BF Plus

An offered
• Step-wise
• Near-term
• Economics-driven
means to CO2 mitigation from BF ironmaking
Vision

- Lower the cost of hot metal
- Maximize energy production
- Provide platform for GHG mitigation
  
  Step 1: Proper apportionment of CO2 across two products (HM+power)
  Step 2: “drop-in” CO2 removal
  Step 3: Precede CO2 removal with “shift reactor”

- Achieved by:
  - Increasing coke displacement
  - Maximizing the value of higher calorific topgas
  - Employing efficient power production technology
  - Taking advantage of fuel gas compression required for Gas Turbine.
Traditional BF Operation

- Gas Cleaning System
  - Cyclone
  - Wet Venturi

- Steam Boiler

- PCI System

- Hot Metal

- Exhaust

- Ore Coke

- Air Blower

- ASU

- Power

- Oxygen

- Condensate

- HOT BLAST STOVES

- ST

- Power

- Exhaust
Top Gas CV and $O_2$ Relationship

Conversion: $1 \text{MJ/Nm}^3 = 25.4 \text{ BTU/SCF}$
BF Plus

Gas Cleaning System
- Cyclone
- Wet Venturi

Electrostatic Precip.

FGC

Power

HOT BLAST STOVES

PCI System (enlarged)

Ore

Coke

Topgas

exhaust

Air Blower

(comb. air)

oxygen

ASU (enlarged)

Power

exhaust

Power

Hot Metal

HOT Blast Stoves

Power

Gas Holder (Buffer)

Power

Power

PF

Power

ST

condensate

HRSG

Compressed Air

Oxygen

GT

Power
Maximizing Energy Export

Converted for:
- Constant coke rate = 262 kg/tHM
- Constant top temperature = 100 °C

Energy Export From BF to Power Plant, $1000 \times $BTU/tHM

Conversion: 1,000 BTU = 1.055 MJ

Hot Blast Temperature, °F

Calculated for:
- Constant coke rate = 262 kg/tHM
- Constant top temperature = 100 °C
Balanced Cold Blast Operation*

Fig. 5 Cold Blast Operation (60 % O₂)
(for 1 ton HM)

COKE  190 kg

COAL  410 kg

COLD BLAST  579 Nm³
60 % O₂

1167 Nm³
6.97 GJ
LCV  5.970 MJ /Nm³

## Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>BF Plus (realizable today)</th>
<th>Future Potential</th>
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<tbody>
<tr>
<td>PCI, kg/THM</td>
<td>120-200</td>
<td>220-260</td>
<td>300+</td>
</tr>
<tr>
<td>Coke Rate, kg/THM</td>
<td>300-360</td>
<td>270-290</td>
<td>260</td>
</tr>
<tr>
<td>Blast Oxygen, %</td>
<td>21-29</td>
<td>~ 40</td>
<td>55 - 60</td>
</tr>
<tr>
<td>Blast Temperature, °C</td>
<td>1050-1250</td>
<td>850-1050</td>
<td>ambient</td>
</tr>
<tr>
<td>Max. Hot Metal Production, %</td>
<td>100%</td>
<td>109%</td>
<td>110%</td>
</tr>
<tr>
<td>Top Gas Calorific Value, MJ/Nm³</td>
<td>3.2 - 3.9</td>
<td>4.5 – 5.0</td>
<td>&gt; 5.9</td>
</tr>
<tr>
<td>Net Export Power Production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(base case 2.3 million tpy BF)</td>
<td>25 - 50 MW</td>
<td>125 - 160 MW</td>
<td>200 - 250 MW</td>
</tr>
<tr>
<td>• MW</td>
<td>~0.2</td>
<td>~0.5</td>
<td>~0.8</td>
</tr>
<tr>
<td>• MWh / THM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ apportioned to Ironmaking, %</td>
<td>100%</td>
<td>91%</td>
<td>82%</td>
</tr>
<tr>
<td>(assigning 0.54 kg CO₂/kWh to power)</td>
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</tbody>
</table>
BF Plus

Gas Cleaning System
- Cyclone
- Wet Venturi

Ore
Coke

PCI System (enlarged)

Hot Metal

Topgas

HOT BLAST STOVES

Air Blower

Exhaust

Electrostatic Precip.

Gas Holder (Buffer)

FGC Power

Power

ASU (enlarged)

Power

HRSG

ST

Condensate

Power

Exhaust

Power
BF Plus with CO₂ Capture

Gas Cleaning System
- Cyclone
- Wet Venturi

PCI System (enlarged)

Ore

Coke

Hot Metal

Topgas

exhaust

HOT BLAST STOVES

BF

Air Blower

(exenlarged)

Electrostatic Precip.

Gas Holder (Buffer)

CO₂ Capture

GT

Power

comb. air

oxygen

ASU (enlarged)

Power

Power

HRSG

condensate

ST

exhaust

Power
BF Plus with Shift Reactor and CO₂ Capture

Gas Cleaning System
- Cyclone
- Wet Venturi

Electrostatic Precip.

Shift Reactor
CO + CO₂ + H₂

CO₂ Capture

Power

Oxygen

HOT BLAST STOVES

PCI System
(enlarged)

Topgas

exhaust

Hot Metal

Air Blower

Power

ASU (enlarged)

Power

Gas Cleaning System
• Cyclone
• Wet Venturi

Power

HRSG

condensate

ST

Power

OGC

Power

PCI System
(enlarged)

Ore

Coke

Power

PCI System
(enlarged)
## BF Plus GHG mitigation options

<table>
<thead>
<tr>
<th></th>
<th>Indicative example(s):</th>
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<tbody>
<tr>
<td><strong>O2 in Blast (%)</strong></td>
<td>~40</td>
</tr>
<tr>
<td><strong>Coke rate (Kg/THM)</strong></td>
<td>270-290</td>
</tr>
<tr>
<td><strong>PCI (Kg/THM)</strong></td>
<td>220-260</td>
</tr>
<tr>
<td><strong>Option</strong></td>
<td><strong>Comb Cycle Power</strong></td>
</tr>
<tr>
<td></td>
<td><strong>With CO2 Capture</strong></td>
</tr>
<tr>
<td></td>
<td><strong>With CO shift +CO2 Capture</strong></td>
</tr>
<tr>
<td><strong>Net Power export (kWh/THM)</strong></td>
<td>546</td>
</tr>
<tr>
<td><strong>CO2 emissions allocated to HM (Kg/THM)</strong></td>
<td>1,367</td>
</tr>
<tr>
<td><strong>Direct CO2 emissions</strong></td>
<td>1,202</td>
</tr>
<tr>
<td><strong>Global CO2 emissions (assuming 0.54 Kg CO2/kWh)</strong></td>
<td>1,202</td>
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</tbody>
</table>
Power Generation and CO2 Reductions for various operating scenarios

- Traditional BF
- BF Plus
- BF Plus with CO2 Removal
- BF Plus with WGS & CO2 Removal, Option A
- BF Plus with WGS & CO2 Removal, Option B

- Power Output
- Total CO2 Emission
- CO2 Emission Assigned to HM after apportioning 0.54 kg CO2/kWh
Summary / Conclusions

- Can combine known technologies
  - To achieve a range of CO$_2$ mitigation
  - While simultaneously improving the economics of BF ironmaking

- “Retrofittable” in a step-wise fashion
  - Minimizes risk and capital outlays
  - Quality of CO$_2$ produced suitable for immediate sequestration (without further upgrade or refinement)

- Known, proven technologies can be combined and implemented to mitigate CO$_2$ emissions from BF ironmaking today.
Thank you