The use of biomass in metallurgical industry – preliminary evaluation

Lab. of Process Metallurgy, Hannu Suopajärvi, 23.11.2011

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Content of the presentation

- Background
- Bioreducer-project
- Research objective
- Topics discussed in this presentation
  - Availability of biomass
  - Conversion routes of biomass to reducing agent
  - Evaluation of the effect of charcoal use in plant scale
  - Price of charcoal
  - The yearly need of biomass
  - Differences between charcoal and fossil-based reducing agents
  - Challenges in biomass-based iron and steelmaking
- Conclusions
- References

Background

- CO_2 problem in steel industry
  - Contributes 5-7 % of world's fossil CO_2 emissions
  - In Finland Ruukki produces 4 to 5 Mt CO_2 yearly (around 6-7 % of CO_2 emissions in Finland)
- Political actions and Steel industry's response
  - Energy efficiency plans with producers
  - Emission trade
  - Increasing material and energy efficiency
  - Adopting new technologies
  - By-product usage of other industries
  - Increasing recycling
  - Adopting new raw materials (**biomass…**)

Bioreducer-project

- Funding mainly from Tekes (2010-2012) and companies
- Biomass-based reducing agents for the use of metallurgical industry
- Objectives
  - To evaluate the availability of raw materials
  - To evaluate the technical potential of biomass-derived reducing agents in metallurgical processes
  - To determine the suitable conversion technologies to produce biomass-derived reducing agents
  - To estimate plant-wide effects (BF-BOF steel plant) of biomass introduction
  - To assess sustainability of biomass use in iron and steelmaking industry
- Methods
  - Availability assessments
  - Process modeling and simulation
  - Sustainability assessment
  - Laboratory experiments
- Project manager Mikko Angerman
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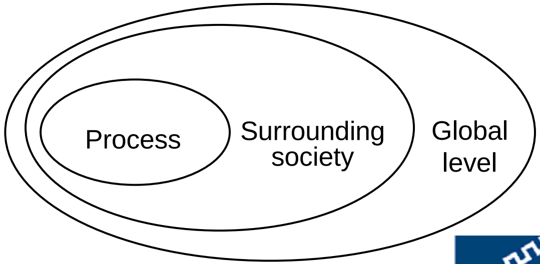
Leverage from the EU 2007–2013
European Union
European Regional Development Fund

Thesis work: Research objective

- ”Hypothesis”:
  - Domestic biomass is sustainable raw material for Finnish iron and steelmaking in a form of reducing agent
- Objective:
  - Creation of embedded sustainability evaluation framework
    - Economic, environmental, social and technological evaluation in separate system levels
  - Methods
    - Combining different analysis tools: process modeling, life cycle assessment, economic calculations, availability evaluations

Evaluation of biomass use in I & S industry in different system levels

System level	Environmental dimension	Economic dimension	Technology dimension	Social dimension
Unit process	The share of fossil CO_2 emissions Effect on by-products (gases, slags)	Technology investments needed Effect on downstream processing	Technology availability Process behavior Product quality	-
Plant level (surrounding society)	Availability of raw materials Possible raw materials Environmental burdens caused by resource acquisition Utilization of by-products	Biomass cost Carbon taxes Waste management costs	Process integration opportunities and restrictions Processing of biomass Utilization of by-products	Laws and regulations Government support Competing uses of biomass Job creation
Global level	Sustainable biomass acquisition Land use problems	Biomass cost on a global scale	Biomass pre-processing, transportation Technology development	Competition with food production The role of biomass in energy production

