At Metso, we aim for:

- Zero harm to personnel, material and non-material assets
- Better employee health and safe work environment
- Operations with efficient material and energy use, minimum waste and damage to the environment
- Products and services with no undue environmental impact, less consuming of energy and natural resources
- Products that can be recycled or disposed of safely
Agenda

- Brief History of Metso in Iron Ore Pelletizing
- Metso’s Capabilities
- Grate Kiln Plants
- Straight grate Plants
- Comparison of Straight Grate vs Grate Kiln
- OCS and VisioPellet for Pelletizing
- Low Nox Burners
History of Pelletizing

- Post WW II, high grade iron ore running out in USA
- Large deposits of low grade taconite in Minnesota
- Easy to liberate and beneficiate with fine grinding and magnetic separation
- Pelletizing developed to agglomerate fines
- Straight or traveling grate adapted from sinter machines
- Grate kiln developed from various kiln processes
- Vertical shaft furnaces outdated by 1970
History of Metso in Pelletizing

- Grate Kiln Pellet Plants developed and sold by Allis Chalmers which became part of Svedala and later Metso
  - Kobe was a licensee of Allis Chalmers

- Straight Grate Pellet Plants developed and sold by Dravo in combination with Lurgi
  - Dravo was broken into pieces in late 70’s. Engineering portion became Davy, then Kvaerner, then Aker, then Jacobs
  - Equipment group became McNally then Svedala and now Metso
  - Now with acquisition of Jacobs pellet group, Metso has recombined the original Dravo pellet group
Metso Iron Ore Pelletizing Capabilities

Engineering

- Feasibility Studies
- Iron Ore Pot Grate Testing
- Plant Site Evaluation
- Flowsheet Development
- Engineering
  - Process Engineering
  - Mechanical Engineering
  - Civil / Structural Engineering
  - Electrical Engineering / Instrumentation
- Project Management
Metso Iron Ore Pelletizing Capabilities

Equipment

- Grate Kiln Induration Machine
- Straight Grate Induration Machine
- Pelletizing Discs / Pelletizing Drums
- Roller Screens / Roller Conveyor
- Reciprocating / Oscillating Conveyor
- Wide Belt Conveyor
- Burners
- Control Systems
- Beneficiation Plants
- EPC package with Partner Companies
Metso Iron Ore Pelletizing Capabilities

Services

- Alignment Service
- Plant Rebuilds
- Modification and Redesign of Equipment and Processes
- Rerating / Upgrading Plants
- Grate Chain Replacements
- Kiln Riding Ring Resurfacing
- Pallet Repair Services
- Machine Inspections
- Installation / Commissioning Supervision
- Maintenance / Operator Training
Metso Iron Ore Pelletizing Capabilities

EPC Arrangements

- With Acquisition of Jacobs, Metso is in a better position to offer complete EPC packages.
- Metso does not do construction and civil works, so has partnered with key companies to do certain projects on an EPC basis.
- Metso will supply the basic and some detail engineering, the “proprietary equipment package” and other key equipment that will affect the process.
- The EPC partner will provide the detail engineering of the BOP and the rest of the equipment and the civil and construction works and overall project management.
Grate-Kiln iron ore pelletizing system

Introduction

• Grate-Kiln systems used in places where coal is abundant and other fuel types are expensive

• Metso is the world’s leading designer of grate-kiln systems, with 54 installations worldwide, equating to an installed capacity of over 140 million tons

• Capacities ranging from 3 million tons per year to 7 million tons per year in a single system
Grate Kiln Iron Ore Pelletizing System

Installation List
## Recent Installation List

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Number of Units</th>
<th>Start Up</th>
<th>Design Capacity Ton/Yr</th>
<th>Ore Type</th>
<th>Balling Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>LKAB III</td>
<td>Kiruna, Sweden</td>
<td>1</td>
<td>1994</td>
<td>4,000,000</td>
<td>Magnetite</td>
<td>Drum</td>
</tr>
<tr>
<td>WISCO</td>
<td>Wuhan, China</td>
<td>1</td>
<td>2005</td>
<td>5,000,000</td>
<td>Hematite/Magnetite</td>
<td>Drum</td>
</tr>
<tr>
<td>LKAB IV</td>
<td>Kiruna, Sweden</td>
<td>1</td>
<td>2008</td>
<td>6,000,000</td>
<td>Magnetite</td>
<td>Drum</td>
</tr>
<tr>
<td>CP Mining</td>
<td>Cape Preston, W. Australia</td>
<td>1</td>
<td>2011</td>
<td>6,000,000</td>
<td>Magnetite</td>
<td>Drum</td>
</tr>
</tbody>
</table>

