



SAIL

Sustainable Decarbonisation of Iron ore Sintering by partial replacement of Coke Breeze with Bamboo Biochar at SAIL Durgapur

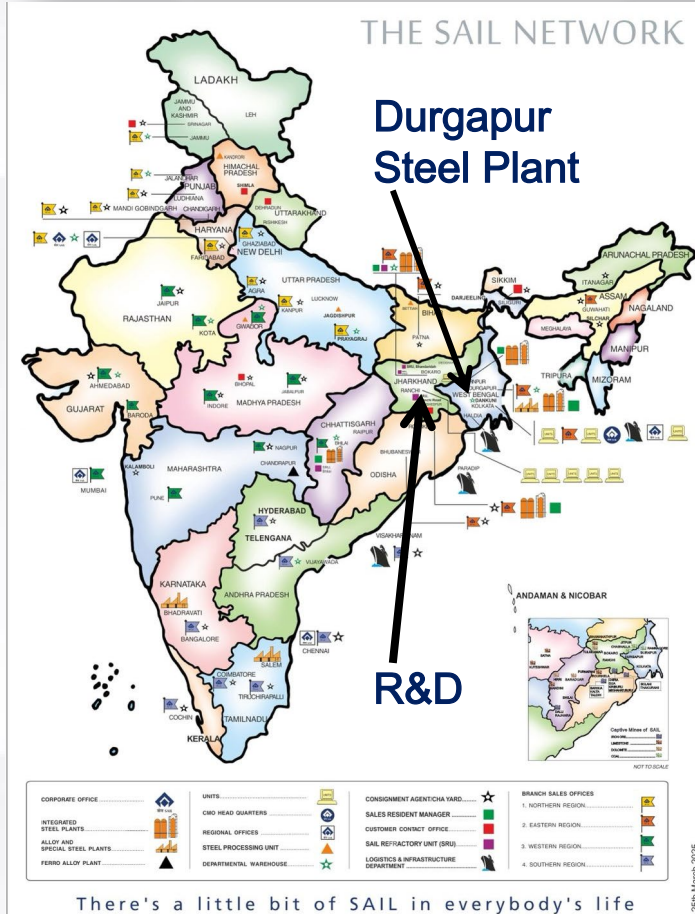
I Majumder, CGM, Sinter Plant

A Mallick, GM & HOG, R&D

S Dhara, DGM, R&D

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SAIL network

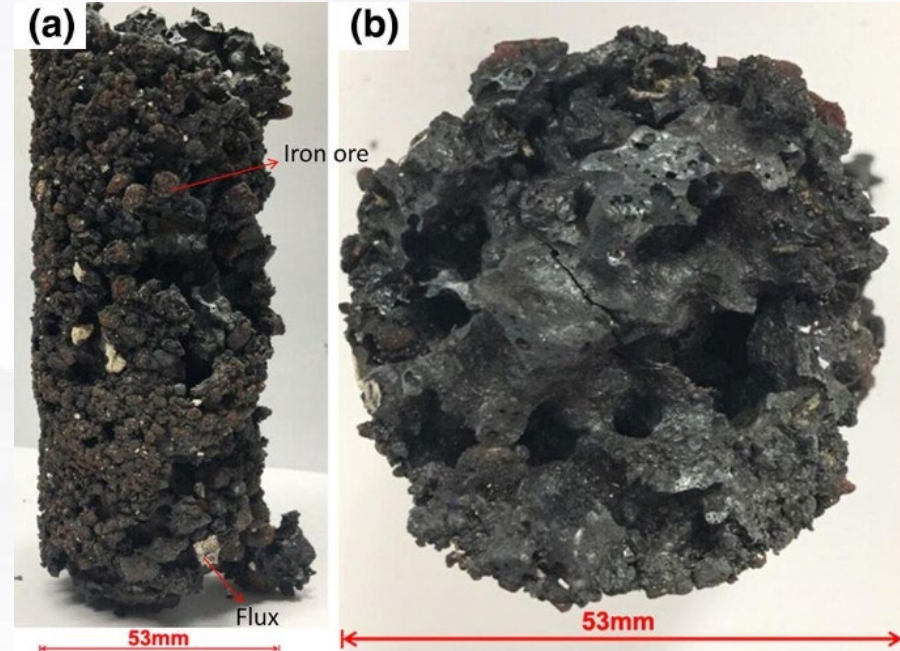


- ❖ India's largest state-owned steel producer, operating five integrated steel plants and several special-steel units.
- ❖ Achieved annual production in FY 2024-25: ~20.31 MT hot metal and ~19.17 MT crude steel.
- ❖ Strategic focus on value-added & special steels, supported by in-house R&D (RDCIS) and captive raw-material mines.

Decarbonisation and sustainability through cleaner steelmaking, higher energy efficiency, renewable energy use, waste reduction, and responsible mining