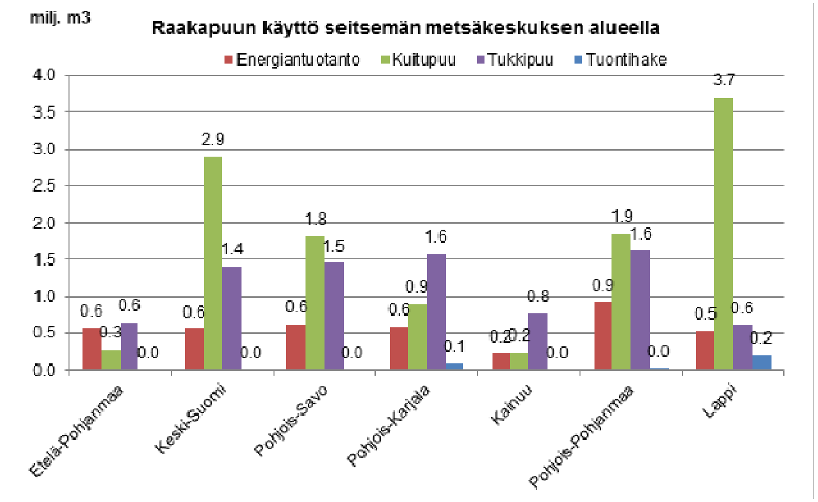


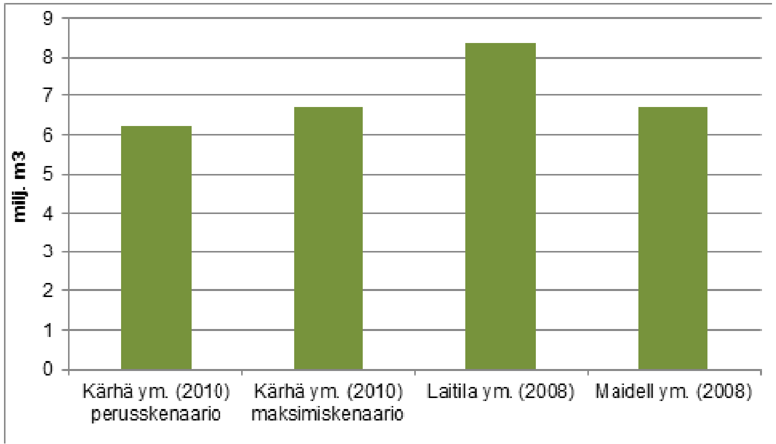
Availability of biomass

- Large acquisition area was assumed
  - Production of charcoal could be done in decentralized manner
  - The main interest was in wood-based biomass because of the large volumes
  - Also other biomass and alternative feedstocks were evaluated
    - Peat
    - Waste wood
    - Plastic
    - Energy crops

Availability of biomass

- Evaluation is based on the 2009 figures
- Seven forest centers were taken into consideration
- The use of wood was 24 Mm^3
- The use of forest chips in heat and power 2.7 Mm^3 (0.4 Mm^3 in households)
- Wood based fuels 6.3 Mm^3
- Several forest chip potential studies have been conducted
  - The assumptions behind estimations differ
  - The use of forest chips can be increased significantly
  - Techno-economic estimations range from 6 to 8.4 Mm^3





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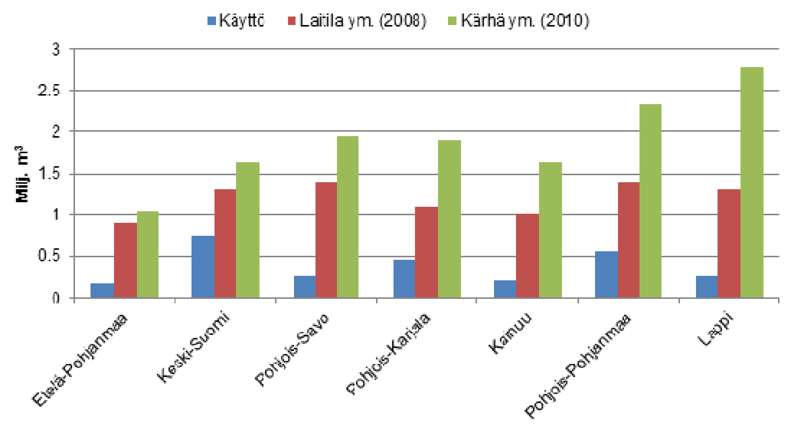
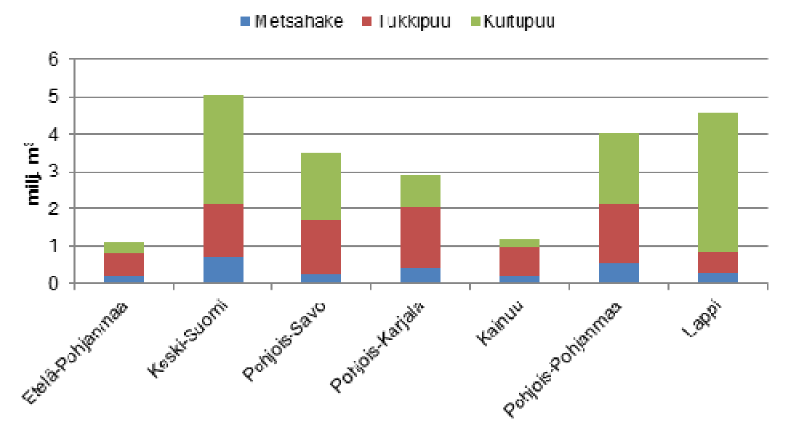
Availability of biomass

