VSB TECHNICAL UNIVERSITY OF OSTRAVA | CENTRE FOR ENERGY AND ENVIRONMENTAL TECHNOLOGIES | ENERGY RESEARCH CENTRE

Valorization of Heterogeneous Waste into Carbon-Rich Solid Residue

Enhancing Circularity of SRF

Vortex-Stabilized Gasification as a Pre-Step for Industrial CO_2 Sorbent Synthesis

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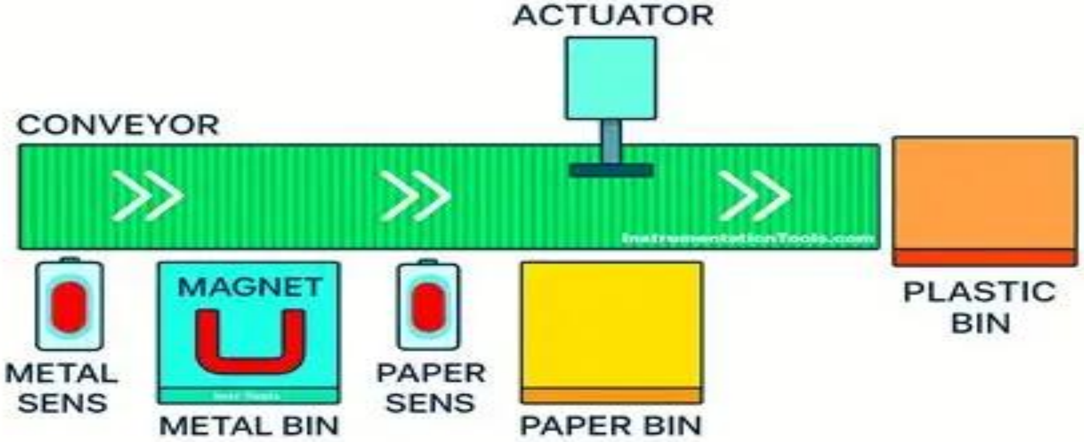


- **Multi material laminates** (paper + plastic + foil) which cannot be mechanically separated efficiently.
- **Contamination with coffee grounds or oils**, reducing the purity of recyclates.
- **Small size and irregular shapes**, especially capsules and sachets, which complicate automated detection and separation.

Why Modern Waste Cannot Be 100% Mechanically Recycled

Economic & Environmental Limits

Heterogeneous Contamination

Food residues, grit, and moisture and Heavily complicated by multilayer and composite packaging.

3.40 Bn Tonnes

Projected global municipal solid waste by 2050

The Structural "Gap": This unrecyclable fraction is currently landfilled or incinerated linearly — a massive unlocked secondary carbon reservoir.

Technical & Material Limitations

- **Multi-Layer Laminates**

  Flexible packaging combines PE, PET, PA, and aluminum foil that cannot be mechanically separated.

- **Thermal Degradation**

  Polymers suffer chain scission during repeat extrusions, degrading structural integrity.

- **Thermosets & Technical Textiles**

  Polyurethane foams and synthetic fiber blends decompose rather than re-melt.

The Gaps Restricting Waste-Derived Chars

Polymer Flashing

Synthetic plastics (PE, PP, PVC) devolatilize rapidly at 400–500 °C

Conventional gasification systems fail beyond this level due to thermal instability, reactor-clogging heavy tars, and sticky liquid phases.

Low-Temperature Slagging

Volatile alkali metals (Na, K) melt below 700 °C without a stable refractory network

Low-melting alkali metals lower ash deformation temperature, causing bed fouling and glassy eutectics that seal carbon pores.

Selectivity vs. Pore-Widening

High-selectivity CO_2 capture requires targeted sub-0.7 nm ultramicropores.

Plastic-derived volatile monomers yield complex aromatic tars that condense within char pores, plugging channels essential for downstream CO_2 capture.

RESEARCH OBJECTIVES

Taming the “Wild Child” – SRF Plastic fraction

01

Potential Solution

Implement a 1:1 strategic wood-biomass enrichment (SRFW-50) to tame the plastic “wild child” and balance thermochemical kinetics.

02

Vortex Hydrodynamics

Utilize cyclonic flow at 780–830 °C to extend particle residence time and crack heavy volatiles.

03

Precursor Engineering

Produce a mineralogically stable carbon skeleton with a neutral surface pH, eliminating costly chemical post-treatment.

Description of Research Methodology

01
Feedstock Preparation

- SRF pellets: 0–35 mm crush, magnetic + density separation
- Thermomechanical sintering at 60–90 °C (plastic as natural binder)
- Wood pellets: A1-grade Picea abies, ø 6 mm

02
SRFW-50 Blend

- 1:1 mass ratio SRF : wood pellets
- Matched ø 6 mm geometry — uniform bed packing
- Bulk density 450–550 kg/m^3

