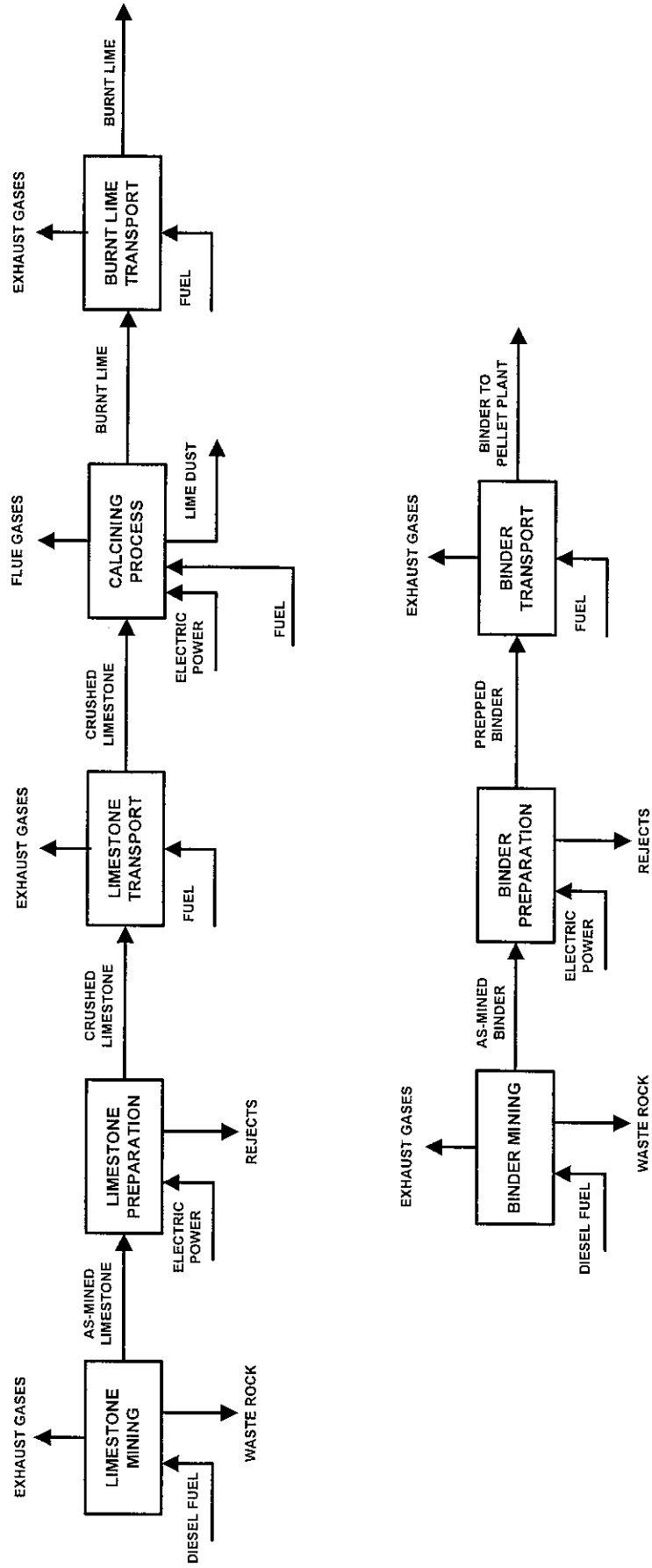


FIGURE A-3  
 COMPONENT BALANCES -  
 BURNT LIME AND PELLETIZING BINDER



## **APPENDIX A-3.4**

### **NON-RECOVERY COKE PROCESS WITH CO-GENERATION**

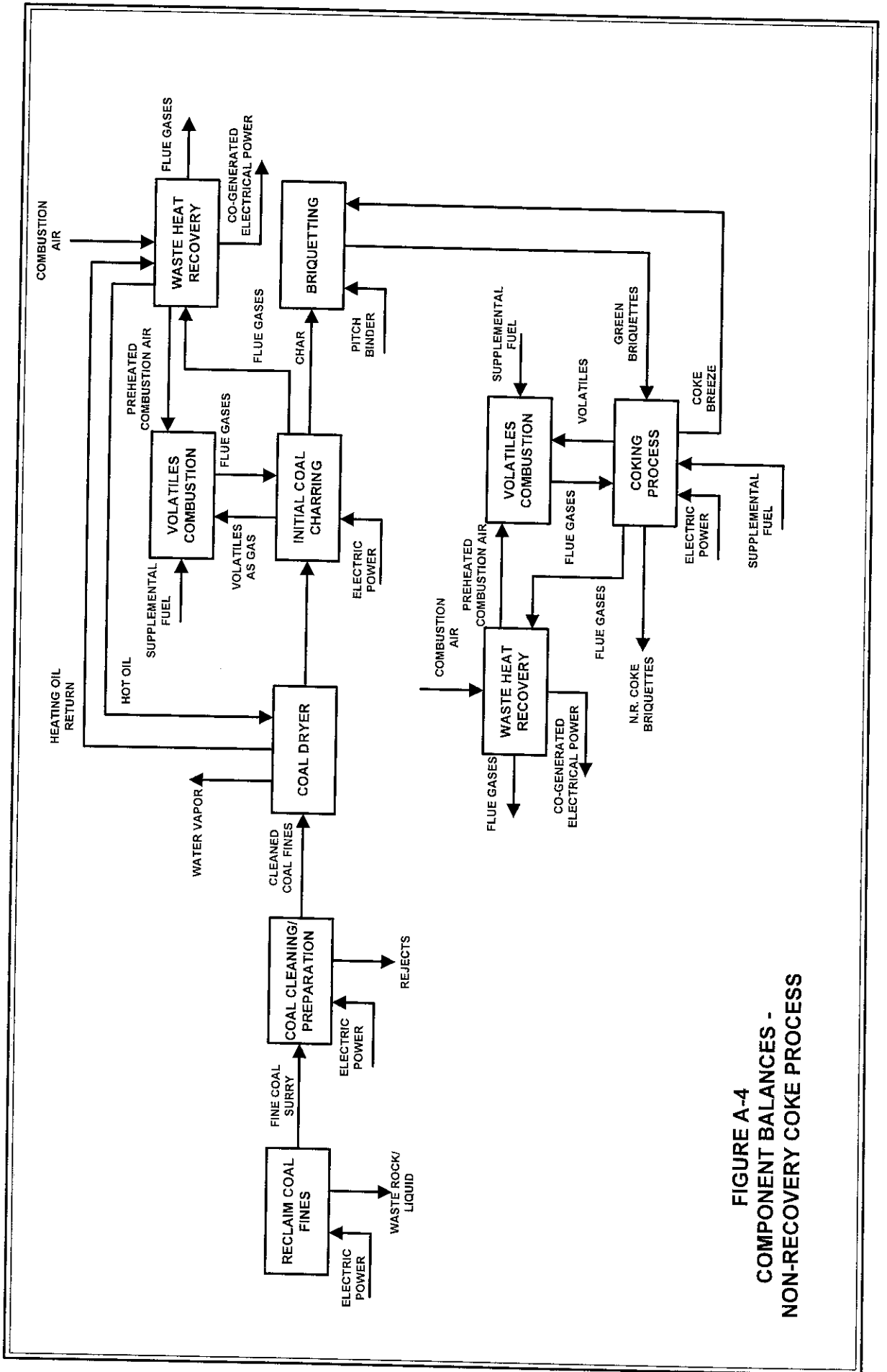
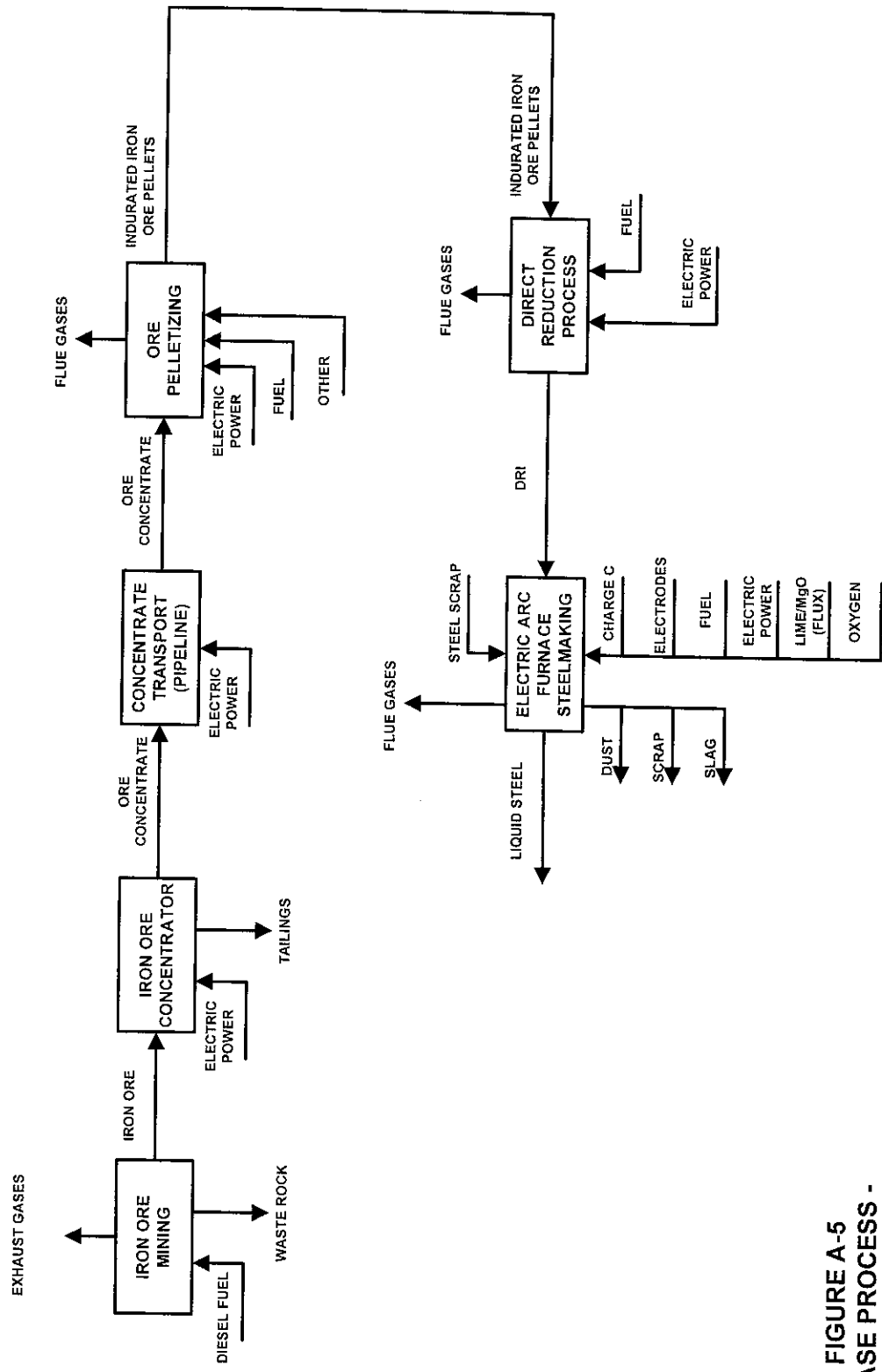