- The current use (2009) of forest chips enables substantial increase
  - Techno-ecological potential is even 13.3 Mm^3 (Kärhä et al. 2010)
  - The potential increase of forest chips use could be over 10 Mm^3! (Kärhä et al. 2010)
- The whole biomass feedstock taken from the forest in 2009 was 26.4 Mm^3 and the potential is bigger
  - If the price of biomass derived reducing agent is not limiting factor the potential is large
- The whole energy wood potential is not earmarked to certain industry



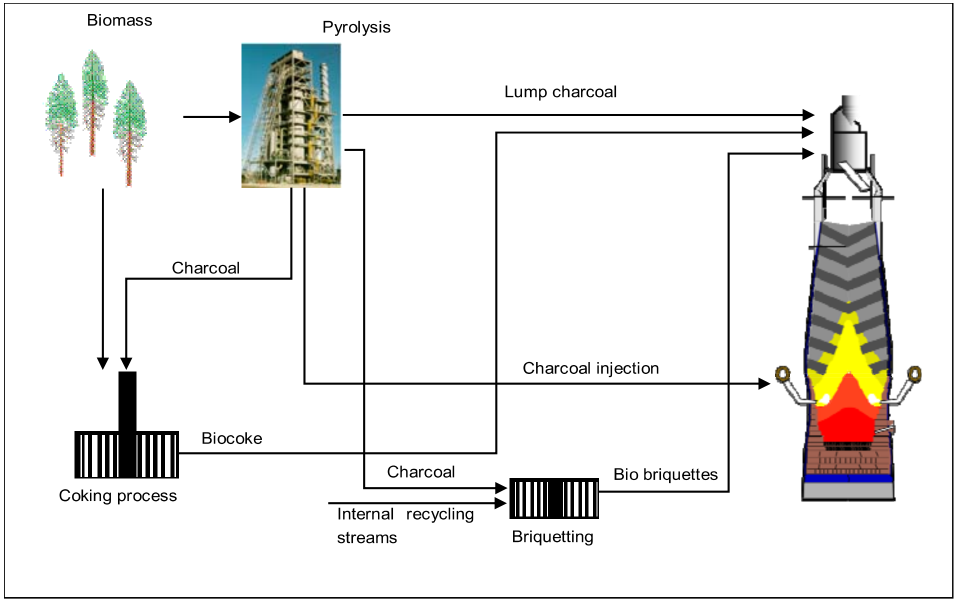


Conversion routes from biomass to reducing agent

- Biomass derived reducing agent could be introduced to blast furnace in solid, gas or liquid form
- Conversion routes:
  - Slow pyrolysis (charcoal)
  - Fast pyrolysis (bio-oil)
  - Gasification (reducing gases (H_2, CO), synthetic natural gas)
- Charcoal case examined more closely