* Designed by a licensee
Grate-Kiln iron ore pelletizing system

Principles of operation

- **Traveling grate**
  - Pellets are dried and partially indurated through multiple cross flow process zones: updraft drying, downdraft drying, tempered preheat, and preheat, strengthening pellets for processing in rotary kiln
  - Average bed depth 180 mm; no hearth layer required as in straight grate

- **Rotary kiln**
  - Final point of pellet induration in grate kiln system
  - Rotation of kiln exposes entire pellet bed to heat radiating from the burner resulting in uniform pellet quality
  - Kiln burner utilizes cooler off gas to heat material bed to nominal of 1340 °C completing the slag bonding and mineral bridging to form pellets

- **Annular cooler**
  - Multiple zone cooler with recuperation ducts to traveling grate
  - Recovers essentially all of the sensible heat from the pellet bed resulting in overall system energy savings
Grate Kiln Iron Ore Pelletizing System

Process Flow Diagram

- Latest design has minimized fuel consumption
- Additional preheat zone improves pellet strength
Plant Plot Plan Drawing
Plant Elevation Drawing
Grate-Kiln System Reference Plant

WISCO – Ezhou, China

This was the first iron ore pelletizing plant installed for Wuhan Iron & Steel Company

Equipment Specifications:
Traveling Grate – 5664 mm x 69500 mm
Rotary Kiln – 6858 mm diameter x 45720 mm long
Annular Cooler – 21945 mm x 3657 mm

Plant Commissioning: March 2006

Iron Ore Feed Material:
Combination of 80% Hematite and 20% Magnetite

Product Specifications:
Iron Ore Pellets for Blast Furnace applications
Grate-Kiln System Reference Plant

LKAB – Kiruna, Sweden

This was the fourth Metso Grate Kiln iron ore pelletizing plant installed for LKAB and the largest system constructed to date

Equipment Specifications:
Traveling Grate – 5664 mm x 70240 mm
Rotary Kiln – 7470 mm diameter x 6858 mm diameter x 40000 mm long
Annular Cooler – 28041 mm x 3657 mm

Plant Commissioning: April 2008

Iron Ore Feed Material:
100% Magnetite

Product Specifications:
Iron Ore Pellets for Blast Furnace and Direct Reduction applications
Straight Grate System
Introduction

• Metso has built or participated in the building of 44 traveling grate pelletizing machines, having a production capacity of over 120 million metric tons per year.

• Capacities ranging from 0.6 million tons per year to 8.5 million tons per year in a single system.
Metso World Wide Pelletizing Plant Installations
## Straight Grate iron ore pelletizing system

<table>
<thead>
<tr>
<th>Map Location</th>
<th>Plant Name</th>
<th>Location</th>
<th>Owner</th>
<th>Rated Tonnage ($10^6$ TPY)</th>
<th>Start-up</th>
<th>Ore Type</th>
<th>No. Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>JSW I</td>
<td>Toranagallu, Karnataka, India</td>
<td>Jindal South West Ltd.</td>
<td>3.0</td>
<td>1999</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>JSPL</td>
<td>Barbil, Orissa, India</td>
<td>Jindal Steel and Power Ltd.</td>
<td>4.0</td>
<td>2009</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>Essar I</td>
<td>Paradeep, India</td>
<td>Essar Steel Ltd.</td>
<td>6.0</td>
<td>2011</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>Essar II</td>
<td>Paradeep, India</td>
<td>Essar Steel Ltd.</td>
<td>6.0</td>
<td>Under Const</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>Essar III</td>
<td>Minnesota, USA</td>
<td>Essar Steel Minnesota LLC</td>
<td>7.0</td>
<td>Under Const</td>
<td>Magnetite</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>JSW 2</td>
<td>Toranagallu, Karnataka, India</td>
<td>Jindal South West Ltd.</td>
<td>3.0</td>
<td>2011</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>28</td>
<td>Monnet</td>
<td>Raigarh, Chhattisgarh, India</td>
<td>Monnet Ispat &amp; Energy Ltd.</td>
<td>2.0</td>
<td>Under Const</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>29</td>
<td>JSPL II</td>
<td>Barbil, India</td>
<td>Jindal Steel and Power Ltd.</td>
<td>4.0</td>
<td>Under Const</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>Amba River Coke</td>
<td>India</td>
<td>Jindal Steel Works Ltd</td>
<td>4.0</td>
<td>Under Const</td>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>Mag Pellet LLC</td>
<td>Indiana, USA</td>
<td>Magnetation Inc.</td>
<td>3.0</td>
<td>Under Const</td>
<td>Magnetite</td>
<td>1</td>
</tr>
</tbody>
</table>
Straight Grate iron ore pelletizing system