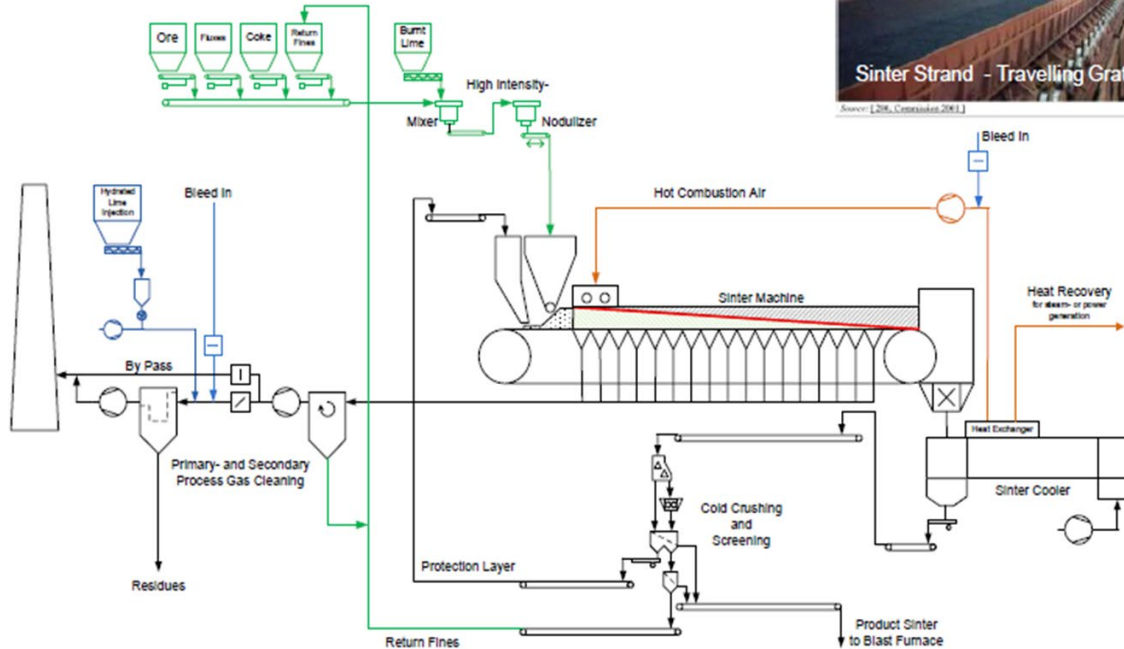
Sintering Basics & Role of Coke Breeze

- Up to 70% of mined material turns into fines—rich in Fe (~62%) and too valuable to discard.
- Iron ore fines cannot enter the blast furnace directly; agglomeration is essential for efficient charging.
- Using sinter conserves fines and supports ecological sustainability.
- Sinter provides pre-reduced material with high softening temperature and narrow softening range.
- Enhances flux utilisation and delivers superior reducibility compared to other burden materials.



Sintering plant layout

Sinter Plant (Travelling Grate Technology)



➤ Coke provides sensible heat and acts as a reductant for iron oxides during sintering.

➤ Approximate Calculation (Conceptual):
Energy needed for heating and reduction: $Q = m \times C_p \times \Delta T + \text{heat of reduction}$

- Coke Breeze Requirement (mass basis):

Coke breeze = $Q / (\text{Calorific value of coke} \times \text{Combustion efficiency})$

- Typical Range:

Theoretical coke breeze requirement generally falls between 6–8% by weight of the sinter mix

Coke Breeze as conventional solid fuel in sintering

Function	Reaction / Equation	Thermodynamic Notes / ΔH	Role in Sintering
Heat Generation (Combustion)	$C(s) + O_2(g) \rightarrow CO_2(g)$	$\Delta H \approx -394 \text{ kJ/mol}$ (exothermic)	Provides primary heat to sinter mix, drives dehydration, calcination, and melt formation
Partial Oxidation / Reducing Gas	$2C(s) + O_2(g) \rightarrow 2CO(g)$	$\Delta H \approx -221 \text{ kJ/mol}$ (exothermic)	Produces CO for iron oxide reduction; maintains controlled pO_2
Boudouard Reaction	$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$	$\Delta H \approx +172 \text{ kJ/mol}$ (endothermic)	Generates additional CO at high temperatures ($\sim 950^\circ\text{C}$); supports $Fe_2O_3 \rightarrow FeO$ reduction
Hematite to Magnetite	$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$	Exothermic	Stepwise reduction; begins in mid-bed temperature zone ($\approx 500\text{--}600^\circ\text{C}$)
Magnetite to Wüstite	$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$	Exothermic	Further reduction; controls Fe^{2+} content in sinter
Wüstite to Metallic Fe (partial)	$FeO + CO \rightarrow Fe + CO_2$	Exothermic	Usually limited; over-reduction avoided to maintain bonding phases
Calcination of Flux	$CaCO_3 \rightarrow CaO + CO_2$	$\Delta H \approx +178 \text{ kJ/mol}$ (endothermic)	Provides CaO for SFCA formation; heat supplied by coke combustion
SFCA / Bonding Phase Formation	$CaO + Fe_2O_3 + SiO_2 \rightarrow \text{Ca-Fe silico-ferrite}$	Slightly exothermic	Forms bonding phases for sinter strength; depends on stable flame front and pO_2

Coke Breeze as conventional solid fuel in sintering

Parameter	Assumptions / Calculation	Energy (MJ/ton sinter)	Coke Breeze Required (kg/ton)
Heat for CaCO_3 decomposition	$100 \text{ kg} \times 178 \text{ kJ/mol} \div 100.1 \text{ g/mol}$	178	—
Heat for dolomite decomposition	$50 \text{ kg} \times \Delta H \approx 296 \text{ kJ/mol} \div 184 \text{ g/mol}$	81	—
Heat for Fe_2O_3 reduction	$500 \text{ kg} \times \sim 50 \text{ kJ/mol}$	157	—
Heat for drying, preheating, melting	$1000 \text{ kg} \times 300 \text{ kJ/kg}$	300	—
Subtotal theoretical heat	—	716	—
Adjusted for 70% yield	$716 \div 0.7$	1023	—
Coke breeze requirement	Coke calorific value 28 MJ/kg	—	36.5

