Supergen Bioenergy | SUSTAINABLE BIOENERGY SYSTEMS FOR OUR LOW-CARBON FUTURE

Development of Biochar-Based Functional Materials: Advancing a Sustainable Platform for Carbon Applications

Team:

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Industrial Partner: Hybrid Gasification

UKRI Engineering and Physical Sciences Research Council

UKRI Biotechnology and Biological Sciences Research Council

Durham University

Hybrid Gasification

SUSTAINABLE BIOENERGY SYSTEMS FOR OUR LOW-CARBON FUTURE

Functional Biochar Materials: Bridging Environmental Responsibility and Regulatory Standards

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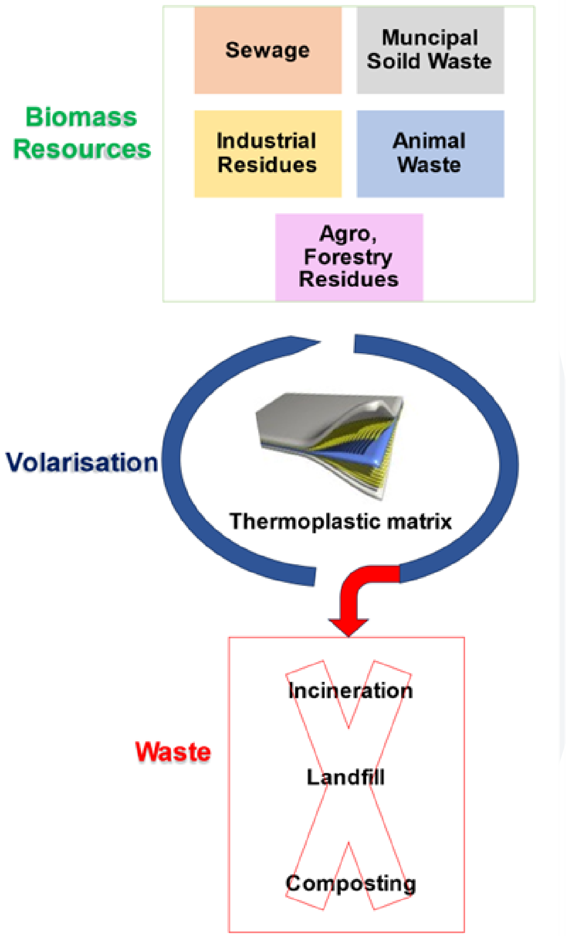

Our project focused on developing **biochar-based functional composites** using agricultural and sludge waste. The goal is to develop and assess biochar-based composites for sustainable applications through property evaluation and life-cycle analysis of their environmental impact and sustainability benefits

Research Objectives:

- ❑ Produce **biochar via pyrolysis** from biomass and waste streams.
- ❑ Fabricate **biochar-reinforced HDPE and PP composites**.
- ❑ Evaluate their **mechanical, thermal, and structural performance**.
- ❑ Conduct **Life Cycle Assessment (LCA)** to the environmental impact and sustainability benefits of biochar-based composites.

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Materials and Methods

The following materials were used for composite preparation:

