Coke

FFF Coal Coke & Carbon in the Met. Ind.
13 – 14 June

Hannes Kruger
Principal Specialist Coke Making
ArcelorMittal South Africa
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  - How big is coke?
- Applications of coke
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  - Test methods
  - Control of properties
- Production of coke
  - Slot ovens
  - Non recovery ovens
  - Other technologies
- Commercial/VIU
- Questions?
Introduction

What is coke?

• Coke is the residue that remains when coking coal is distilled in the absence of oxygen. Coking coal is distinguished from other coal by its fluidity and caking ability at intermediate temperatures.

• Coke is the fuel, reductant and burden support in the blast furnace, and it give gas permeability in the shaft, cohesive zone and tuyere raceway area of the furnace (AM)

• the solid residue - hard, strong & porous - formed when bituminous coal is heated strongly in the absence of air (ResourceNet)
Introduction
How big is coke?

- World coke capacity in 2011 about 731 mtpa
- Actual production <700 mtpa due to crisis

<table>
<thead>
<tr>
<th>Region</th>
<th>2006</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>56.0</td>
<td>49.2</td>
<td>51.0</td>
</tr>
<tr>
<td>FSU / CIS</td>
<td>69.3</td>
<td>64.5</td>
<td>66.4</td>
</tr>
<tr>
<td>North America</td>
<td>23.4</td>
<td>22.9</td>
<td>22.4</td>
</tr>
<tr>
<td>Latin America</td>
<td>12.0</td>
<td>15.9</td>
<td>16.4</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>4.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Maghreb &amp; Middle East</td>
<td>7.8</td>
<td>7.2</td>
<td>7.7</td>
</tr>
<tr>
<td>Asia</td>
<td>409.1</td>
<td>537.1</td>
<td>560.1</td>
</tr>
<tr>
<td>Asia excl China</td>
<td>83.6</td>
<td>96.6</td>
<td>99.6</td>
</tr>
<tr>
<td>Australasia</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>585.0</td>
<td>703.8</td>
<td>731.0</td>
</tr>
<tr>
<td><strong>Net Change YoY</strong></td>
<td>+23.2</td>
<td>+27.2</td>
<td></td>
</tr>
</tbody>
</table>

- Most capacity and growth in China, with India to follow
- Sub-Saharan capacity in table equal Southern Africa (ResourceNet, 2011)
Applications of coke
Overview-1

- Coke is used widely in many industries where a reductant is required, see next slide.
- In tonnages the use of coke is dominated completely by the production of pig iron; >>90%.
- However, in Southern Africa the coke consumption of the combined Ferro Alloys and base metals is approximately 35% of total coke use; making them much more important than in rest of the world.
## Applications of coke

### Overview

<table>
<thead>
<tr>
<th>Grade</th>
<th>Replacements</th>
<th>Approx Coke Rate – a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig Iron</td>
<td>Injection of pulverized coal (PCI) or other materials into the blast furnace can cut coke rate down to 0.3-0.35 per tonne HM.</td>
<td>0.5</td>
</tr>
<tr>
<td>Ferrochrome</td>
<td>Gas coke and char in South Africa cut coke rate by up to 50%. Phos content critical (&lt;0.015%) adding to constrained supply.</td>
<td>0.65-0.7</td>
</tr>
<tr>
<td>Manganese Alloys</td>
<td>Technically, more possibility to reduce coke in Mn alloys than FeCr production. Anthracite and coal are main replacements.</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Calcium Carbide</td>
<td>Petroleum coke and anthracite are main replacements. European capacity being progressively closed.</td>
<td>0.6</td>
</tr>
<tr>
<td>Base Metals</td>
<td>Some smelting processes for lead, zinc and copper use coke, but are increasingly being phased out on cost and environmental grounds.</td>
<td>various</td>
</tr>
<tr>
<td>Soda Ash, Sugar</td>
<td>For carbon dioxide production in lime kilns. Coke can be replaced up to 100% with anthracite in this application.</td>
<td>Low (&lt;0.15)</td>
</tr>
</tbody>
</table>