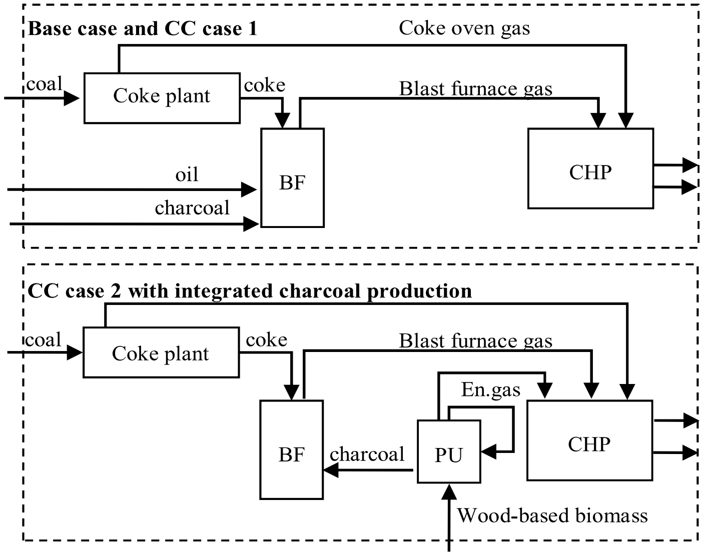
Possible use forms

- In Brazil there are blast furnaces that are run solely with charcoal
  - Smaller
- In modern Integrated steelworks
  - Coke oven
    - ”Biocokes” (part of the coal blend)
  - Sintering
    - Fuel
  - Blast furnace
    - To replace nut coke
    - Biocokes
    - Charcoal injection
- Electric steelmaking
  - Slag foaming
- Ferrochrome production
  - Reducing agent



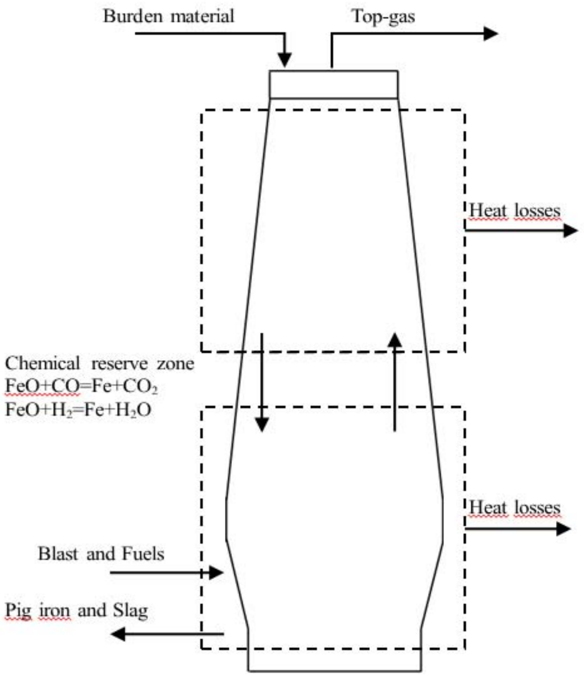
Evaluation of the effect of charcoal use in plant scale

- Prior research done by other researchers has shown that charcoal is suitable blast furnace injectant (reducing agent)
- The effect of charcoal production and use in integrated steelworks was examined
  - The evaluation is based on the process modeling approach with mass and energy balances
  - The most important unit process to be modeled was blast furnace
- Different simulations were performed and compared to base case with traditional blast furnace reducing agents
  - In Base case, coke and specific heavy oil are used as reducing agents
  - In CC case 1 the specific heavy oil is replaced by charcoal produced outside the integrated steelworks
  - In CC case 2 the amount of charcoal is further increased and the production of charcoal is integrated to steelworks structure

