Integrated Bioprocesses for a Circular Carbon Economy

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The transition from a linear, fossil-based economy requires innovative strategies that address the dual crises of climate change and persistent material waste. This research program establishes a novel framework for a truly circular economy by developing and integrating processes that valorize both atmospheric carbon and post-consumer waste streams. The platform synergistically combines sustainable biomass production, a versatile green biorefinery capable of processing diverse feedstocks, and multifaceted carbon sequestration.

The framework is founded on two complementary feedstock sources. The first is photosynthetically-derived biomass, with a focus on microalgae grown in advanced photobioreactors. This serves as a biological carbon capture system, converting atmospheric CO_2 into feedstock. The second is challenging material waste, specifically targeting the chemical decoupling and upcycling of waste plastics.

The core of the platform is a next-generation biorefinery designed for flexibility and sustainability. A central innovation enabling the processing of both biomass and plastics is the development of novel green solvents. We place particular emphasis on pioneering CO_2-switchable solvent technology, which allows for tunable, energy-efficient separations across different applications, be it extracting valuable compounds from algae or breaking down polymer chains.

A defining feature of this framework is the dual utilization of CO_2. It serves first as a primary nutrient for growing microalgal biomass and second as a volatile chemical switch to control the solvent's properties during refining. In a significant departure from conventional approaches that would recycle this switching CO_2, our proposal aims for its permanent sequestration. The process-derived CO_2 is intentionally directed into a mineralization pathway where it is reacted with alkaline industrial residues, such as steel slag. These waste materials contain the chemical triggers to permanently immobilize the CO_2 as geologically stable solid carbonates. This dual-capture mechanism, which valorizes multiple waste streams to create a carbon sink, establishes a powerful and verifiable pathway towards truly carbon-negative operations. By integrating biological capture with advanced chemical recycling and waste-driven mineralization, this research demonstrates a robust blueprint for a restorative economic model.

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