

# Coal gasification for DRI production – An Indian solution

India's limited supplies of natural gas and abundant supplies of thermal coal make it an ideal location for combining direct reduction plant with a coal gasifier as Jindal Steel & Power has recently decided to adopt. **By Rob Cheeley\* & Markus Leu\*\***

APPROXIMATELY 58% of India's steel is currently produced in electric furnaces – induction furnaces (IF) as well as electric arc (EAF). Given the lack of domestic scrap and the good availability of iron ore, thermal coals and natural gas, direct reduction has provided much of the iron units required for growth in steel production. Direct Reduced Iron (DRI) production has increased tremendously since 1980, from essentially zero to over 21Mt in 2008, as shown in Fig 1. Of the total DRI production in 2008, 74% was produced from coal in rotary kilns and 26% from natural gas in shaft furnaces. India is now the world's largest producer of DRI.

Currently, there are two primary means of DRI production in India: small-scale rotary kilns using local coal and iron ore lump, and large-scale shaft furnace plants using natural gas and iron oxide pellets and lump. In recent years, almost all the growth in DRI production has been due to the installation of rotary kiln facilities and there are now over 350 of these plants. Many are small-scale and it is believed that over 100 have capacities from 10 -20kt/y. There are only seven natural gas-fired shaft furnace plants – including six Midrex® Direct Reduction Modules – but they produce 25% of the total DRI in India.

## Future Steelmaking Growth

For India to grow its steel production significantly, what are the options? Direct reduction using coal-fired rotary kilns or natural gas-fired shaft furnaces are logical choices as production in blast furnaces is constrained by the need to import coking coal. Rotary kiln DRI capacity has been installed because it makes use of domestic iron ore and coal, but there is a limit to the growth of this technology because rotary kilns cannot be built larger than about 200kt/y. Thus, it is probably not feasible to build a steel mill to produce 1Mt/y or more via this route. Also, there are product quality issues because of the use of lump ore and coal with high levels of ash and sulphur. Direct reduction plants using natural gas would be an ideal choice, but there

is little additional natural gas available for further expansion.

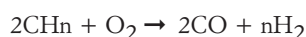
## Coal Gasification Option

An alternative option generating significant interest in India is the use of a coal gasification plant in combination with a Direct Reduction plant. The coal gasification plant would use local Indian coals to generate a synthesis gas (or syngas) that can be an acceptable reducing gas source for producing DRI in a shaft furnace.

## Coal Gasification

There are three general types of coal gasifiers: fixed bed, entrained flow, and fluidised bed. All three technologies are based on partial oxidation (gasification) of a carbonaceous (carbon containing) feed material.

The general partial oxidation reaction is:



In addition to the desired CO and H<sub>2</sub>, the syngas exiting a gasifier also contains CO<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub>, H<sub>2</sub>S, NH<sub>3</sub>, and particulates. If a fixed bed gasification technology is used, the syngas will also contain aromatic organic compounds.

While each of the gasifier types can make an acceptable reducing gas for a DR plant, the fixed bed and fluidised bed technologies are the preferred choice for India because they can accommodate the high ash domestic coals. The leading fixed bed process is the Lurgi Gasification process, licensed by Lurgi Clean Coal Technology Company. The Lurgi Gasification technology is well-proven, with over 102 gasifiers in commercial operation worldwide, the earliest of these built in 1955. Eighty of these units are deployed in South Africa, using high ash coals very similar to Indian coals (Fig 2).

## Lurgi Coal Gasification

In the Lurgi Gasification process, coal is gasified at elevated pressures by reacting with high pressure steam and high purity oxygen to produce a syngas suitable for the production of fuels and chemicals. The gasifier operates at a temperature below the ash melting point so the coal ash is discharged from the gasifier as a solid. Because of this low operating temperature, the Lurgi Gasification process requires significantly lower quantities of oxygen than the entrained flow gasification processes which melt the ash.