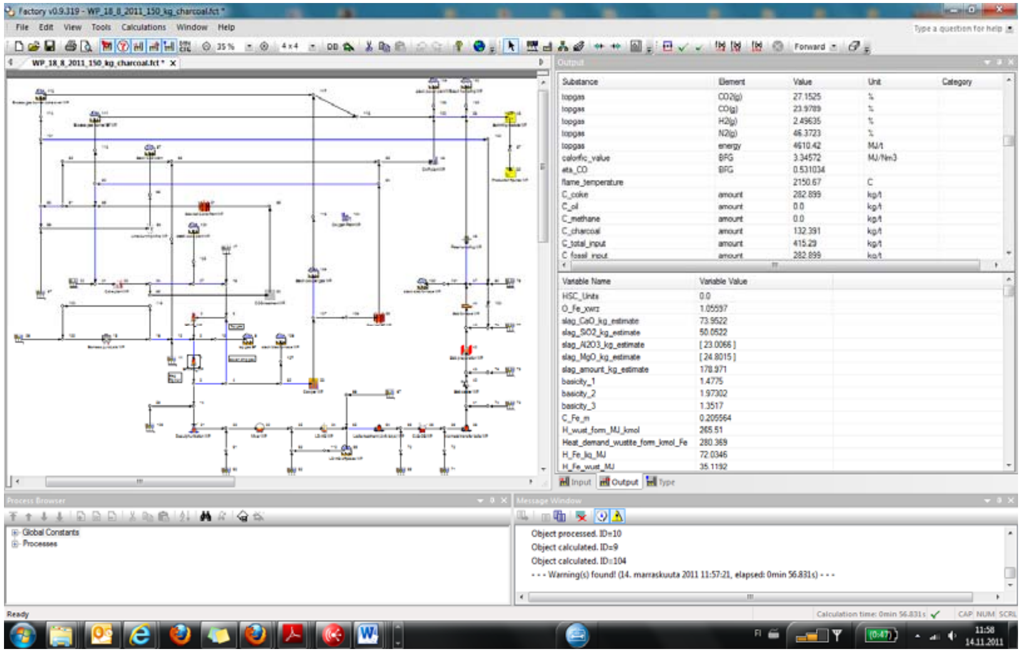


Blast furnace model

- Based on mass and heat balances
  - Calculation of reduction and heating energy requirements, slag formation, etc.
  - Basically based on RIST diagram
- Chemical and thermal reserve zone between upper and lower active zones
  - In chemical reserve zone CO/CO_2 and $H2/H_2O$ ratios are fixed with thermodynamic equilibrium at certain temperature of TRZ (e.g. 1200 K)
- Developed for evaluating the performance of different input materials
  - Special emphasis on tuyére injected fuels
- Calculates e.g. the needed coke and blast amount, slag amount and the composition of top-gas
- All the process specific simulations are performed against one ton of hot metal



Plant site model



- The major integrated steelwork unit processes (with Factory Simulation tool)
- Mass and heat balances
- The material and energy flows between unit processes form a complex entity
- Plant site model includes also pyrolysis plant that produces charcoal and by-products that are used in energy production
- All the plant site simulations were performed against functional unit (FU) of one ton of hot rolled plate

Results: BF simulation

- Blast furnace operation
  - Changes in blast volume
  - Slag volume decreases
  - Top-gas composition and amount change
    - The top-gas energy decreases
- How charcoal can substitute coke:
  - Coke replacement ratio RR is 1.12 for oil
  - RR for charcoal is 0.97
  - To replace 1 kg oil, 1.15 kg charcoal is needed
- The temperature of the blast must be increased to maintain adiabatic flame temperature (AFT) when charcoal amount is increased to 150/t HM
- Charcoal injection could be even higher if lower AFT is allowed

Results: Plant site simulation

- The environmental burden of plant system is smaller when charcoal is used
- The fossil CO_2 emissions decrease in plant scale
  - With 2.6 Mt (Ruukki capacity) hot metal production the reduction is:
    - From 4.63 Mt → 3.92 Mt (15.4 % decrease) (CC case 1)
    - From 4.63 Mt → 3.41 Mt (26.4 % decrease) (CC case 2)
- The use of coking coal decreases in CC case 2, which further decreases the environmental burden and cost of raw materials

Results: Plant site simulation

- Gas balance and use of energy changes when charcoal is introduced
- Minor changes when only specific heavy oil is replaced with charcoal
  - The BF top-gas energy decreases
  - → The energy going to power plant decreases
- Significant changes when pyrolysis process is integrated to steelworks infrastructure
  - The production of gases per FU (without converter gases)
    - Base case: 7.8 GJ/FU, CC case 1: 7.3 GJ/FU, CC case 2: 10.5 GJ/FU
  - Almost all the electricity could be produced internally with energetic by-product off-gases
  - Would require major investments to power plant capacity
  - The aqcuisition area of feedstock would be reduced

