BIOMASS: PROVIDING A LOW CAPITAL ROUTE TO LOW NET CO_2 EMISSIONS

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Background

- The **Australian Steel Industry CO_2 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]

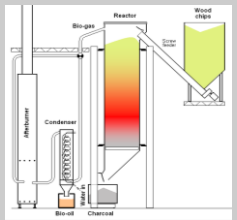
Techno-Economic Modelling (TEM): Jahanshahi *et al* (2014) [6]

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

Biomass Supply

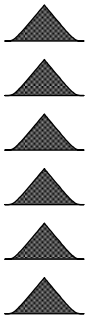
Haque *et al* (2008) [1]

Charcoal Production



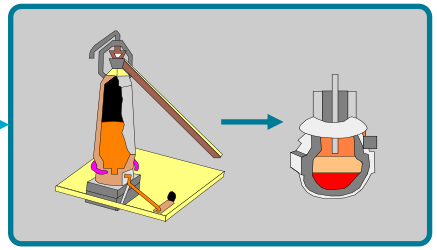
Deev *et al* (2012) [2]

Designer Char Types

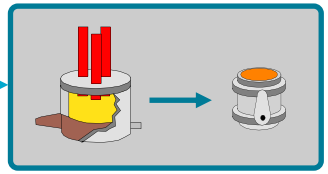


Specifications:
Mathieson *et al* (2012) [3]
Improvements:
Somerville *et al* (2012) [4]

Integrated Steelmaking



EAF Steelmaking



Iron and Steelmaking Applications:
See Pages 6-8, 20

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!]

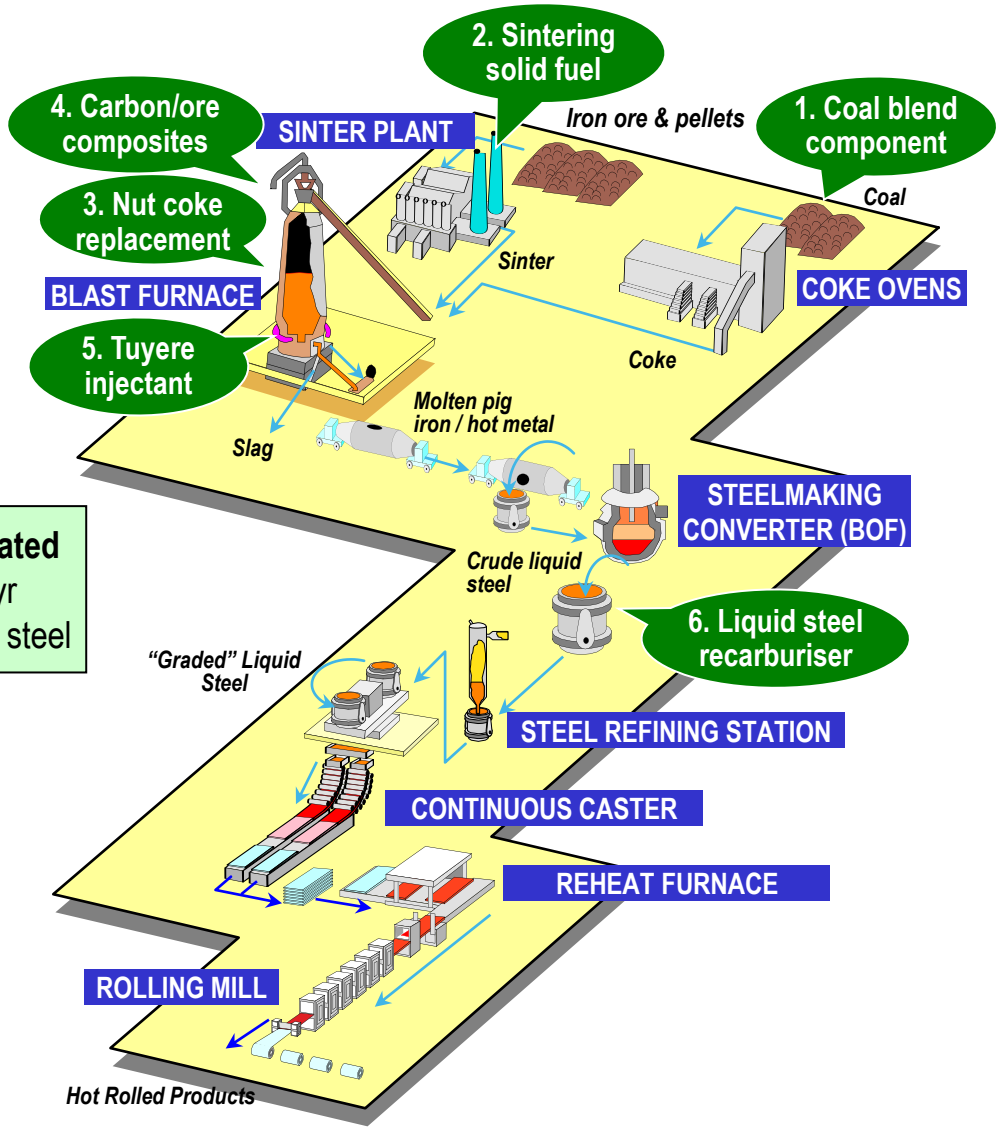
- Is there a large-scale pyrolysis process that has high yields, utilizes by-products, and satisfies all environmental standards?

No. But CSIRO has commenced development [2]. See Pages 16-18.

