Industry: 1/3 of global final energy use and 40% of total energy related CO₂ emissions

75% of total direct CO₂ emissions

- Chemicals
- Iron & Steel
- Cement
- Pulp
- Non-Ferro

✓ Need to actively act for global reduction of CO₂ and green growth policies

☞ Mini-mills need a breakthrough in Energy Reduction
Developments in EAF Technology

Productivity

- High efficiency
- Energy reduction
- Resources reduction
- Environmental regulations

The Oil Crisis (1st, 2nd)

Development Tendencies

- UHP furnace
- Computerized monitoring
- Foaming slags
- Water-cooled roofs, Oxy-fuel, Burners

Electric energy consumption

- Oxygen blowing
- 630 kwh/t
- 180 min
- 6.5 kg/t

Tap-To-Tap

- LF furnace
- EBT
- Scrap preheating (SPH)
- DC furnace
- Bottom stirring
- Lance manipulator
- High secondary voltage

Electrode consumption

- Water-cooled walls
- 260 kwh/t
- 30 min
- 1.3 kg/t

Main Developments

- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

59% ↓
83% ↓
80% ↓
## Diversification and Efficiency of Energy Sources

### KES (Klockner Electric Steel process)
- **Maker**: Danieli
- **Way of Using natural gas**
- **Using HPR (High Power Rotary) burner**: Up-and-down, rotation movement
- **Reduction of electric energy**
- **Low initial installation cost of HPR**
- **Reduction of electrode consumption**
- **Maker**: Institute Metallurgy
- **Smorgon Steel (AUS)**
  - $O_2: 12$ Nm$^3$/t $↑$
  - $C: 14$ kg/t $↑$
  - Power: 90 kwh/t $↓$
- **Bhushan Steel (IND)**
  - Power: about 181 kwh/t (Hot metal+DRI)
- **Bekabad Uzbekistan (UZB)**
  - Natural gas: 22.3 Nm$^3$/t
  - $O_2: 74.8$ Nm$^3$/t
  - $C: 22.6$ kg/t
  - Power: 128 kwh/t ($\frac{1}{3}$ of the others)

### DANARC (DANieli electric ARC)
- **Amount of oxygen and carbon $↑$ and efficiency improvement**
- **Bottom blowing $→$ stirring effect**
- **Bottom tuyere (oxygen + inert gas)**
- **Lump coal: charging with scrap**
- **Pulverized coal: charging into Bath**
- **Bottom tuyere (oxygen + inert gas)**
- **Side wall injector (oxygen + carbon)**
- **Maker**: Danieli

### CONARC (CONverter–ARC furnace)
- **2-way furnace (BOF–EAF)**
- **2 Furnace frames**
- **High flexibility in materials**
  - (Hot metal/DRI/Pig iron/Scrap)
- **High flexibility in using energy**
  - (Electricity/Oxygen)
- **Maker**: SMS–Demag

### FAF (Fuel Arc Furnace)
- **Way of Using natural gas**
- **Using HPR (High Power Rotary) burner**: Up-and-down, rotation movement
- **Reduction of electric energy**
- **Low initial installation cost of HPR**
- **Reduction of electrode consumption**

### Diagrams
- EAF Operation With K-EB
- Diagrams of KES, DANARC, CONARC, and FAF
## Energy Reduction Facilities

<table>
<thead>
<tr>
<th>TWIN</th>
<th>Consteel</th>
<th>Shaft Furnace</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="TWIN Diagram" /></td>
<td><img src="image2.png" alt="Consteel Diagram" /></td>
<td><img src="image3.png" alt=" Shaft Furnace Diagram" /></td>
</tr>
<tr>
<td><strong>1 Power source, 2 furnaces</strong></td>
<td><strong>Continuous preheating and feeding</strong></td>
<td><strong>MSP (Multistage Scrap Preheater)</strong></td>
</tr>
<tr>
<td>Using EAF instead of preheating Basket</td>
<td>Automatically transported to EAF by conveyor system.</td>
<td>Comelt</td>
</tr>
<tr>
<td>No switch–off time (tapping, repair, first charging, etc.)</td>
<td>Preheated by off–gas from EAF</td>
<td>UL–BA (Ultimate BAch)</td>
</tr>
<tr>
<td><strong>Maker : NSC, NKK, SMS–Demag, CLECIM</strong></td>
<td>Continuously charge the scrap into EAF</td>
<td>DANARC Plus (DANel electric ARC Plus)</td>
</tr>
<tr>
<td></td>
<td>Flat bath melting</td>
<td>IHI Shaft Furnace</td>
</tr>
<tr>
<td></td>
<td><strong>Maker : Intersteel Technology</strong></td>
<td>ECOARC (ECologically friendly &amp; EConomical ARC furnace)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Kansai Billet Center (JPN)</strong></th>
<th><strong>Nucor (USA)</strong></th>
<th><strong>Von Roll Stahl (ESP)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power : 35~40 kwh/t ↓ (60% preheating)</td>
<td><strong>O₂ : 33 Nm³/t</strong></td>
<td><strong>O₂ : 4 Nm³/t ↓</strong></td>
</tr>
<tr>
<td>65 kwh/t ↓ (100% preheating)</td>
<td><strong>Power : 325 kwh/t</strong></td>
<td><strong>C : 10 kg/t ↓</strong></td>
</tr>
<tr>
<td><strong>Hyundai Steel</strong></td>
<td><strong>Dongbu Steel</strong></td>
<td><strong>Power : 40~75 kwh/t ↓</strong></td>
</tr>
<tr>
<td>120T 1 furnace (’97.12)</td>
<td>160T 2 furnaces (’09.7)</td>
<td><strong>Dongkuk Steel</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>120T 1 furnace (’10.11 as scheduled)</td>
</tr>
</tbody>
</table>