Principles of operation

- In this process, the wet pellets are dried, preheated, indurated, and cooled on a continuous moving grate without intermediate transfers.
- The process air introduced for pellet cooling is circulated from the cooling zone of the grate in a multi-pass manner to the other process zones to obtain thermal efficiency.
- The indurating machine will be fed continuously with green pellets across the full width of the machine on top of a protective hearth layer.
- The gas flow scheme will be designed to recuperate a significant amount of sensible heat from the process gas streams. High level heat will be recuperated directly from the first cooling zone. Low level heat will be recovered from the second cooling zone for drying pellets.
Straight Grate iron ore pelletizing system
First Plant installed for JSPL in Barbil. 4 MTPY Plant

**Equipment Specifications:**
Traveling Grate – 4 m x 116 m

**Plant Commissioning:** November 2009

**Iron Ore Feed Material:**
Blend of Orissa Blue Dust 100% Hematite

**Product Specifications:**
Iron Ore Pellets for Blast Furnace and DRI Feed
Straight Grate System Reference Plant
Essar Paradeep Line 1, India – Hematite

First Plant installed for Essar in Par deep. 6 MTPY Plant

Equipment Specifications:
Traveling Grate – 4 m x 186 m

Plant Commissioning: May 2011

Iron Ore Feed Material:
Blend of Orissa Fines 100% Hematite

Product Specifications:
Iron Ore Pellets for Blast Furnace Feed
Straight Grate System Reference Plants

Current Projects

Current Projects in Various states of Completion

**Essar Paradeep Line 2:**
Traveling Grate – 4 m x 186 m in India

**Essar Minnesota:**
Traveling Grate – 4 m x 186 m in USA

**JSPL Barbil Line 2:**
Traveling Grate – 4m x 128 m in India

**Monnet Line 1:**
Traveling Grate – 4m x 84 m in India

**JSW Amba River Coke Line 1:**
Traveling Grate – 4m x 116 m in India

**Magnetation Mag Pellet:**
Traveling Grate – 4m x 96 m in USA
Comparison of GK and SG
### Comparison Straight Grate vs. Grate Kiln

#### Capital Cost

<table>
<thead>
<tr>
<th>Straight Grate</th>
<th>Grate Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Overall indurating machine length is similar</td>
<td>• Overall indurating machine length is similar</td>
</tr>
<tr>
<td>• Slightly narrower width</td>
<td>• Slightly wider width</td>
</tr>
<tr>
<td>• Similar total plant area when balance of plant is considered</td>
<td>• Similar total plant area when balance of plant is considered</td>
</tr>
<tr>
<td>• Balling area is lower (elevation) because entire machine is at one elevation</td>
<td>• Balling area is significantly higher (elevation) so as to feed traveling grate</td>
</tr>
<tr>
<td>• Less structural steel required because of lower balling area elevation</td>
<td>• More structural steel required</td>
</tr>
<tr>
<td>• Lower capital cost by about 10%</td>
<td>• Higher capital cost</td>
</tr>
</tbody>
</table>
## Comparison Straight Grate vs. Grate Kiln