03
Gasification Reactor

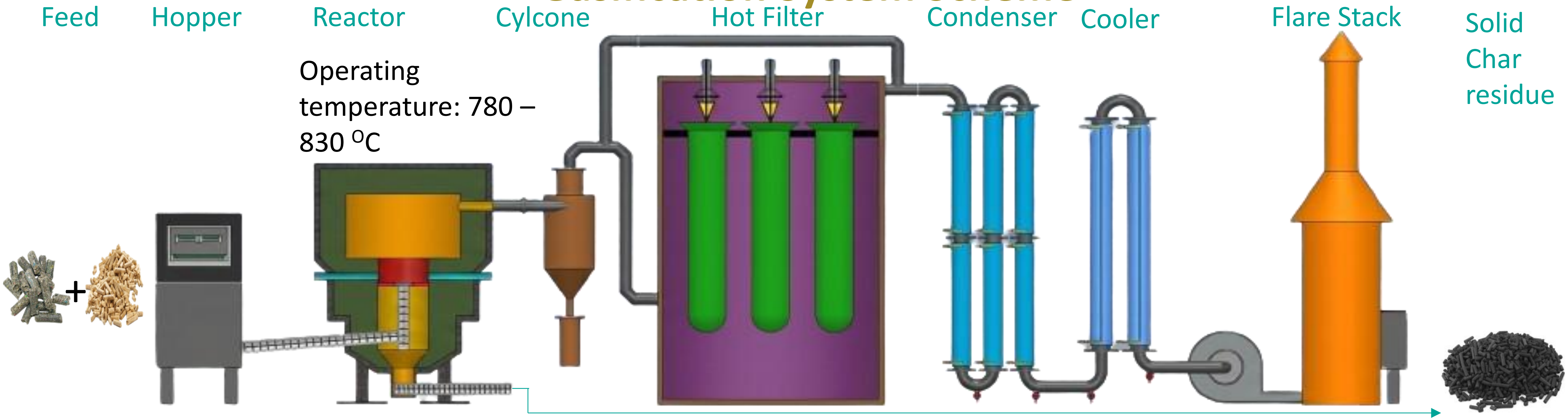
- Hybrid cross/updraft reactor, circular rotating grate
- Tangential air injection creates aerodynamic trapping at 780–830 °C; $\lambda \approx 0.25$ (autothermal)
- Tangential air → vortex flow → Boudouard reaction

04
Syngas, Liquids, and Char Recovery & Analysis

- Van Krevelen (H/C, O/C) + Carbon Concentration Factor, pH of Char
- Proximate / ultimate analysis of Char
- Syng gas Quality Tars/Condensates Quality

Objective: evaluate the 1:1 SRFW blend as a pathway to Functional Carbon Material (FCM) synthesis — shifting thermochemical waste treatment from energy recovery to material production.

Gasification System Scheme



Parameter	Carbon (Cr)	Hydrogen (Hr)	Nitrogen (Nr)	Sulfur (Sr)	Oxygen (Or)	Ash	LHVr (MJ/kg)
SRF Value	54.65	7.08	1.26	0.13	21.27	10.97	22.46
Wood Pellet Value	47.10	5.61	< 0.20	0.02	39.72	0.33	17.50
Standard	EN ISO 16948	-	-	EN ISO 16994	EN ISO 16993	EN ISO 18122	EN 18125

The Gasification reactor

- **Thermal Buffering**

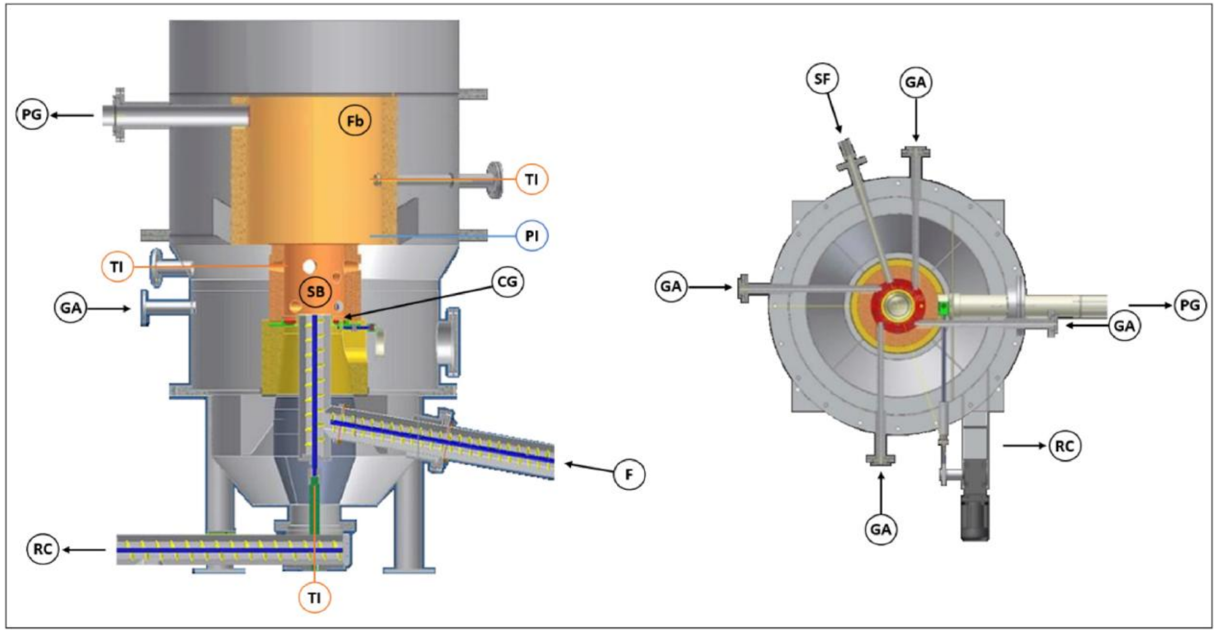
  High-volatile wood biomass stabilizes hearth temperatures and releases oxygenated radicals to crack long-chain polymer radicals.