**FSF (Finger Shaft Furnace)**
Heat Balance of EAF/Reheating Furnace

Input:
- Slag reaction: 1.1%
- Electrode oxidation: 1.8%
- Electric power: 65.0%
- Fuel/others: 32.1%
- Total: 100%

Molten steel: 50.5%
- Slag: 7.7%
- Electric loss: 3.1%
- Cooling water: 6.8%
- Off-gas/others: 32.0%

Output:
- Scale: 7.3%
- Charging materials: 43.2%
- Fuel: 41.7%
- Air: 7.8%
- Total: 100%

Extracting materials: 70.0%
- Cooling water: 6.4%
- Scale: 1.9%
- Radiation: 3.8%
- Off-gas/others: 18.0%

EAF
Reheating Furnace
Heat Balance (World Best Operation)

- Electrical Energy: 343.8 kWh/t
- Carbon: 150.1 kWh/t (Lump/Inj./Electrodes)
- Exoth. Reactions: 102.8 kWh/t
- Sensible Heat: 3.8 kWh/t
- Burners: 36.8 kWh/t

Total: 637.3 kWh/t

- Electrical Losses: 10.3 kWh/t
- Heat Losses: 57.8 kWh/t
- Slag: 43.4 kWh/t
- Off gas: 141.9 kWh/t

Steel: 383.9 kWh/t
# Heat Energy Recovery

## Heat Energy Recovery

- **Separate them into ‘Higher Heat Energy’ and ‘Middle・Lower Heat Energy’**

<table>
<thead>
<tr>
<th>Heat Energy Recovery</th>
<th>Higher heat energy recovery</th>
<th>Middle・Lower heat energy recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>High Temperature &gt; 500℃</td>
<td>Middle・Low Temperature &lt; 500℃</td>
</tr>
<tr>
<td><strong>Energy Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAF</td>
<td>High temperature off-gas and heat in the dusts</td>
<td>Heat (about 300℃) in off-gas after higher heat energy recovery</td>
</tr>
<tr>
<td>Reheating furnace</td>
<td>· Cooling water</td>
<td>· Off-gas</td>
</tr>
<tr>
<td></td>
<td>- Heat from cooling water in skid and post pipes to support reheating furnace</td>
<td>- Middle・lower energy from off-gas (250~400℃) emitted to the end of heat exchanger</td>
</tr>
<tr>
<td><strong>Utilization</strong></td>
<td>· Direct recovery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Scrap Preheating: SPH, Consteel, Shaft Furnace, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>· Indirect recovery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Steam: Operation(VOD, VAD, etc.), Cooling&amp;Heating, Cooking, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Electric Power: Utilizing electric power from steam turbine generators</td>
<td></td>
</tr>
</tbody>
</table>
### Higher Heat Energy Recovery

<table>
<thead>
<tr>
<th>Description</th>
<th>Direct Recovery (Scrap Preheating)</th>
<th>Indirect Recovery</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Past</strong></td>
<td>SPH (Scrap Preheater)</td>
<td>Making steam or electric power via heat exchanging from Off–gas(ECS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Directly heat the scraps in charging bucket</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Present</strong></td>
<td>Shaft Furnace</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Directly heat the scraps at the shaft on the top of EAF</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Details</strong></td>
<td>Stopped using SPH due to white smoke</td>
<td></td>
<td>Stopped using SPH in our plant in 2005</td>
</tr>
<tr>
<td></td>
<td>・Combustion of volatile materials in the scraps resulted in environmental pollutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Stopped using SPH due to white smoke</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Unpopularized because of maintenance difficulties and short life</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Also consteel has maintenance difficulties</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Efficiency of heat energy recovery is lower than Shaft Furnace, but cost reduction is better than SPH&amp;Consteel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Low initial cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>・High operational stability</td>
<td></td>
<td></td>
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<td>・Efficiency of heat energy recovery is lower than Shaft Furnace, but cost reduction is better than SPH&amp;Consteel</td>
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<td></td>
<td>・High operational stability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Higher Heat Energy Recovery