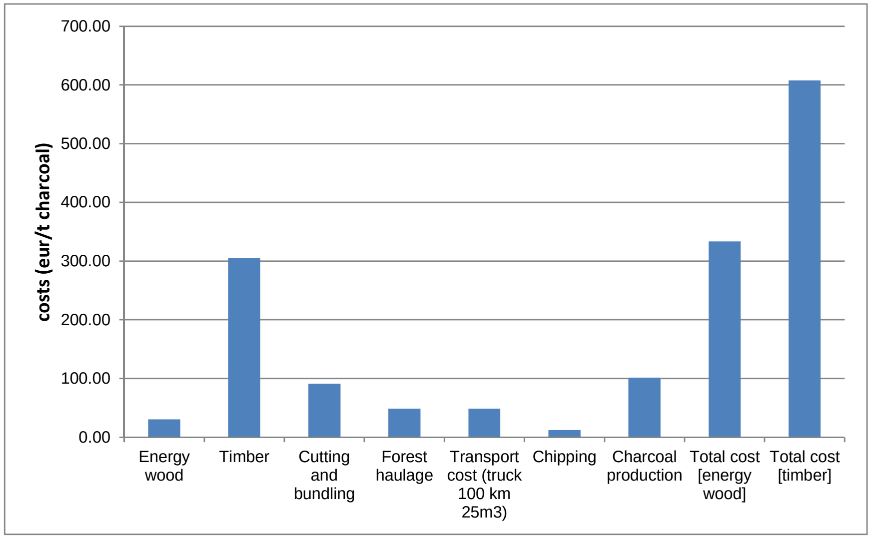
Production cost of charcoal

- The price of the charcoal is critical factor for industry
- The price of charcoal from different feedstock derived from the literature

Production cost	Biomass cost	Country	Reference
254.60 US$/ton	91.6 US$ (euc.)	Brazil	Noldin (2011)
386 US$/ton	260 US$ (ND)	Australia	Norgate & Langberg (2009)
162 €/ton	ND (euc.)	Brazil	Fallot et al. (2008)
272 US$/ton (calc)	83$/ton (corn stover)	US	Brown et al. (2011)

Production cost of charcoal

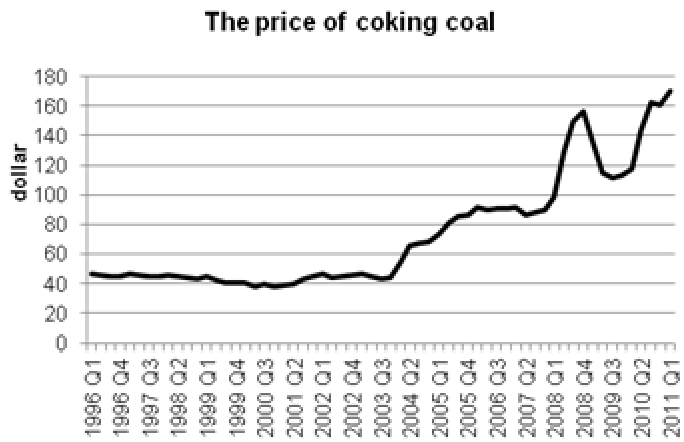
- Assumptions
  - 100 000 t charcoal
  - Yield 35 % (from 20 % moisture wood)
  - Investment cost 40 M€
  - Cost of energy wood 5 €/m^3
  - Cost of timber 50 €/m^3
  - Other cost taken from literature
  - Handling and transportation costs assumed to same with energy wood and timber
- The price of charcoal could range from 330 to 610 €/t
- The by-product benefit not taken into account!
- More in depth assessment is needed!



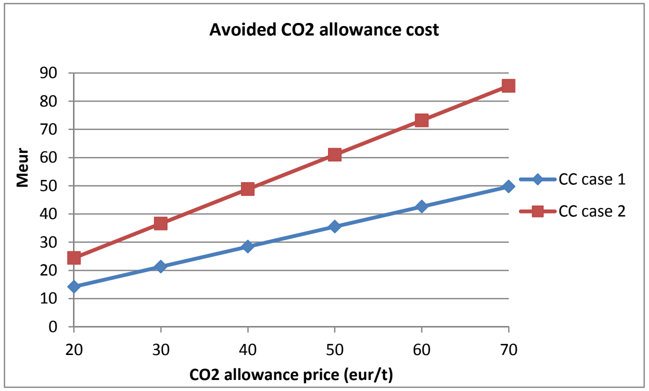
Calculations updated from: Suopajärvi H & Angerman M (2011) Layered sustainability assessment framework. METEC InSteelCon. Proc. of 1st Int. Conference on Energy Efficiency and CO2 reduction in the Steel Industry, Düsseldorf, Germany