(Production of elemental phosphorous and silicon carbide also require carbon reductants.)

\[a – \text{with no coke replacement}\]

www.resource-net.com
Applications of coke
Blast Furnace – Basics-1

- Blast Furnaces are a critical (and visible) part of all integrated steel plants
- Very high structure, >50 m
- BF Gas off take pipes and the flare platform
- Raw material supply to the top of the furnace
- Much was learned from planned freezes of several BFs in Japan in 70s
Applications of coke
Blast Furnace – Basics-2

Brief description

- In BF, iron ore and reducing agents (coke, coal) are transformed to hot metal and slag (ore burden gangue, coke and coal ashes)
- Hot metal and slag don’t mix, slag floating on top of higher density hot metal
- BF is a counter current reactor where hot gases coming from the bottom, heat iron ore and coke in order to start chemical solid/gas and solid/liquid reactions.
- Heat source is the combustion of carbon (coke and coal)

Sample BF Parameters

- **Fukuyama n° 5**
  - High 32 m
  - Internal diameter 14,4 m
  - Volume 3 930 m³
- **Input**
  - Iron ores 1 600 kg/t.h.m.
  - Coke 250 to 300 kg/t.h.m.
  - Injected coal 180 to 230 kg/t.h.m.
  - Blown air 1 000 Nm³ (1550 K)
- **Output**
  - Hot metal
    - Productivity ~ 12 000 t/d
    - (1760 to 1800 K) iron (4-5%C)
  - Slag 320 kg/t
  - Gas (CO 22%, CO₂ 22%, H₂ < 5%)
Applications of coke

Blast Furnace – Ideal coke quality

- H2O, ash: impact on mass & heat balance and BF process & stability
- S and P: impact cost of removal at steel shop
- K2O: Impact BF process & stability (total reducing agent rate) + steel shop impact (S removal)
- Coke size: impact on I 40, which impacts PCI rate and BF productivity
- Coke cold strength I 40 and I 10 : impact on PCI rate (cost of reductants) and on stability in BF .
- Coke strength after reaction (CSR): impact on rate of reducing agents.
- Smaller BFs and lower PCI rates allow lower coke specifications

<table>
<thead>
<tr>
<th>chemical analysis</th>
<th>specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2O</td>
<td>&lt;4%</td>
</tr>
<tr>
<td>Ash</td>
<td>&lt;11%</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>&lt;0,7%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>&lt;0,75%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>&lt;0,04%</td>
</tr>
<tr>
<td>K2O</td>
<td>&lt;0,15%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size: ISO Standard</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>%&lt;25mm</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>%&lt;40mm</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>%&gt;90mm</td>
<td>&lt;5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical strength: ISO standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>I10</td>
</tr>
<tr>
<td>I40</td>
</tr>
<tr>
<td>M10</td>
</tr>
<tr>
<td>M40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coke strength after reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSR</td>
</tr>
<tr>
<td>CRI</td>
</tr>
</tbody>
</table>

FFF Coke 10 October 2012
### Applications of coke

**Blast Furnace – Real coke quality**

#### Export coke qualities

*(ResourceNet, 2011)*

<table>
<thead>
<tr>
<th>Physical Analysis:</th>
<th>Australia</th>
<th>China</th>
<th>Colombia</th>
<th>Japan</th>
<th>Poland</th>
<th>Russia</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke Strength after Reaction (CSR) %</td>
<td>70-73</td>
<td>58-70</td>
<td>&gt;65</td>
<td>60-62</td>
<td>57-63</td>
<td>62-64</td>
<td>48-52</td>
</tr>
<tr>
<td>Drum Strength M40 %</td>
<td>84-90</td>
<td>82-91</td>
<td>75-83</td>
<td>&gt;80</td>
<td>75-82</td>
<td>80-82</td>
<td>76-78</td>
</tr>
<tr>
<td>Drum Strength M10 %</td>
<td>6-7</td>
<td>6-8</td>
<td>7-8.5</td>
<td>&lt;8</td>
<td>6-7</td>
<td>7.5-8.5</td>
<td>7.5-8.5</td>
</tr>
</tbody>
</table>