The syngas exiting the gasifier is hot, dirty,

<b>Operating pressure</b>	<ul style="list-style-type: none"> <li>• 20-40 barg</li> </ul>
<b>Feedstocks/ Utilities</b>	<ul style="list-style-type: none"> <li>• Lump coal (5-50mm)</li> <li>• Oxygen (approx 99 mol%)</li> <li>• High pressure (HP) steam</li> </ul>
<b>Gas Cleaning &amp; Conditioning</b>	<ul style="list-style-type: none"> <li>• Hot syngas is cleaned and cooled by a direct contact water scrubber, followed by indirect air cooling and water cooling</li> <li>• Trace components, most of the sulphur (as H<sub>2</sub>S), and a significant amount of the CO<sub>2</sub> are removed by a Lurgi Rectisol® unit at the tail end of plant</li> <li>• Sulphur is recovered in an OxyClaus® process with Claus tail gas processed in an LTGT® process, achieving &gt;99% sulphur recovery.</li> </ul>
<b>Produces valuable and saleable co-products</b>	<ul style="list-style-type: none"> <li>• Phenols</li> <li>• Ammonia</li> <li>• Coal oil</li> <li>• Elemental sulphur</li> <li>• Low pressure (L P) steam</li> </ul>

Table 1 Characteristics of the Lurgi Gasification plant

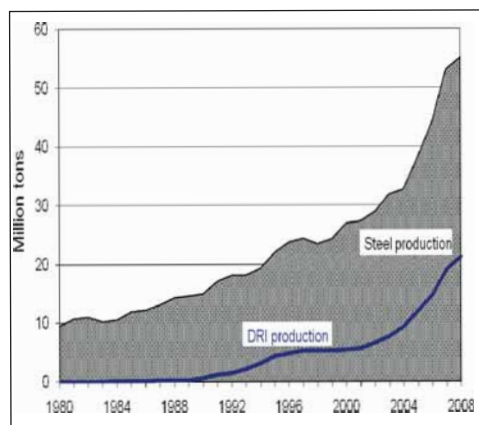
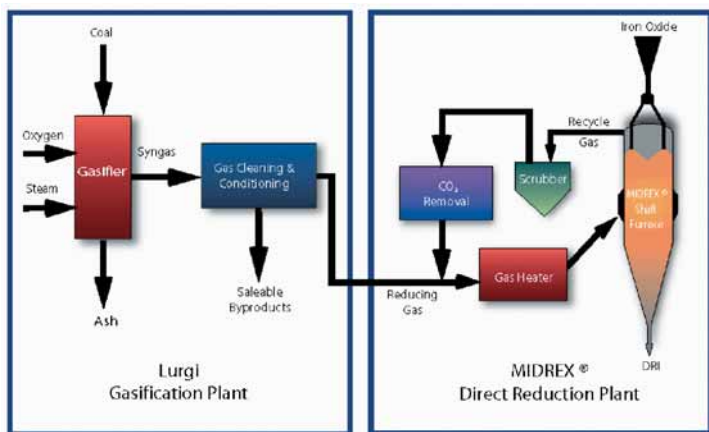


Fig 1 Growth of steel and DRI production in India

Fig 2 Lurgi coal gasifiers at Secunda, South Africa



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**Fig 3 Simplified Lurgi Gasification plant supplying Midrex DRI module**

**Fig 4 Inclined hot transport conveyor at Hadeed Module E**



and contains a significant amount of non reducing gas components. Downstream of the gasifier, the syngas is cleaned and conditioned to remove most of the undesired components, many of which are saleable byproducts that can be used as petrochemical plant feedstocks.

**Fig 3** contains a simplified process flowsheet for combining the Lurgi Coal Gasification technology with a Midrex plant.