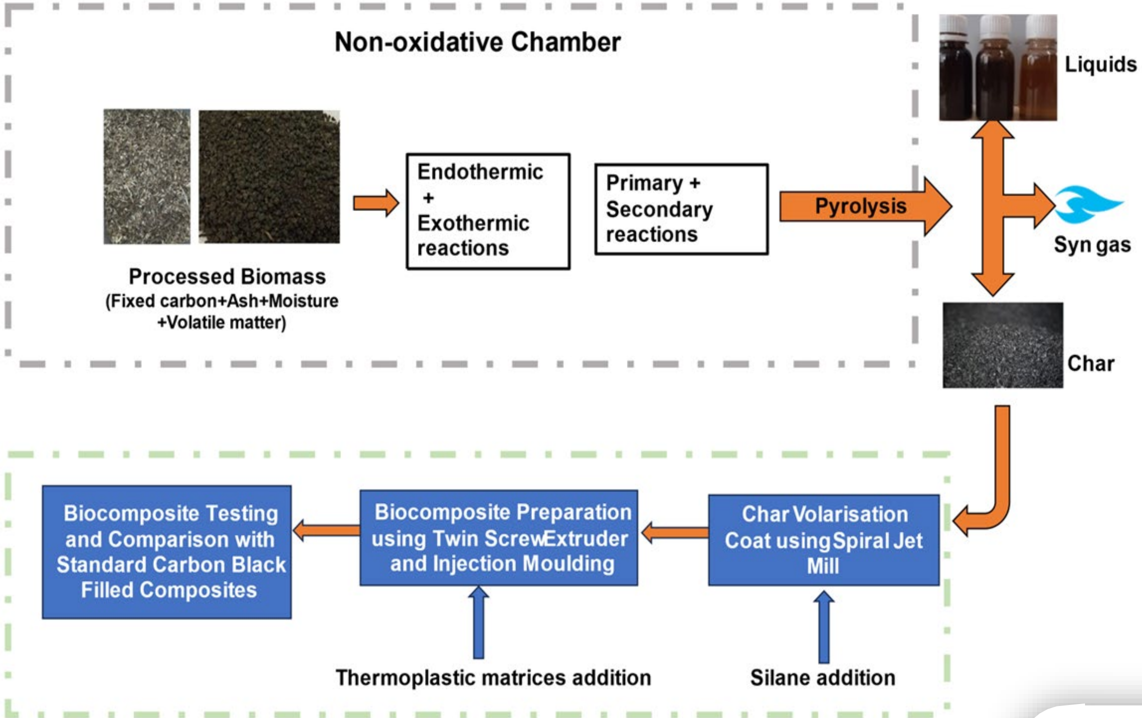
- High Density Polyethylene (HDPE); Polypropylene (PP)
- 3-Aminopropyltriethoxysilane (APTES)

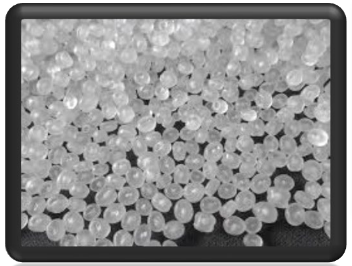
Char derived from:

- Mustard Straw (MS); Rice Husk; Corn Straw (CS); Wheat Straw (WS); Sludge Waste (SW)

We blended silanised biochar (5–15 wt%) with HDPE and PP using twin-screw extrusion and injection moulding.

Testing covered: Tensile and impact strength; Hardness and density





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Key Findings

High Density Polyethylene (HDPE):

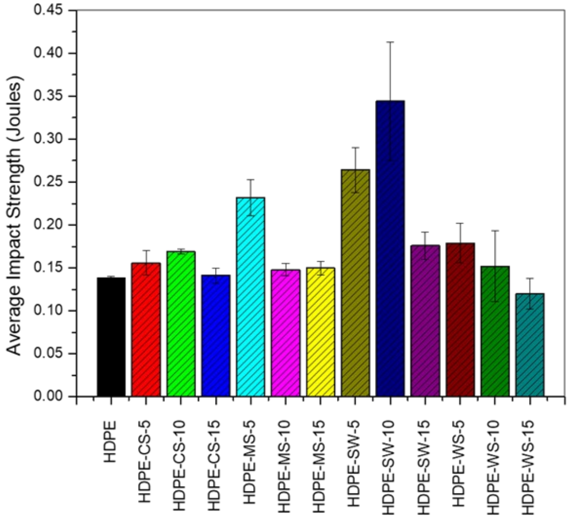
Best Overall Performer: **Sludge Waste (SW) Char at 10 wt%**

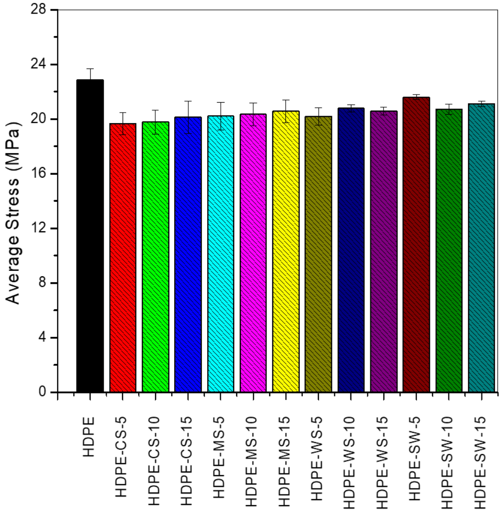
Reasons: Impact Strength: Highest recorded among all HDPE composites (0.344 J), indicating excellent toughness.

