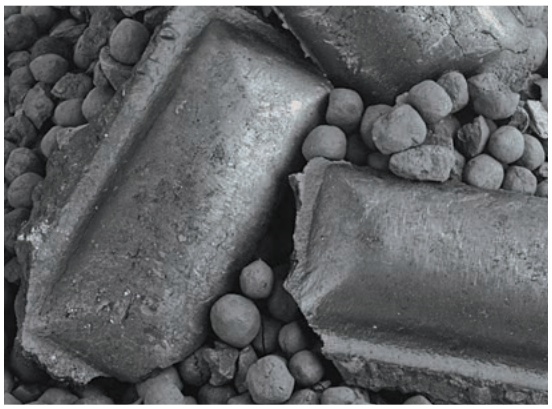
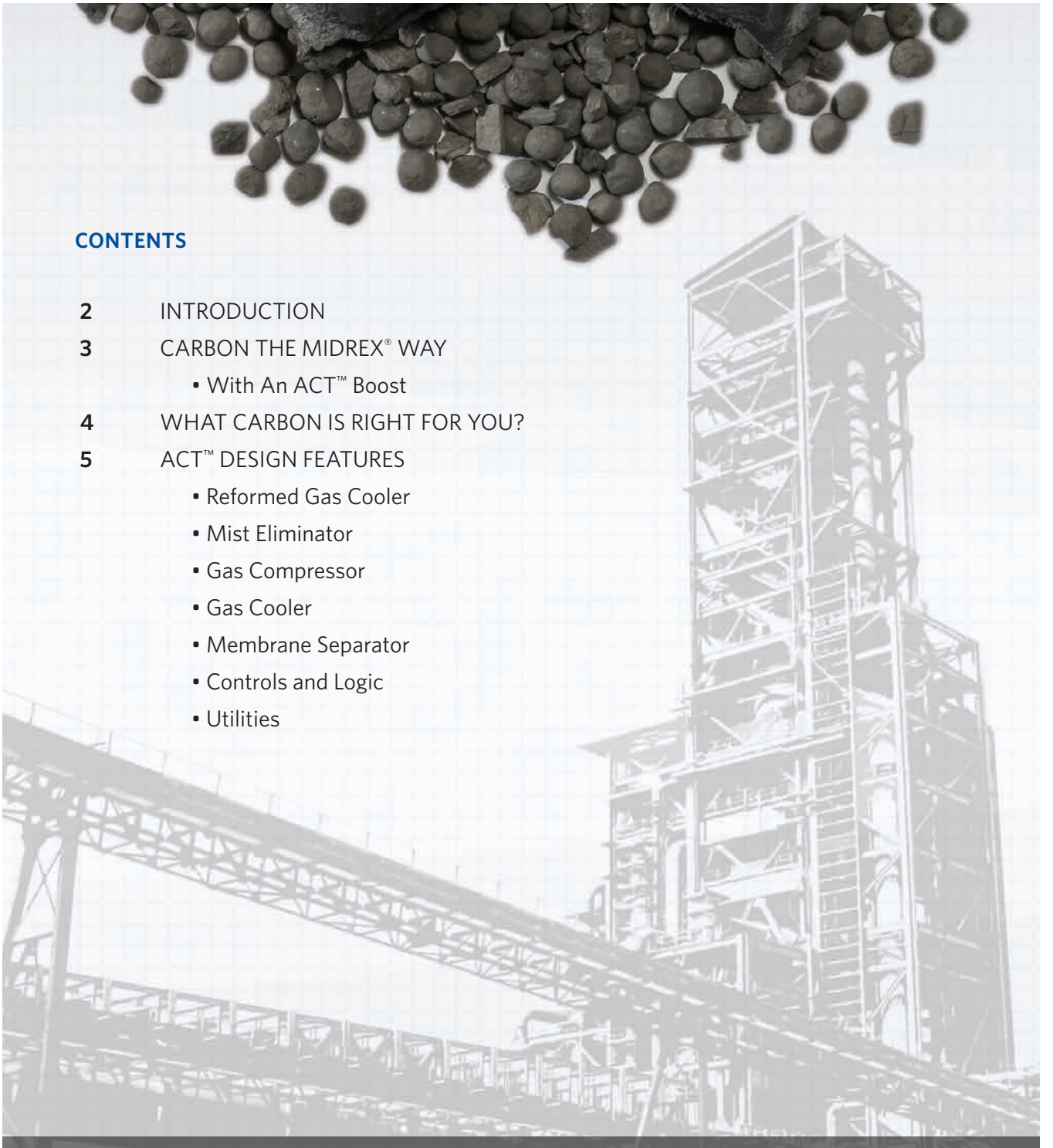
MIDREX