- **Vortex Core Dynamics**

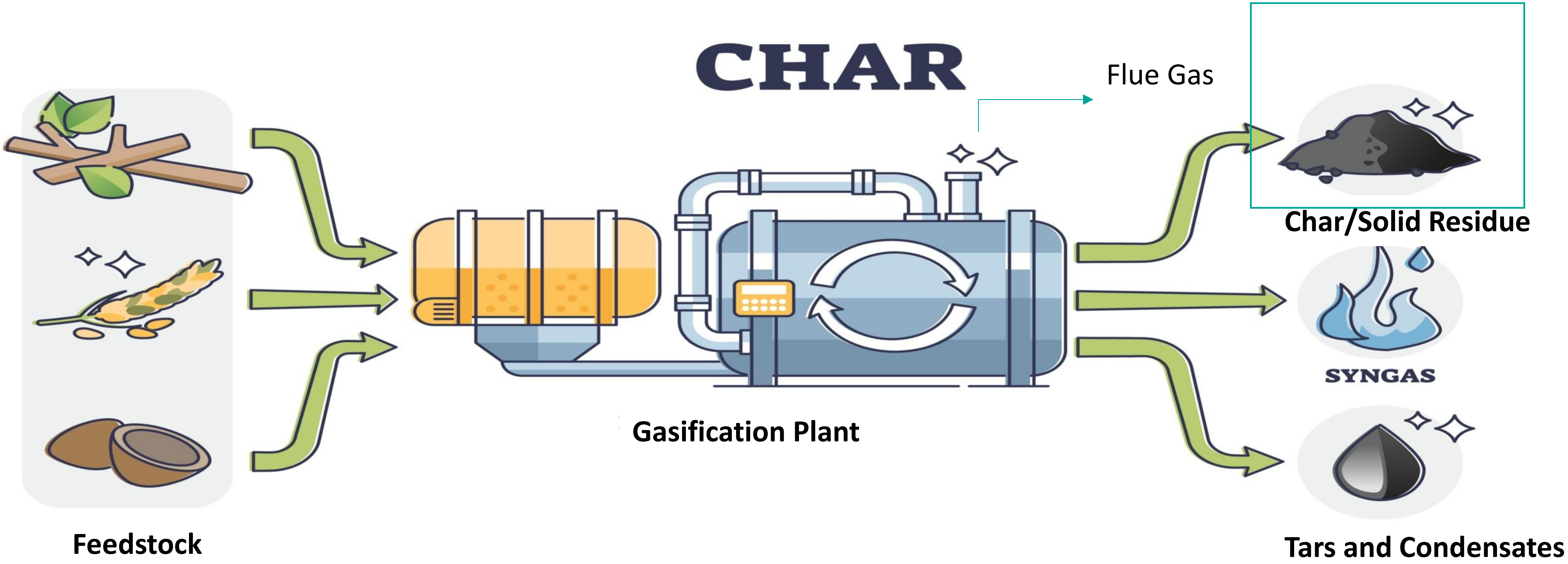
  The high-intensity turbulent core acts as an internal thermal cracker, stripping sticky volatiles before they condense in pores.

- **The "Tar-Shifting" Mechanism**

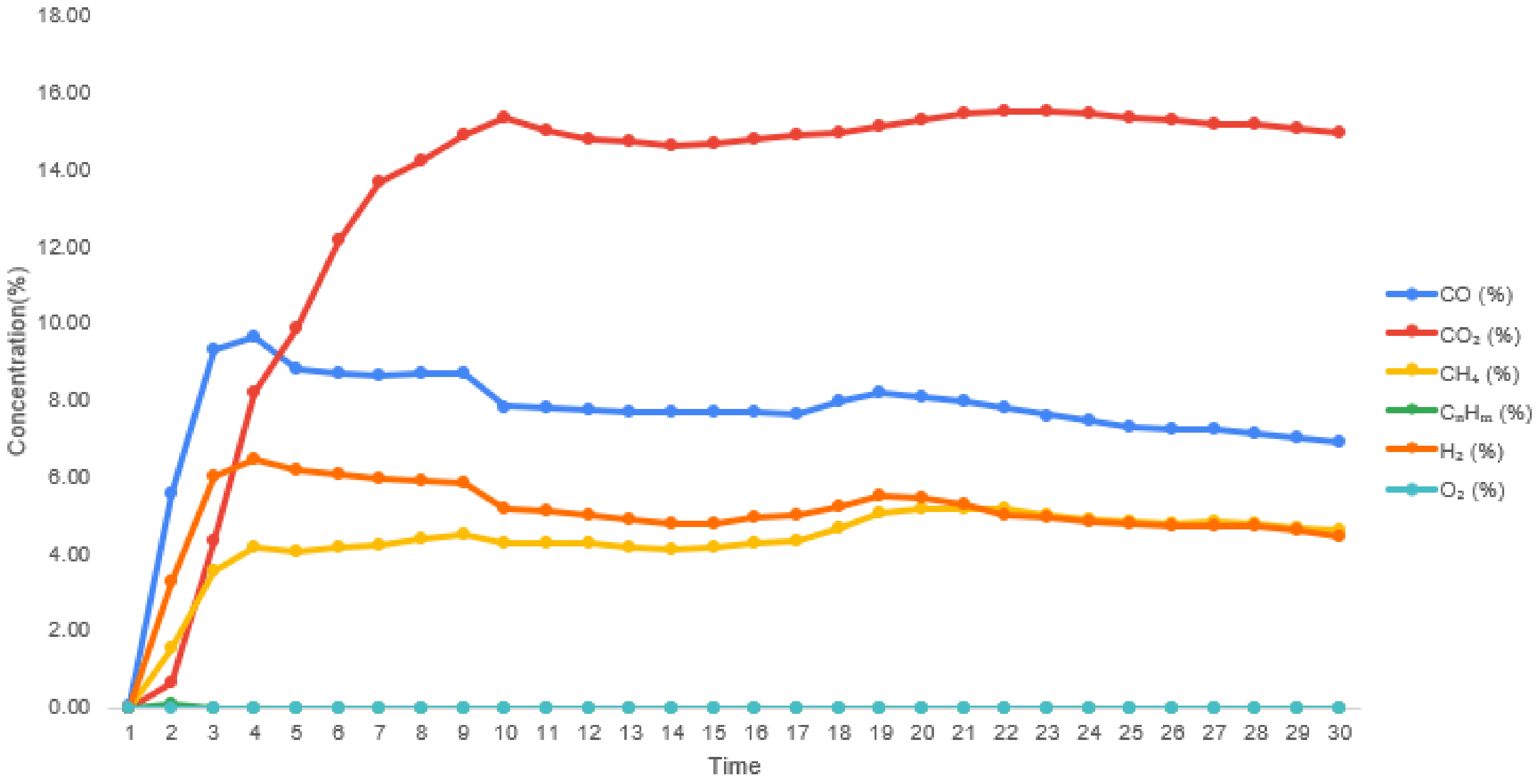
  Instead of escaping as tar emissions or clogging pores, volatile hydrocarbons are sequestered directly into the char skeleton as stable aromatic clusters.