#### Chemical Analysis:

<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th>China</th>
<th>Colombia</th>
<th>Japan</th>
<th>Poland</th>
<th>Russia</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash %</td>
<td>11.5-12.0</td>
<td>11.0-13.5</td>
<td>10.0-12.0</td>
<td>10.0-10.5</td>
<td>8.5-10.0</td>
<td>11.0-12.5</td>
<td>11.0-12.0</td>
</tr>
<tr>
<td>Volatile Matter %</td>
<td>0.2-0.5</td>
<td>1.2-1.5</td>
<td>1.0-2.0</td>
<td>0.55-0.75</td>
<td>&lt;1.0</td>
<td>0.8-1.0</td>
<td>0.7-1.0</td>
</tr>
<tr>
<td>Sulphur %</td>
<td>0.35-0.45</td>
<td>0.50-0.55</td>
<td>0.75-0.85</td>
<td>0.60-0.70</td>
<td>0.50-0.70</td>
<td>0.45-0.55</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>Phosphorous %</td>
<td>0.07-0.09</td>
<td>0.025-0.030</td>
<td>0.03-0.04</td>
<td>0.03-0.04</td>
<td>0.055-0.065</td>
<td>0.03-0.04</td>
<td>0.015-0.02</td>
</tr>
<tr>
<td>Alkalis %</td>
<td>&lt;0.12</td>
<td>0.25-0.40</td>
<td>-</td>
<td>0.17-0.20</td>
<td>0.35-0.45</td>
<td>0.35-0.45</td>
<td>0.30</td>
</tr>
<tr>
<td>Fixed Carbon %</td>
<td>87.0-87.5</td>
<td>85.5-88.0</td>
<td>85.0-87.0</td>
<td>88.0-90.0</td>
<td>88.0-89.0</td>
<td>87.0-88.0</td>
<td>87.0-88.0</td>
</tr>
</tbody>
</table>
Applications of coke
Ferro Alloys

• There are 4 furnace technologies in use for FeCr production
• The reductants are used in different ratios for different furnaces and different alloys
• The desirable properties for the reductants and coke overlap, but differ from BF coke
• Coke is by far the most expensive of the reductants and are therefore minimized
• Coke is either sourced as “by-product” nut coke from BF coke production or from dedicated production from cheaper coking coals

FeCr Furnace technologies
– Conventional Process
– C Arc Furnace Process
– Outokumpu Process
– Premus Process

Reductants
– Coal
– Anthracite
– Char
– Coke

Reductant qualities
– Low gas phase reactivity
– High Liquid phase reactivity
– High electrical resistivity
– Low sulphur, phosphorous, ash and volatile matter
Applications of coke
Ferro Alloys-2

- The FeCr coke clients are not primarily interested in BF coke strength indexes; see AMSA coke specification below.
- Actual coke analysis in table on right. Note low strength indexes.
- Import coke offer several benefits to especially the FeMn smelters.