In practice, **actual coke use is higher** (~55–65 kg/ton) due to **inefficient combustion, uneven flame front, and sinter bed variability, heat losses, LOI and moisture variation etc..**

- **Biochar as a Substitute as alternate fuel**

- Biomass char is considered a carbon-free resource; an attractive option to reduce emissions from iron and steel production (Worldsteel).
- “Within the biospheric carbon cycle, bioenergy can be carbon neutral because the carbon that is released during combustion has previously been sequestered from the atmosphere and will be sequestered again as the plants regrow, i.e. if sustainably produced (IEA)
- Biochar use is recognised by United Nations Framework Convention on Climate Change (UNFCCC) to mitigate carbon emissions.
- Many agro-forestry residue identified for biochar production in GREENING THE STEEL SECTOR IN INDIA roadmap & action plan September 2024, MoS, Govt. of India

Biochar



Biochar is a stable, carbon-rich material produced by heating organic waste (e.g. bamboo, wood residues) in an oxygen-free pyrolysis process



Derived from 100% biodegradable and renewable biomass, making it a fully sustainable alternative to fossil carbon



Higher carbon stability compared to conventional charcoal, enabling long-term carbon sequestration



Can replace coal or coke in various steelmaking processes, reducing fossil carbon dependence



Supports circular economy by converting agricultural and forestry waste into a valuable industrial input



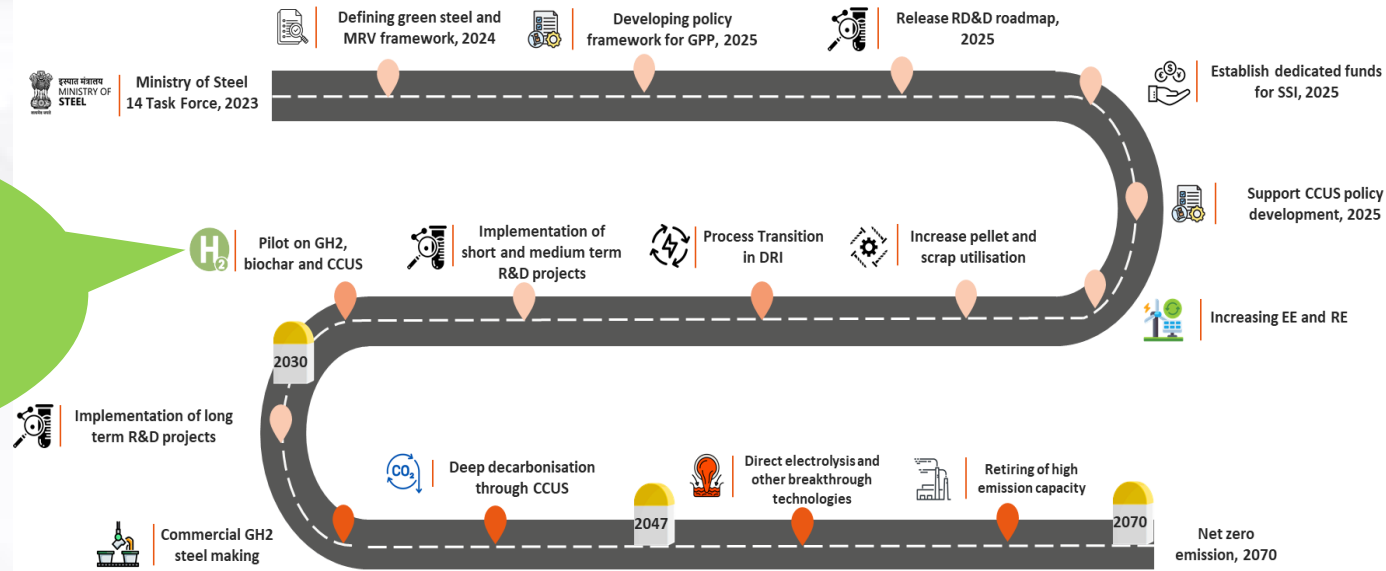
Low emissions pathway—its biogenic carbon content helps lower the steel sector's net CO₂ footprint



Scalable technology, compatible with existing industrial systems (DRI, sintering, and blast furnace injection)

Biochar potential for decarbonisation

Biochar has an emission reduction potential of up to 1.19 tCO₂/tcs.