POTENTIAL FOR BIOMASS APPLICATIONS IN IRONMAKING AND STEELMAKING

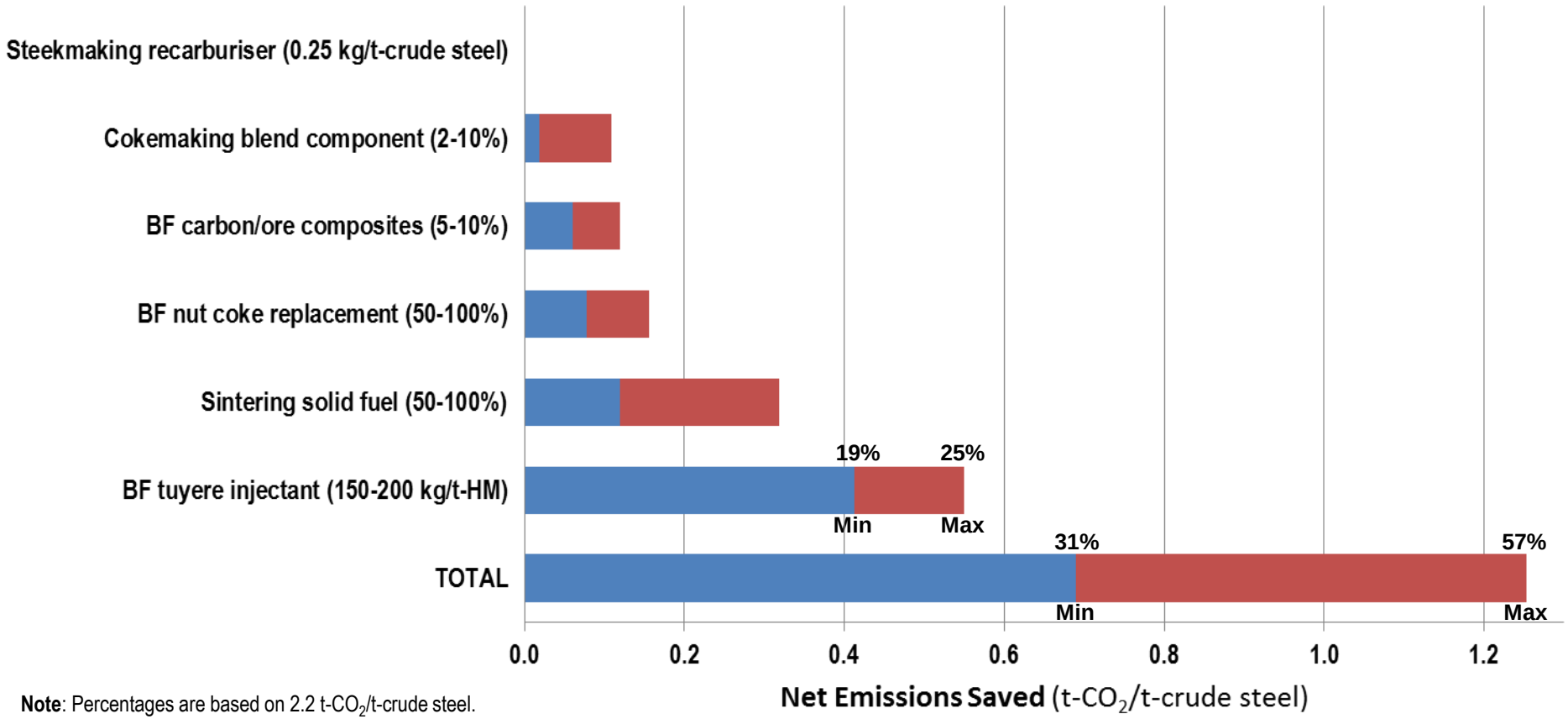
Assumption: Results based on direct materials substitution (except as specified)

Biomass Applications: Integrated BF-BOF Route



Australian Integrated
~ 3.8 Mt-steel/yr
~ 2.2 t-CO_2/t crude steel

Biomass Applications: Integrated BF-BOF Route

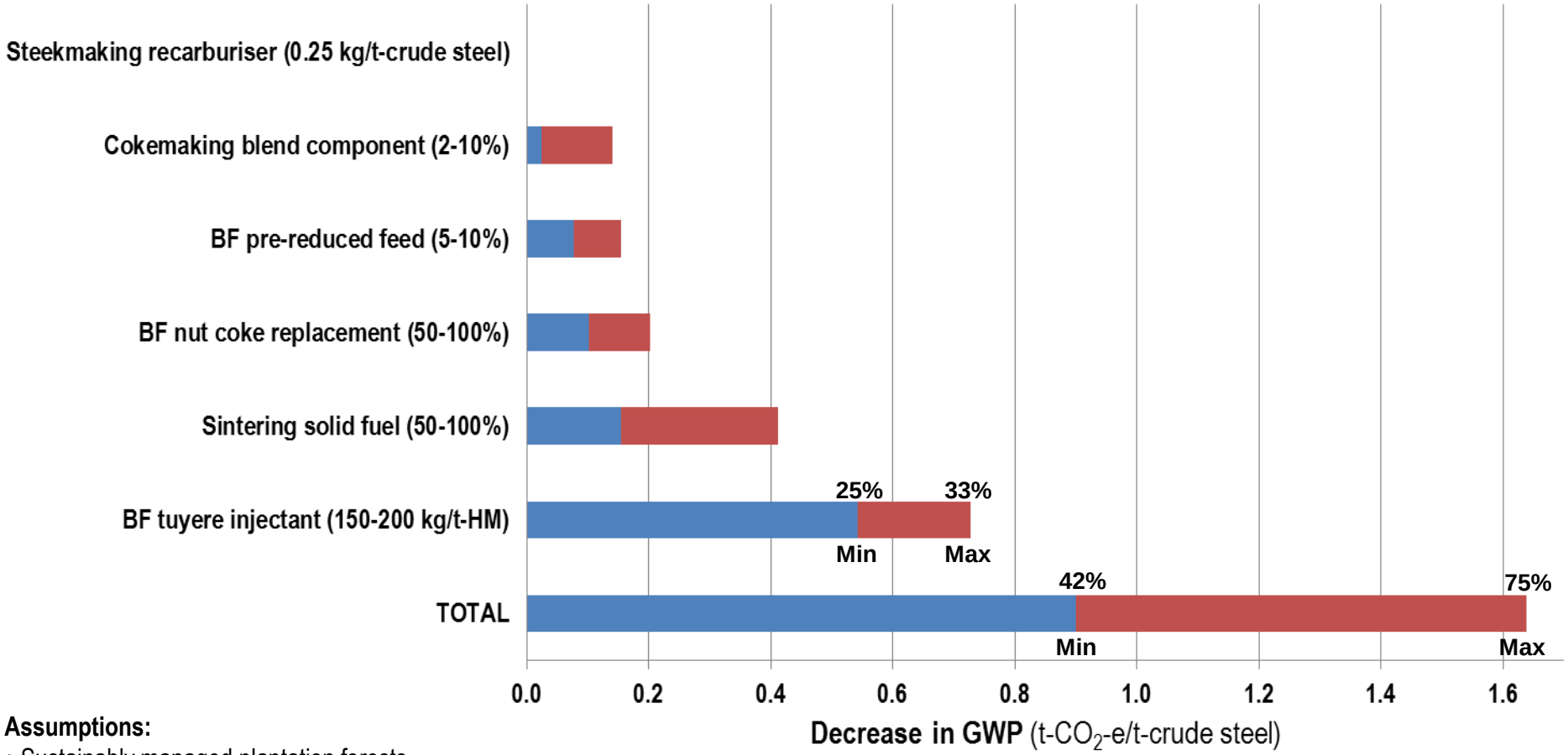


Note: Percentages are based on 2.2 t-CO_2/t-crude steel.