<table>
<thead>
<tr>
<th>Chemical Analyses</th>
<th>Typical Chemical Analyses</th>
<th>Rejection Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatiles</td>
<td>0.6%</td>
<td>2.0% Max</td>
</tr>
<tr>
<td>Ash</td>
<td>16.5%</td>
<td>18.0% Max</td>
</tr>
<tr>
<td>Dry Fixed Carbon</td>
<td>83.0%</td>
<td>82.0% Min</td>
</tr>
<tr>
<td>Phosphorus (As P)</td>
<td>0.010%</td>
<td>0.013% Max</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.82%</td>
<td>1.00 Max</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moisture</th>
<th>Average</th>
<th>Rejection Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-80mm</td>
<td>9%</td>
<td>18%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
<th>Typical analyses</th>
<th>Rejection levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over size</td>
<td>Under size</td>
</tr>
<tr>
<td>30-80mm</td>
<td>5%</td>
<td>5% Max</td>
</tr>
</tbody>
</table>

FeCr Coke ex
AMSA Newcastle

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Ash</td>
<td>15.1</td>
</tr>
<tr>
<td>% S</td>
<td>0.97</td>
</tr>
<tr>
<td>% Vol</td>
<td>0.9</td>
</tr>
<tr>
<td>P</td>
<td>0.009</td>
</tr>
<tr>
<td>M40</td>
<td>35.3</td>
</tr>
<tr>
<td>I40</td>
<td>13.6</td>
</tr>
<tr>
<td>I10</td>
<td>16.4</td>
</tr>
<tr>
<td>CRI</td>
<td>46.8</td>
</tr>
<tr>
<td>CSR</td>
<td>27.6</td>
</tr>
</tbody>
</table>

Colombiam Coke Offer

- Moisture: 7%
- Ash (db): 12%
- VM (db): 1.5%
- FC (db): 85% min
- S (db): 0.75%
- Phos (db): 0.005
- CRI: 21 min
- CSR: 64 min
- Size: 10 x 40mm
Properties of coke
Functions in the BF-1

The three functions of coke in the BF

**CHEMICAL**
- Indirect reduction
- Direct reduction
- Softening

**THERMAL**
- Heating
- Melting
- Tuyere
- Tapping

**PERMEABILITY**
- Gas permeability
- Gas distribution
- Roots stability
- Liquids permeability

Temperature profile and charging sequence:
- Permeable layers
- Melting zone
- Dead man
- Combustion zone
- Slag
- Hot iron

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Properties of coke
Functions in the BF-2

The chemical function (1)

• Production of reducing gas at tuyeres
  – Hot blast + oxygen + injection + coke
    $\rightarrow$ Tuyere gas: CO $\sim$ 38 % - H2 $\sim$ 8 % - N2 $\sim$ 54 %

• Reduction of iron oxides (1)
  – Hematite (Fe$_2$O$_3$) + CO $\rightarrow$ Magnetite (Fe$_3$O$_4$) + CO$_2$
  – Magnetite (Fe$_3$O$_4$) + CO $\rightarrow$ Wustite ($\sim$ FeO) + CO$_2$
  – Wustite ($\sim$ FeO) + CO $\rightarrow$ Iron (Fe) + CO$_2$
  
  – Similar reactions with H2 $\rightarrow$ formation of H2O
  – The CO, CO$_2$, H2, H2O compositions are linked by a chemical equilibrium (water gas shift equilibrium)
The chemical function (2)

- Regenerating the reducing power of the gas
  - If the temperature is greater than a limit:
    Coke + CO₂ (coming from reduction) → 2 CO
  - This limit corresponds to the coke reactivity temperature
    - ~ 950 °C for industrial cokes
    - For T > 950 °C, the reducing gas only contains CO and H₂
  - The regeneration reaction (called solution-loss reaction) is highly endothermic
    - Very fast drop of the gas temperature between the flame temperature at tuyeres and 950 °C
Properties of coke
Functions in the BF-4

The chemical function (3)

- Coke is the major contributor for producing hot reductant gas
  - Gas performs the reduction of iron oxides into iron
  - Heat is needed to get the complete reduction reactions and to smelt the hot metal and slag (separation)
  - Coke can be partly substituted by PCI (pulverized coal) and injections (as Nat gas, oil, tar.)
  - Coke consumption is in the range 250-550 kg/t hm:
  - Main differences for coke rate caused by:
    - Injection level (substitution of coke by PCI, nat gas, …) 0-200 kg/t hm
    - BF technology (hot blast temperature, top pressure), process control
    - Burden quality (slag volume, lump rate, quality, etc),
    - Coke quality: e.g. ash content 8.5-13.5%
Properties of coke
Functions in the BF-5