CG – circular grate; F – fuel input; Fb – freeboard; GA – gasification agent intake; PG – producer gas output; RC – residual char output; PI – pressure indicator; SB – sliding bed; SF – start-up flame; TI – temperature indicators.


CHAR
Flue Gas
Char/Solid Residue
SYNGAS
Tars and Condensates
Gasification Plant
Feedstock

Gas Compostion and Energy content



LLV: 5MJ/Nm^3

Aromatic Maturity of Tars & Syngas Cleanliness

≈ 0.00%

Syngas Cleanliness

CnHm volatiles dropped to near-zero; particulate matter emissions fell 88% (from 24.00 g/m³ in standard SRF to 2.88 g/m³ in the SRFW).

727.31 µg/mL

Aromatic Fate

Benzene dominates the cracked-tar profile at late-stage operation — full BTEX breakdown below.

<0.1 mg/kg

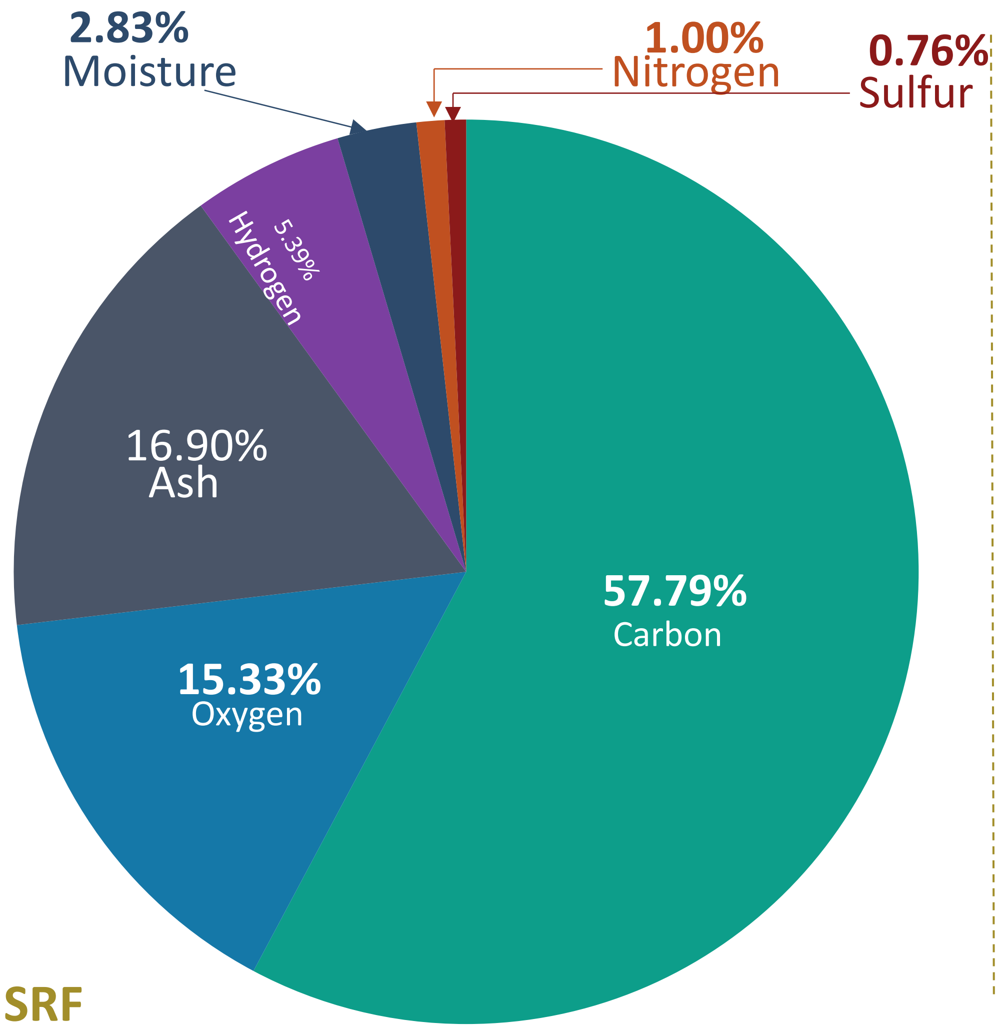
Pollutant Capture

Mercury trapped below detection threshold.