FIGURE A-4  
 COMPONENT BALANCES -  
 NON-RECOVERY COKE PROCESS

## **APPENDIX A-3.5**

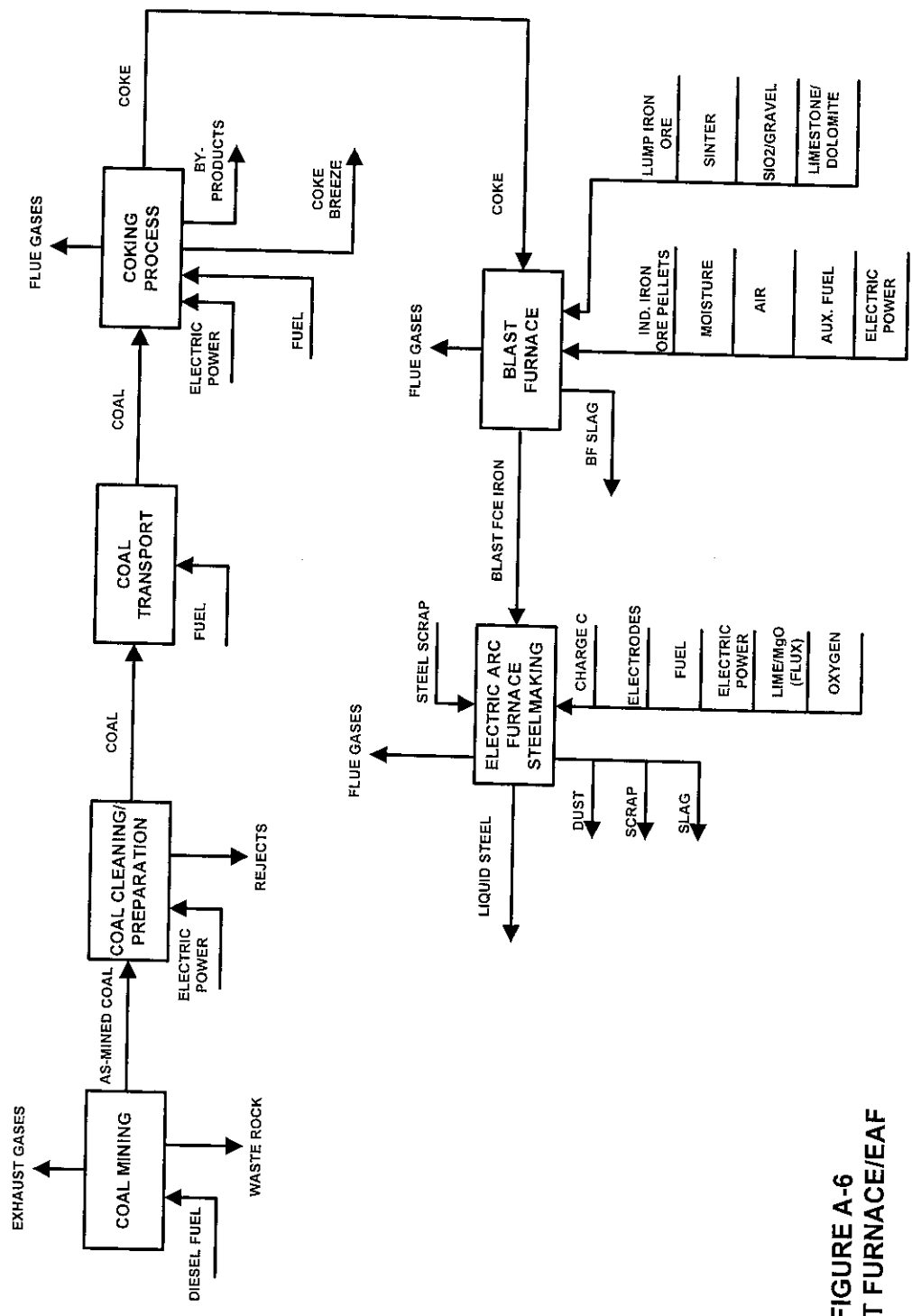
### **BASE PROCESS - DRI/EAF**



**FIGURE A-5  
BASE PROCESS -  
DR/IEAF**

# **APPENDIX A-3.6**

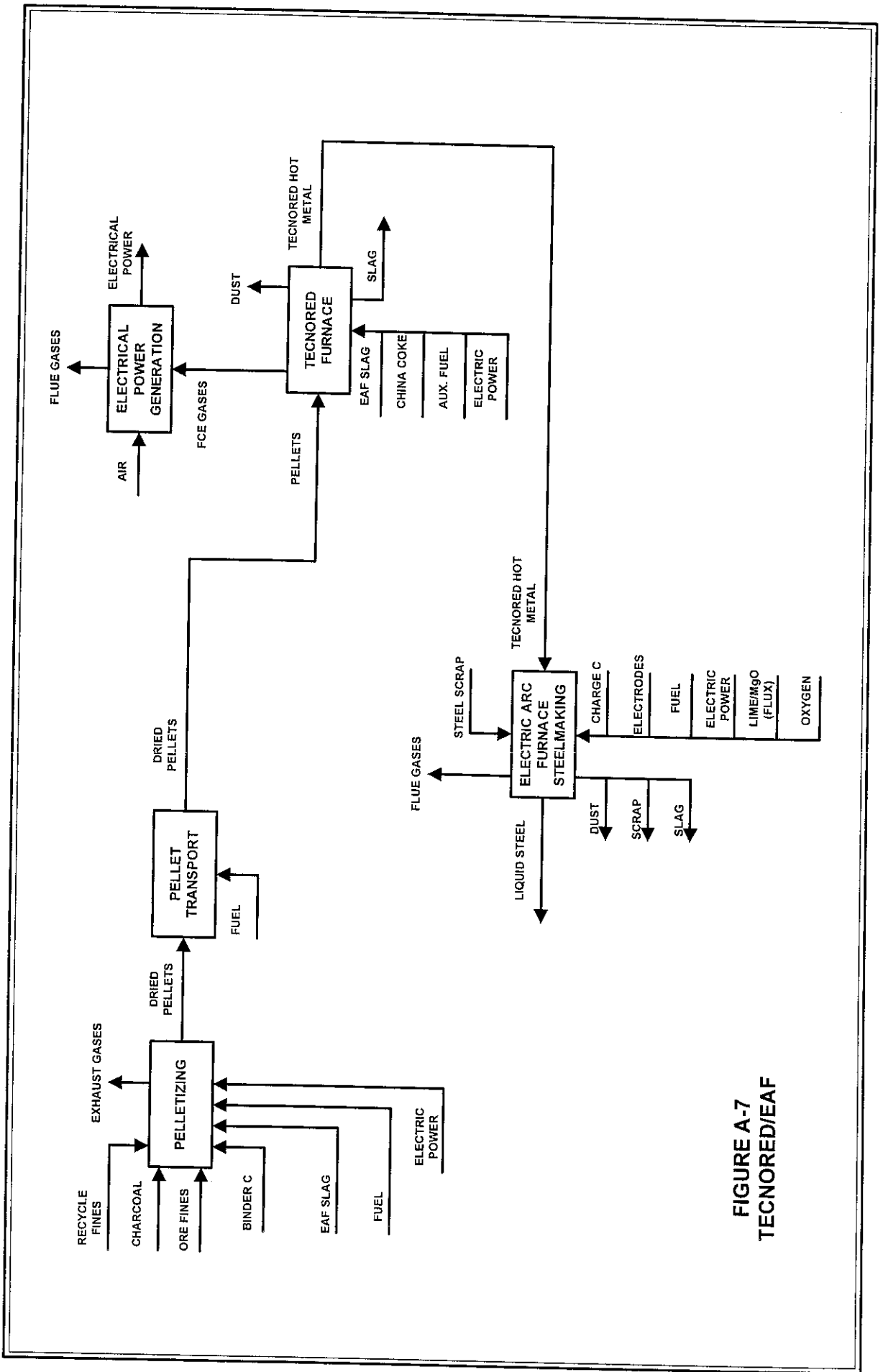
## **BLAST FURNACE/EAF**



**FIGURE A-6  
BLAST FURNACE/EAF**

# **APPENDIX A-3.7**

**TECNORED/EAF**

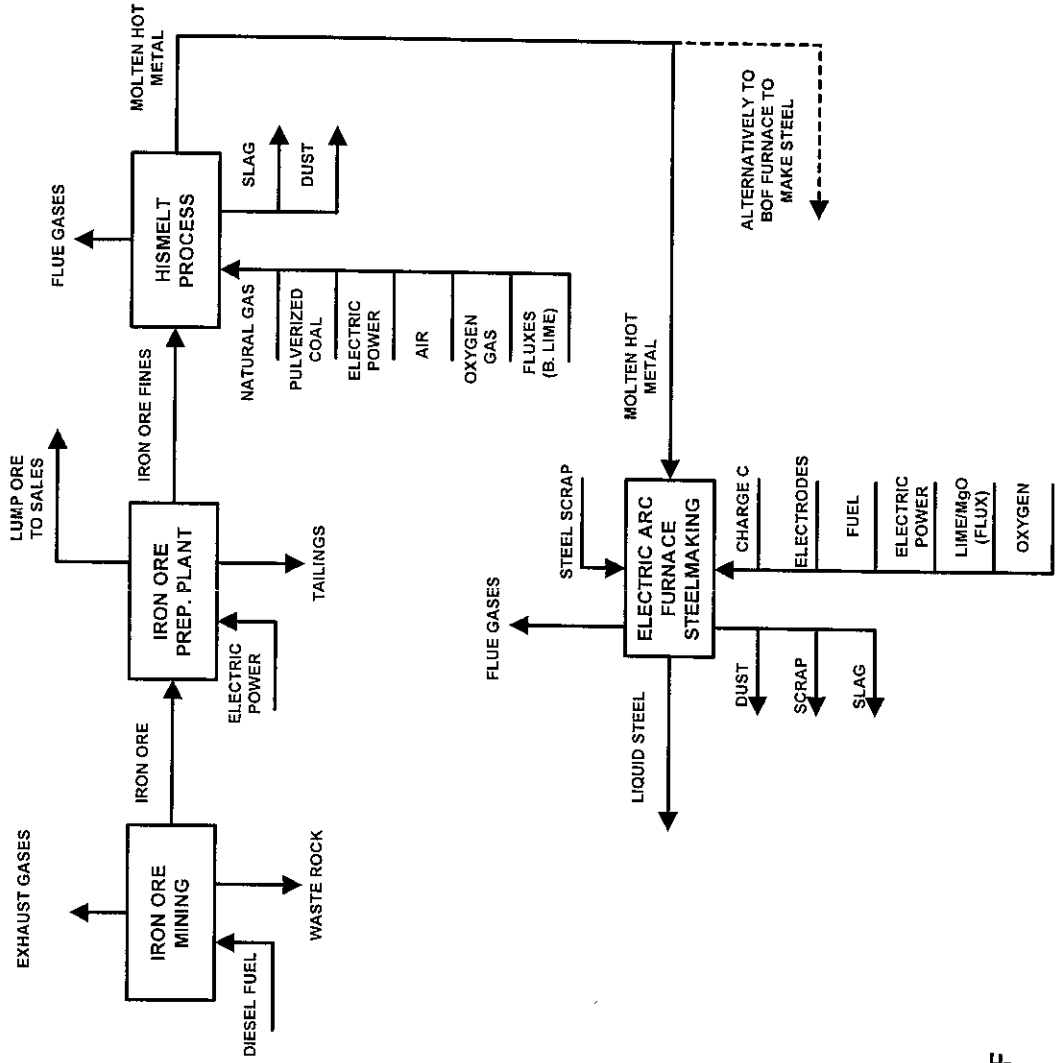


**FIGURE A-7  
TECNORED/EAF**



# **APPENDIX A-3.8**

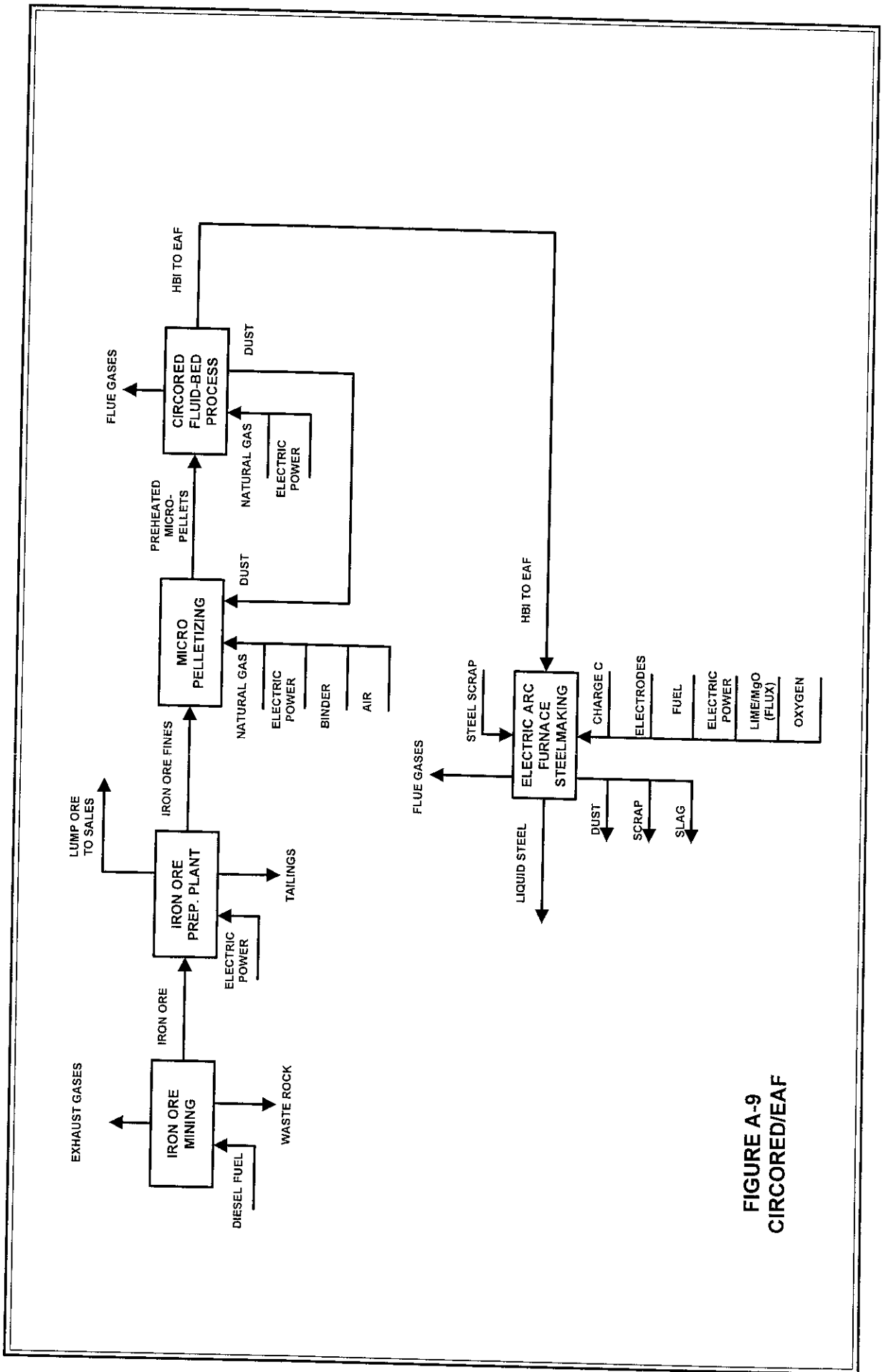
**HISMELT/EAF**



**FIGURE A-8  
HISMELT/EAF**