Production cost of charcoal

- Willingness to pay?
- Which reducing agent charcoal would replace?
  - The price of coking coal 126 €/ton
  - The price of pulverized coal is lower
  - The price of specific heavy oil 150-300 €/ton
  - The price of metallurgical coke up to 400 €/ton
- The effect of CO_2 taxes and other political actions may change the status quo
  - CO_2 allowance cost avoided (20 to 70 €/t)
  - 14 to 50 Meur CC case 1
  - 24 to 85 Meur CC case 2
- The possibility to integrate charcoal production with energy or chemical production



http://www.steelonthenet.com/files/metallurgical_coal.html



The amount of needed biomass: Case injection

- The needed biomass in charcoal in injection is high
- The injection of 200 kg/t hot metal should be possible
  - Charcoal yield 30 % (from 20 % moisture)
  - Density of green wood 750 kg/m^3 (50 % moisture)
  - The yearly hot metal production 2.6 Mt

→ The amount of green biomass 3.7 Mm^3

→ To replace the oil injection (100 kg/t hot metal) approximately 2.1 Mm^3 of biomass is needed

→ Even though the figures are large, there are available biomass that hasn't been yet earmarked to certain industry

Challenges in biomass-based iron and steelmaking

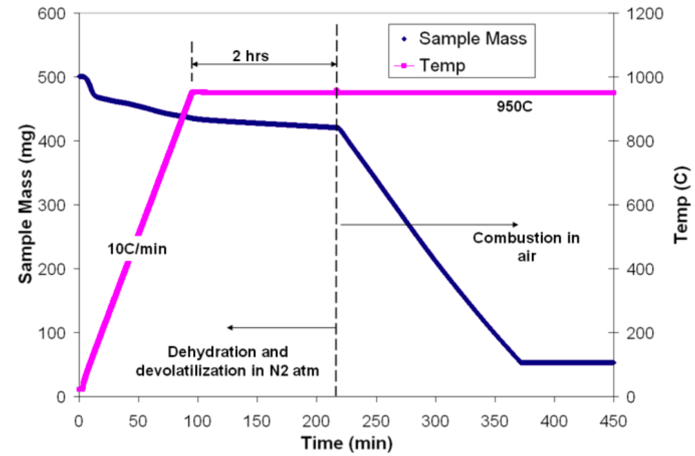
- The capacity of charcoal production should be approximately 1000-times larger compared to present level
- The injection equipment in Ruukki doesn’t allow solid material injection
- Competing use of raw material
  - Energy and power industry
  - Transportation fuel production
  - Pulp industry
- The utilization of by-products
  - What would be the most suitable integration alternative?
- Political actions have big effect
  - Is energy wood going to charcoal production and to reducing agent purposes entitled to government support
  - The development of CO_2 emission allowances
- Price of charcoal

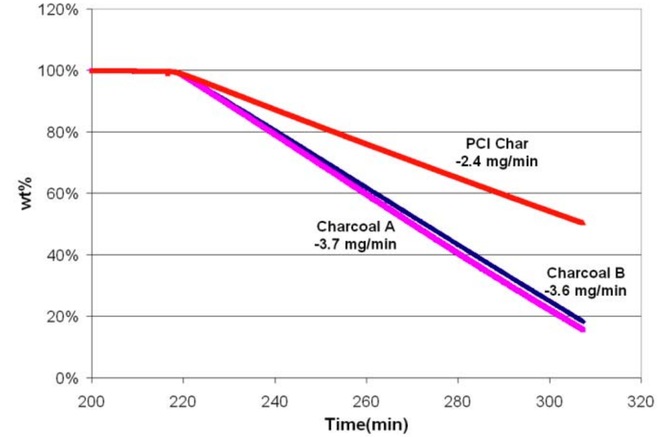
Studies from others: Laboratory experiments

- In the Laboratory of Process Metallurgy the laboratory experiments have been started with biomass
  - The results are not published yet
- Biggest differences compared to fossil reducing agents
  - Reactivity
  - Mechanical strength
  - Ash amount and composition
  - Structure
- Research has been done in different levels
  - Reactions, kinetics,…
  - Process behavior
  - Environmental burden

Charcoal compared to fossil-based reducing agents

- Injected as pulverized charcoal
- Ash composition is different
    - Charcoal ash is basic
    - Pulverized coal (PC) ash is acid
    - The needed amount of fluxes can be decreased
    - Slag amount can be reduced → More efficient blast furnace operation
- The ash amount is smaller in charcoal
    - Typical PC ash share around 10 %
    - Typical charcoal ash share around 1-4 %
    - The alkali load is quite same with PC
- The structure of the charcoal is more porous than pulverized coal
- Combustion is faster
    - Affects the gas distribution of blast furnace

