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Renewable Carbon Integration in HIsarna Ironmaking Process

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HIsarna ironmaking is a breakthrough smelting reduction technology with the potential to reduce CO_2 emissions by 90% when using coal combined with CCS and negative CO_2 footprint when using biochar and CCS. This study evaluates biochar production integration to the HIsarna process operations from the perspective of raw ma-terial consumption, unit wise energy requirements, and by-product utilisation using a flowsheet modelling ap-proach. The model demonstrates a strong thermal synergy between the ironmaking and pyrolysis processes, with HIsarna off-gas heat recovery and recycled pyrogas collectively satisfying the thermal demand of continuous slow pyrolysis process. The economic evaluation shows that the integrated system is profitable and the profita-bility structurally governed by co-product markets particularly CO_2 credits and bio-oil sales rather than biochar value itself.

KEYWORDS: HISARNA; SLOW PYROLYSIS; PROCESS INTEGRATION; DECARBONIZATION; METSIM, BIOCHAR.

INTRODUCTION

The HIsarna smelting reduction process is uniquely positioned for carbon-neutral ironmaking that facilitates 100% replacement of coal with biochar. Life Cycle Assessments confirm that HIsarna process operating with bio-based reductants can achieve net-negative emissions as low as -0.5 t CO_2/t steel [1], but these macro-level studies stop at system boundary definitions and aggregate mass flows. No prior work has been carried out on mass, energy, CO_2, and economic balances of integration of possible on-site slow pyrolysis plant sized to the full biochar to meet the demand of a commercial 1 Mt/yr HIsarna facility. This work develops an integrated steady-state METSIM flowsheet simulation model bridging that gap. The comprehensive detail of modelling is described in the paper [2], and this paper presents the key functional performance indicators and strategic implications.

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MODELLING METHODOLOGY

A steady-state mass and energy balance model was developed with METSIM commercial software to simulate the integration of a slow pyrolysis biochar production plant with a commercial HIsarna ironmaking facility producing 1 Mt/yr of hot metal. The model is structured around three boundary input domains: the Biochar Production Plant (the primary unit under study), and its two external supporting systems: HIsarna process data and power plant/utilities. While the HIsarna and power plant units provide the necessary energy inputs (sensible heat and electricity), they exist outside the specific biochar production unit operations. The primary material outputs are biochar, bio-oil, and biogas, and recovered heat. Unit operations in the flowsheet including drying, grinding, pyrolysis, heat exchange, and briquetting are considered for continuous rotary slow pyrolysis kiln operating at 550°C, with HIsarna off-gas sensible heat at 900°C supplying indirect pyrolysis heating supplemented by recycled pyrogas.

KEY RESULTS

System thermal synergy: Total process energy intensity is 7.2 GJ/t biochar. As shown in figure 1, thermal stages (drying + pyrolysis) account for 90% of this demand which satisfied by HIsarna off-gas heat and recycled pyrogas. Flowsheet heat balance is shown in table 1 for 83 t/h production of biochar integrated into HIsarna ironmaking.

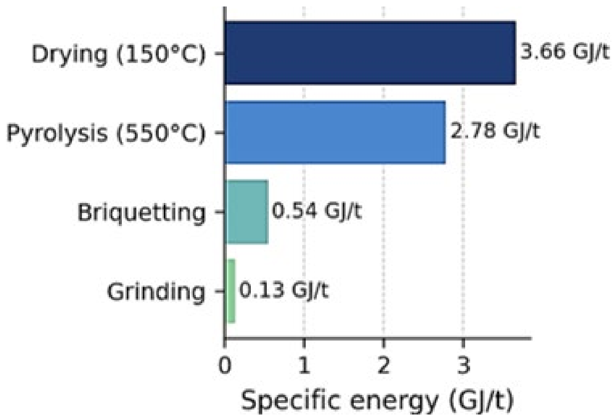

Fig.1 - Process energy distribution by unit operation.

Tab.1 - Heat balance of biochar production integrated to HIsarna.

ENERGY IN	MW	ENERGY OUT	MW
Chemical energy in biomass	1357	Biochar energy	670
Heat from HIsarna gas	68	Bio-oil energy	367
Electricity (grind + briquet)	16	Biogas energy left	97
		Recovered power	34.8
Total energy input	1441	Pyrolysis + dryer loss	28
		Other loss	244

Cost and revenue analysis: Biomass procurement alone consumes 60% of total raw material cost (figure 2(a)), confirming that feedstock supply chain risk, not energy cost, is the dominant operational vulnerability. Figure 2(b) shows that the profitability is structurally co-determined by two externally governed market variables CO_2 credits and bio-oil sales. The assessment shows a net margin (revenue minus expense) of 236 €/t of biochar, indicating that the integrated system is profitable. The margin is therefore resilient to energy price swings but exposed to simultaneous adverse movements in bio-oil price and carbon credit price, making revenue hedging the critical commercial safeguard for deployment.