# APPENDIX A-3.9

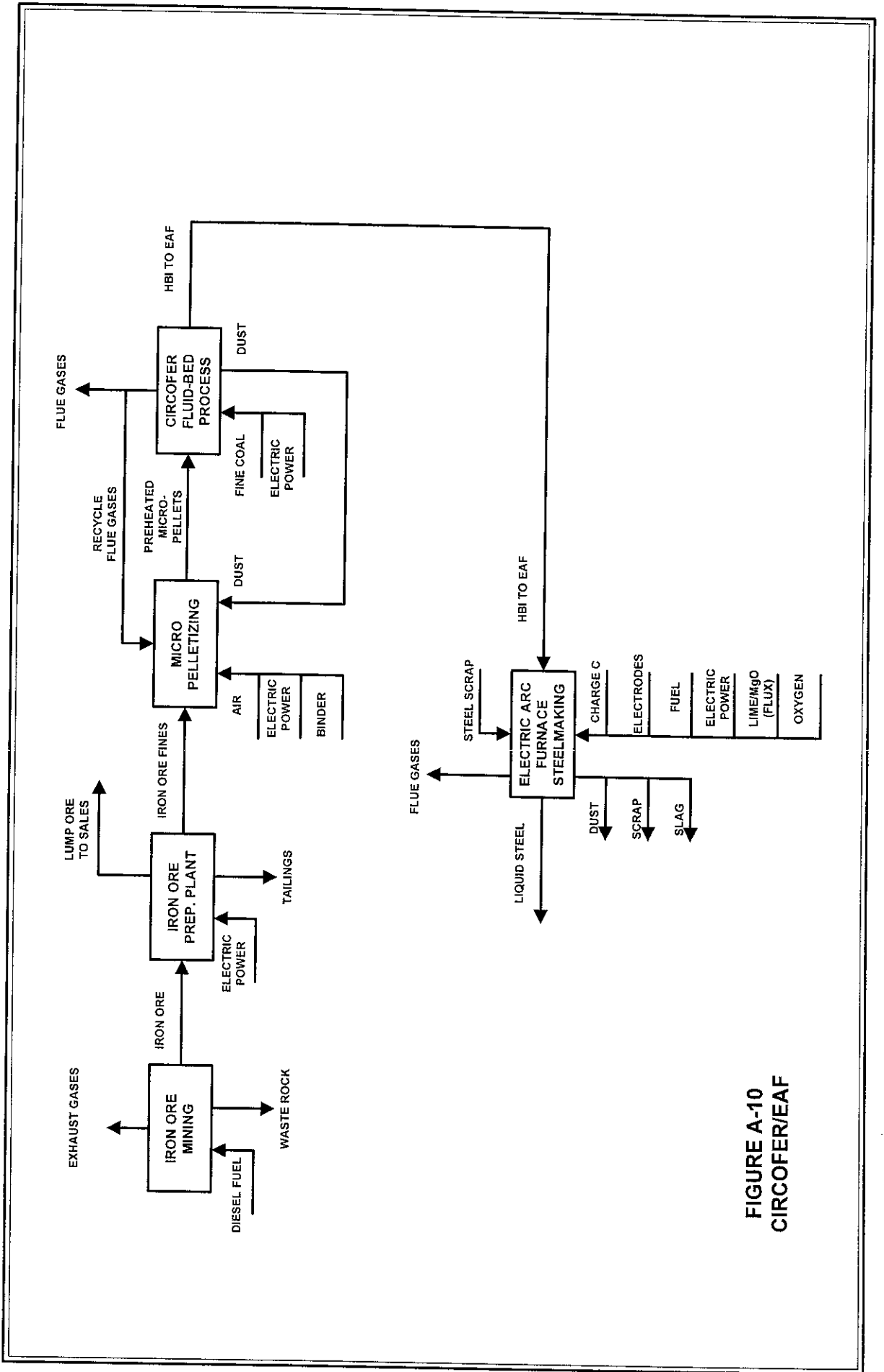
CIRCORED/EAF



**FIGURE A-9  
CIRCORED/EAF**

# **APPENDIX A-3.10**

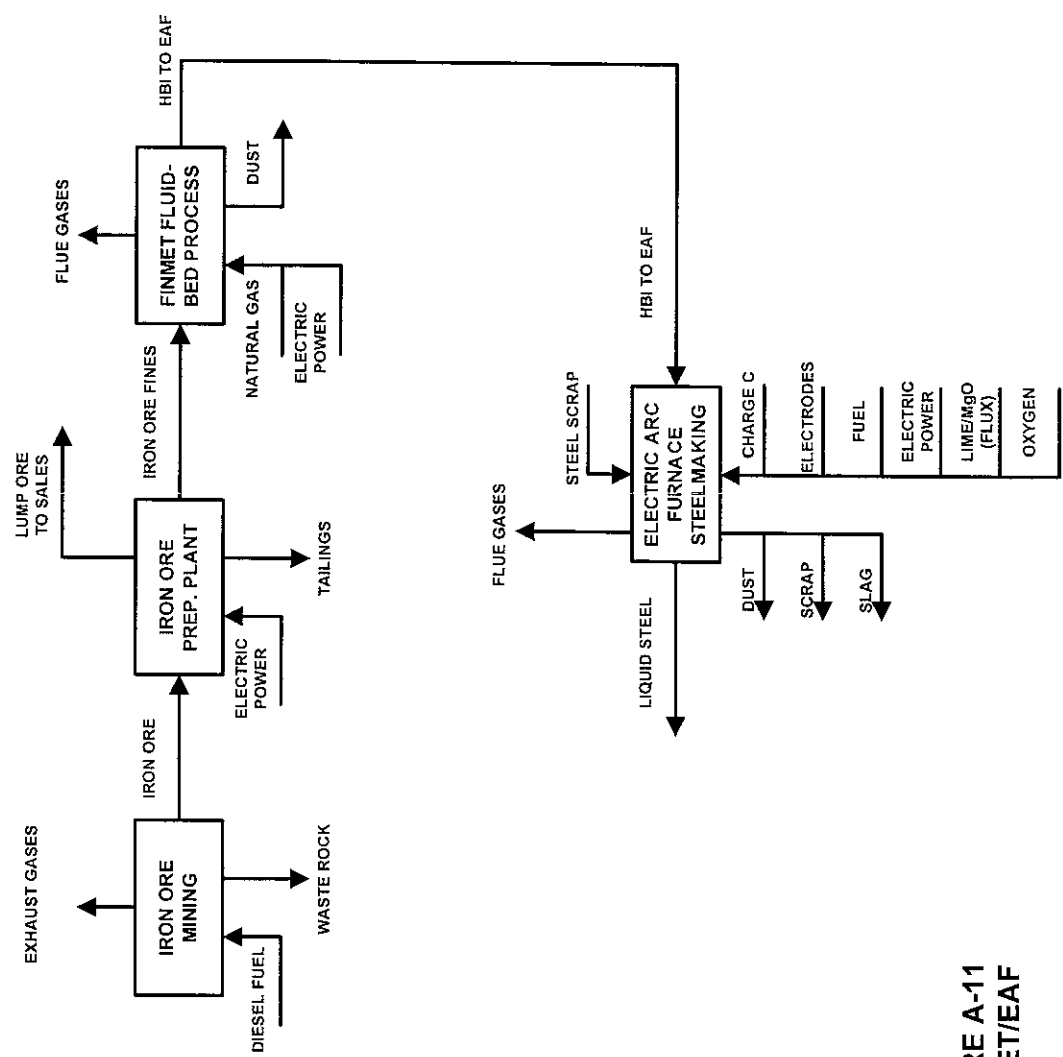
**CIRCOFER/EAF**



**FIGURE A-10  
CIRCOFER/EAF**

# **APPENDIX A-3.11**

**FINMET/EAF**

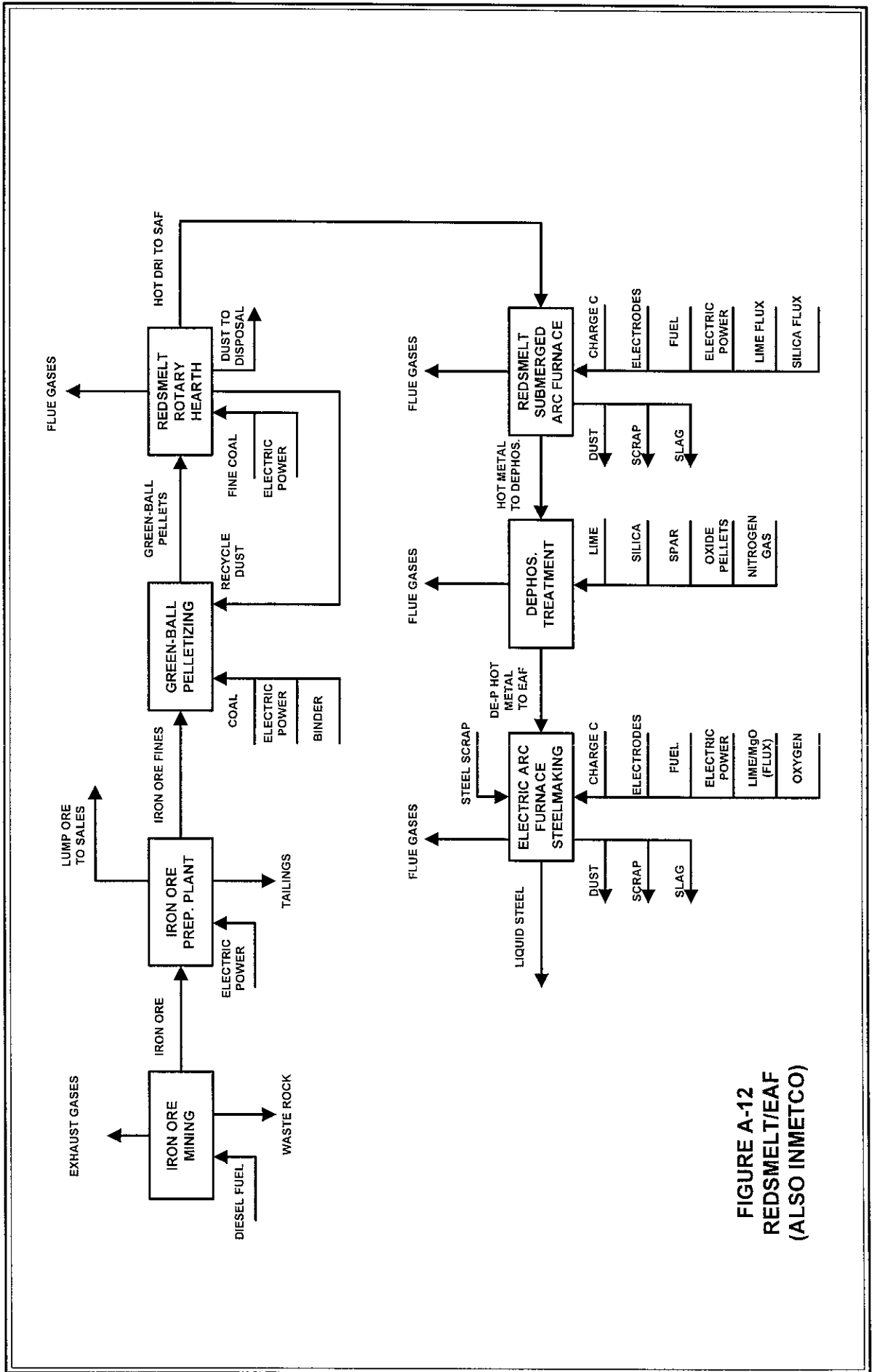


**FIGURE A-11  
FINMET/EAF**



# **APPENDIX A-3.12**

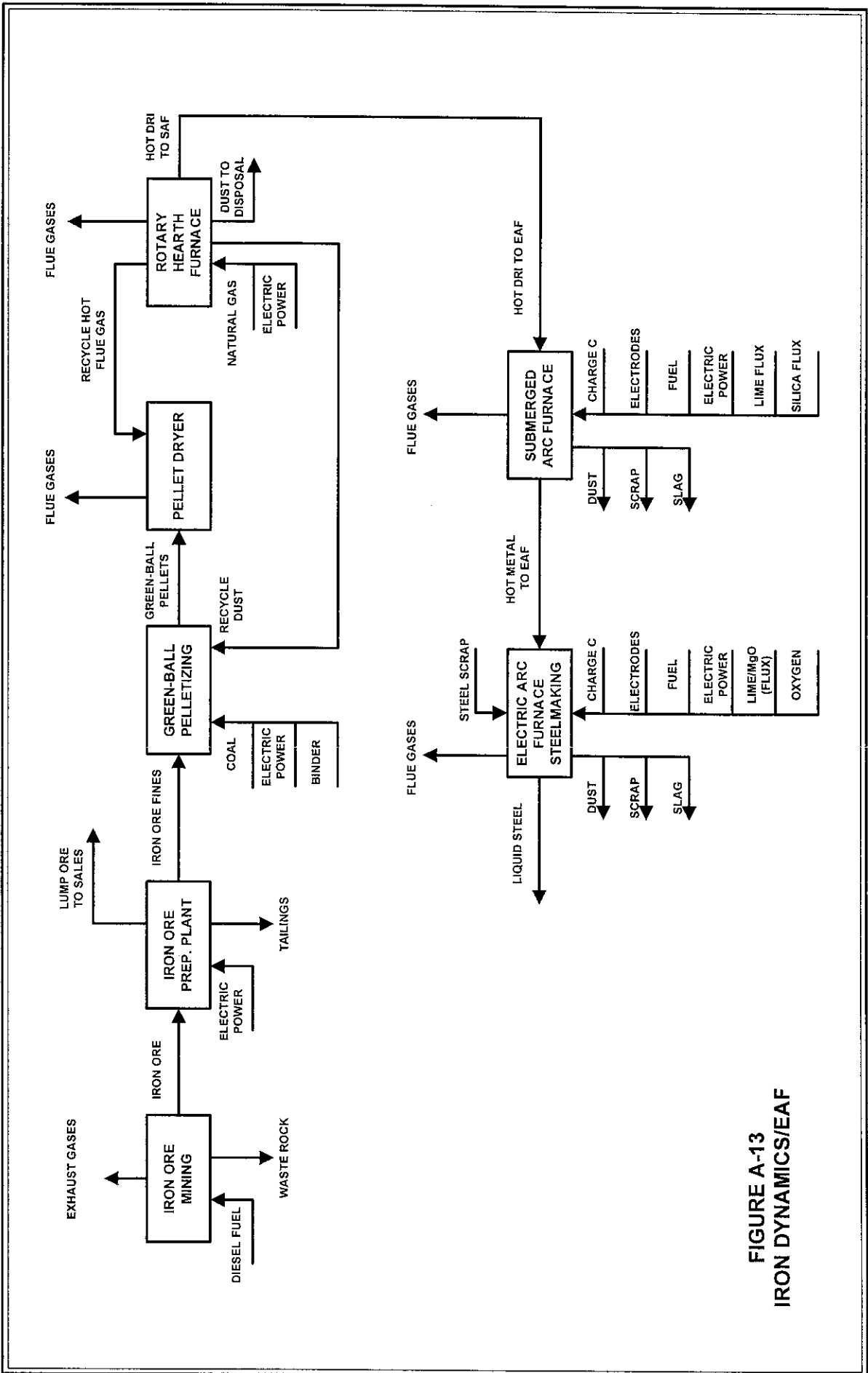
**REDSMELT/EAF**



**FIGURE A-12  
REDSMELT/EF  
(ALSO INMETCO)**

# **APPENDIX A-3.13**

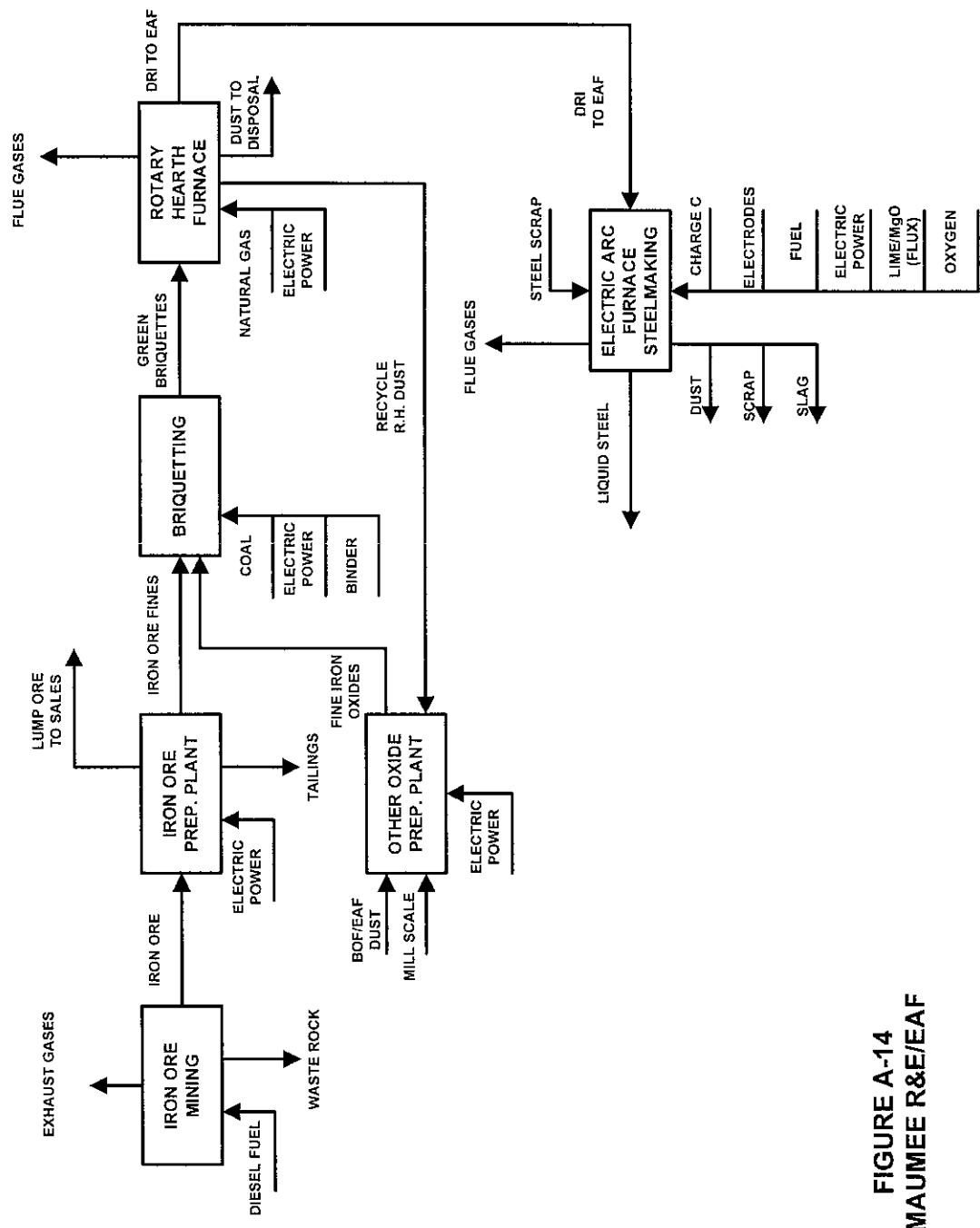