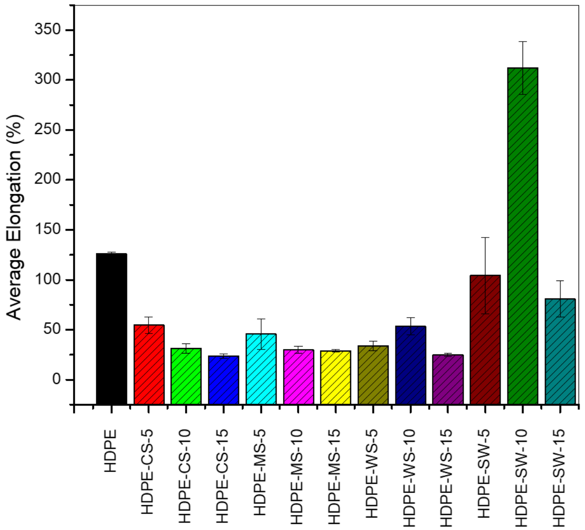
Tensile Strength: Comparable to neat HDPE and other char types (20.72 MPa), without significant loss in load-bearing capacity.

Elongation at Break: Exceptionally high (312.06%), far exceeding neat HDPE (125.87%) a unique result suggesting favourable polymer–filler interaction or flexible microstructure.

Sludge Waste char is optimal for HDPE when a combination of high toughness, retained ductility, and structural integrity is desired.







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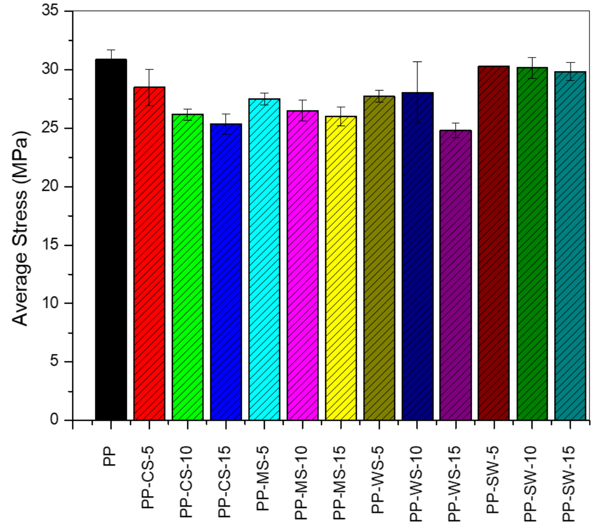
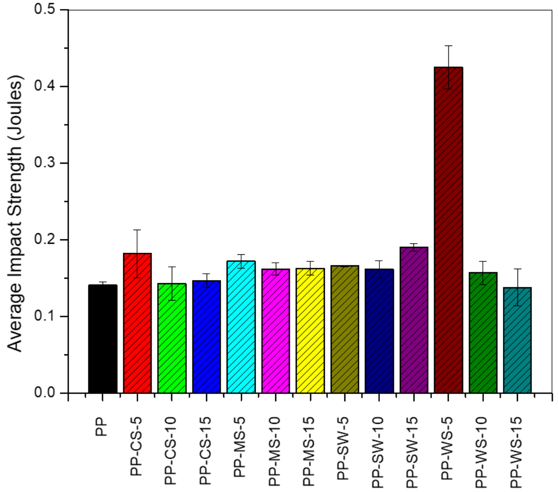
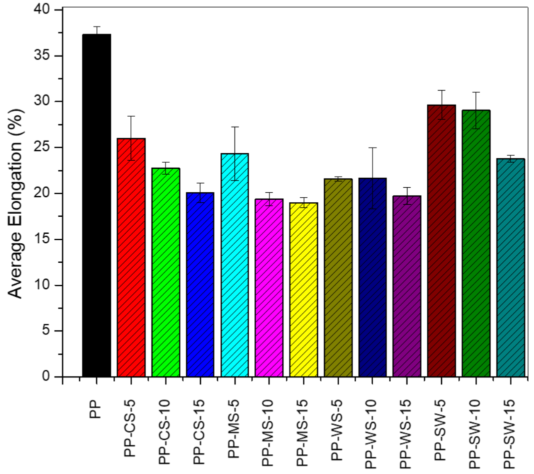
Key Findings

