BIOMASS: PROVIDING A LOW CAPITAL ROUTE TO LOW NET CO₂ EMISSIONS

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Background

• The **Australian Steel Industry CO₂ Breakthrough Program** commenced in mid-2006

• It is a collaboration between Australia’s two major steelmakers and CSIRO

• Work has concentrated in two areas:
  - Applications of **biomass-derived chars** in ironmaking and steelmaking
  - Development of a **Dry Slag Granulation** process, with heat recovery

• **CSIRO** is Australia’s national research organisation

• **Arrium** (formerly OneSteel) is Australia’s long steel producer

• **BlueScope Steel** is Australia’s flat steel producer
Areas covered by our biomass work...

**Cradle-to-Gate Life-Cycle Assessment (LCA):** Norgate *et al* (2012) [5], Mathieson *et al* (2012) [3]


**Life-Cycle Assessment (LCA) - Charcoal:** Norgate *et al* (2012) [5]

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**Biomass Supply**

*Haque* *et al* (2008) [1]

**Charcoal Production**

*Deev* *et al* (2012) [2]

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**Designer Char Types**

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**Integrated Steelmaking**

**EAF Steelmaking**

**Specifications:**

Mathieson *et al* (2012) [3]

**Improvements:**


**Iron and Steelmaking Applications:**

See Pages 6-8, 20

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**Key**

*Most recent publications [x]*
Key Findings: Biomass supply and charcoal making

- Can charcoal be considered to be a “sustainable fuel” with near zero net CO$_2$ emissions?
  **Yes.** CSIRO LCA studies [5] indicate net CO$_2$ emissions for charcoal manufacture can be **negative**, if have (a) sustainable forestry, and (b) pyrolysis by-products utilised.

- Are there sufficient low-price forest resources available in eastern Australia to produce 1 Mt/yr of charcoal?
  **Yes.** CSIRO [1] and other studies show sufficient forest residue, building and demolition wastes.

- Can charcoal be produced at a cost comparable with coal/coke now?
  **Yes.** Already achieved in Brazil. CSIRO TEM study [7] positive for Australia [but the economics is constantly changing!]

- Is there a large-scale pyrolysis process that has high yields, utilizes by-products, and satisfies all environmental standards?
  **No.** But CSIRO has commenced development [2]. See Pages 16-18.
POTENTIAL FOR BIOMASS APPLICATIONS IN IRONMAKING AND STEELMAKING

**Assumption:** Results based on direct materials substitution (except as specified)
Biomass Applications: Integrated BF-BOF Route

1. Coal blend component
2. Sintering solid fuel
3. Nut coke replacement
4. Carbon/ore composites
5. Tuyere injectant
6. Liquid steel recarburiser

**Australian Integrated**
~ 3.8 Mt-steel/yr
~ 2.2 t-CO₂/t crude steel
Biomass Applications: Integrated BF-BOF Route

<table>
<thead>
<tr>
<th>Process</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steelmaking recarburiser (0.25 kg/t-crude steel)</td>
<td>31%</td>
<td>57%</td>
</tr>
<tr>
<td>Cokemaking blend component (2-10%)</td>
<td></td>
<td></td>
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<tr>
<td>BF carbon/or ore composites (5-10%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF nut coke replacement (50-100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sintering solid fuel (50-100%)</td>
<td>19%</td>
<td>25%</td>
</tr>
<tr>
<td>BF tuyere injectant (150-200 kg/t-HM)</td>
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</tr>
</tbody>
</table>

**TOTAL**

Net Emissions Saved (t-CO₂/t-crude steel)

Min: 31%  Max: 57%

**Note:** Percentages are based on 2.2 t-CO₂/t-crude steel.

Reference: J Mathieson, H Rogers, M Somerville, P Ridgeway, S Jahanshahi, EECR-METEC InSteelCon, Dusseldorf, June 2011 [7].
Assumptions:
- Sustainably managed plantation forests
- GWP for manufacture of 1 t charcoal is negative, i.e. -1006 kg CO$_2$-e
- Efficiencies when using charcoal included
- Percentages are based on 2.2 t-CO$_2$/t-crude steel.