## **IRON DYNAMICS/EAF**



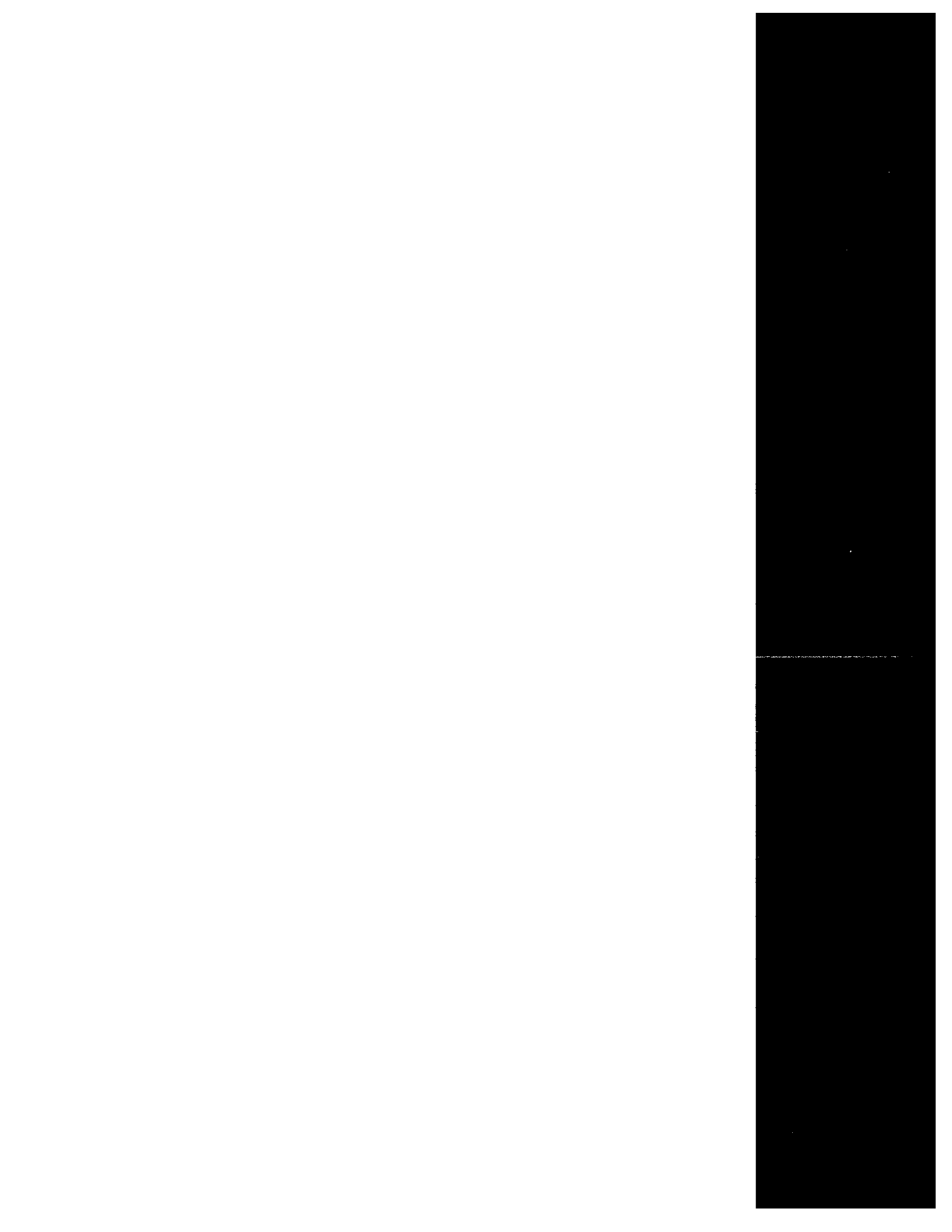
**FIGURE A-13**  
**IRON DYNAMICS/EAF**

# **APPENDIX A-3.14**

**MAUMEE R&E/EAF**



**FIGURE A-14  
MAUMEE R&E/EAF**



**APPENDIX A-4:**  
**GROUPINGS OF PROCESSES**



## A. IRONMAKING PROCESSES BY REDUCTION PROCESS TYPE

### 1) SHAFT FURNACE

Blast Furnace  
Corex  
Midrex  
Hylsa (HYLIII etc.)  
Tecored

### 2) ROTARY KILN

SL/RN

### 3) ROTARY HEARTH

Redsmelt  
Fastmet/Fastmelt  
Itmk3  
Inmetco  
Iron Dynamics  
MauMee

### 4) FLUIDIZED BED

Finmet  