Reference: J Mathieson, H Rogers, M Somerville, P Ridgeway, S Jahanshahi, *EECR-METEC InSteelCon*, Dusseldorf, June 2011 [7].

Forest-to-Steel LCA Results: Integrated Route

Measure: Global Warming Potential (GWP)



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.

Reference: J Mathieson, T Norgate, S Jahanshahi, M Somerville, N Haque, A Deev, P Ridgeway, P Zulli, 6th ICSTI, Rio de Janeiro, October 2012 [3].

EARLY RESULTS FROM CURRENT WORK AT CSIRO:

- **Charcoal-ore composites**
- **Development of bio-coke**
- **Large-scale pyrolysis process**

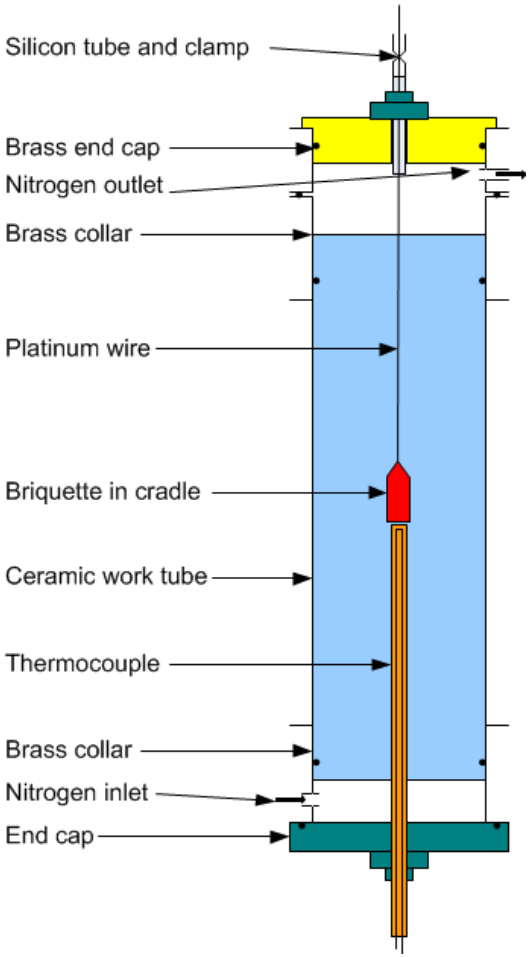
Reduction of Charcoal/Ore Composites

Key issues

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

Experimental

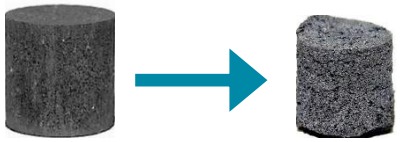
- High strength green briquettes
  - Binder: 2 % starch
  - Pressure: 100 MPa
  - Moisture content: 10 to 20 %
  - Diameter: 25 mm Height: 30 mm
- Factors studied – strength after reduction
  - C/Fe ratio
  - Temperature
  - Firing time
  - Range of carbon and iron sources

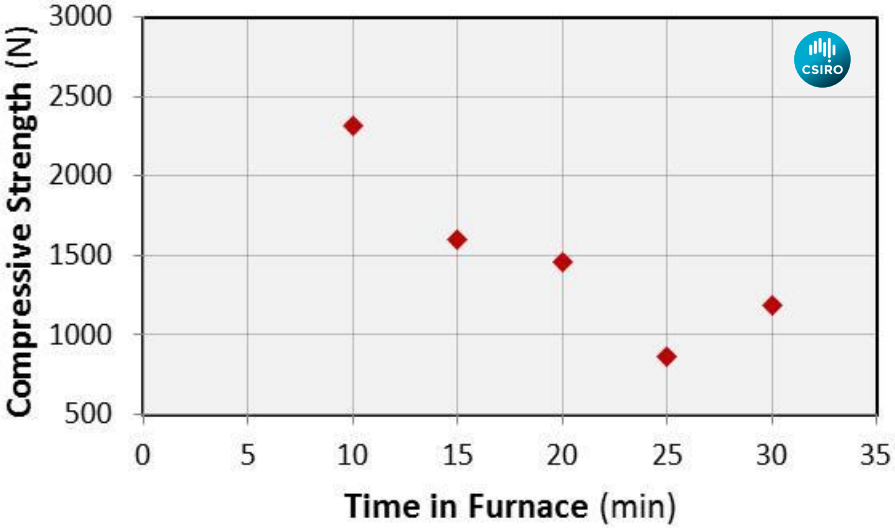


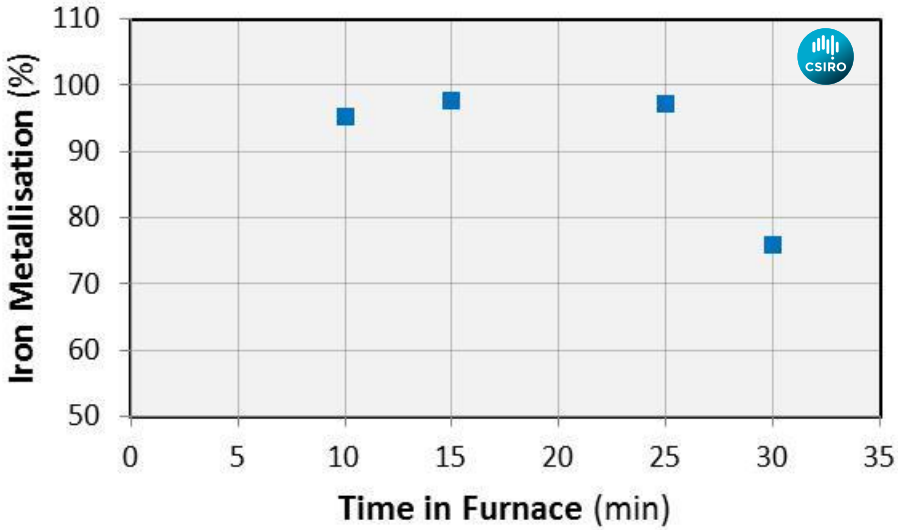
Experimental results (preliminary)