The thermal function(1)

• Production of hot gas in the tuyeres
  – Combustion of injected coal and coke
  – Adiabatic flame temperature ~ 2150 °C

• Satisfying thermal needs
  – Heating and melting of iron-bearing materials
  – Heating hot metal and slag to tapping temperature: 1470 ± 10 °C
  – Heating coke up to 1500 °C
  – Heat for solution-loss reaction
  – Sensible heat of top gas (~ 150 °C)
  – Thermal losses
The thermal function(2)

Heat balance: a remarkable efficiency
- Energies not recovered < 10%
- Coke, coal injection and the hot blast each provide about one third of heat inputs
- The formation of hot metal and slag and solution-loss reaction constitute the main needs
- The LCV of top gas (~3500 kJ/Nm3) makes its valorisation in the plant possible
Properties of coke
Functions in the BF-7

The permeability function (1)
• Goal:
  – optimisation of the contact between the gas and the materials optimising the completion of the two preceding functions,
  – drainage of the liquids in the hearth

• Main impacted aspects
  – Permeability / Productivity of the blast furnace
  – Blast furnace life time
  – Reducing agents consumption
Properties of coke
Functions in the BF-8

The permeability function (2)

- Aerodynamics in granular bed mainly
  - Lumpy zone (or dry zone)
    - Solids / Gas counter-current
    - Permeability described by Ergun’s law
      \[
      \frac{\Delta P}{L} = 150. \mu \cdot \frac{(1 - \varepsilon)^2}{(\varepsilon \cdot d_p \cdot \varphi)} \cdot \frac{U}{\varepsilon} + 1.75 \cdot \rho \cdot \frac{(1 - \varepsilon)}{(\varepsilon \cdot d_p \cdot \varphi)} \cdot \frac{U^2}{\varepsilon^2}
      \]
    - Main limit: hanging / slips
  - Dripping zone
    - Liquids / Gas counter-current on coke grate
    - Main limit: the flooding phenomenon
  - The Hearth
    - Drainage of metal and slag
    - Hearth life
### Properties of coke

#### Testing Methods for coke

<table>
<thead>
<tr>
<th>Roles</th>
<th>Tests</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical role:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• hold the burden</td>
<td>IRSID, MICUM</td>
<td>ISO 556:1980 – Coke (greater than 20 mm in size) – Determination of mechanical strength</td>
</tr>
<tr>
<td>• maintain permeability of the burden</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain size distribution</td>
<td>ISO 728:1995 – Coke – size analysis by sieving</td>
<td></td>
</tr>
<tr>
<td><strong>Chemical role:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• reduction of iron ore</td>
<td>CRI, CSR</td>
<td>ISO 18894:2006 – Determination of coke reactivity CRI/CSR</td>
</tr>
<tr>
<td>• combustion (source of heat)</td>
<td>“Intrinsic” reactivity</td>
<td>UN recommendation, JIS, GOST Standards</td>
</tr>
<tr>
<td></td>
<td>ISO 562:2010 – Hard coal and coke - Determination of volatile matter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 687:2010 – Coke – determination of moisture</td>
<td></td>
</tr>
<tr>
<td>Ash chemistry</td>
<td>ASTM D 4326 – X-ray fluorescence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM D 3682 – Atomic absorption</td>
<td></td>
</tr>
</tbody>
</table>
## Properties of coke
### Testing Methods for coke-