Circored  
Circofer  
Nucor/ICH (Single-Stage IC)  
Qualitech/Kawasaki (Two-Stage IC)  
Procedyne (Multi-stage IC)

### 5) OTHER (REACTOR ETC.)

Hismelt  
Dios  
Romelt  
Gridsmelter  
Comet  
PlasmaRed

## B. IRONMAKING PROCESSES BY PRODUCT TYPE:

### 1) PROCESSES PRODUCING MOLTEN HOT METAL/PIG IRON

- Blast Furnace
- Corex
- Redsmelt
- Iron Dynamics
- Tecnored
- Fastmet/Fastmelt
- Hismelt
- Gridsmelter
- Dios
- Romelt

### 2) PROCESSES PRODUCING DRI/HBI

- Midrex
- Hylsa (HYLIII etc.)
- Circored
- Finmet
- Inmetco
- SL/RN
- ITmk3
- Circofer
- MauMee
- Comet
- PlasmaRed

### 3) PROCESSES PRODUCING IRON CARBIDE

- Nucor/ICH (Single-Stage IC)
- Qualitech/Kawasaki (Two-Stage IC)
- Procedyne (Multi-Stage IC)

**C. IRONMAKING PROCESSES BY STAGE OF COMMERCIAL DEVELOPMENT**

1) PROVEN COMMERCIAL PROCESSES

Blast Furnace  
Midrex  
Hylsa (HYLIII, HYLIV, etc.)  
Corex  
SL/RN

2) PROCESSES AT SEMI-COMMERCIAL OR FIRST-OF-A-KIND STAGE OF DEVELOPMENT

Finmet  
Circored  
Iron Dynamics  
MauMee  
Inmetco  
Redsmelt  
Nucor/ICH (Single-Stage IC)  
Qualitech/Kawasaki (Two-Stage IC)