Polypropylene (PP):

- Best Overall Performer: **Sludge Waste (SW) Char at 15 wt%** *(close tie with Wheat Straw (WS) at 5% for impact-heavy applications)*
- Reasons:
  - Tensile Strength: Among the highest for PP composites (29.82 MPa), very close to neat PP (30.85 MPa) — minimal strength loss.
  - Impact Strength: Solid performance (0.190 J), though WS at 5% had the highest impact (0.425 J) but with lower tensile retention.
  - Elongation at Break: Balanced (23.76%), avoiding excessive brittleness seen in some other char types.
- Special Note:
  If impact resistance is the top priority for PP, WS char at 5% is unmatched (0.425 J) but comes at the cost of tensile strength drop. For a balanced property profile, SW char at 15% is the better choice.







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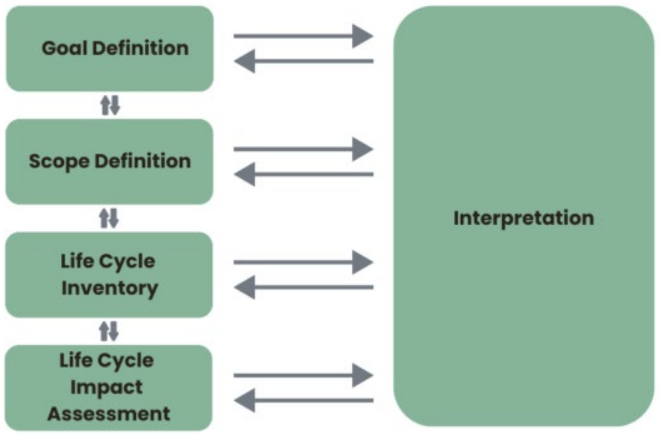
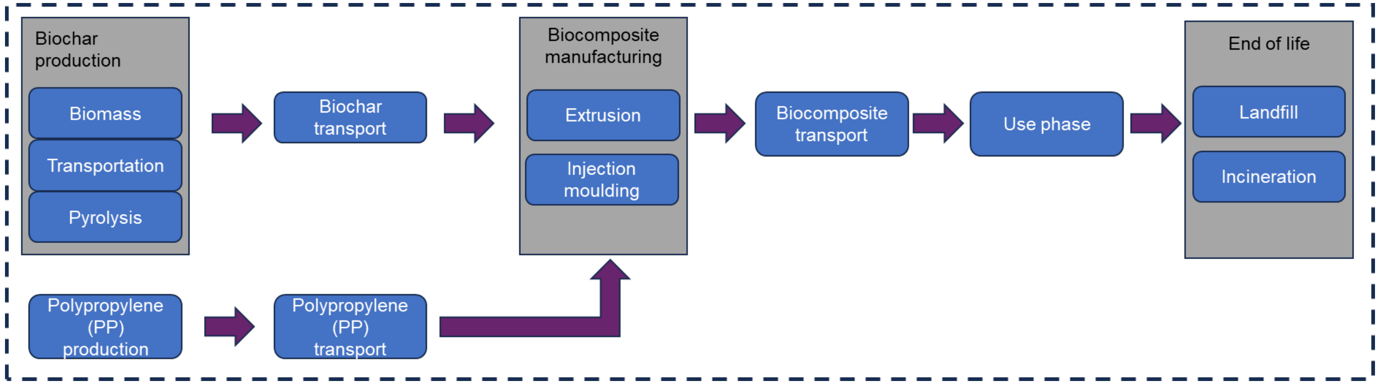
LCA and Sustainability Impact