**Table 1** summarises the major characteristics of the Lurgi Gasification plant.

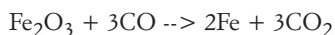
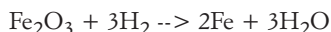
### Midrex plant with syngas

The high pressure syngas exiting the Lurgi gasification plant contains approximately 85%  $H_2+CO$ , 2.5%  $CO_2$ , and 12.5%  $CH_4$ . The  $H_2/CO$  ratio is about 1:6, which is the same as used in a natural gas-based Midrex plant after reformation.

In the Midrex plant, the cold syngas is first depressurised to about 3 barg. If the syngas flowrate is high enough, it may be economical to use a turbine generator to depressurise the syngas so as to recover energy as electricity.

The low pressure syngas is then mixed with recycled gas to produce the required reducing gas. The mixed syngas is then heated to over 900°C. The hot reducing gas enters the shaft furnace where it reacts with the iron oxide to produce DRI.

The reduction reactions are:



The spent reducing gas (top gas) exiting the shaft furnace is scrubbed and cooled, then passed through a  $CO_2$  removal system. This reduces the  $CO_2$  content to 5% or less, which ensures that the mixed reducing gas (syngas from the gasification plant and recycled top gas from the Midrex plant) has an acceptably high reductants ( $H_2+CO$ ) to oxidants ( $H_2O+CO_2$ ) ratio for efficient iron oxide reduction. The  $CO_2$  removal system will also remove the sulphur gases contained in the recycled top gas.

### DRI Hot Transport

The DRI can be discharged from the Midrex shaft furnace at temperatures up to 700°C. Many of the newer DRI plants are designed to transport the hot DRI to a nearby electric arc furnace to take advantage of the available sensible heat. Depending on the distance from the plant to the steel mill, there are different options for method of hot DRI transport. **Table 2** identifies which hot transport option is recommended.

DRI Transport Distance (m)	Hot Transport Mode
0 – 40	HOTLINK®
40 – 200	Hot Transport Conveyor or Hot Transport Vessels
> 200	Hot Transport Vessels

**Table 2 Hot charging links to EAF**

Input	Units	Quantity hot DRI
Iron Ore	t	1.42
Coal (as mined) <sup>4</sup>	t	0.75
Coal (ash free) <sup>4</sup>	t	0.41
HP steam	t	0.6
LP steam	t	0.4
Oxygen	Nm <sup>3</sup>	150
Nitrogen	Nm <sup>3</sup>	200
Electricity	kWh	175
Maintenance & indirect costs	USD	10

**Table 3 Predicted major operating consumptions for Indian conditions for 1.8Mt/y module with hot DRI charging and Lurgi gasifier**

*The Hotlink process* primarily uses gravity to feed DRI from the Midrex Shaft Furnace into storage bins located directly above the EAF. This hot transport mode requires the bottom of the Midrex Shaft Furnace to be at a higher elevation than the EAF. The Hotlink Process is under construction at ESISCO in Egypt and at Shaded in Oman.

*Hot Transport Conveyor:* The hot transport conveyor option continuously transports HDRI from the discharge of the Midrex Shaft Furnace via an inclined bucket conveyor into inerted storage bins located directly above the EAF. For this hot transport mode, the Midrex Shaft Furnace discharge can be at a significantly lower elevation than the EAF. This hot transport mode is operating at Hadeed Module E in Saudi Arabia. **Fig 4** shows the Hot Transport Conveyor option at Hadeed Module E. The conveyer can be seen linking the Midrex Shaft Furnace (right) to the melt shop (left).

*Hot Transport Vessel:* In the hot transport vessel option, the HDRI exiting the Midrex Shaft Furnace is discharged into refractory-lined containers. These containers are then transported by truck or rail to the steel mill. At the steel mill, a crane is used to lift the containers above the EAF so that the HDRI can be discharged directly into the furnace. The hot transport vessel approach has been used by Essar Steel since

1998 and is also operating at the Lion Group plant in Malaysia.