Compound (µg/mL)	TAR1 (Ramp)	TAR2 (Steady-State)	TAR3 (Late-Stage)
Benzene	179.89	259.41	727.31
Toluene	22.24	39.64	219.80
Ethylbenzene	n.d.	0.83	8.55
m,p-Xylene	n.d.	0.63	17.63
o-Xylene	1.31	1.18	54.81
Trichloroethylene	n.d.	n.d.	n.d.
Tetrachloroethylene	n.d.	n.d.	n.d.
Total BTEX	**203.44**	**301.70**	**1,028.10**

RESULTS & Discussion

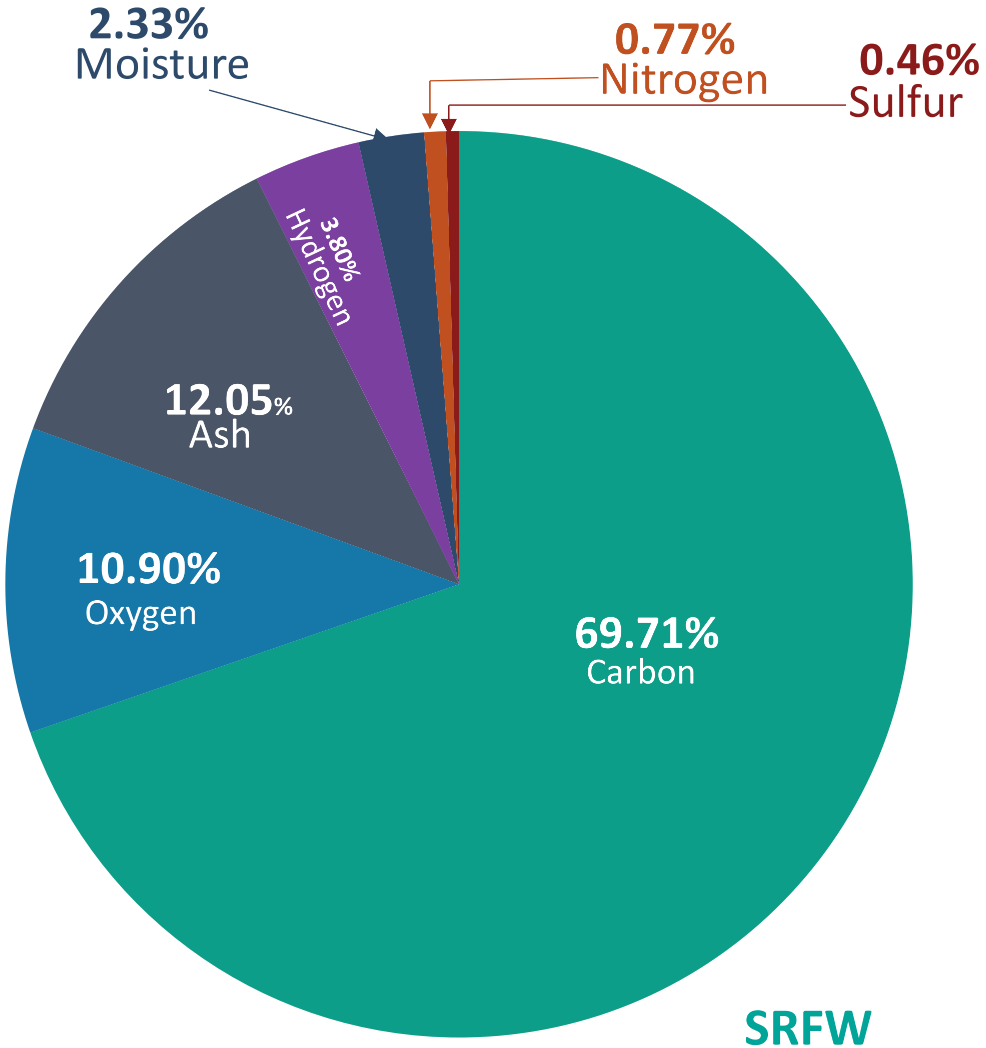
Solid Residue properties (CHNS/O + Ash) CHNS628S analyzer



SRF

Component

Component	SRF	SRFW
Carbon	57.79%	69.71%
Oxygen	15.33%	10.90%
Ash	16.90%	12.05%
Hydrogen	5.39%	3.80%
Moisture	2.83%	2.33%
Nitrogen	1.00%	0.77%
Sulfur	0.76%	0.46%