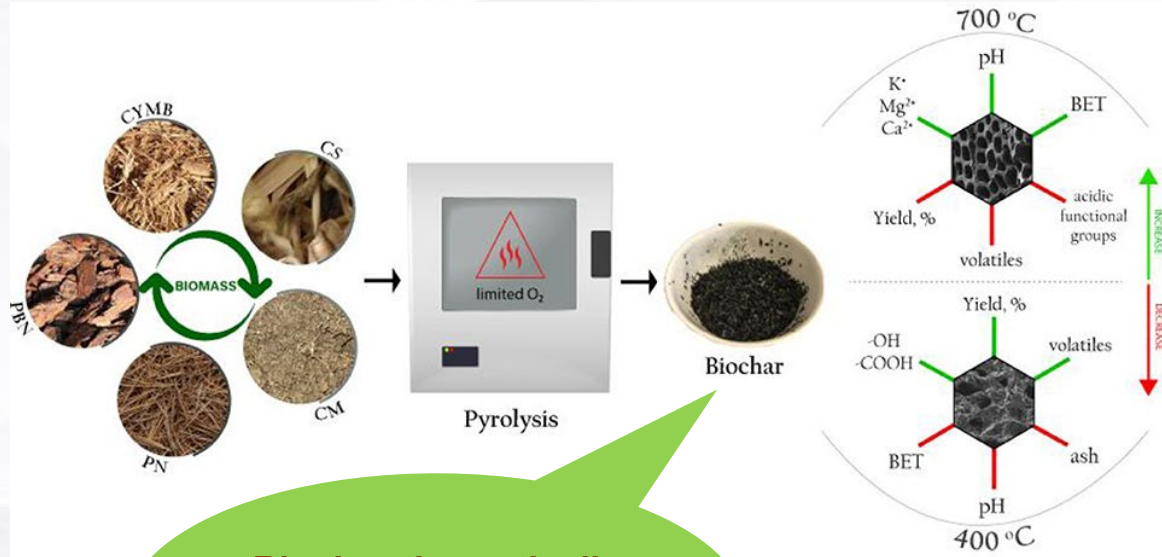


- Emission intensity of steel produced in India, at 2.54 tCO₂/tcs
- The steel industry accounts for 10-12% of India's total emissions.
- Steel decarbonisation is imperative for India to meet its climate goals.
- Decarbonisation focuses on **three key pillars**: the incentivisation and ecosystem development for green steel, levers to enable decarbonisation, and avenues to support the transition.

Sinter Plants 2nd highest CO₂ emitter in BF-BOF steel making



- Biochar is a stable carbonaceous material produced by heating organic waste, like bamboo, wood waste, etc. in a oxygen-free environment through pyrolysis technology



Biochar theoretically suitable for sintering application

- ❖ Biomass pyrolysis above 700 deg C, under prolonged time
 - Increased fixed carbon
 - Decreases volatile matter
 - Increases calorific value
- ❖ Product yield
 - Biochar- (~25–35 % of mass)
 - Syngas ($H_2 + CO + CH_4 + CO_2$ mixture)
 - Bio-oil (tar fraction)

Characterisation & Comparison

Characterization of biochars vis-à-vis coke breeze

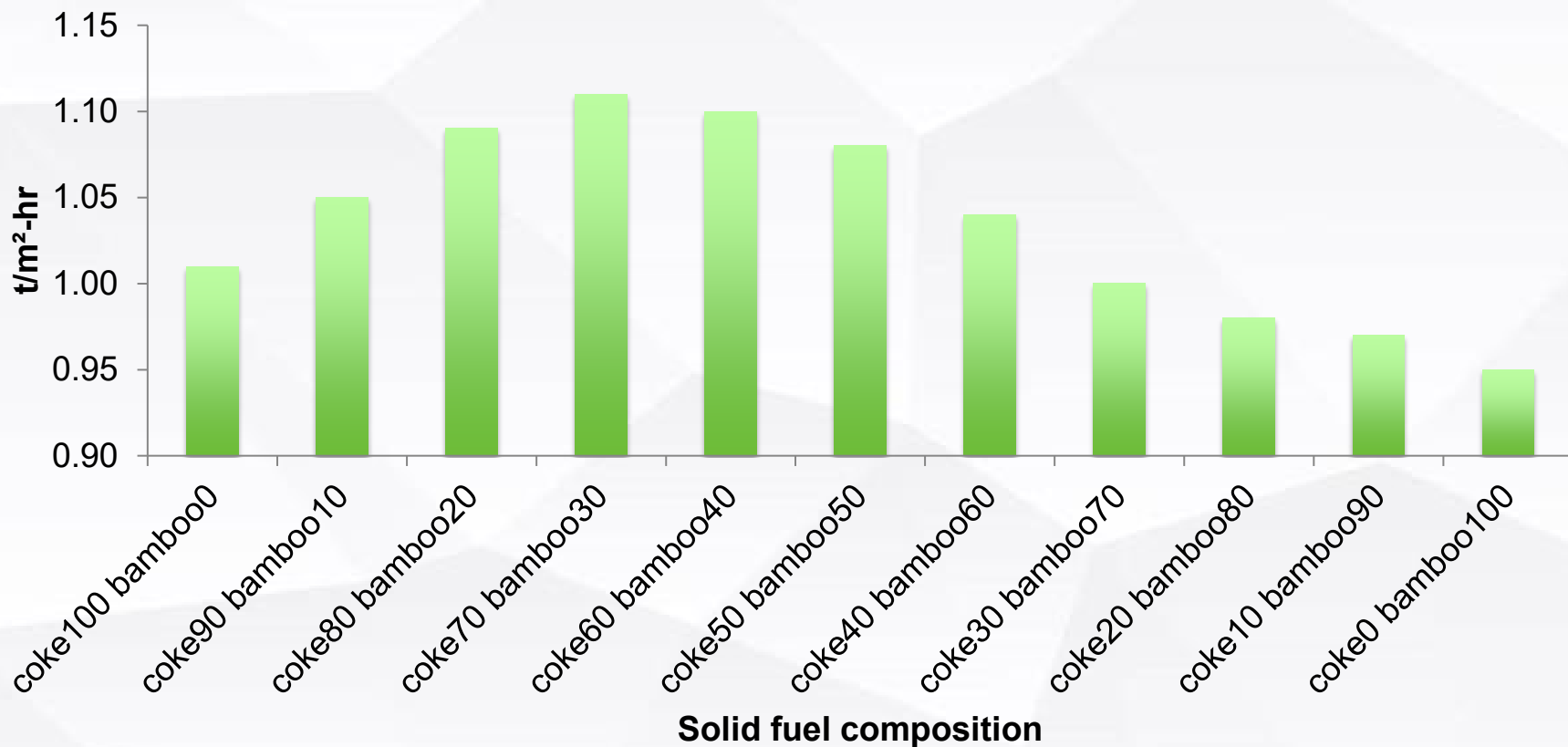
Solid fuel	Coke breeze	Prosopis Juliflora (English Babul)	Bamboo	Waste wood	Coconut shell
Proximate analysis					
Analytical moisture, wt.%	0.6	9.0	9.5	10.2	10.1
Volatile matter, wt.%	0.8	11.8	16.4	4.3	11.0
Ash, wt.%	17.9	4.6	10.9	5.8	4.0
Fixed carbon, wt.%	80.7	74.6	63.2	79.7	74.9
Ultimate Analysis					
Carbon, wt.%	77.53	81.18	71.68	84.16	82.09
Hydrogen, wt.%	0.27	2.09	2.69	1.71	2.70
Nitrogen, wt.%	1.17	1.32	1.05	0.86	0.89
Sulphur, wt.%	0.43	0.34	0.36	0.18	0.21
Gross Calorific value	6036	6640	5915	6621	6729