### Midrex plant capacities

Midrex plants can be designed and built for a wide range of DRI capacities. Modules are currently being designed with nominal capacities ranging from 400kt/y to 2.2Mt/y.

To be commercially viable to link to a coal gasification plant a module size of at least 1Mt/y is recommended.

Forty-six Midrex DR Modules presently in operation have rated capacities between 400kt/y and 800kt/y (six more are under construction), seven operating Midrex Modules have rated capacities between 1.0 to 1.4Mt/y (one more is under construction), and five have rated capacities of 1.5Mt or higher (three more are under construction). Hadeed Module E is presently the largest Midrex plant, with a rated capacity of 1.76Mt/y and has been operating since 2007. This Module uses the Hot Transport Conveyor concept to deliver hot DRI at > 600°C into the EAF.

Predicted operating consumptions are presented in **Table 3** for:

- The hot DRI product characteristics are: 93% metallization, 1.8% carbon, and 700° C discharge;
- Quantities are for the combined Lurgi Gasification plant and Midrex DR plant;
- The consumption values will vary depending on the actual coal quality and the project requirements;
- Value assumes typical high ash Indian coal.

In conclusion, combining the Lurgi Gasification technology with the Midrex Direct Reduction Process is a viable solution in India.

Advantages of the combined Lurgi Gasification plant plus Midrex plant in India include:

- Uses well-proven Lurgi Gasification and Rectisol® technologies. The Lurgi Gasifier can readily use the low rank, high ash domestic Indian coals as feed material.
- Uses well-proven Midrex direct reduction process. This technology can readily use domestic Indian iron oxides as feed material.
- Produces DRI with quality comparable to natural gas-based Midrex plants
- The DRI can be hot charged into a nearby EAF to significantly reduce electricity requirement and significantly increase EAF productivity.
- The Lurgi Gasification plant + Midrex plant combination can be paired with an EAF-based minimill to produce high quality long or flat steel products.
- No coke, coke ovens, or sinter plant required.

### JSPL to install Midrex-Lurgi plant

Jindal Steel & Power Ltd (JSPL) announced in December 2009 that it will build a 1.8Mt/y Midrex DR plant with a Lurgi coal gasification plant to supply the reductant gas in Angul, Orissa, India. The Midrex module will pair commercially available gasification technology from Lurgi of Germany, together with a 7.15m diameter shaft furnace to produce direct reduced iron (DRI) for use in meltshop applications. This will be the first time a Lurgi gasifier will be paired with a Midrex shaft furnace; the new installation will use domestic coal and iron ore.

The Midrex module will have the flexibility to produce both cold and hot DRI (HDRI) for a new greenfield meltshop to be supplied by SMS Siemag of Germany and will use a hot transport conveyor similar to that installed at Hadeed Module E in Saudi Arabia. This system is supplied by Aumund Fördertechnik of Germany.

The world's first application of coal gasification to produce DRI in a Midrex plant started up in 1999 at ArcelorMittal Steel South Africa (formerly Saldanha Steel). This facility includes a Corex plant, supplied by Siemens VAI, which uses a melter/gasifier to simultaneously produce pig iron and a by-product synthesis gas that feeds a Midrex Megamod shaft furnace.

The coal gas Midrex DR plant is an economical and environmentally sound solution for the iron and steel industry in areas of the world where natural gas as a fuel is not a viable option.

A coal gasification plant can use a wide range of low cost fuels, such as bituminous and sub-bituminous coal, lignite, pet coke, and petroleum refinery bottoms to generate a synthesis gas.

- Lower specific capital cost than a traditional BF-BOF integrated steel works.
- Lower air emissions than an integrated steel works.
- Ability to capture high purity CO<sub>2</sub> for sequestering or injecting into oil and gas fields.
- Much larger capacities than rotary kilns: up to 2.2Mt/y in a single module.
- Higher quality DRI product than rotary kilns. ■

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