<table>
<thead>
<tr>
<th></th>
<th>MICUM (100 rev)</th>
<th>IRSID (500 rev)</th>
<th>ASTM</th>
<th>JIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>coke size</td>
<td>&gt; 20 mm *</td>
<td>&gt; 20 mm *</td>
<td>(51-76 mm)</td>
<td>&gt; 50 mm sq</td>
</tr>
<tr>
<td>total sampling</td>
<td>200 kg</td>
<td>11,3 kg</td>
<td>40 kg</td>
<td></td>
</tr>
<tr>
<td>sample in the drum</td>
<td>50 kg</td>
<td>10 kg</td>
<td>10 kg</td>
<td></td>
</tr>
<tr>
<td>drum dimension</td>
<td>914x457 mm</td>
<td>1,5 x 1,5 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 corners 100 mm</td>
<td>2 corners 51 mm</td>
<td>6 corners 250 mm</td>
<td></td>
</tr>
<tr>
<td>rotations</td>
<td>100 at 25 revt/min</td>
<td>500 at 25rev/min</td>
<td>1400 at 24 rev/min</td>
<td>30 ou 150 at 15 rev/min</td>
</tr>
<tr>
<td>screen used</td>
<td>40 - 20 - 10 mm</td>
<td>idem</td>
<td>27 and 6,75 mm</td>
<td>15 - 25 - 50 mm</td>
</tr>
<tr>
<td>index</td>
<td>M 10 = % &lt; 10 mm</td>
<td>I 10 = % &lt; 10 mm</td>
<td>Stability f. = % &gt; 25,4 mm</td>
<td>DI 30/15 = % &gt; 15 mm (30 rev)</td>
</tr>
<tr>
<td></td>
<td>M 40 = % &gt; 40 mm</td>
<td>I 40 = % &gt; 40 mm</td>
<td>Hardness f. = % &gt; 6,35 mm</td>
<td>DI 150/15 = % &gt; 15 mm (150 rev)</td>
</tr>
</tbody>
</table>

- Different methods for determination of mechanical strength
- Schematic of IRSID drum
Properties of coke
Testing Methods for coke-3

Reactivity (CRI) and Hot strength (CSR)

Gasification retort
CO$_2$ 5 l/min 1100 °C during 2 hours

I drum test
CO$_2$ 5 l/min 1100 °C during 2 hours 20 rev/min during 30 minutes
Properties of coke
Control of properties

• Chemical properties of coke
  – Ash, ash chemistry, sulphur, phosphorous: all fully dependent on the coal properties

• Reactivity (CRI), cold (I10, I40, etc.) and hot strength (CSR)
  – Primarily dependent on coal rank, macerals, ash chemistry, caking & fluidity properties
  – Can get secondary improvement from increased bulk density of charge, via briquettes, oil addition or stamp charging
  – Can get small discriminatory changes by increased coking temperature, reduced coking time or additives (e.g. tar, pitch)
Production of coke
Technologies – Slot Oven-1

• Slot ovens are typically 4-8 meters in height and vary from about 380mm to 650mm in width. Newer ovens are typically >6 meters in height. Coal charges range from 15 t to 45 t per oven depending on the height and width.

• Slot ovens take about 16-24 hours to coke. Typically 25mm per hour is used. It should be noted that the coke oven is a reducing atmosphere and the oven should be air tight. Leakage can occur around openings such as doors, lids, flues etc.

• In the slot oven, heat is supplied by the two adjacent flue walls. Time is required to allow the heat to go from the walls to the centre of the coal charge. Typically, coal is charged into an oven when the neighbouring oven is at 50% of the coking process.