Characterization of biochars vis-à-vis coke breeze in sintering

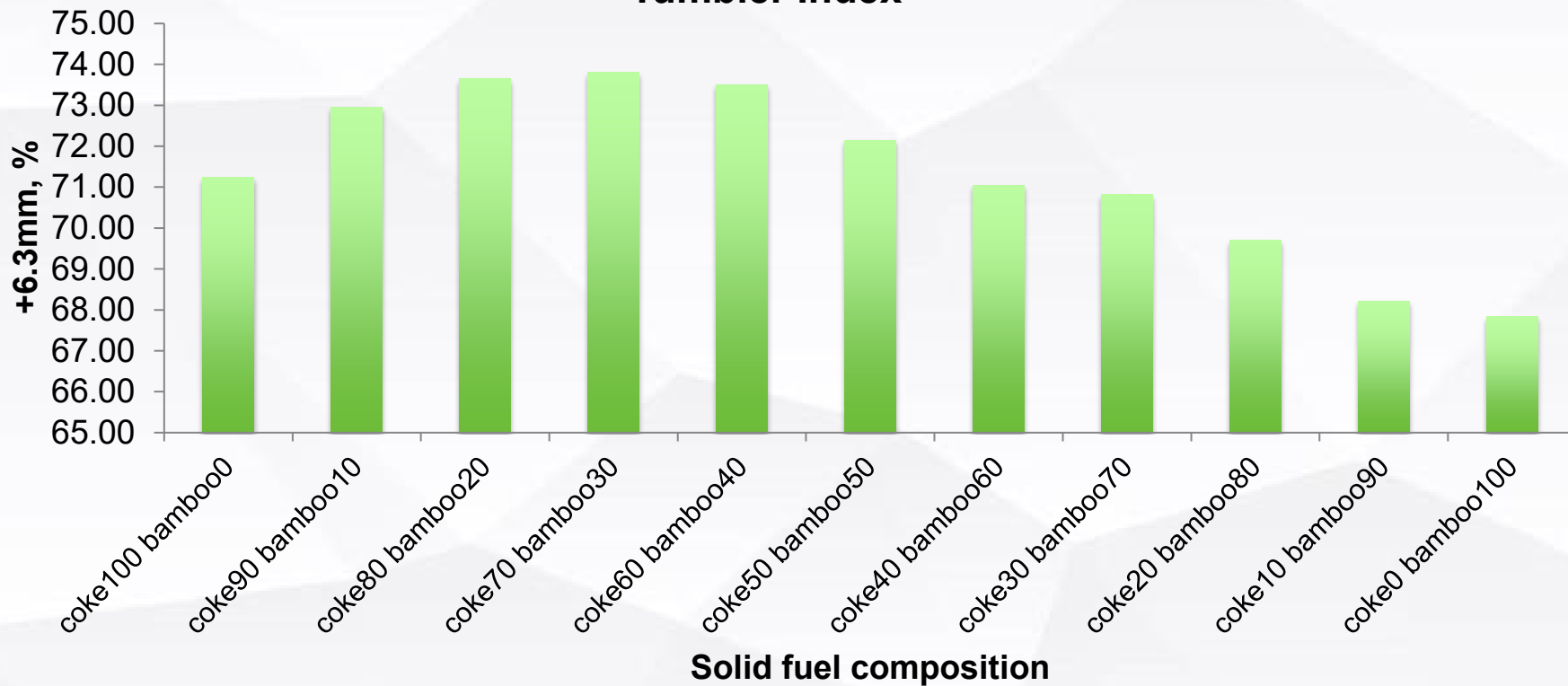
Aspect	Coke Breeze	Biochar	Implications
Combustion Rate	Slow, steady	Fast, sharp	Biochar accelerates flame front; coke ensures stable heat propagation.
Surface Area & Porosity	Low	High	Biochar reacts faster, increases early CO generation; coke is slower, controlled.
Primary CO Generation	Later (~950°C)	Earlier (~850–900°C)	Biochar shifts reduction reactions to lower temperatures.
Boudouard Reaction	Slower	Faster	Biochar enhances CO production; may over-reduce FeO in upper layers.
Flame Front Width	Broad	Narrow	Narrow front with biochar may reduce high-T residence time for SFCA formation.
SFCA Formation	Stable, controlled	Risk of lower formation	Requires careful thermal management with biochar.
Reduction Potential	Moderate, gradual	High, rapid	Biochar can accelerate $\text{Fe}_2\text{O}_3 \rightarrow \text{FeO}$, affecting sinter strength if excessive.

