Alternative sustainable carbon sources as substitutes for metallurgical coal

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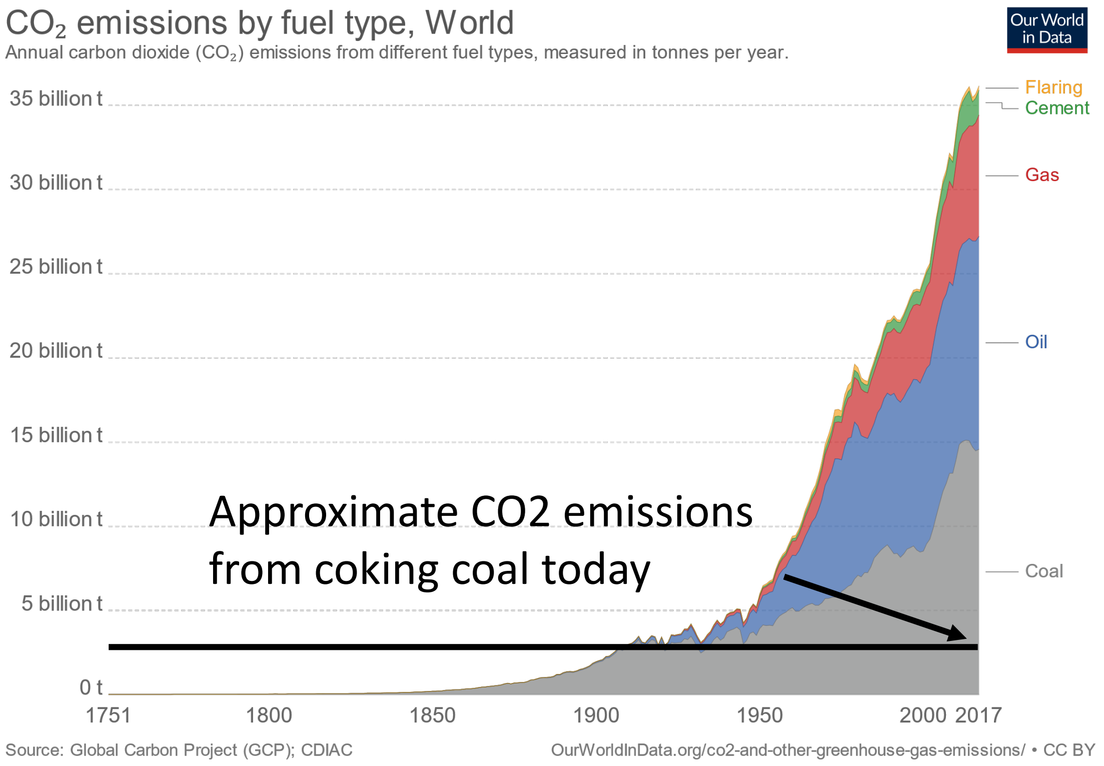
Coal represents the largest single source of fossil fuel CO2 emissions

Most coal is used for producing power, however…

- Approximately 1.1 billion tonnes of met coal (15% of total coal production) is consumed annually. This means that around 3 billion tonnes of CO2 comes from the steel making process.
- Due to the energy requirements to produce iron and steel, about 27 % of CO2 emissions of **the global manufacturing sector** come from iron and steel production.