Conditions:

- Australian hematite ore: 13 µm mean size
- Charcoal (500°C, 19.5% VM): 6 µm mean size
- 2% $CaCO_3$ as flux
- C/Fe ratio: 0.23
- Temperature: 1300°C





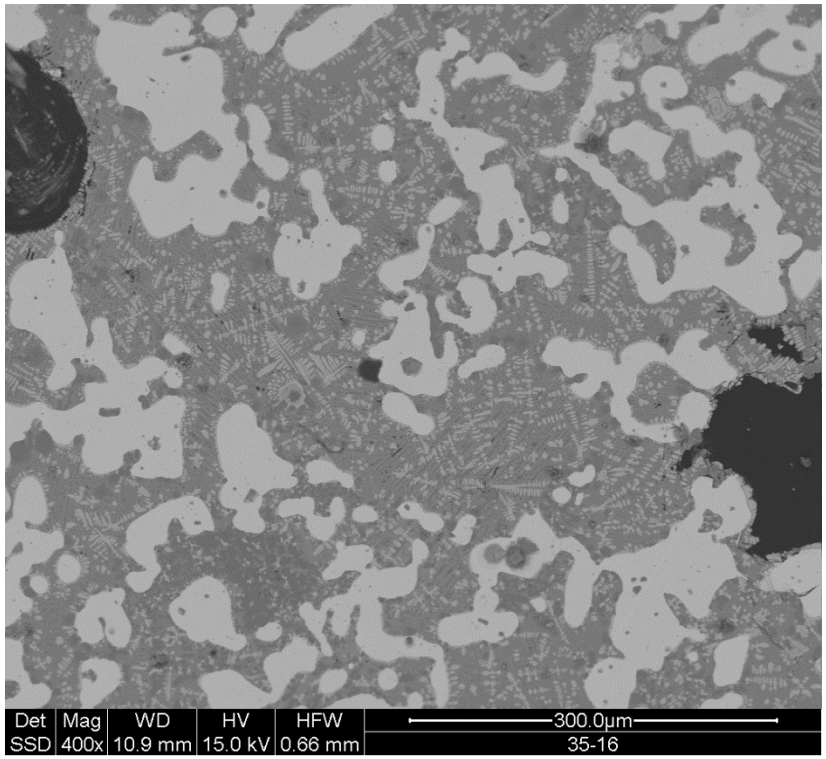


- Compressive strength is high, but decreases at longer times
- Iron metallisation is high, but may decrease at longer times

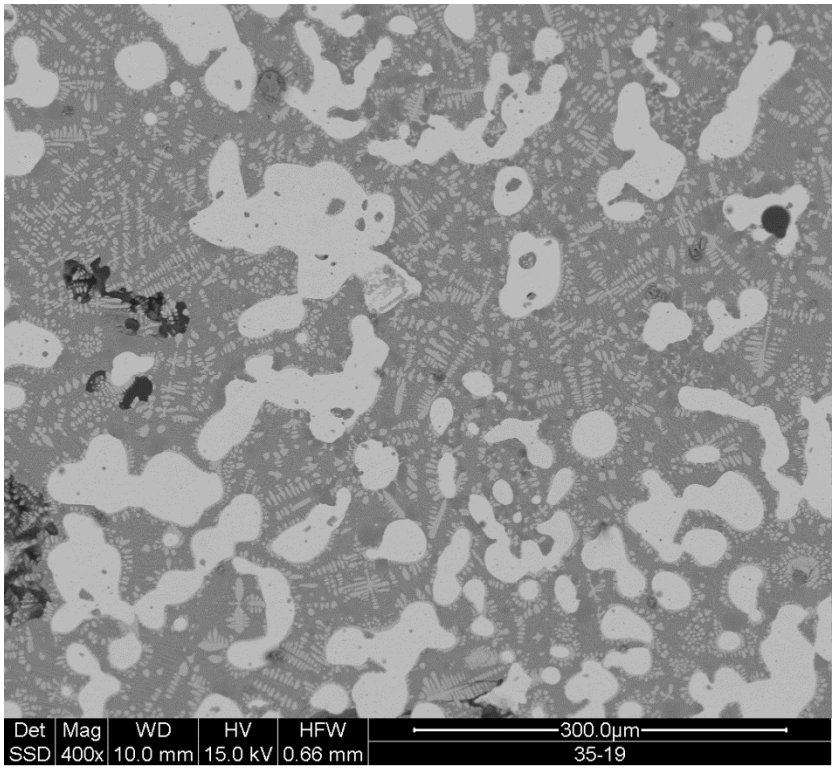
NEXT STEP: Pilot or industrial RHF trials

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

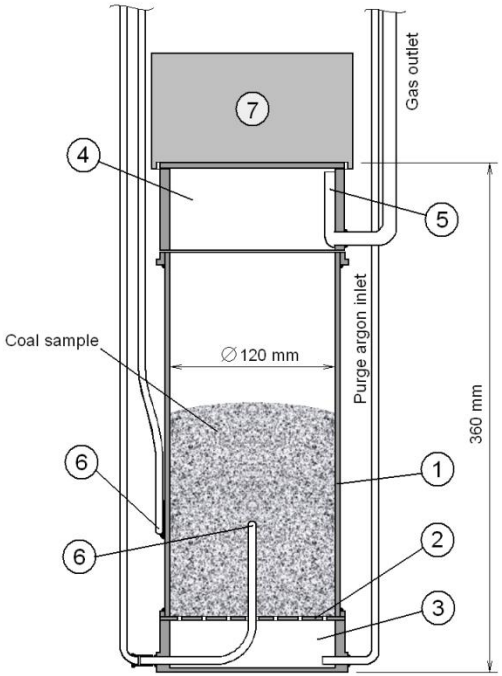
Development of Bio-Coke

OBJECTIVES:

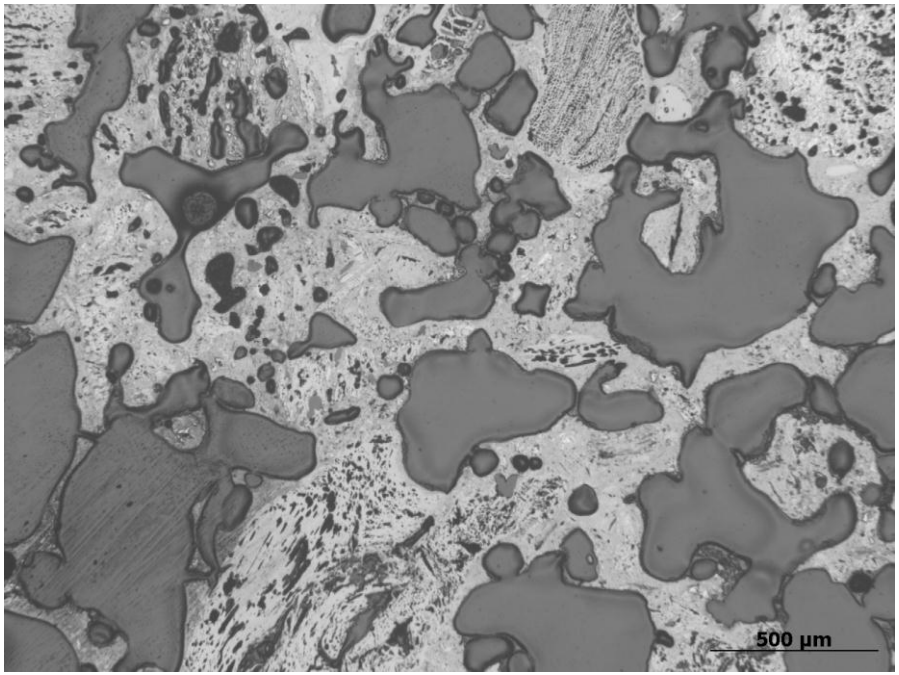
- Maximize biomass/charcoal content in coke that is acceptable for the BF
- Build on prior published work.

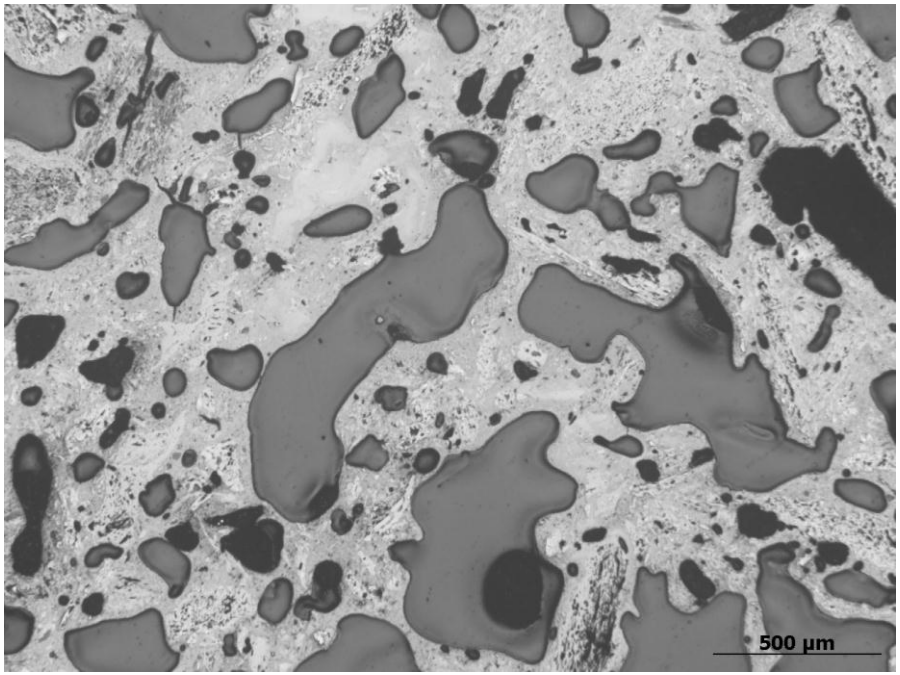
METHOD:

- Base coal blend: Commercial battery feed
- Dense charcoal: 570°C; VM 5.8%; Ash 1.9%; Area 392 m^2/g; Density 941 kg/m^3
- 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





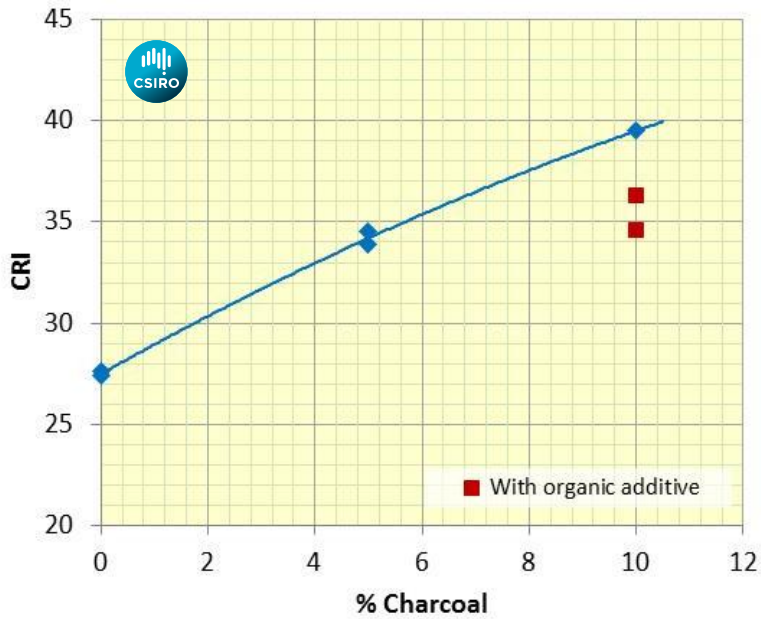
CASE 1: 90% Base Coal Blend +
+ 10% Charcoal (–1.0 +0.5) mm