MIDREX ACT™

Achieving Higher Carbon in MIDREX® DRI Products



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ENVIRONMENTAL ASSURANCE

Midrex Technologies, Inc. along with its parent company Kobe Steel, Ltd., recognizes the importance of protecting the environment and conserving natural resources. Through the years we have been proactive in increasing efficiency, productivity, reliability and safety while reducing the environmental impact of our processes.

MIDREX® Plants are designed to minimize water, noise and air pollution.

MIDREX® Plants meet applicable World Bank standards and more importantly, Midrex can and will provide DRI Plants designed to meet any local emissions or environmental standards regardless of location.

MIDREX ADJUSTABLE CARBON TECHNOLOGY – ACT™

• THE FREEDOM TO CHOOSE THE CARBON YOU WANT
• INCREASING CARBON WITHOUT TEMPERATURE LOSS

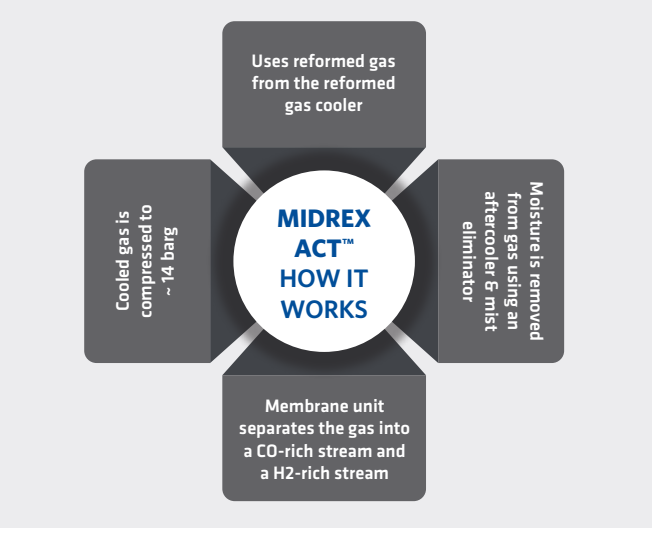
To meet the market interest in DRI products with a wider range of carbon content (from 0.5% and 4.5%), Midrex has introduced the new **ACT™ (Adjustable Carbon Technology)**. This technology is now commercially available and can be added to new plants or retrofitted to existing **MIDREX® Shaft Furnaces** to increase carbon without lowering temperature.

Flexible Carbon

Electric arc furnace (EAF) steelmaking and direct reduced iron (DRI) have been closely associated for half a century.

DRI products are used primarily in EAFs as supplementary iron units for the production of various steel products. Depending on the available metallic charge (scrap, hot metal, pig iron, etc.) and the steel product and grade being manufactured, carbon in the DRI can have a beneficial effect on EAF operation; however, the desired percentage of carbon will vary for each melt-shop.

The new **ACT™** gives **MIDREX® Plants** even greater control over the range of carbon, allowing higher carbon content in the DRI without sacrificing temperature.



DRI PRODUCTS	CDRI	HBI	HDRI
			
Product Form	Pellet & lump	Briquettes* (density ≥ 5.0 grams per cubic centimeter (g/cc)	Pellet & lump
Product Temperature	Ambient	Ambient	550° C or Higher
Where used	EAF & BOF	EAF, BOF & BF	EAF
Charging Method	Continuous & Batch	Continuous & Batch	Continuous & Batch

Carbon the MIDREX® Way

Challenged to develop technology which could adjust carbon content of DRI products while maintaining the product discharge temperature, the Midrex Research and Technology Development group developed the ACT™ concept. In the MIDREX® Shaft Furnace, carbon is added to DRI in three places *(see Figure 1):*

- The reduction zone – In the MIDREX® Process, the main purpose of the reduction zone is to metallize the iron to the desired product metallization using reductants CO and H_2 produced by the MIDREX® Reformer; some carbon is added in the reduction zone derived from CH_4 and CO. Carbon from CH_4 is endothermic (i.e., consumes heat), while carbon from CO is exothermic (i.e., liberates heat).