• These ovens have a certain pushing sequence so that the machines are optimized for each coke plant.
Production of coke Technologies – Slot Oven-2
Production of coke Technologies – Slot Oven-3

We can break the typical coke making process into several sections:

– Coal receiving and storage
– Coal process and coal blending
– Coal charging
– Coke oven battery or batteries
– Coke pushing
– Coke quenching
– Coke wharf
– Coke screening and processing
– Coke delivery or stockpiling
– By-product plants, incl water treatment (slot only)
– Power plant (non recovery only)
Production of coke Technologies – Slot Oven-4

Coke oven battery pusher Side

![Coke oven battery pusher Side](image-url)
Production of coke Technologies – Slot Oven-5

Battery Top

Charging hole

Flue Wall
Production of coke Technologies – Slot Oven-6

Coke Side
Production of coke Technologies – Slot Oven-7

Wharf after Water Quench of Coke
Production of coke
Technologies – Non Recovery Oven

• Where the slot oven is heated from both adjoining vertical flue walls, the non-recovery oven is a horizontal oven which is heated from the bottom and top of the charge.

• Heating is accomplished from the floor flue on the bottom and from the top by the combustion of off gases that are generated during the coking cycle.

• Controlled air is allowed to enter the coke oven to allow combustion of these gases. This is an important difference in these ovens compared to slot ovens.

• Because air enters into the oven, there are potentially zero emissions during the coking process.

• Another major technical item is that the coke oven by-products are used as fuel during the coking process, so there is no need for traditional by-product plants or processes. The waste heat is usually captured using a heat recovery system such as a co-generation plant to produce electricity.

• These ovens use about 40-50 t on coal, but also require about 48 hours to coke because of the much deeper coke bed.
Production of coke Technologies – Non Recovery Oven-2

Uptake Dampers
Uptakes
Crown
Buckstays
Oven Floor
PCM Trackwork
Airspace
Sole Flues

Waste Heat Tunnel
Coal/Coke Bed
Downcomers

Figure 7: Sun Coke Heat Recovery Oven

Position of Re-solidified Plastic Layer in Non Recovery Oven
Production of coke Technologies – Other

• SCOPE 21
  – Rapid heating of coal,
  – Rapid carbonization and
  – Medium to low temperature coke reforming.
  – In operation in Japan since 2010
• Continuous coke making processes
  – Calderon (USA)
  – CTC (USA)
  – Carbonyx, Carbonite (USA)
• Vertical non recovery ovens
  – Several recent plants in China and India
• Success of other coke technologies also greatly determined by developments in alternative iron making technologies
Coking Coal Commercial

- Coke Price characteristics
- Long low price history pre-2002, risk of forecasts (right top)
- Peaks due to coal, coke capacity, commodity cycle's, etc
- Effects of Chinese export tax
- Implications for SA; new capacity unlikely, long term capacity reduction, Zim capacity uncertain.
Questions?
Back up slides
# Blast furnace coke analysis

## Roles

### Mechanical role:
- hold the burden
- maintain permeability of the burden

### Chemical role:
- reduction of iron ore
- combustion (source of heat)

## Tests

### Mechanical role:
- IRSID, MICUM

### Chemical role:
- CRI, CSR
  - “Intrinsic” reactivity

## Standards

<table>
<thead>
<tr>
<th>Roles</th>
<th>Tests</th>
<th>Standards</th>
</tr>
</thead>
</table>
| Mechanical role:  
- hold the burden  
- maintain permeability of the burden | IRSID, MICUM | ISO 556:1980 – Coke (greater than 20 mm in size) – Determination of mechanical strength |
| Grain size distribution | ISO 728:1995 – Coke – size analysis by sieving |
| Chemical role:  
- reduction of iron ore  
- combustion (source of heat) | CRI, CSR  
“Intrinsic” reactivity | ISO 18894:2006 – Determination of coke reactivity CRI/CSR  
UN recommendation, JIS, GOST Standards |
ISO 562:2010 – Hard coal and coke - Determination of volatile matter  
ISO 687:2010 – Coke –determination of moisture  
| Ash chemistry | ASTM D 4326 – X-ray fluorescence  
ASTM D 3682 – Atomic absorption |
Chinese Domestic Coke Prices

Source: ResourceNet, 2011
Coking Coal Commercial-2

Nominal Chinese coke export prices, 12.5% ash content, ($/tonne fob)