### Operation

<table>
<thead>
<tr>
<th>Straight Grate</th>
<th>Grate Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Capable of firing gas, or liquids (no solid fuels)</td>
<td>• Capable of firing solid fuel, gas, or liquids</td>
</tr>
<tr>
<td>• Higher electrical power consumption due to deep bed of pellets</td>
<td>• Significantly lower electrical power consumption</td>
</tr>
<tr>
<td>• Fuel consumption is similar</td>
<td>• Fuel consumption is similar</td>
</tr>
<tr>
<td>• Single machine</td>
<td>• 3 separate machines — traveling grate, kiln, annular cooler, allows control of residence time in each</td>
</tr>
<tr>
<td>• Multiple burners provides process flexibility</td>
<td>• Single burner in kiln, additional burners in traveling grate when processing hematite</td>
</tr>
</tbody>
</table>
## Comparison Straight Grate vs. Grate Kiln

### Operation

<table>
<thead>
<tr>
<th>Straight Grate</th>
<th>Grate Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Some variation in product quality due to variations across the deep bed of pellets</td>
<td>• More consistent product quality because kiln exposes all pellets to the high temperature zone</td>
</tr>
</tbody>
</table>
## Comparison Straight Grate vs. Grate Kiln
### Maintenance

<table>
<thead>
<tr>
<th>Straight Grate</th>
<th>Grate Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pallet cars can be taken off-line for maintenance</td>
<td>• System must be shut-down for maintenance</td>
</tr>
<tr>
<td>• Pallet cars made of alloy steel parts</td>
<td>• Grate chain and all plates are made of alloy steel parts</td>
</tr>
<tr>
<td>• Less refractory maintenance</td>
<td>• More refractory maintenance, but done at annual shut-down (mostly kiln)</td>
</tr>
<tr>
<td>• Single machine, one drive to maintain</td>
<td>• 3 separate machines – traveling grate, kiln, annular cooler, 3 drives to maintain</td>
</tr>
</tbody>
</table>
Comparison Straight Grate vs. Grate Kiln

### Emissions

<table>
<thead>
<tr>
<th>Straight Grate</th>
<th>Grate Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ESP or baghouse required to meet particulate emissions limits</td>
<td>ESP or baghouse required to meet particulate emissions limits</td>
</tr>
<tr>
<td>• SOx emissions are a function of ore and fuel, same for either process</td>
<td>SOx emissions are a function of ore and fuel, same for either process</td>
</tr>
</tbody>
</table>
## Comparison Straight Grate vs. Grate Kiln

### Emissions – NOx

<table>
<thead>
<tr>
<th>Straight Grate</th>
<th>Grate Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Existing plant - NOx emissions are approximately 4 - 6 lb/MBtu</td>
<td>• Existing plant - NOx emissions are approximately 4 - 6 lb/MBtu</td>
</tr>
<tr>
<td>• Low NOx Retrofit plant - NOx emissions are approximately 1.25 lb/Mbtu</td>
<td>• Low NOx Retrofit plant - NOx emissions are approximately 1.25 lb/Mbtu</td>
</tr>
<tr>
<td>• Current operation in laboratory conditions - NOx emissions are approximately 0.25 Lb/Mbtu *</td>
<td></td>
</tr>
<tr>
<td>• Expected BACT - NOx emissions 0.25 lb/Mbtu *</td>
<td></td>
</tr>
</tbody>
</table>

* The 0.25 lb/MBtu level has not yet been proven in commercial operation
OCS© for Iron Ore Pelletizing Plants

Introduction

• OCS© optimizing control
  - Continuous real-time expert level process assessment
  - Supervisory level decision making
    • Provide consistency through operating shifts
    • Utilize deep process knowledge and understanding
  - Automatic set point optimization

• Balling process
  - VisioPellet™ technology
  - Optimize pellet size distribution & feed rate
  - 21 systems (Vale, Brazil)

• Induration process
  - OCS© advanced control technology
  - Optimize production, energy usage, product quality, environmental emissions
  - 14 systems with on-line modeling
VisioPellet™ Technology

**Expert System**
OCS© Optimizing Control System

- Optimization algorithm

**Vision Software**
VisioPellet™

- Analyze pellet size distribution

**Regulatory Control**
DCS or PLC

- Optimized feed rate and disc speed set points
- Adjust disc operation

Camera at discharge of disc

Pelletizing Disc
OCS© for Iron Ore Pelletizing Plants

Implementation

• Provide complete solution
  - Hardware
  - Software
  - Advanced control engineering