3) PROCESSES AT PILOT PLANT STAGE OF DEVELOPMENT

Tecnored  
Hismelt  
Fastmet/Fastmelt  
Itmk3  
Dios  
Romelt

4) PROCESSES AT COMPONENT TEST STAGE OF DEVELOPMENT

Procedyne (Multi-stage IC)  
Circofer  
Gridsmelter  
Comet  
PlasmaRed

## D. IRONMAKING PROCESSES BY IRON UNIT FEED MATERIAL

### 1) LUMP IRON ORE/PELLET/BRIQUETTE/RECYCLE IRON UNITS AND/OR SINTER

Blast Furnace  
Corex  
Midrex  
Hylsa (HYLIII, HYLIV, etc.)  
SL/RN  
Tecnores  
Fastmet/Fastmelt  
Redsmelt  
Itmk3  
Inmetco  
Iron Dynamics  
MauMee

### 2) FINE ORE DIRECT

Finmet  
Circored  
Circofer  
Nucor/ICH (Single-Stage IC)  
Qualitech/Kawasaki (Two-Stage IC)  
Procedyne (Multi-stage IC)  
Hismelt  
Dios  
Romelt  
Gridsmelter  
Comet  
PlasmaRed

## E. IRONMAKING PROCESSES BY PRIMARY REDUCTANT TYPE

### 1) COKE

Blast Furnace  
TecnoRed

### 2) COAL

Corex  
SL/RN  
TecnoRed (optional)  
Redsmelt  
Fastmet/Fastmelt  
Inmetco  
Iron Dynamics  
MauMee  
Circofer

### 3) NATURAL GAS/HYDROGEN/REFORMED GAS

Midrex  
Hylsa (HYLIII etc.)  
Circored  
Finmet  
Nucor/ICH (Single-Stage IC)  
Qualitech/Kawasaki (Two-Stage IC)  
Procedyne (Multi-stage IC)  
PlasmaRed

### 4) COAL/NATURAL GAS MIXTURE

Itmk3  
Hlsmelt  
Dios  
Romelt  
Gridsmelter  
Comet

F. IRONMAKING PROCESSES BY TARGET NOMINAL SIZE OF REDUCTION UNIT/TRAIN

1) LESS THAN 200,000 MTPY

MauMee  
Inmetco  
Romelt  
Gridsmelter  
Comet  
PlasmaRed

2) 200,000 TO 500,000 MTPY

Tecnored  
HIs melt  
Iron Dynamics  
SL/RN  
Circofer  
Nucor/ICH (Single-Stage IC)  
Qualitech/Kawasaki (Two-Stage IC)  
Procedyne (Multi-stage IC)

3) 500,000 TO 1,000,000 MTPY

Finmet  
Circored  
Redsmelt  
Fastmet/Fastmelt  
Itmk3  
Dios

4) GREATER THAN 1,000,000 MTPY

Blast Furnace  
Corex  
Midrex  
Hylsa (HYLIII, HYLIV, etc.)

# IRONMAKING PROCESSES BY PRODUCT TYPE

## HOT METAL/PIG IRON

BLAST FURNACE  
COREX  
REDSMELT  
IRON DYNAMICS  
TECNORED  
FASTMET/FASTMELT  
HISMELT  
GRIDSMEILER  
DIOS  
ROMELT

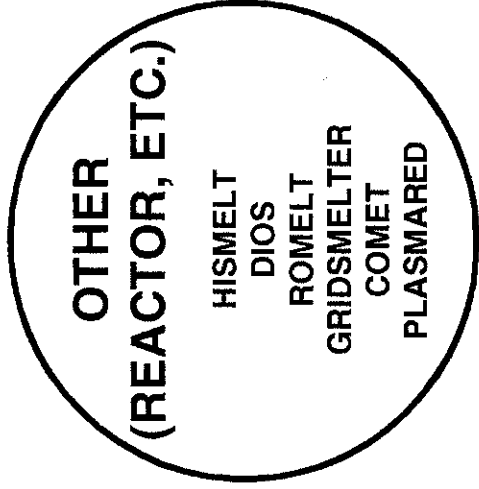
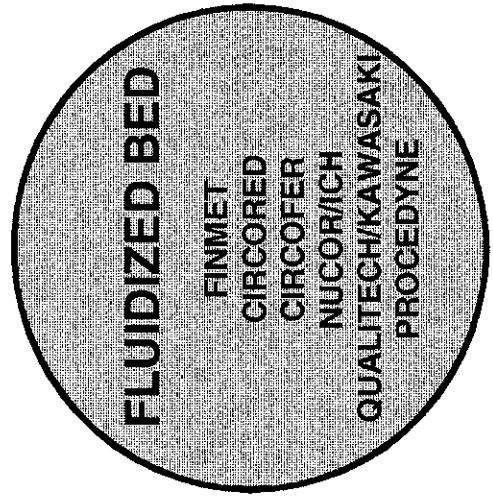
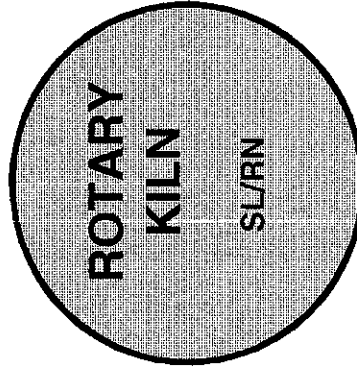
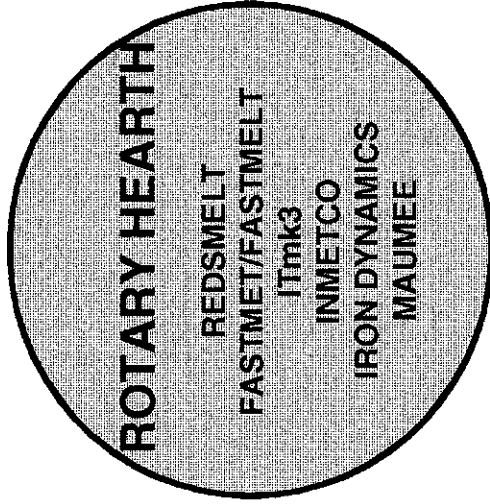
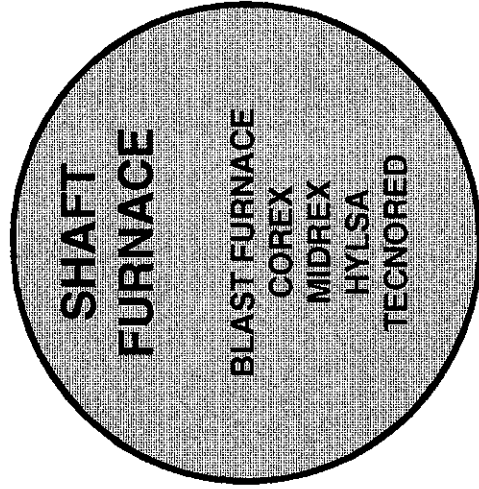
## DR/HBI