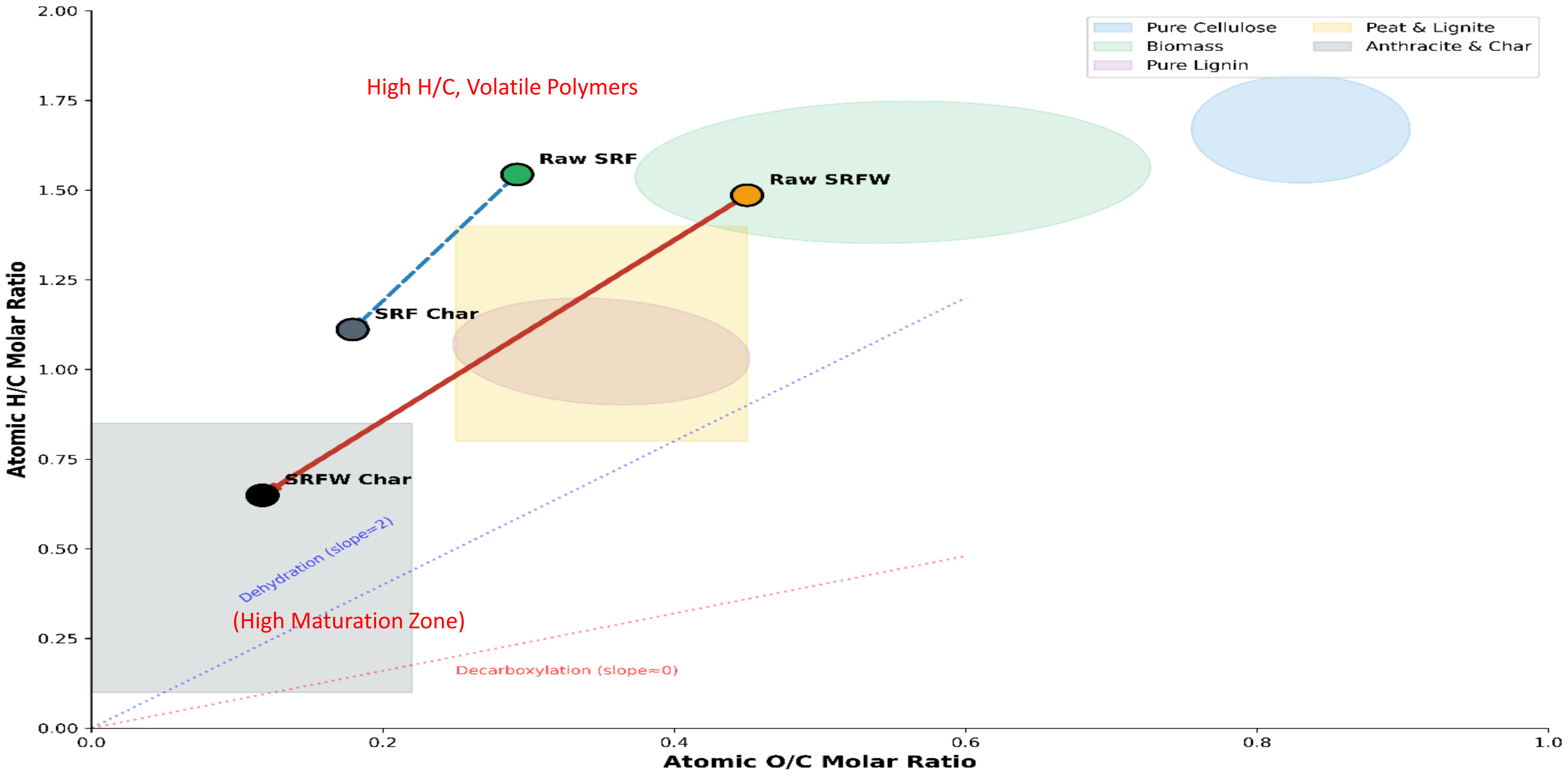
SRFW

Parameter	SRF Baseline	SRFW Blend (1:1)
Net Calorific Value	22.46 MJ/kg	19.98 MJ/kg
Chlorine (Cl)	0.58%	0.29%

Parameter	SRF Char	SRFW Char
Chlorine (Cl)	0.49%	0.90%

RESULTS & Discussion

Van Krevelen Plot: Carbon Preservation & Concentration



Shift from Biomass towards coal-like material: The downward shift toward the bottom-left corner proves we have engineered a highly carbonaceous, mature anthracite-like matrix.

Char Properties

	Inorganic Class	Mechanistic Impact	Structural & Chemical Mechanism	Strategic Intervention
CONSTRUCTIVE *(Leverage)*	**Alkali / Alkaline Earth** Ca 5.11%, K 0.82%, Mg 0.49%	✓ Positive	Catalyzes gasification and forms water-soluble molten salt templates (**$CaCl_2$**, **KCl**) that act as structural pillars.	Keep during activation; wash post-activation to unlock pores.
	Transition Metals Fe 1.97%, Ni 0.04%	✓ Positive	Catalyzes localized carbon etching; integrates into the matrix to leave self-doped catalytic sites.	Keep in-situ for cross-valorization.
DETRIMENTAL *(Mitigate)*	**Ash / Inert Minerals** Si 3.26%, Al 1.68%	⚠ Mitigate	Forms inert, low-melting-point glassy eutectics that seal off the carbon micropore network, drastically lowering S_{BET}.	Mitigate via pre-treatment or acid wash if accumulation occurs.
	Halogens & Sulfur S 1.49%, Cl 0.90%	⚠ Mitigate	Evolves highly corrosive **HCl** and **H_2S** gases under high-temperature steam conditions.	Scrub off-gas stream.
	Trace Toxics Pb, Sb, Zn	⚠ Mitigate	Volatilizes and partitions into the exhaust gas stream rather than stabilizing in the solid char.	Condense and capture in the downstream off-gas train.

Surface Neutrality — the “Chemical Tug-of-War”

pH = 7.2

Near-neutral surface pH directly out of the reactor

The Mechanism

A thermochemical “chemical tug-of-war” in which alkaline wood-ash minerals (K_2O, CaO) neutralize acidic SRF decomposition species (HCl, SO_x).

Zero Liquid Discharge (ZLD)

Eliminates expensive acid/alkali post-washing and toxic chemical wastewater streams — a direct process-economics benefit of the neutral char.

Slagging Mitigation & Ash Chemistry

BAI = 0.96
Alkali–Iron Index

Eutectic Suppression

A high Fe_2O_3-to-alkali ratio suppresses low-melting eutectics, eliminating slag and clinker formation.

$$\frac{Fe_2O_3}{Na_2O + K_2O}$$

+240 °C
Ash Melting Buffer

Fouling Safety Buffer

Initial Shrinkage Temperature (SST) at 1070 °C provides a 240 °C operating margin above hearth gasification temperatures.

Fe / Ca
Molecular Porogens

Self-Doped Catalysts

Trapped iron and calcium centers act as pre-dispersed catalytic “drills” for targeted micropore etching in the upcoming activation phase.