**ECS (Evaporating Cooling System)**

**Water Cooling System (AS-IS)**

- Cooling water inlet: 6 bar / 30 °C
- Cooling water outlet: 6 bar / 45 °C

Circulation after re-cooling

**ECS (Evaporation Cooling System)**

- Water + Steam inlet: 20 bar / 215 °C
  - Steam ratio: 0~5%

- Water + Steam outlet (mixed): 20 bar / 215 °C
  - Steam ratio: 10~15%

- Increase of steam ratio (but equal temperature)

- Making steam & electric power

- Accumulator
Higher Heat Energy Recovery

Energy Recovery System Lay-out of Hyundai Steel in Incheon

- EAF
  - 70T, 80T, 90T, 120T
- Steam ACC.
  - 2
    - size: 3.6m x 18m
- Steam Drum
  - 4
    - inside of each EAF
    - size: 2.1m x 12m
- Heat Exchanger
  - 1
    - size: 4.9m x 4.9m

Supply to district heating corporations

<table>
<thead>
<tr>
<th></th>
<th>The number of Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF</td>
<td>4</td>
</tr>
<tr>
<td>Steam ACC.</td>
<td>2</td>
</tr>
<tr>
<td>Steam Drum</td>
<td>4</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>1</td>
</tr>
</tbody>
</table>

* size: diameter x length

<table>
<thead>
<tr>
<th></th>
<th>AS-IS</th>
<th>TO-BE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of emission</td>
<td>1,597,635</td>
<td>1,517,753</td>
</tr>
<tr>
<td>(tCO₂e)</td>
<td></td>
<td>(↓ 5%)</td>
</tr>
<tr>
<td>Amount of emission</td>
<td>0.451</td>
<td>0.428</td>
</tr>
<tr>
<td>per ton (tCO₂e/T)</td>
<td></td>
<td>(↓ 5%)</td>
</tr>
</tbody>
</table>

※ Amount of crude steel in 2009: 3,542,428 ton
Higher Heat Energy Recovery

Energy Recovery in Reheating Furnace

: Energy recovery from cooling water absorbing off-gas between 850℃ and 1300℃ → This is Higher heat energy recovery and uniform energy recovery is possible
Use of Heat sources (Heat Energy Recovery from Off-gas)

| Energy sources | Middle&low temperature off-gas via heat exchange after reheat the materials in the reheating furnace  
|                | Off-gas from EAF after higher heat energy recovery |
| Features of off-gas | Consist of gas of middle&lower temperature (250~400°C)  
|                    | Energy is lower than higher heat energy, but heat sources are stable and steady |
| Utilizing off-gas  | Production of warm water: Possible to make and supply warm water for demands  
|                    | Production of electric power: Possible to recover uniform energy by using stable heat sources during production of electric power  
|                    | Efficiency is generally lower than warm water production system, suited to small power generation |

Production of Electric Power via Lower Heat Energy Recovery (ORC System)

<table>
<thead>
<tr>
<th>Capacity of generator</th>
<th>400kW ~ 2MW (modules up to 7MW)</th>
</tr>
</thead>
</table>
| Features of ORC System | Heat sources: middle temperature (120°C~350°C)  
|                        | Circulating thermal oil (260°C~312°C), heated by heat sources, twice (max) → electric power  
|                        | Possible to use different type of oil or unsteady heat due to thermal oil  
|                        | Electrical efficiency: 17%~19% (Max: 24%) |
| Reference              | Constructed and operating at 141 power plants of 12 countries (in March 2010) |
Middle&Lower Heat Energy Recovery

ORC (Organic Rankine Cycle) System

Heat Source → Evaporator → Pump → Condenser → Turbine → Generator → 40°F~90°F → Cooling Tower

Key:
- Red = hot water
- Green = working fluid
- Blue = cold water

Electric Power Output

Industrial Processes

Combined Cycles

ORC

Air Cooler

Thermal Oil Loop

Hot Water

Industrial And Thermal Users
Energy Recovery Potentials in Mini-Mills

Heat Sources
- EAF Off-gas
- RM RHF Off-gas

Energy Transfer
- Evaporation cooling
- ORC (Organic Rankine Cycle)

Recovery Equipment
- Steam Jet Pump
- Absorber
- Turbo Generator
- Heat Exchanger

Application
- Electric Power Generation
- Compressed Air
- Cold Production
- Process/building Heating

Heat Sources
- Slag Pit
- CCM R/T Cooling bed
- RM Cooling line

Heat Radiation
- Heat Exchanger

Applications
- Warm Water Applications