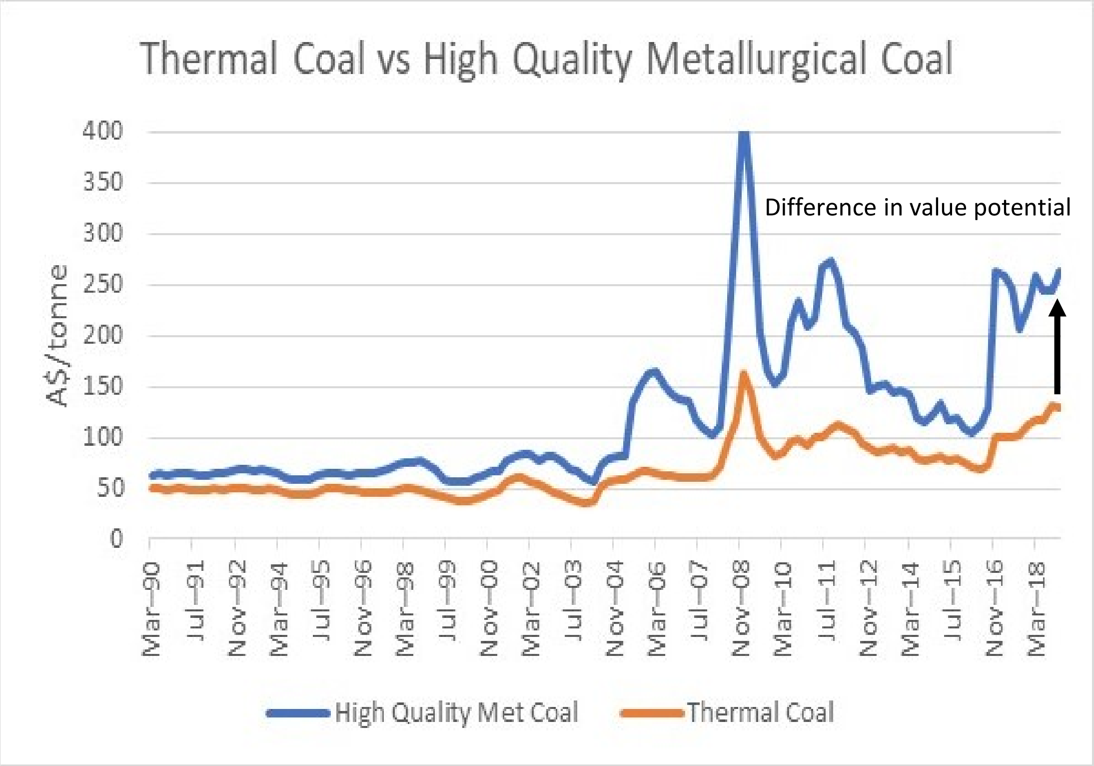


Metallurgical coal is higher value but must satisfy more requirements

Coking coal sells around double the price of thermal coal

- Thermal coal's value simply comes from the value of the energy potential utilised in a power plant
- Met coal must also be a reductant and is also used for physical support (structure in a blast furnace)
- There are 4 main types of steel-making process:

  - Blast furnace-basic oxygen (BF-BOF)
  - Smelting reduction iron in BOF (SRI-BOF)
  - Direct reduction iron – electric arc furnace (DRI-EAF)
  - Direct smelting of scrap (Mini-mill)



Source Data: Resources and Energy Quarterly – March 2019

IEA Bioenergy
Technology Collaboration Programme

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The opportunity

Substitutes could present an economic and environmental opportunity

Steel industry is looking for opportunities to diversify away from coal

- Cost of coking coal has been rising
- Depletion of high-quality coking coal worldwide
- Tightening environmental regulations regarding CO2 generation

- However, more sustainable alternatives must be able to deliver a substitute:
  - Without large associated capital costs
  - Reduce the carbon footprint without seriously affecting process efficiency

Steel making "101" – Background to steel making

Coke roles…

- **Physical role:** *In blast furnaces, coke influences the gas distribution in the shaft, provides mechanical support to the charge column and permeable bed below the cohesive zone.*
- **Chemical role:** *Coke produces and regenerates the reducing gases to reduce iron and other oxides and provides carbon to carburise the molten iron.*
- **Thermal role:** *Carbon as a source of fuel providing the heat and energy required for endothermic reaction and melting of iron and slag.*

Selected results from trials

Two sets of trials were carried out using the various reductants

- The team at the SMaRT@UNSW centre carried out two sets of trials on the various sustainable reductants. A full review of the results can be read in the report entitled "Alternative sustainable carbon sources as substitutes for metallurgical coal"
- Two tests carried out were:

  - Thermal degradation of C-bearing materials. This test was designed to investigate the material's behavior at various temperatures

  - Iron oxide reduction using C-bearing materials. This test was to determine the effectiveness of the reduction of iron oxide to metallic iron using the various carbon bearing materials

Composition of the substrates – significant differences

Four substrates = 4 different chemical compositions

- Elemental composition of the substrates was determined by combustion/XRF analysis.
- Lignin has a relatively high lime content of 0.5% which is a positive for steel making as it can be used as a fluxing agent.
- The highest ash content was found in Met Coal of which 60% is silica.

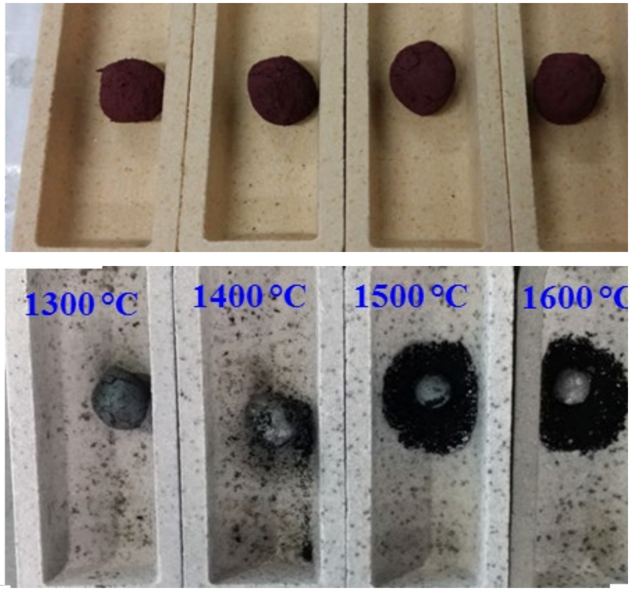
	Met Coal	Lignin (average)
Solid Carbon (wt%)	85.5	20.0
Ash (wt%)	11.5	6.1
Total Carbon (wt%)	85.5	40.7