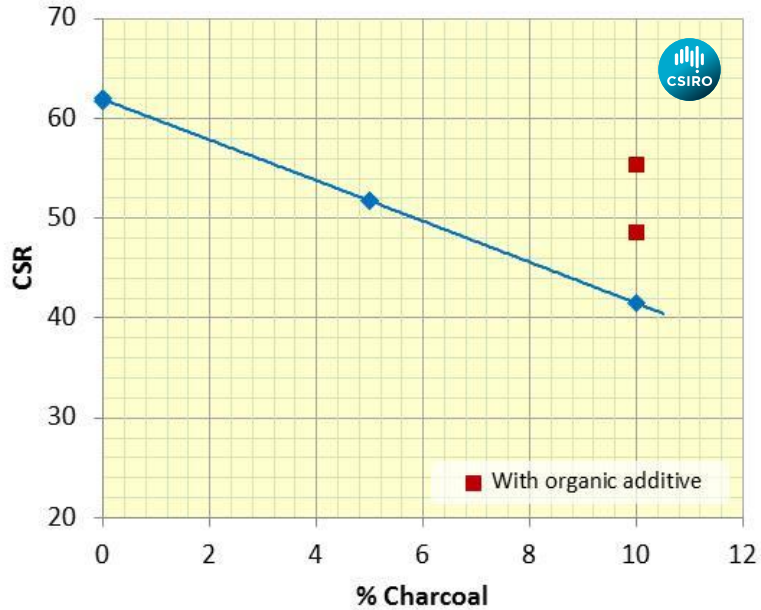
- Some charcoal grains with poorly incorporated surfaces
- Some fracture development in pore walls

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

- Near complete encapsulation of charcoal
- Penetration of reactives into the periphery of the charcoal grains
- Only minor fracture development

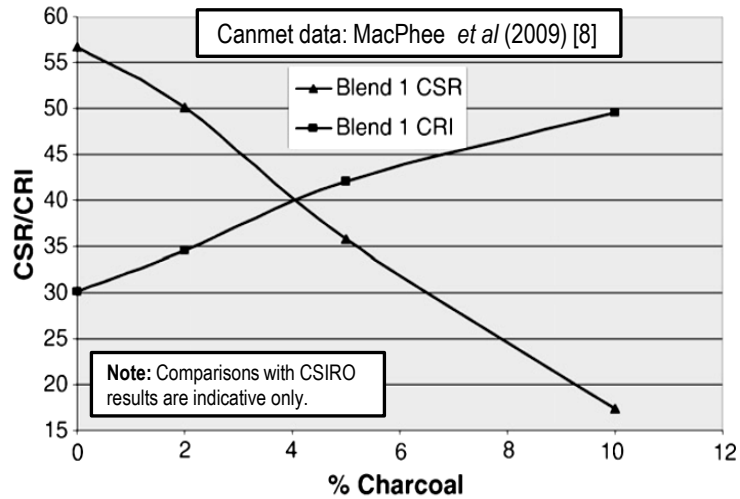
Reactivity to CO_2 (CRI) and Hot Strength (CSR)





- 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]



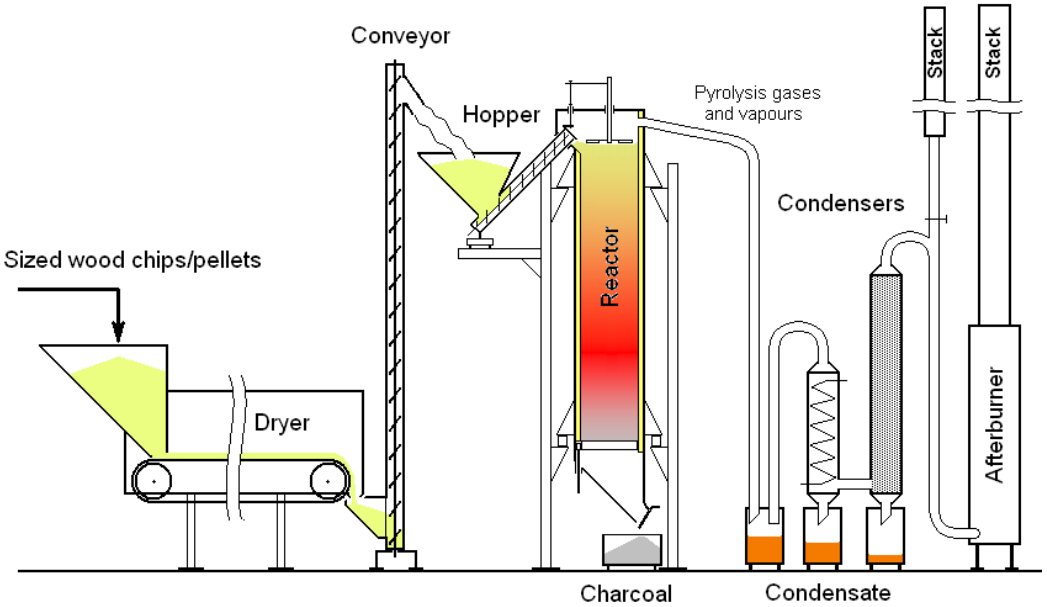
CSIRO's large-scale pyrolysis process technology

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

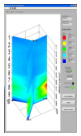
- Slow pyrolysis reactions are exothermic
- Autogenous operation possible (dry feed)
- No heating at steady state (scalable)
- Slow pyrolysis maximises yield (30%)
- No air required (dilution of by-products)
- Capable of continuous operation and a high degree of automation.