B/A = 0.82
Base-to-Acid Ratio

Refractory Mineralogy

A Base-to-Acid ratio of 0.82 promotes high-melting Gehlenite and Anorthite mineral phases (> 1200 °C).

$$\frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

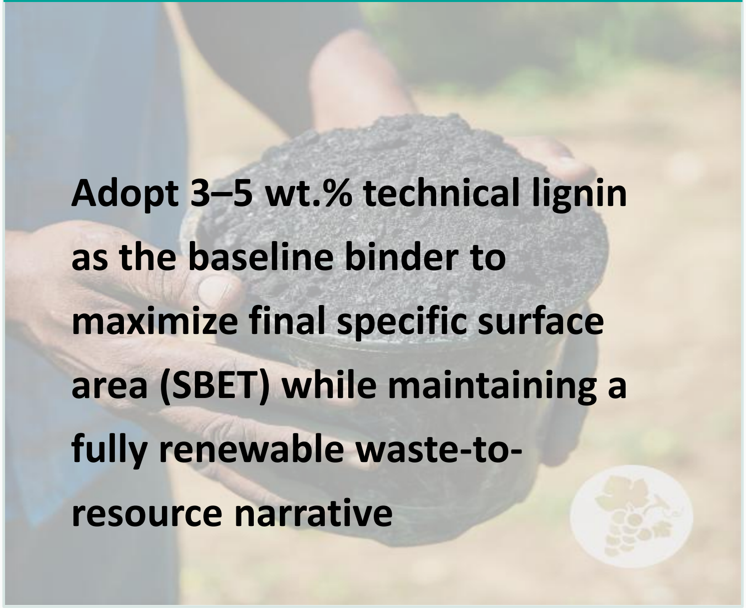
Future Direction & targets: Exceeding Commercial Baselines

Performance Metric	Commercial Bituminous	Premium Coconut Shell AC	Our Engineered SRFW Target
Surface Area (BET)	900–1100 m^2/g	1100–1400 m^2/g	**> 1000 m^2/g (baseline > 650)**
Total Pore Volume (V_t)	0.30–0.35 cm^3/g	0.35–0.45 cm^3/g	**> 0.40 cm^3/g**
Ultramicropore Fraction	Moderate	High	**> 70–75% (0.5–0.7 nm)**
CO_2 Uptake (1 bar, 25°C)	1.8–2.2 mmol/g	2.2–2.4 mmol/g	**≥ 2.5 mmol/g**

Technical Takeaway: Gasification is the structural enabler. By eliminating tar blockage and mineral sintering today, our char can withstand steam activation (700–850 °C) to compete directly with premium commercial sorbents.

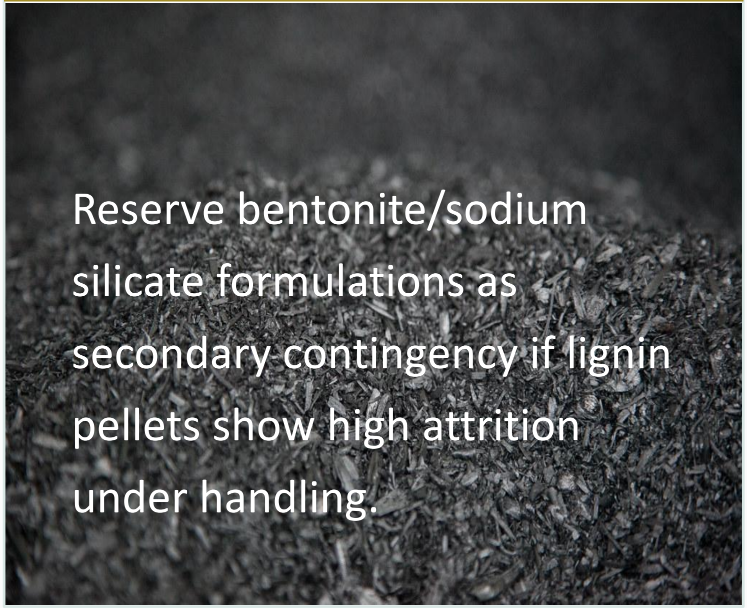
Future Direction: Overcoming the char structural challenges

SRF Structure



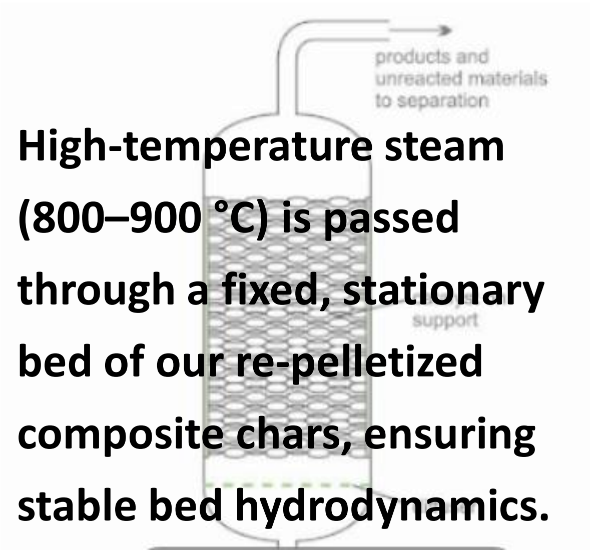
Adopt 3–5 wt.% technical lignin as the baseline binder to maximize final specific surface area (SBET) while maintaining a fully renewable waste-to-resource narrative

Fallback Route (Inorganic Clay)



Reserve bentonite/sodium silicate formulations as secondary contingency if lignin pellets show high attrition under handling.