- The transition zone – A controlled flow of transition zone natural gas is added, which is the main method of adding and controlling the amount of carbon in MIDREX® DRI Products. The natural gas feedstock to MIDREX® Plants contains hydrocarbons, mostly methane, and using methane as an example, the carbon comes by:

$$3Fe + CH_4 \longrightarrow Fe3C + 2H_2 \quad \text{(endothermic)}$$
$$CH_4 \longrightarrow C + 2H_2 \quad \text{(endothermic)}$$

These carbon-forming reactions are endothermic and cool the DRI, it makes it desirable for plants producing CDRI but not necessarily so for plants producing HDRI or HBI.

- The cooling zone – MIDREX® Plants that have a cold discharge furnace use cooling gas to cool the DRI. The cooling gas contains hydrocarbons and carbon is added in a similar manner as in the transition zone.

MIDREX® SHAFT FURNACE

- Iron Oxide pellets and/or lump are fed to top of furnace and flow downward
- Iron Oxide is heated and converted to DRI by a high temperature reducing gas
- Products can be discharged hot or cold in combinations that include CDRI, HBI or HDRI

REACTIONS WITHIN THE MIDREX® SHAFT FURNACE

REACTION	HEAT	DESCRIPTION
$3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2$	Exothermic	Reduction by CO
$3Fe_2O_3 + H_2 \longrightarrow 2Fe_3O_4 + H_2O$	Exothermic	Reduction by H_2
$Fe_3O_4 + CO \longrightarrow 3FeO + CO_2$	Endothermic	Reduction by CO
$Fe_3O_4 + H_2 \longrightarrow 3FeO + H_2O$	Endothermic	Reduction by H_2
$FeO + CO \longrightarrow Fe + CO_2$	Exothermic	Reduction by CO
$FeO + H_2 \longrightarrow Fe + H_2O$	Endothermic	Reduction by H_2
$3Fe + CH_4 \longrightarrow Fe_3C + 2H_2$	Endothermic	Carburizing Reaction
$3Fe + 2CO \longrightarrow Fe_3C + CO_2$	Exothermic	Carburizing Reaction
$3Fe + CO + H_2 \longrightarrow Fe_3C + H_2O$	Exothermic	Carburizing Reaction

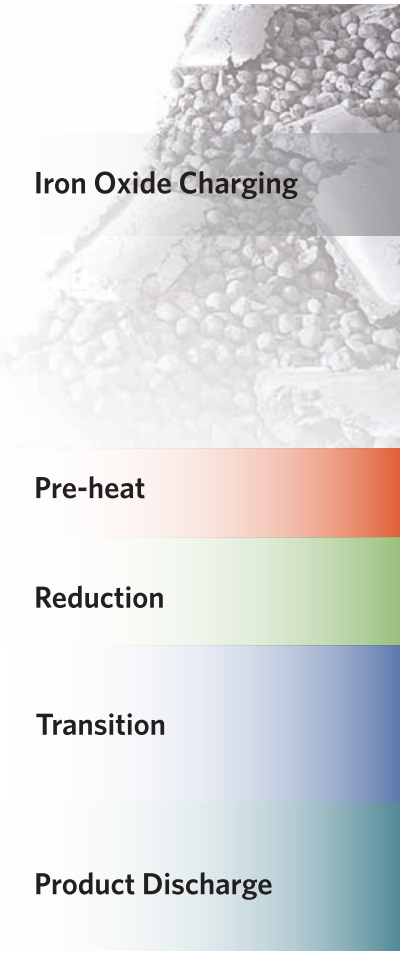


FIGURE 1. *MIDREX® Shaft Furnace*

WITH AN ACT™ BOOST

With the MIDREX ACT™, carbon monoxide (CO), made in the MIDREX® Reformer, is added to the transition zone in the form of a CO-rich gas stream. The CO contacts the DRI bed and the resulting exothermic reactions provide extra energy:

$$3Fe + CO + H_2 \longrightarrow Fe_3C + H_2O \quad \text{(exothermic)}$$
$$3Fe + 2CO \longrightarrow Fe_3C + CO_2 \quad \text{(exothermic)}$$
$$CO + H_2 \longrightarrow C + H_2O \quad \text{(exothermic)}$$
$$2CO \longrightarrow C + CO_2 \quad \text{(exothermic)}$$