Source: CRU, 2011
## Coking Coal Commercial-3

**Platts Daily Metallurgical Coal Assessments, October 4**

### Asian-Pacific coking coal ($/mt)

<table>
<thead>
<tr>
<th></th>
<th>FOB Australia</th>
<th>CFR China</th>
<th>CFR India</th>
<th>Change Australia</th>
<th>Change China</th>
<th>Change India</th>
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<tbody>
<tr>
<td>HCC Peak Downs Region</td>
<td>142.00</td>
<td>155.50</td>
<td>157.00</td>
<td>-0.50</td>
<td>0.00</td>
<td>-0.50</td>
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<tr>
<td>Premium Low Vol</td>
<td>142.00</td>
<td>155.50</td>
<td>157.00</td>
<td>-0.50</td>
<td>0.00</td>
<td>-0.50</td>
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<tr>
<td>HCC 64 Mid Vol</td>
<td>127.00</td>
<td>140.50</td>
<td>142.00</td>
<td>-0.50</td>
<td>0.00</td>
<td>-0.50</td>
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<tr>
<td>Low Vol PCI</td>
<td>105.00</td>
<td>118.50</td>
<td>120.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
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<tr>
<td>Low Vol 12 Ash PCI</td>
<td>96.50</td>
<td>110.00</td>
<td>111.50</td>
<td>-0.50</td>
<td>0.00</td>
<td>-0.50</td>
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<td>Semi Soft</td>
<td>92.50</td>
<td>106.00</td>
<td>107.50</td>
<td>-0.50</td>
<td>0.00</td>
<td>-0.50</td>
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<tr>
<td>Met Coke</td>
<td>-</td>
<td>-</td>
<td>316.00</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
</tr>
</tbody>
</table>

### HCC Assessed Specifications

<table>
<thead>
<tr>
<th></th>
<th>CSR</th>
<th>VM</th>
<th>Ash</th>
<th>S</th>
<th>P</th>
<th>TM</th>
<th>Fluidity</th>
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<tbody>
<tr>
<td>HCC Peak Downs Region</td>
<td>74%</td>
<td>20.7%</td>
<td>10.5%</td>
<td>0.60%</td>
<td>0.030%</td>
<td>9.5%</td>
<td>400</td>
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<tr>
<td>Premium Low Vol</td>
<td>71%</td>
<td>21.5%</td>
<td>9.3%</td>
<td>0.50%</td>
<td>0.045%</td>
<td>9.7%</td>
<td>500</td>
</tr>
<tr>
<td>HCC 64 Mid Vol</td>
<td>64%</td>
<td>25.5%</td>
<td>9.0%</td>
<td>0.60%</td>
<td>0.050%</td>
<td>9.5%</td>
<td>1,700</td>
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</table>

### Penalties & Premia: Differentials ($/mt)

<table>
<thead>
<tr>
<th></th>
<th>Within Min-Max</th>
<th>% of Premium Low Vol</th>
<th>FOB Australia assessment price</th>
<th>Net Value ($/mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per 1% CSR</td>
<td>60-74%</td>
<td>0.50%</td>
<td>0.50%</td>
<td>0.71</td>
</tr>
<tr>
<td>Per 1% VM (air dried)</td>
<td>18-28%</td>
<td>0.50%</td>
<td>0.50%</td>
<td>0.71</td>
</tr>
<tr>
<td>Per 1% TM (as received)</td>
<td>8-11%</td>
<td>1.00%</td>
<td>1.00%</td>
<td>1.42</td>
</tr>
<tr>
<td>Per 1% Ash (air dried)</td>
<td>7-10.5%</td>
<td>1.25%</td>
<td>1.25%</td>
<td>1.78</td>
</tr>
<tr>
<td>Per 0.1%S (air dried)</td>
<td>0.3-1%</td>
<td>1.00%</td>
<td>1.00%</td>
<td>1.42</td>
</tr>
</tbody>
</table>
End