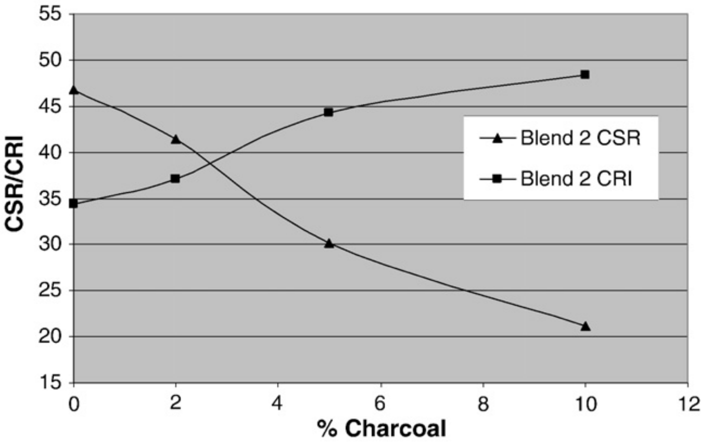




Ng KW, Giroux L, MacPhee T & Todoschuk T (2011) Biofuel Ironmaking Strategy from a Canadian Perspective: Short-Term Potential and Long-Term Outlook. Proc. of 1st Int. Conference on Energy Efficiency and CO2 reduction in the Steel Industry, Düsseldorf, Germany.

Charcoal compared to fossil-based reducing agents

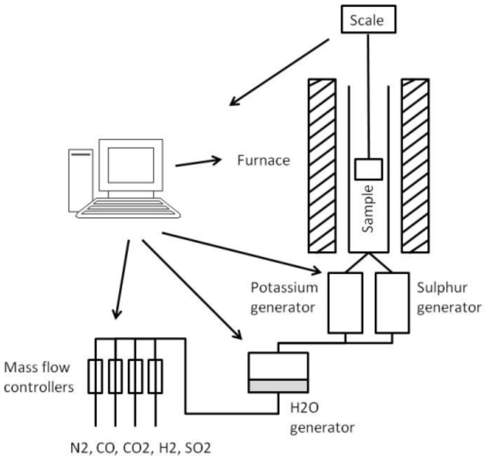
- Charcoal added to coal blend to produce metallurgical coke
  - Reactivity ($C+CO_2=2CO$) (CRI test)
  - Hot Strength (CSR)
- Reactivity increases with increasing amount of charcoal
  - Catalytic effect of alkalis
  - High reactivity causes the increase in porousness of the outer layer of coke
- Strength of coke decreases
  - When the amount of charcoal is increased
  - When particle size is smaller



MacPhee JA, Gransden JF, Girous L & Price JT (2009) Possible CO2 mitigation via addition of charcoal to coking coal blends. Puel Processing Technologies 90: 16-20.

Laboratory experiments in Lab. of Process Metallurgy

- Metallurgical coke production including different biomass raw materials to coal mix
- Evaluation of coke quality
  - Basic coke quality tests CRI, CSR
  - TGA (reactivity)
  - Gleeble (hot strength)
  - Electrical conductivity
  - Wavelet-texture analysis
    - Microscope images evaluated with mathematical algorithms (pores, isotropic, mosaic, banded coke)
- Biocoke in process conditions e.g.
  - Blast furnace simulator
    - Behavior of Biocoke in different gas atmospheres



Haapakangas J, Mattila O & Fabritius T (2011) Effect of injection rate on coke dust formation and coke gasification in a blast furnace shaft. Proc. of 6 th European Coke and Ironmaking Congress, Düsseldorf, Germany

Conclusions

- Biomass is available, the potential increase in biomass feedstock use is not earmarked yet
- Biomass in a form of charcoal is suitable injectant – no major technological limitations, more laboratory work is however needed
- Charcoal use can decrease the environmental burden of steelmaking and thus increase the sustainability
- Integration of charcoal production to integrated steelworks would change the gas balance and external energy need quite much
- Integration possibilities of charcoal production should be further evaluated
  - Centralized or decentralized production
- The evaluation of life cycle emissions of charcoal production have to be evaluated
- More in-depth economic calculations are needed with by-product utilization and CO_2 emission costs

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Thank You