Lab-scale Experiments

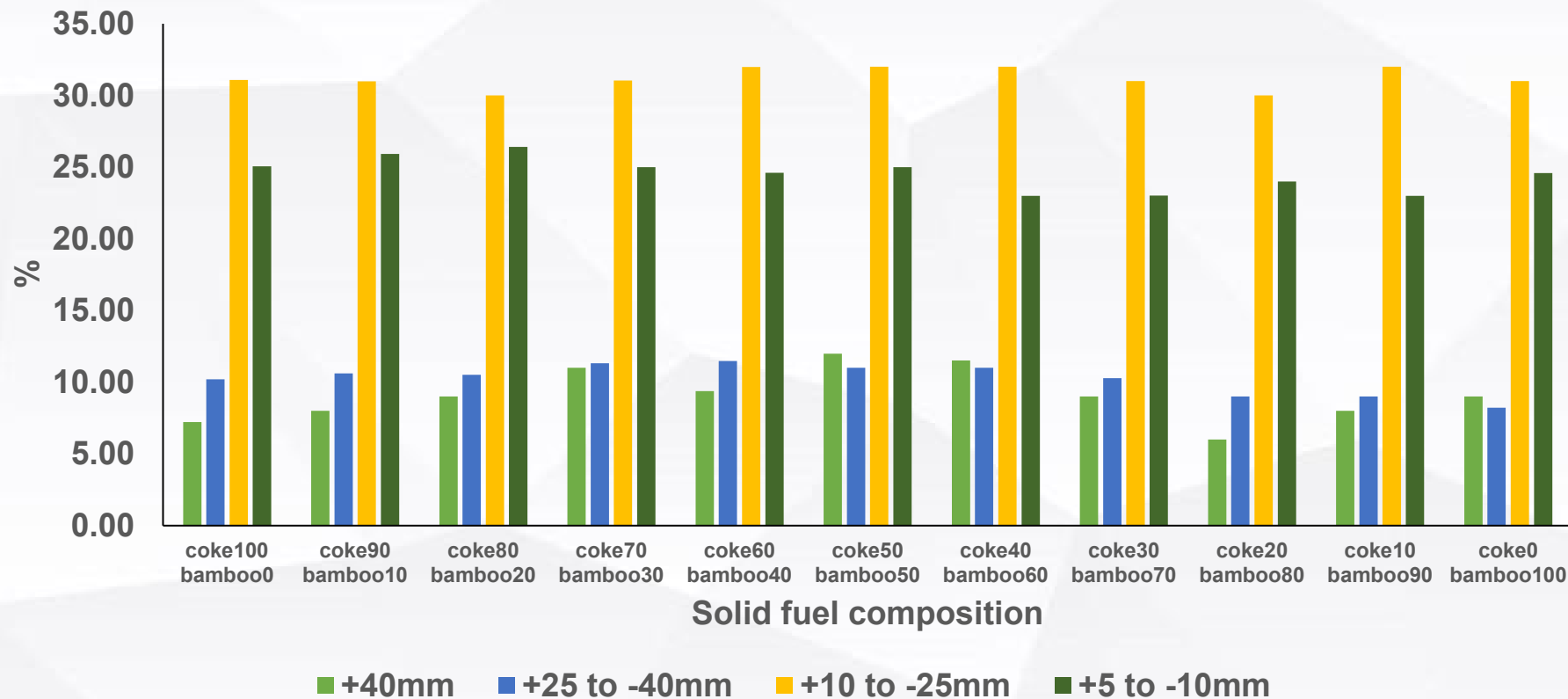
Sp. Productivity



Tumbler Index



Sinter granulometry



Emission potential of coke breeze vis-à-vis biochar

Biochar Sub (%)	Coke (kg)	Biochar (kg)	CO ₂ (kg/ton)	Volatiles (kg/ton)	NO _x (kg/ton)	SO _x (kg/ton)
0%	65	0	202	0.52	0.76	0.30
10%	58.5	7.6	182	1.69	0.68 + 0.082 ≈ 0.76	0.27 + 0.027 ≈ 0.30
20%	52	15.2	162	2.85	0.61 + 0.16 ≈ 0.77	0.24 + 0.055 ≈ 0.30
30%	45.5	22.8	142	4.01	0.53 + 0.25 ≈ 0.78	0.21 + 0.082 ≈ 0.29
50%	32.5	38	101	6.34	0.38 + 0.41 ≈ 0.79	0.15 + 0.14 ≈ 0.29

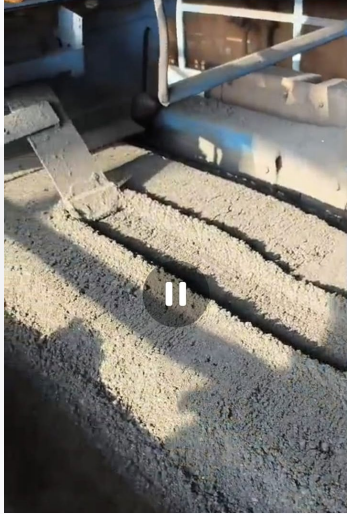
Plant-scale Trial & Pallet Dissection

Plant scale trial - material suitability

Parameter	Biochar	coke breeze
Bulk density	0.324 gm/ml	0.67 gm/ml
Tap density	0.384 gm/ml	0.76 gm/ml
Hausner ratio	1.185	1.13
Carr ratio	15.625	11.84
Angle of repose	55-60 deg	45-55 Deg
Time of flow (constant weight of fuel in flow measurement device)	3 min	1.5 min

- Very low bulk density (0.324 g/ml) → poor bed stability and air permeability.
- Higher Hausner (1.185) & Carr (15.625) → cohesive, poor flow, prone to clogging.
- Steep angle of repose (55–60°) → uneven spreading on sinter bed.
- Slow flow time (3 min) → increases feeding irregularity.