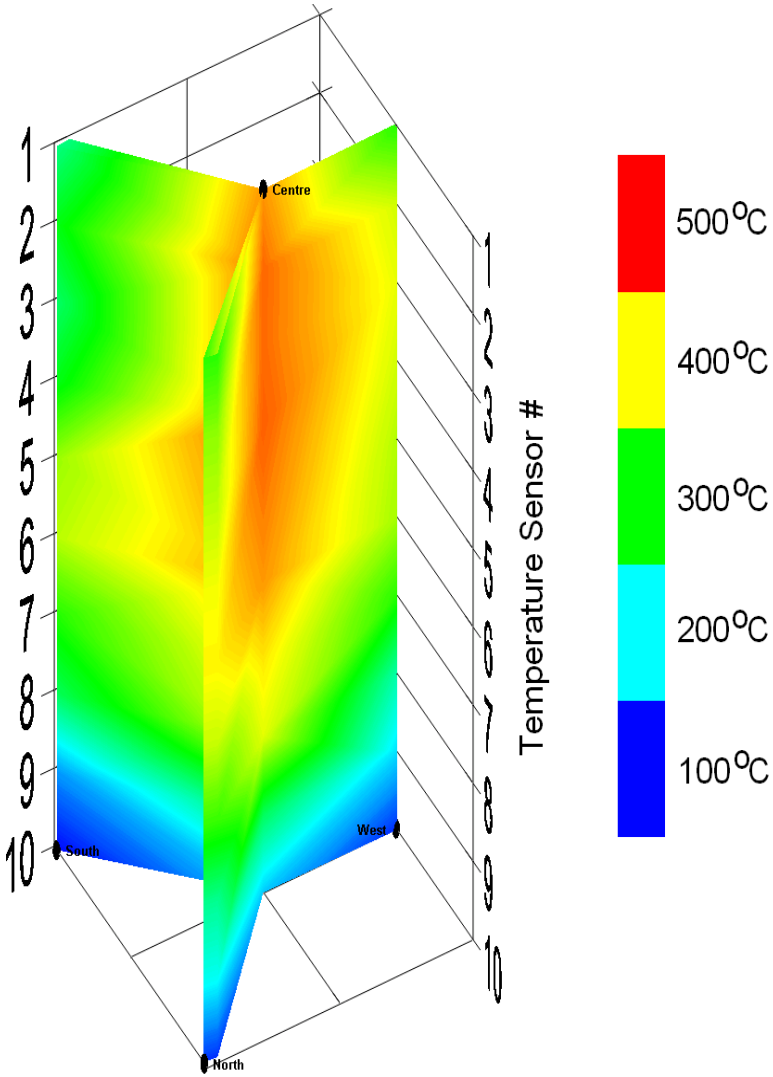


CSIRO Pyrolysis Pilot Plant (Clayton, VIC)

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

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

† 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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14. L Wibberley, J Nunn, P Scaife, A Zivlas, L Andrews, B Coomber, R Dickson, D Gardne, and A. Cowie, "Large Scale use of Forest Biomass for Iron and Steelmaking", NSW Government Sustainable Energy Research Development Fund (SERDF) Report by BHP Minerals Technology and NSW State Forests, 2001.

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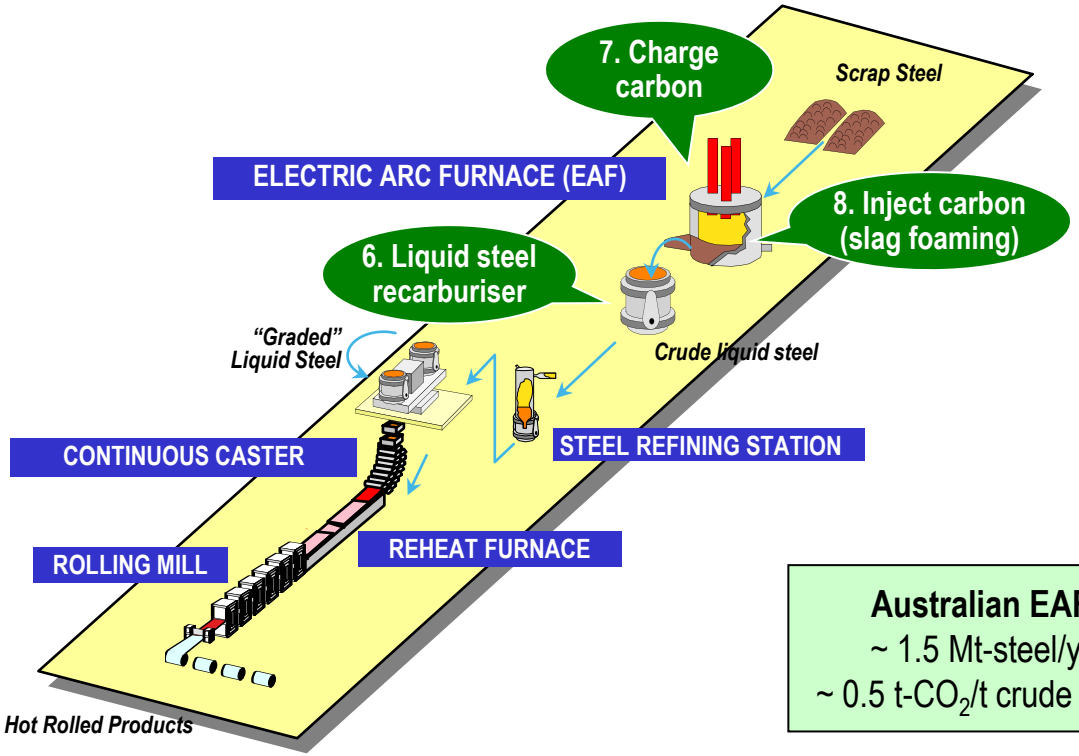
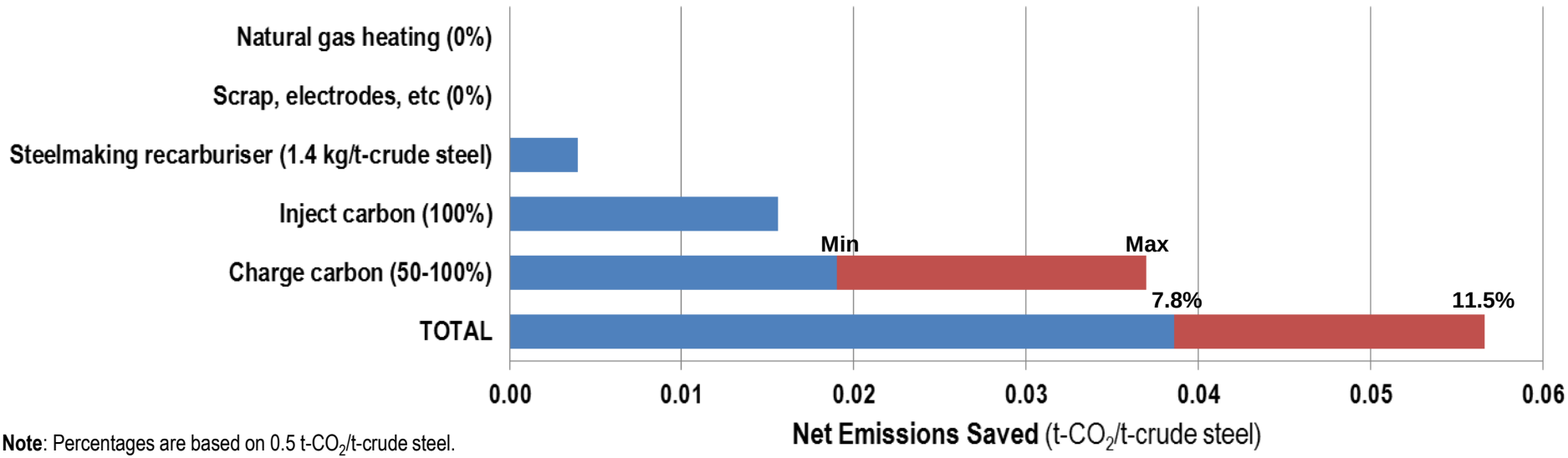
EAF Mini-Mill