Transition zone natural gas is added along with the CO-rich stream, using the CO-generated energy to provide the energy to produce additional carbon without sacrificing temperature:

$$3Fe + CH_4 \longrightarrow Fe_3C + 2H_2 \quad \text{(endothermic)}$$
$$CH_4 \longrightarrow C + 2H_2 \quad \text{(endothermic)}$$

By adjusting the amount of CO in the transition zone, the plant operator can adjust the amount of energy added to the HDRI. Adjusting the natural gas addition will control the carbon content of the DRI. Using these simple principles, this technology allows for independent control of the temperature increase and amount of carbon added.

CARBON ENRICHMENT IN FURNACE TRANSITION ZONE

A CO-rich gas stream is sent to the transition zone, where the exothermic reactions generate heat (and some carbon deposition) and the endothermic reactions deposit carbon, thus increasing the carbon content of the DRI product:

- Carbon level up to 4.5%
- Maintain product discharge temperature

WHAT CARBON IS RIGHT FOR YOU?

Based on the individual needs of their steelmaking operation or the merchant metallic markets they serve, MIDREX® Plants have different operational requirements and goals. The MIDREX ACT™ will enable MIDREX® Plants to produce cold DRI (CDRI), hot briquetted iron (HBI) or hot DRI (HDRI) with higher carbon content while maintaining a consistent discharge temperature. 85-90% of the carbon created by the MIDREX ACT™ will be in the form of iron carbide (Fe_3C).

The MIDREX ACT™ increases product flexibility of existing or new MIDREX® Plants by providing an independent means to increase the carbon level of the DRI products or to increase the discharge temperature at a given carbon level. For applications where higher carbon is desired, the amount of carbon added is controllable and the DRI discharge temperature is maintained.

WITH THE MIDREX ACT™, A MIDREX® PLANT WILL HAVE THE ABILITY TO:

- Produce CDRI with higher carbon content.
- Produce HDRI with either higher carbon or at higher temperature or both.
- Produce HBI with higher carbon content without detrimental loss of temperature at the briquetting machine or increasing briquetting temperature at a given carbon content.
- Merchant plants (CDRI and HBI) can tailor their product chemistry and produce a value-added product to the specifications of their end users.
- Flexibility to chose to operate with the MIDREX ACT™ when higher carbon levels are desired or to operate without the MIDREX ACT™ when lower carbon levels are desired.

The MIDREX ACT™ is designed for retrofitting into existing plants, as well as installing in new plants. The equipment used in the technology is well proven, and the design is of the same robust nature as all MIDREX® Technology solutions.

ACT™ DESIGN FEATURES

THE **MIDREX ACT**™ STARTS BY DIVERTING A PORTION OF THE REFORMED GAS, WHICH IS RICH IN H_2 AND CO TO THE REFORMED GAS COOLER. A SIMPLIFIED FLOWSHEET IS SHOWN BELOW. EVERYTHING SHOWN TO THE LEFT OF THE MIDREX® SHAFT FURNACE IS ALREADY A PART OF THE MIDREX® PLANT. THE EQUIPMENT LOCATED TO THE RIGHT OF THE SHAFT FURNACE IS PART OF THE **MIDREX ACT**™. ALL OF THE EQUIPMENT EMPLOYED IN MIDREX ACT IS WELL PROVEN.