Plant scale trial



Coke breeze feeding



Bamboo biochar sampling

SAIL Durgapur Steel Plant commences India-First industrial large scale Trial with Bamboo Biochar

PSU CONNECT DATE: 28-02-25 - [MINISTRY OF STEEL](#)

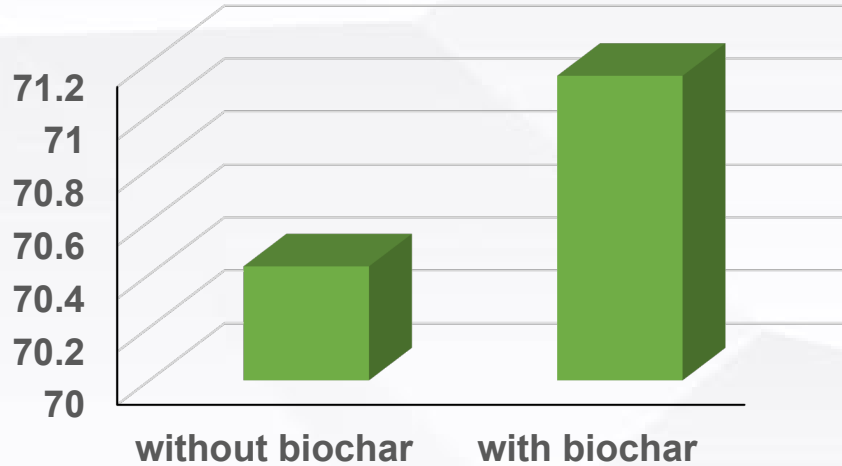
This pioneering step in utilizing greener solid fuel is expected to significantly reduce the consumption of fossil fuels and decrease CO₂ emissions in the steel production process.