MIDREX  
HYLSA  
FINMET  
CIRCORIED  
INMETCO  
SL/RN  
ITmk3  
CIRCOFER  
MAUMEE  
COMET  
PLASMARED

## IRON CARBIDE

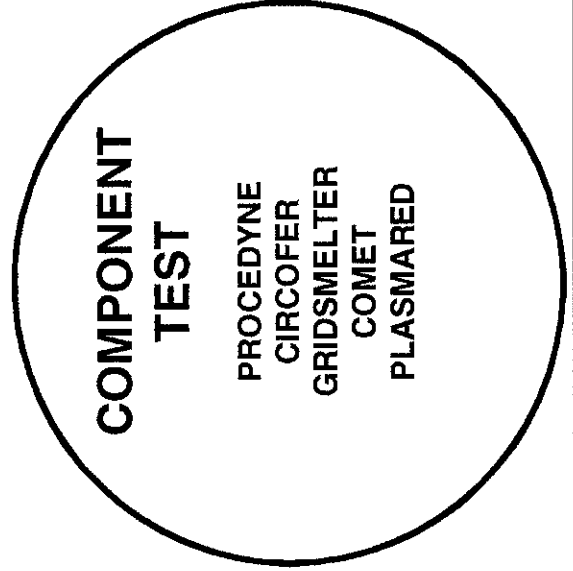
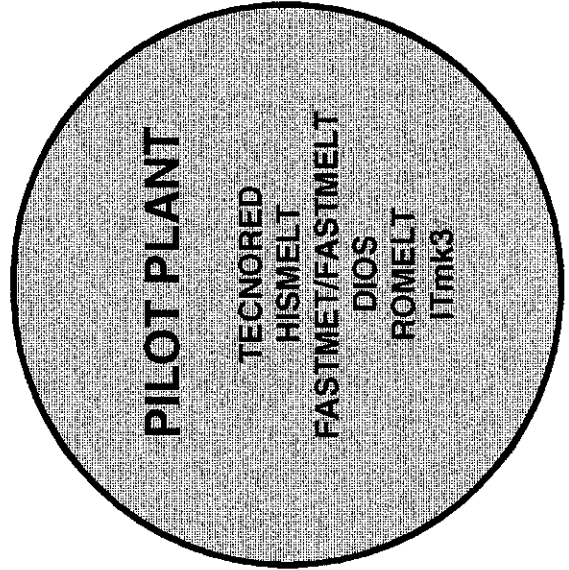
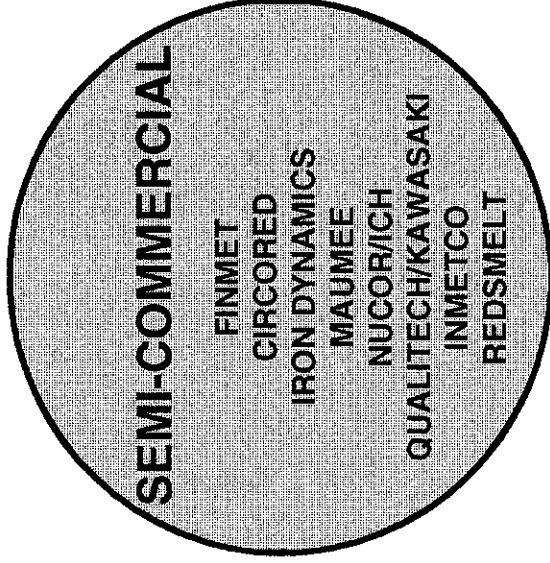
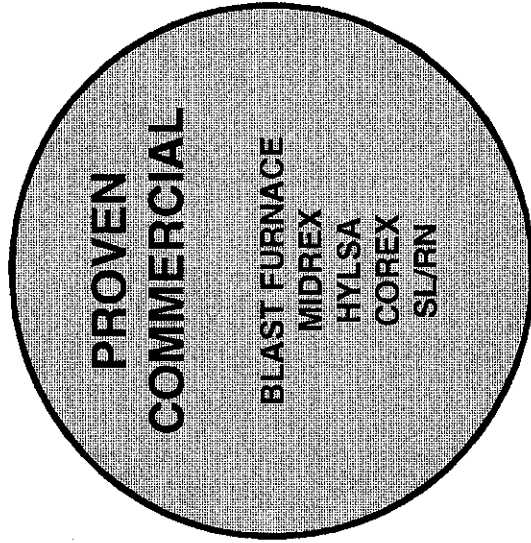
NUCOR/ICH  
QUALITECH/KAWASAKI  
PROCEDYNE

# IRONMAKING PROCESSES BY REDUCTION PROCESS TYPE





# IRONMAKING PROCESSES BY STAGE OF COMMERCIAL DEVELOPMENT



# IRONMAKING PROCESSES BY IRON UNIT FEED MATERIAL

## LUMP ORE/PELLET/BRIQUETTE/ RECYCLE IRON UNITS, ETC.

BLAST FURNACE

COREX

MIDREX

HYLSA

SL/RN

TEGNORED

FASTMET/FASTMELT

ITmk3

REDSMELT

INMETCO

IRON DYNAMICS

MAUMEE

## FINE ORE

FINMET

CIRCORED

CIRCOFER

NUCOR/ICH

QUALITECH/KAWASAKI

PROCEDYNE

HISMELT

DIOS

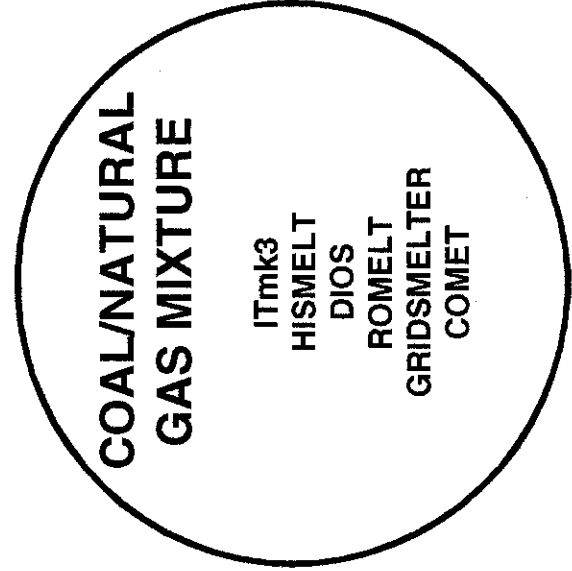
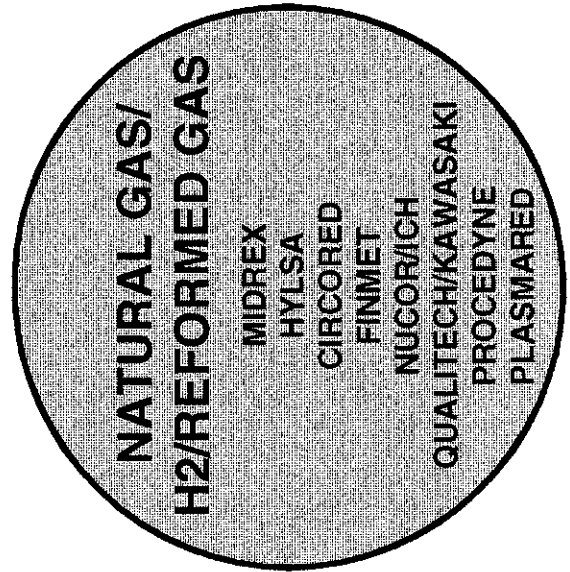
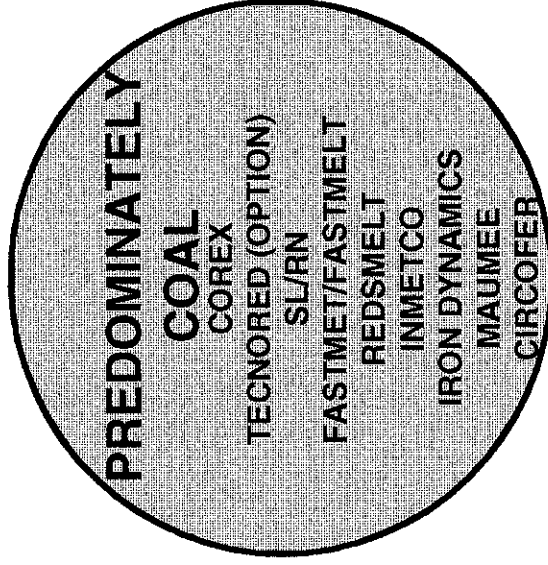
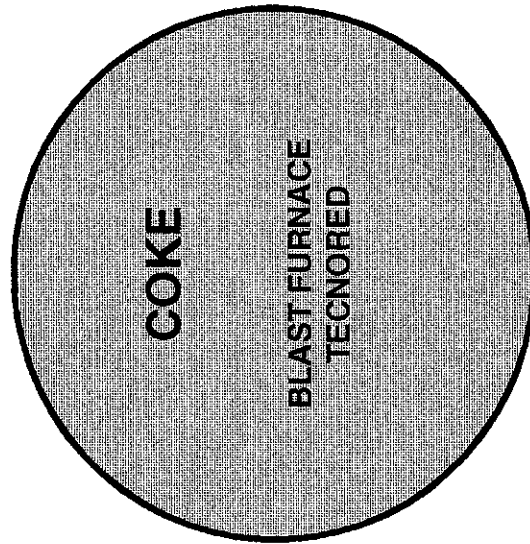
ROMELT

GRIDSMEALTER

COMET

PLASMARED

# IRONMAKING PROCESSES BY PRIMARY REDUCTANT TYPE



# IRONMAKING PROCESSES BY TARGET NOMINAL SIZE OF REDUCTION UNIT/TRAIN

**LESS THAN  
200,000 MTPY**

MAUMEE  
INMETCO  
ROMELT  
GRIDSMELTER  
COMET  
PLASMARED

**200,000 TO  
500,000 MTPY**

TEGNORED  
HISMELT  
IRON DYNAMICS  
SL/RN  
CIRCOFER  
NUCOR/ICH  
QUALITECH/KAWASAKI  
PROGEDYNE

**500,000 TO  
1,000,000 MTPY**

REDSMELT  
FINMET  
CIRCORED  
FASTMET/FASTMELT  
ITMK3  
DIOS

**GREATER THAN  
1,000,000 MTPY**

BLAST FURNACE  
COREX  
MIDREX  
HYLSA