EARLY RESULTS FROM CURRENT WORK AT CSIRO:

• Charcoal-ore composites
• Development of bio-coke
• Large-scale pyrolysis process
Reduction of Charcoal/Ore Composites

Key issues
- Strength of green briquette
- Strength after reduction: target >500 N
- Iron metallisation [wet method]

Experimental
- High strength green briquettes
  - Binder: 2 % starch
  - Pressure: 100 MPa
  - Moisture content: 10 to 20 %
  - Diameter: 25 mm    Height: 30 mm
- Factors studied – strength after reduction
  - C/Fe ratio
  - Temperature
  - Firing time
  - Range of carbon and iron sources
Experimental results (preliminary)

**Conditions:**
- Australian hematite ore: 13 μm mean size
- Charcoal (500°C, 19.5% VM): 6 μm mean size
- 2% CaCO₃ as flux
- C/Fe ratio: 0.23
- Temperature: 1300°C

**NEXT STEP:** Pilot or industrial RHF trials

- Compressive strength is high, but decreases at longer times
- Iron metallisation is high, but may decrease at longer times
Reduced briquette microstructures...

1300°C ● 15 minutes ● x 400

1300°C ● 25 minutes ● x 400

• Very well-formed slag network present (good fluxing)
• Increasing breakdown of strong iron network with time, and formation of more spherical iron particles - may lead to observed decrease in briquette strength
Development of Bio-Coke

OBJECTIVES:
• Maximize biomass/charcoal content in coke that is acceptable for the BF
• Build on prior published work.

METHOD:
• Base coal blend: Commercial battery feed
• Dense charcoal: 570°C; VM 5.8%; Ash 1.9%; Area 392 m²/g; Density 941 kg/m³
• Charcoal: 5, 10 and 15%
• Enhancement: 2% organic additive
• Retorts: 1 kg capacity (253 MA stainless steel)
• Cokemaking: 6 h profile, quenching, stabilisation
• Testing: Drum, Tumbler, CRI, CSR, microscopy
Petrography: Bio-coke

CASE 1: 90% Base Coal Blend +
+ 10% Charcoal (–1.0 +0.5) mm

- Some charcoal grains with poorly incorporated surfaces
- Some fracture development in pore walls

CASE 2: 88% Base Coal Blend
+ 10% Charcoal (–1.0 +0.5) mm
+ 2% organic additive

- Near complete encapsulation of charcoal
- Penetration of reactivies into the periphery of the charcoal grains
- Only minor fracture development
Reactivity to $\text{CO}_2$ (CRI) and Hot Strength (CSR)

- Coke reactivity increases with charcoal addition
- Coke hot strength decreases with charcoal addition
- Use of organic additive was very beneficial
- Use of high density charcoal may be beneficial
  [but comparisons require caution at this stage]

**NEXT STEP:** Pilot scale testing [400 kg]
CSIRO’s large-scale pyrolysis process technology

The Challenge

- Large production volumes needed (and scalable)
- Low-cost production (high yield, low heat requirements)
- Feed: wood chips or pellets
- Capture and exploit value of by-products (bio-oil, bio-gas)
- Satisfy all environmental standards

The Solution

- Slow pyrolysis reactions are exothermic
- Autogenous operation possible (dry feed)
- No heating at steady state (scalable)
- Slow pyrolysis maximises yield (30%)
- No air required (dilution of by-products)
- Capable of continuous operation and a high degree of automation.
CSIRO Pyrolysis Pilot Plant (Clayton, VIC)

Main Reactor Design:
- Int. Diameter: 600 mm;
- Shaft Height: 2750 mm;
- Inner Volume: 0.7 m³
- Feed rate: 100 - 300 kg/h
Pyrolysis technology development – commissioning

• Autogenous mode of operation achieved for
  ▪ batch process
  ▪ 30 min continuous operation