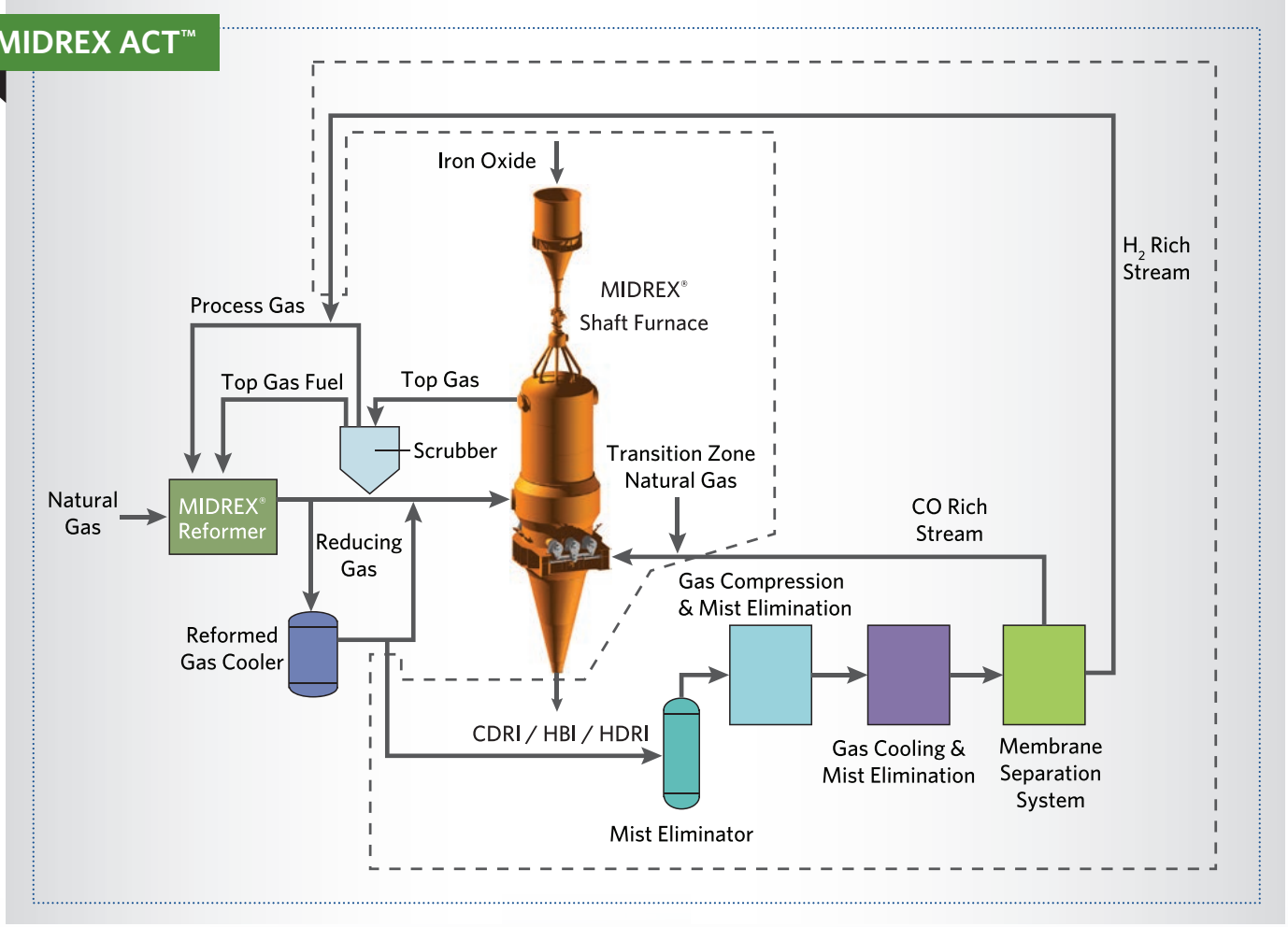


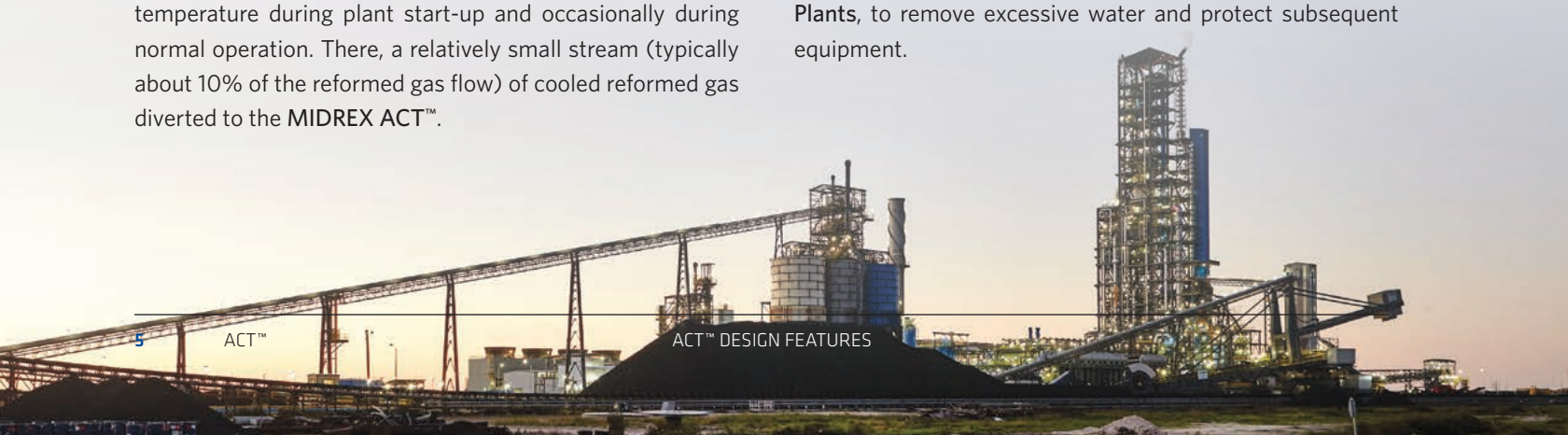
FIGURE 2. *Simplified ACT™ Flowsheet*

REFORMED GAS COOLER

All new MIDREX® Plants (and most existing ones) have a reformed gas cooler, which is used to control bustle gas temperature during plant start-up and occasionally during normal operation. There, a relatively small stream (typically about 10% of the reformed gas flow) of cooled reformed gas diverted to the MIDREX ACT™.

MIST ELIMINATOR

The cooled reformed gas is then sent to a mist eliminator, which is similar in design to ones already used in MIDREX® Plants, to remove excessive water and protect subsequent equipment.



GAS COMPRESSOR

The gas is then compressed to approximately 14 barg. This pressure is needed for the downstream membrane unit.

GAS COOLER

The gas from the compressor is hotter than needed for the downstream membrane unit, so it is cooled by a syngas aftercooler and the mist is removed by a mist eliminator, similar to equipment already used by Midrex.

MEMBRANE SEPARATOR UNIT

The gas, having been suitably compressed and cooled, enters the membrane unit. This technology, which is used in gas separation industries, employs a pressure difference to selectively allow some of the gas components in the feed stream to permeate across a membrane, separating the feed into two product streams. In this case, a CO-rich stream and a H_2-rich stream are produced. The CO-rich stream is sent to the transition zone, where the exothermic reactions generate heat (and some carbon deposition) and the endothermic reactions deposit carbon. The H_2 rich stream (i.e., the low-pressure stream from the membrane unit) is recycled to the discharge of the process gas compressors. The gas entering the membranes is cleaned and suitably conditioned within the membrane system, the features of which have been tailored for the MIDREX® Process.