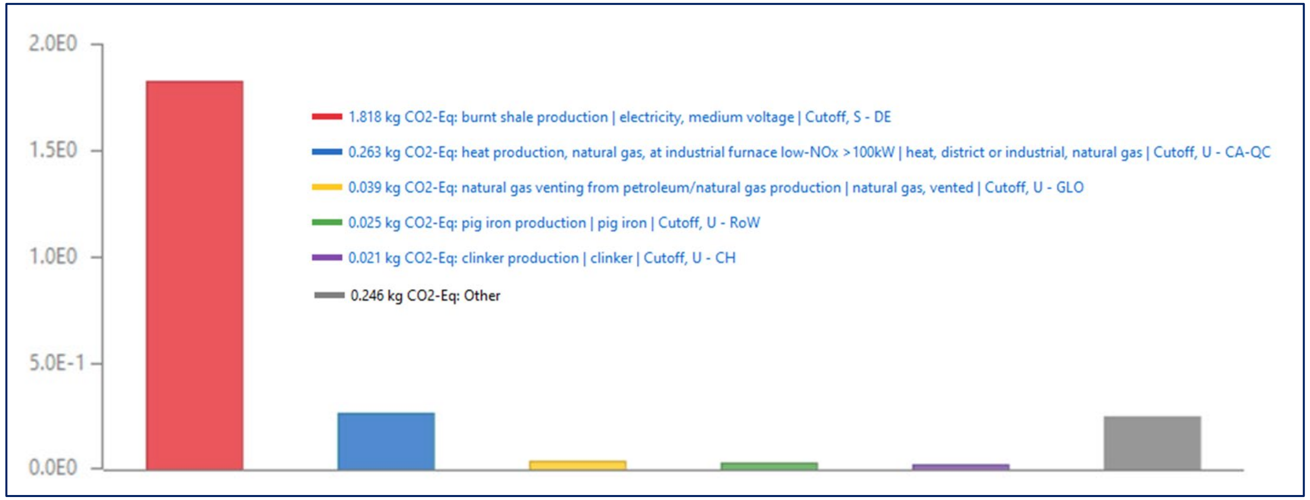


- Life Cycle Assessment (LCA) carried out to evaluate the environmental performance of the system. The LCA framework includes four key phases- Goal and Scope Definition, Life Cycle Inventory, Life Cycle Impact Assessment, and Interpretation-which together provide a comprehensive understanding of the system's overall environmental impacts.
- Developed models for the life cycle of sewage sludge-based bio composite - consists of 85% PP and 15% silanised biochar by weight- to promote environmental sustainability and supports cleaner, low-carbon material production.

Key Takeaways

Impact category	Reference unit	Cradle-to-Grave Result
Acidification	mol H+-Eq	0.006474189
Climate change	kg CO_2-Eq	2.411827651
Ecotoxicity: freshwater	CTUe	2.430142674
Ecotoxicity: freshwater, inorganics	CTUe	2.364823504
Ecotoxicity: freshwater, organics	CTUe	0.06531917
Energy resources: non-renewable	MJ, net calorific value	19.86211066
Eutrophication: freshwater	kg P-Eq	0.000115021
Eutrophication: marine	kg N-Eq	0.001331124
Eutrophication: terrestrial	mol N-Eq	0.016380078
Ionising radiation: human health	kBq U235-Eq	0.013832459
Land use	dimensionless	12.72354132
Material resources: metals/minerals	kg Sb-Eq	6.72336E-06
Ozone depletion	kg CFC-11-Eq	6.573E-09
Particulate matter formation	disease incidence	5.60378E-08
Photochemical oxidant formation: human health	kg NMVOC-Eq	0.004515075
Water use	m3 world Eq deprived	0.406615342

CML baseline results (per kg of Sewage biochar-PP)



Climate Change - GHG emissions

- Climate impact quantification: The process emits ≈2.41 kg CO_2-eq, indicating its contribution to global warming potential.
- Environmental significance: This reflects total greenhouse gas emissions across all life cycle stages.
- Benchmarking potential: The CO_2-equivalent value can serve as a baseline for comparison with other processes or improvement scenarios (e.g., using renewable energy, waste valorisation, or carbon capture).
- Sustainability insight: Lower CO_2-eq emissions signify better environmental sustainability and progress toward low-carbon goals.

Conclusion

Our work aligns with Challenge 2: **Regulatory & Reputational Risk Management** by:

- ❑ Utilizing waste-derived, non-toxic feedstocks that meet regulatory safety standards.
- ❑ Integrating LCA early to anticipate compliance and market risks.
- ❑ Supporting Unilever's goals for responsible sourcing and transparent environmental metrics.
- ❑ Our Supergen collaboration can provide Unilever with quantitative tools, validated materials data, and LCA-backed insights to accelerate sustainable product innovation - achieving both environmental and regulatory excellence.

THANKS

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