Iron oxide reduction performance – Lignin

Lignin – Sponge Iron at lower temps, complete reduction at higher temps

- At the lowest temperature (1300), the largest volume of metal was produced with no carbon around it. This is known as "sponge iron" where the lignin is still trapped as free carbon inside the sinter. This type of material is an important feedstock into many Electronic Arc Furnace (EAF) and Blast Furnaces (BF) around the world.

a) densified pellets of iron (III) oxide/LRC (ratio of 3 g-atoms of carbon to 1 g-mole of iron(III) oxide), b) reduced pellets at different temperatures

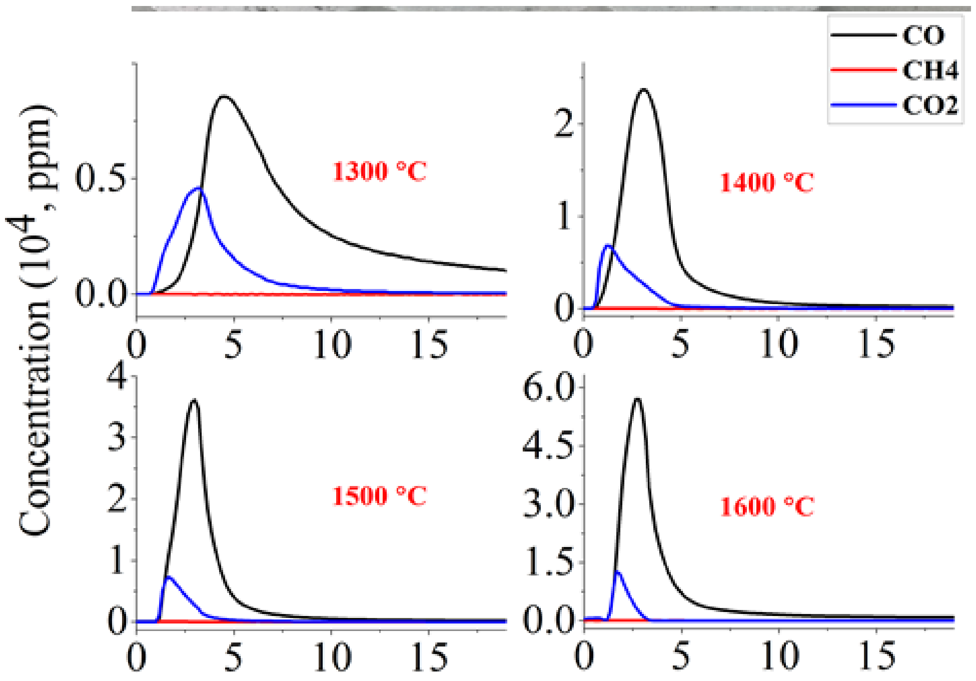


Iron oxide reduction performance – Lignin cont.

Lignin – Sponge Iron at lower temps, complete reduction at higher temps

- Gas products from the reduction process was measured for each of the 4 different temperatures
- The amount of carbon monoxide produced can be used as an indicator of the completion of the reduction process.
- In the case of lignin, at temperatures above 1500 degrees C the reduction reached equilibrium. This is a typical duration for most types of carbon

gas product analysis of iron(III) oxide reduction



Lignin could be a met coal substitute

Conclusions so far…

- There are several potential alternative sustainable alternatives to metallurgical coal
- To really make a difference, lignin presents the greatest opportunity due to potential future volumes
- Testing of lignin by the SMaRT@UNSW centre has shown that:

  - The thermal transformation of lignin resulted in a reasonable yield of solid carbon

  - Although composition varied, most detected impurities in the lignin would be tolerated or be advantageous in making steel

  - That the reduction of pure iron oxide required a relatively low value of activation energy

  - At high temps, reduction is complete and even at low temps, a typical sponge product is produced

Lignin as a met coal replacement could be “win-win”

Benefits to the environment and economics

- One of the keys to accelerating the deployment of 2G bioethanol is to improve project economics
- Assuming that lignin produced from a 2G ethanol plant could be sold as a met coal replacement then…
- … a 2G ethanol plant could increase it revenues over 10% due to the lignin value doubling
- … at essentially little or no additional production cost
- Using lignin for steel making would lower the long-term risk of needing met coal substitutes
- As met coal becomes more difficult to access lignin as a met coal replacement could result in lower steel costs

Ref: Mayyas, M., Khayyam Nekouei, R., Sahajwalla, V., Valorization of Lignin Biomass as Carbon Feedstock in Steel Industry: Iron Oxide Reduction, Steel Carburizing and Slag Foaming, 2019, Journal of Cleaner Production, 219, 971-980.