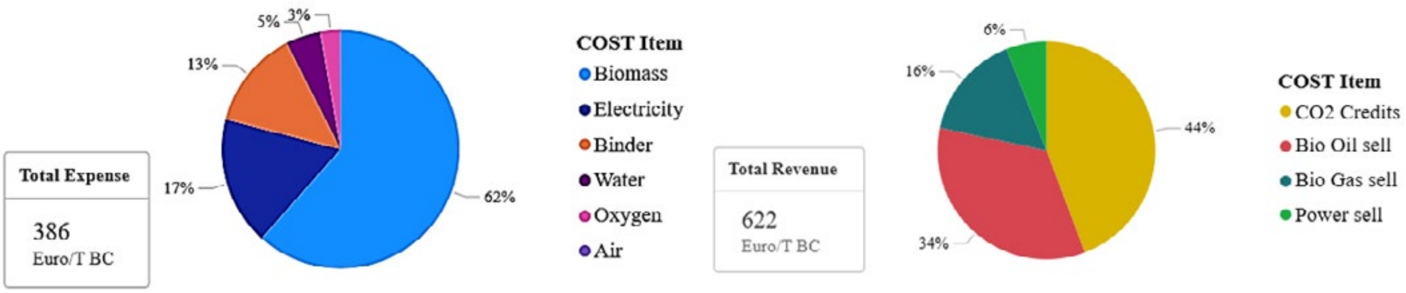

Fig.2 - (a) Raw material cost and (b) revenue distribution expressed as euro per tonne of biochar produced for the biochar production integrated into HIsarna process.

Sensitivity analysis: Biomass feedstock cost and CO_2 credit price based on figure 2 are the two principal uncertain market parameters governing production economics, the former representing the dominant operating cost and the latter the primary policy-driven revenue stream. Figure 3 shows that low bio-oil prices (50–100 €/t), the system is broadly loss-making, with break-even confined to low biomass costs and high carbon credits. As bio-oil price rises to 150-250 €/t, the break-even boundary shifts progressively, expanding the viable region across a wider range of both biomass prices and carbon credit levels. This confirms bio-oil revenue is the strongest single economic lever in the integrated system, capable of compensating for both high biomass costs and low carbon credit environments.

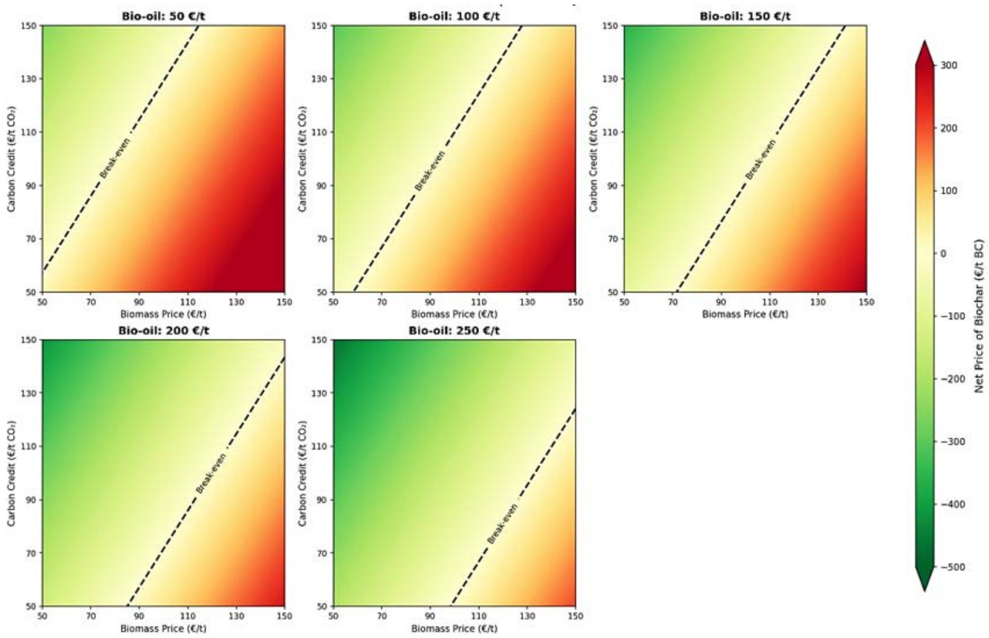

Fig.3 - Sensitivity analysis of the net price of biochar as a function of biomass price and CO_2 credit values for different bio-oil prices.

CONCLUSIONS

Based on the METSIM steady-state simulation the following conclusions are drawn:

1. HIsarna off-gas heat recovery and recycled pyrogas combustion together could fully sustain continuous slow pyrolysis at commercial scale, confirming the process is thermally self-sufficient.
2. The integrated system is economically viable, but profitability is structurally governed by co-product markets rather than biochar value itself.
3. Bio-oil price is the primary driver of profitability. The main risk is not energy volatility, but a simultaneous decline in bio-oil and carbon credit values.

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