CONTROLS AND LOGIC

The amount of carbon added to the MIDREX® DRI Products is adjusted by the flowrate of gas to the membrane unit (affecting mostly temperature) and the flowrate of transition zone natural gas (affecting mostly carburization), which provides operators an independent control loop for carbon and temperature.

The necessary engineering was performed for piping, controls, instrumentation, gas composition measurements, isolation and control logic for normal operation, start-up, shutdown and isolation of the MIDREX ACT™.

UTILITIES

The MIDREX ACT™ has the following utilities requirements:

- Electricity – Electrical consumption for the MIDREX Plant will increase approximately 20 kWh/ton of DRI due mainly to the compressor and the electric heater in the membrane unit.
- Cooling water – Machinery cooling water is needed for compressor cooling and the syngas aftercooler.
- Nitrogen – A small amount of nitrogen is needed intermittently for system purging.
- Instrument Air – A small amount of instrument air is needed for control valves.

MIDREX ACT™ BENEFITS

- Can be used in every type of **MIDREX® Plant** (CDRI, HDRI, HBI or a combination)
- Allows amount of carbon in DRI to be adjusted up or down
- Carbon can be added without cooling the DRI
- 85-90% of the carbon in the DRI products will be in the form of iron carbide (Fe_3C)
- Can be retrofitted into existing **MIDREX® Plants**, as well as included in new **MIDREX® Plants**
- Can be turned on and off to suit the desired carbon level without disrupting plant operation (i.e., **MIDREX® Process** can operate with or without it)

MIDREX

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