• 520°C maximum core temperature predicted for continuous operation

• VIDEO: Evolution of the temperature field during a 3 h run

NEXT STEPS:
– Complete commissioning
– Characterise process with two feeds: wood chips and wood pellets
– Seek partners
OVERALL STATUS OF DESIGNER CHARCOAL APPLICATIONS IN IRONMAKING AND STEELMAKING
## Status of iron and steelmaking applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Optimized Quality Parameters† [3]</th>
<th>Last Stages Completed</th>
<th>Next Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sintering solid fuel</td>
<td>Low VM: &lt;3%</td>
<td>Pilot scale testing [9, 10]</td>
<td>Industrial trials</td>
</tr>
<tr>
<td></td>
<td>High density*: &gt;700 kg/m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size: 0.3 - 3 mm</td>
<td></td>
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<tr>
<td>Cokemaking blend component</td>
<td>Low to mid VM: &lt;10%</td>
<td>Bench-scale R&amp;D</td>
<td>Pilot oven trials</td>
</tr>
<tr>
<td></td>
<td>High density*: &gt;700 kg/m³</td>
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</tr>
<tr>
<td></td>
<td>Size: &lt;1 mm</td>
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<td></td>
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<td></td>
<td>Low alkalis</td>
<td></td>
<td></td>
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<tr>
<td>BF tuyere injectant</td>
<td>Higher VM: 10 - 20%</td>
<td>Theoretical analysis [7] &amp; combustion testing [11]; Mini-BF commercial operations in Brazil</td>
<td>Trial on large BF</td>
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<tr>
<td></td>
<td>Low ash: &lt;5%</td>
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<tr>
<td></td>
<td>Low alkalis</td>
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<td></td>
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<tr>
<td>BF nut coke replacement</td>
<td>Low to mid VM: &lt;7%</td>
<td>Mini-BF commercial operations [12]</td>
<td>Trial on large BF</td>
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<tr>
<td></td>
<td>Higher density</td>
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<tr>
<td></td>
<td>Size: 20 - 25 mm</td>
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<td></td>
</tr>
<tr>
<td>Carbon/ore composites</td>
<td>Low VM: &lt;5%</td>
<td>Bench-scale R&amp;D</td>
<td>Pilot or industrial trials (RHF)</td>
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<tr>
<td></td>
<td>Size: 80% passing 75 µm</td>
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<tr>
<td>Steel recarburiser</td>
<td>Low VM: &lt;3%</td>
<td>Industrial trial [13]</td>
<td>Industrial trial with optimized charcoal</td>
</tr>
<tr>
<td></td>
<td>Low moisture: &lt;2%</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>High density*: &gt;500 kg/m³</td>
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<tr>
<td>EAF charge carbon</td>
<td>Low to mid VM: &lt;7%</td>
<td>Proposed</td>
<td>Industrial trial</td>
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<tr>
<td></td>
<td>Size: 20 - 30 mm</td>
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<td></td>
<td>Low alkalis</td>
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<tr>
<td>EAF foaming agent/ inject carbon</td>
<td>Low to mid VM: 2 - 7%</td>
<td>Industrial trial [14]</td>
<td>Industrial trial with optimized charcoal</td>
</tr>
<tr>
<td></td>
<td>Moisture: 1 - 7%</td>
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<tr>
<td></td>
<td>Size: 0.5 - 5 mm</td>
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<td></td>
<td>Low alkalis</td>
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</tbody>
</table>

† Applications not requiring very low moisture levels require relatively dry charcoal, say <12% moisture.

* This is particle (not bulk) density.
Conclusions

• A comprehensive forest-to-steel biomass R&D program has been undertaken over seven years (2006 - 2013)
• Deep cuts in CO$_2$ emissions and Global Warming Potential are possible
• Laboratory-scale work has been completed for most applications
• Establishing a low-cost, large-scale pyrolysis industry is crucial to widespread implementation
• Coal/coke substitution by biomass-derived chars can provide a low capital path to low CO$_2$ emissions from integrated steelmaking plants

• **Next steps:**
  - Full industrial trials of key applications, especially BF injection [hopefully assisted by Government funding]
  - Scale-up of CSIRO pyrolysis process.
References


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CSIRO
Thank you

Dr Sharif Jahanshahi
Theme Leader – Sustainable Metals Production
Minerals Down Under National Research Flagship

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EAF Mini-Mill

- Scrap Steel
- ELECTRIC ARC FURNACE (EAF)
- “Graded” Liquid Steel
- Crude liquid steel
- Liquid steel recarburiser
- CONTINUOUS CASTER
- STEEL REFINING STATION
- ROLLING MILL
- REHEAT FURNACE

7. Charge carbon
8. Inject carbon (slag foaming)

Australian EAF
~ 1.5 Mt-steel/yr
~ 0.5 t-CO$_2$/t crude steel

6. Liquid steel recarburiser

Hot Rolled Products
Biomass Applications: EAF Route

Note: Percentages are based on 0.5 t-CO$_2$/t-crude steel.

- Natural gas heating: 0%
- Scrap, electrodes, etc: 0%
- Steelmaking recarburiser: 1.4 kg/t-crude steel
- Inject carbon: 100%
- Charge carbon: 50-100%
- TOTAL

Net Emissions Saved (t-CO$_2$/t-crude steel):
- Min: 7.8%
- Max: 11.5%

Emissions (t-CO$_2$-e/t-crude steel):
- Process carbon
- Electricity
- TOTAL
- 85%
- 11.5%
What is predicted to happen?

ULCOS Scenario Modelling: Carbon Constraint Case (F2)

Messages:
- Strong growth in EAF
- Strong growth in charcoal
- Little new technology penetration till 2025