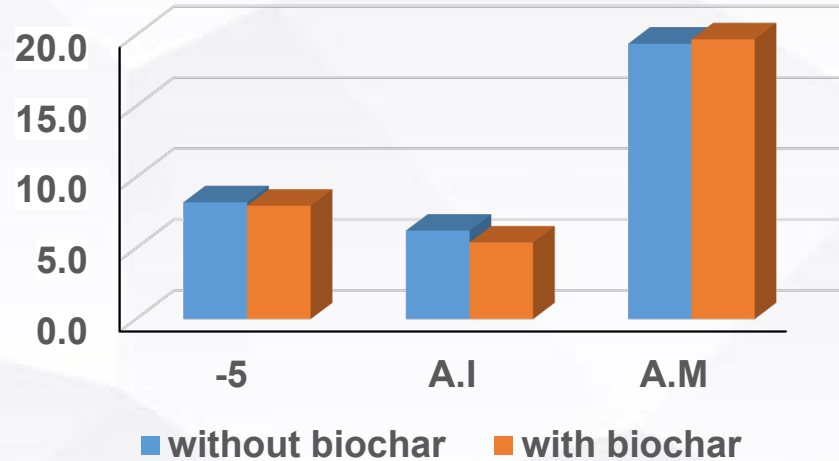
Trial Results

Plant scale trial

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sinter granulometry



Pallet dissection process

Pallet top Left side

Pallet top middle side

Pallet top right side

Pallet middle Left side

Pallet middle middle side

Pallet middle right side

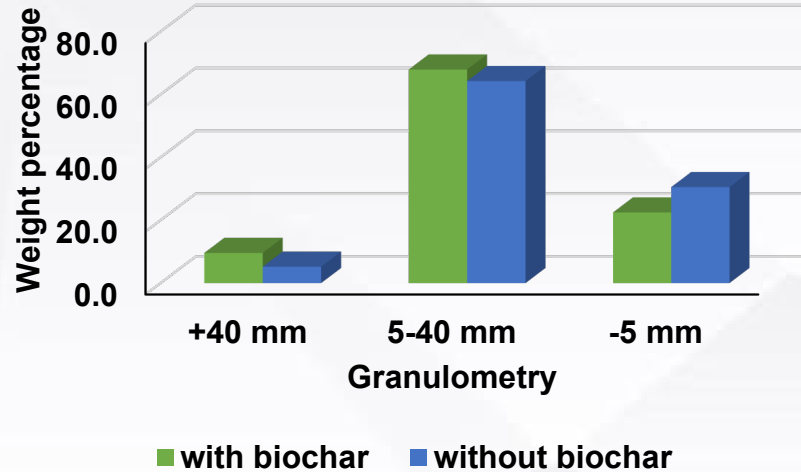
Pallet bottom Left side

Pallet bottom middle side

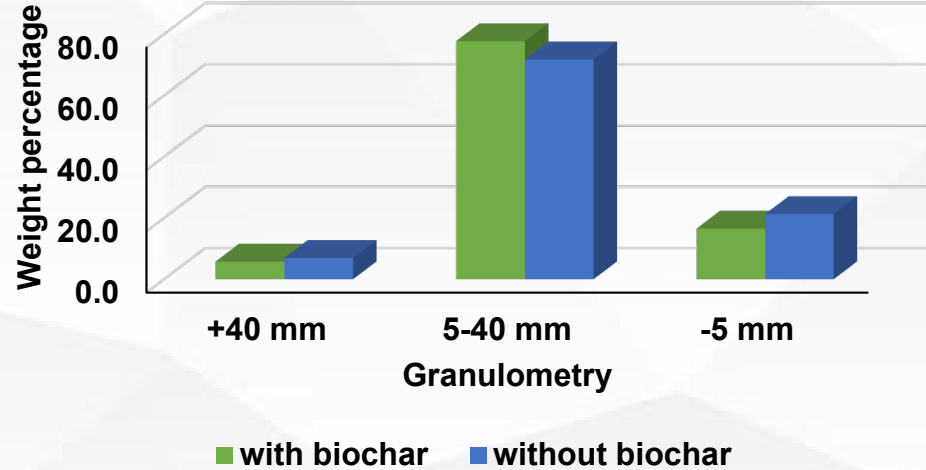
Pallet bottom right side

Pallet dissection results

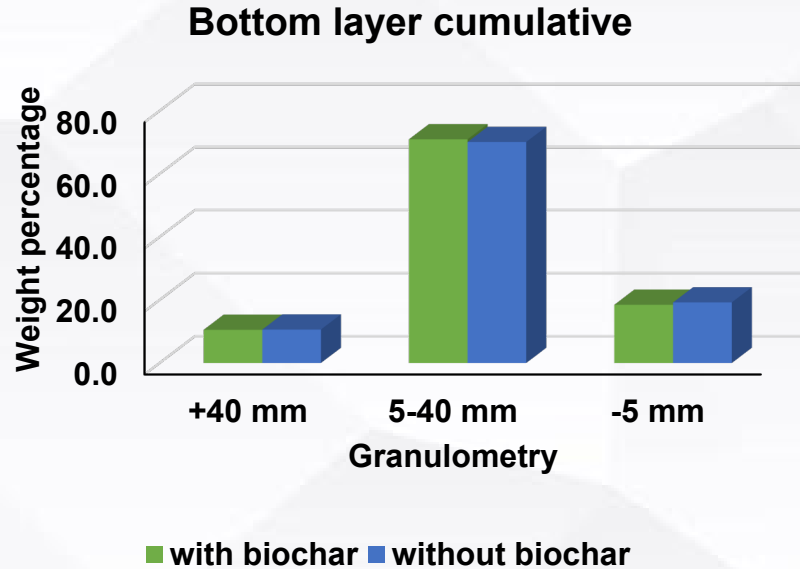
Top layer cumulative



Middle layer cumulative



Pallet dissection results



- The substitution of coke breeze with bamboo biochar led to a significant reduction in coke consumption, with a **reduction of 2–2.5 kg/tgs corresponding to 8.5 kg CO₂/tgs (0.009-0.01 tCO₂/tcs) less emitted.**
- Sinter productivity improved slightly, and the **tumbler index increased from 70.7 to 71,** demonstrating enhanced mechanical strength.
- Furthermore, the amount of **sinter fines (-5 mm) decreased from 7.7% to 7.4%,** indicating better sinter quality.

Results & discussion

Limitation	Explanation / Impact
Lower calorific value	Biochar requires higher fuel input to achieve the same temperature.
High volatile content	Lead to early gas evolution , causing fluctuations in flame front and uneven heating .
Rapid combustion / high reactivity	Biochar burns faster due to high surface area, which can over-accelerate the flame front , reducing high-temperature residence time for SFCA formation.
Flame front control issues	Narrower flame front compared to coke may result in localized overheating or under-heating , affecting sinter quality.
Potential over-reduction of Fe oxides	Faster CO generation can over-reduce $\text{Fe}_2\text{O}_3 \rightarrow \text{FeO} \rightarrow \text{metallic Fe}$ in top layers, compromising sinter strength.
Lower mechanical strength of fuel particles	Biochar can break down more easily , affecting bed permeability and airflow distribution.
Ash composition variability	Biochar ash contain alkali, phosphorous, or sulfur , which may affect sinter chemistry or bonding phases .
Storage and handling challenges	Biochar is dusty and hygroscopic , increasing handling difficulties and potential safety hazards .

Future Scope

Future direction

Category	Parameter / Insight	Value / Scenario (Con. Mod. Aggre)
National Decarbonisation	Biomass cultivation area	0.2M • 0.5M • 1.0M
	Biomass yield (t/ha/yr)	15 • 20 • 25
	Total biomass (Mt/yr)	3 • 10 • 25
	Biochar yield (Mt/yr)	0.9 • 3 • 7.5
	Syngas energy (PJ/yr)	15 • 50 • 125
	Total CO ₂ impact (Mt/yr)	≈12 • ≈38 • ≈90
Integration Benefits	Local biomass sourcing	Cost stability; rural income
	Biochar in sinter	10–20% CO ₂ reduction
	Syngas co-firing	5–10% CO ₂ reduction
	Biochar soil return	Long-term sequestration
Example Cluster (any Indian steel plant)	Land available	5,000 ha
	Biomass yield	100,000 t/yr
	Pyrolysis products	30 kt biochar + 70 kt syngas
	CO ₂ reduction	~100,000 t/yr

- 100% replacement of fossil fuel with biochar experimentally done- **GREEN SINTER**
- One km² bamboo plantation area can absorb around 4000 tons CO₂ annually, produces biomass of around 2000 tons biomass~ 800 tons biochar
- Closed-loop decarbonisation model for the Indian sinter plants: cultivating biomass on degraded land near steel plants, using that feedstock for biochar and syngas co-production, and recycling both into sinter making

" THANK YOU "

There's a little bit of SAIL in everybody's life