Steam Activation

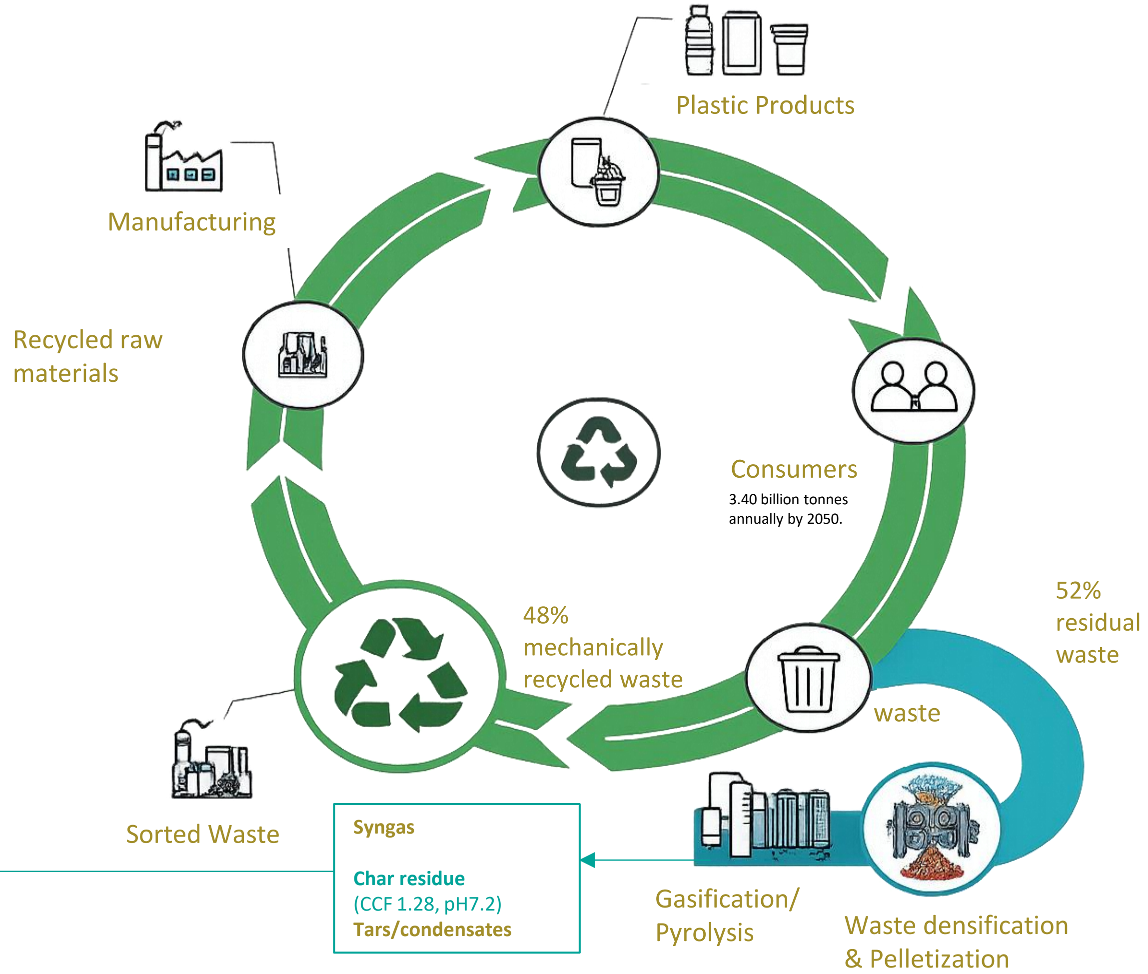


High-temperature steam (800–900 °C) is passed through a fixed, stationary bed of our re-pelletized composite chars, ensuring stable bed hydrodynamics.

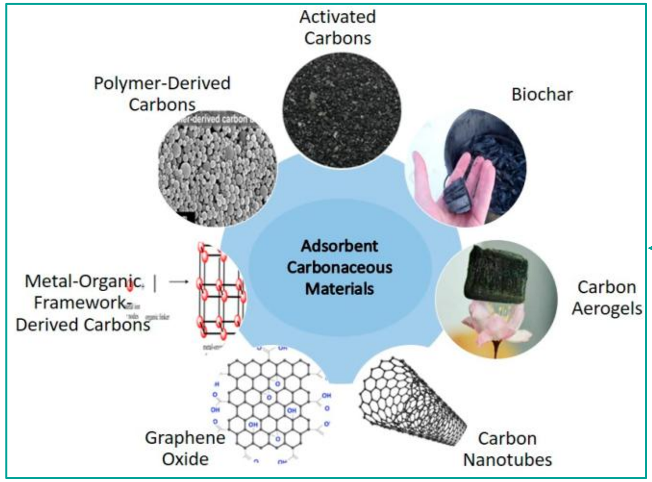
Conclusion

Transitioning from Liability to Asset

- **Paradigm Shift:** Reframes heterogeneous waste (SRF) from an unpredictable liability into a valuable chemical resource.
- **Chlorine Mitigation:** Employs in-situ mineral trapping CaO to capture chlorine in the solid char and eliminate gas toxicity.
- **Tar Cracking:** Uses vortex thermochemistry to break down heavy tars into manageable single-ring aromatics.
- **Slagging Control:** Blends wood biomass to raise ash melting points and prevent reactor bed fouling.
- **Sorbent Precursor:** Yields a high-density carbonaceous matrix designed for future high-efficiency sorbent activation.
- SDG Alignment: Supports UN SDGs **7** (Affordable and Clean Energy), **9** (Industry, Innovation, and Infrastructure), **11** (Sustainable Cities and Communities), **12** (Responsible Consumption and Production), and **13** (Climate Action) for sustainable industry.



Operate 240 ^{O}C below ash shrinkage point (1070°C)



CLOSING

Thank You for Listening

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