• Synergy of expertise
  - Metso has wealth of experience with iron ore pelletizing plant optimization
  - Client has experience with their plants
  - Both parties have ownership in results

• Simple & smooth integration
  - Metso manages integration and commissioning
  - No plant disturbances necessary
  - Minimize client resources needed
OCS© for Iron Ore Pelletizing Plants

Induration: 14 full control systems with on-line models
(last one in progress)

- Vale Vitoria, 7 straight-grates, Brazil
- Vale São Luis, 1 straight-grate, Brazil
- Samarco Ubu, 2 straight-grates, Brazil
- Tata Steel (Corus), 1 straight-grate, The Netherlands
- U.S. Steel Minntac, 2 grate-kilns, USA
- Cliffs NR Tilden, 1 grate-kiln, USA
OCS© for Iron Ore Pelletizing Plants

Results

- **Proven results (balling)**
  - 3.6 % improvement in target size
  - 16.4% reduction in target size standard deviation

- **Proven results (induration)**
  - 2% to 5% production increase
  - 3% to 9% energy decrease
  - 20% to 40% decrease in quality standard deviation

- **Return on investment**
  - 2-4 months typical ROI

- **Satisfied users**
  - OCS© is maintained and continues to operate for years
  - Return customers:
    - Tata Steel, U.S. Steel, & Vale
Low NOx in Pelletizing Furnaces
Where has Low NOx been required for Pelletizing Furnaces?

- Recently, new furnaces in Brazil have targeted NOx emissions levels of 400 mg/Nm$^3$ (corrected to 15% O$_2$).

- A recent (2009) installation in the Middle East required NOx emissions to be less than 150 mg/Nm$^3$ (uncorrected).

- State of Minnesota, USA requires 70% to 90% reduction in NOx emissions (compared to traditional technology) for all new pelletizing furnaces.
Reducing NOx in Pelletizing Furnaces: A Difficult Problem

Combustion Factors that contribute to NOx Formation:

- High Peak Flame Temperatures
  - High Process Temperatures
  - Large Temperature Flame Temperature Gradients
  - High Air Preheat Temperatures
- High Oxygen Concentration in Products Of Combustion
- Long Residence Time at High Temperature

All of These Factors Exist in Pelletizing Furnaces!
Metso and Low NOx Pelletizing

• September 2008 – Metso, jointly with a burner manufacturer, were engaged by the plant owner to present a solution that reduces combustion NOx formation in a straight-grate indurating furnace.

  - Study Scope Included:
    • Listing of relevant experience, data and references for similar applications of the proposed technology
    • CFD Modeling and other technical information to substantiate the estimated NOx emission rates associated with providing process gas at approximately 2400 F to feed into the iron ore bed
    • Bench-Scale Laboratory NOx testing
    • Estimated fuel usage and oxidant flows
    • Preliminary arrangement drawings
NO$_X$ Emissions Results from ¼-Scale Testing: Natural Gas

NO$_X$ vs. Process Temperature for Pelletizing Furnaces
Firing Natural Gas

- NOX Emissions, Standard Burners
- NOX Emissions, Standard Burners with Low NOX Insert
- NOX Emissions, LE Ultra Low NOX Burners
- 90% NOX Reduction

© Metso
The Environmental Benefits of Low NO\textsubscript{X} Pelletizing Burners are Significant

![Graph showing Annual Burner NO\textsubscript{X} Emissions for a 6.5 MTPY Pelletizing Furnace Firing Natural Gas. The graph compares NO\textsubscript{X} Emissions for Standard Burners, Standard Burners with Low NO\textsubscript{X} Insert, and Ultra Low NO\textsubscript{X} Burners against Process Temperature. The graph shows a significant decrease in emissions for Ultra Low NO\textsubscript{X} Burners.]
CFD Comparison of LE Low NOx Pelletizing Burner with Baseline Conventional Burner

Baseline

LE Burner Low NOx

Contours of Mole fraction of no
FLUENT 6.3 (3d, pbns, spe, rke)
Jan 29, 2009

Contours of Mole fraction of no
FLUENT 6.3 (3d, pbns, spe, rke)
Jan 29, 2009
Thank you