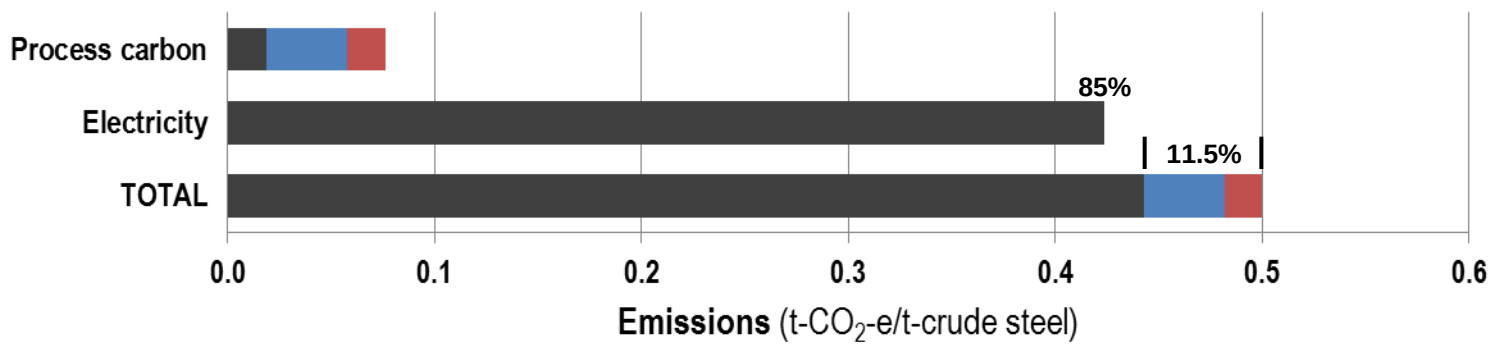


Australian EAF
~ 1.5 Mt-steel/yr
~ 0.5 t-CO_2/t crude steel

Biomass Applications: EAF Route

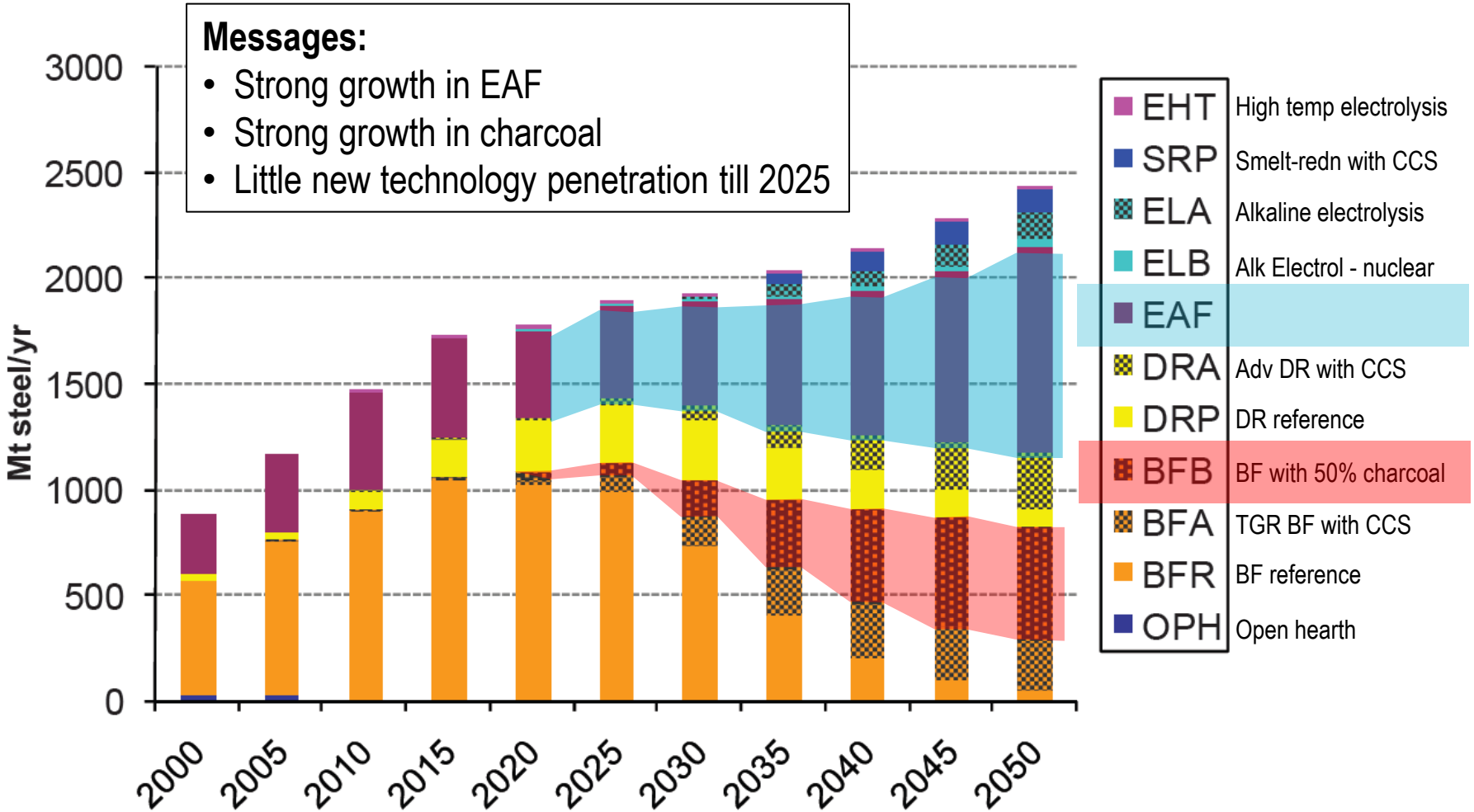


Note: Percentages are based on 0.5 t-CO_2/t-crude steel.



What is predicted to happen?

ULCOS Scenario Modelling: Carbon Constraint Case (F2)



Source: E Bellevrat and P Menanteau, *Revue de Metallurgie*, Vol.9, pp.318-324 (2009)