

# A Thermally Coupled Thermochemical–Biological Platform for Carbon Utilization and Biostimulant Production via Biochar-Mediated Processing

## Abstract

We describe an integrated thermochemical–biological platform that couples carbon dioxide utilization, biochar-assisted biomass harvesting, staged anaerobic bioprocessing, and thermally coordinated process control to produce high-value plant biostimulants. Carbon dioxide generated as an effluent stream from a thermochemical reactor (TCR) is redirected as a feedstock for cyanobacterial cultivation in photosynthetic bioreactors (PBRs). Biomass is harvested via microfine biochar-assisted flocculation, forming a concentrated cyanobacteria–biochar substrate. This substrate is processed within a multi-stage anaerobic bioreactor (ABR), where temperature-segregated microbial communities drive controlled biochemical transformations, yielding a biologically active digestate used to formulate REGENiGROW™ plant biostimulants. Thermal energy recovered from the TCR is distributed across the system via a centralized control architecture (Natural Solutions Engine, NSE), enabling precise regulation of biological environments in both the ABR and PBRs. Minor quantities of methane and hydrogen are generated as supplemental fuels and blended with TCR-derived syngas for on-site energy production. The system represents a closed-loop, thermally integrated platform that prioritizes biological product formation while maximizing resource efficiency.

## 1. Introduction

Regenerative agricultural systems increasingly require integrated technologies capable of converting waste carbon streams into biologically functional products that enhance soil health and plant productivity. Conventional anaerobic digestion systems are typically optimized for biogas production, often at the expense of digestate quality (Appels et al., 2008). In contrast, emerging approaches emphasize the generation of biologically active amendments, including microbial metabolites and humic substances (Canellas and Olivares, 2014).

The platform described herein integrates thermochemical and biological processes into a unified system. Carbon dioxide generated during thermochemical biomass conversion is reutilized as a feedstock for photosynthetic biomass production (Singh et al., 2011). The harvested biomass is subsequently conditioned using engineered carbon materials and processed through staged anaerobic pathways designed to maximize the formation of biologically active compounds. The system is explicitly designed to prioritize **biostimulant production**, with energy recovery functioning as a secondary component.

## **2. System Architecture and Process Flow**

### **2.1 Thermochemical Carbon Generation and Utilization**

The thermochemical reactor (TCR) converts lignocellulosic biomass into syngas, generating both usable thermal energy and a concentrated carbon dioxide effluent stream. Integration of thermochemical and biological carbon pathways has been identified as a promising strategy for carbon recycling and energy efficiency (Lehmann and Joseph, 2015).

### **2.2 Cyanobacterial Cultivation Using Recycled CO<sub>2</sub>**

Cyanobacteria cultivated in open raceway PBRs utilize CO<sub>2</sub>, water, and nutrients to produce biomass via photosynthesis (Singh et al., 2011). Raceway systems enable scalable, low-cost biomass production, particularly when coupled with recycled carbon streams.

### **2.3 Biochar-Assisted Flocculation and Biomass Concentration**

Microfine biochar is used as a flocculation agent to aggregate cyanobacterial biomass. Biochar's surface chemistry and porosity facilitate adsorption and particle bridging, enabling efficient harvesting (Ahmad et al., 2014). This process yields a concentrated biomass substrate while allowing water reuse within the system.

## **3. Thermally Segregated Anaerobic Bioreactor (ABR) Processing**

### **3.1 Multi-Stage Temperature-Controlled Microbial Conversion**

The ABR employs temperature-stratified stages to support distinct microbial communities. Temperature is a critical parameter governing microbial pathways in anaerobic digestion, influencing hydrolysis, acidogenesis, and methanogenesis (Chen et al., 2008).

### **3.2 NSE-Controlled Thermal Integration**

The Natural Solutions Engine (NSE) regulates heat distribution across the ABR and PBR systems. Thermal integration has been shown to significantly improve process efficiency in coupled bioenergy systems (Zhang et al., 2017).

### **3.3 Digestate Formation as Primary Output**

The digestate produced is enriched in microbial metabolites and organic compounds that contribute to plant growth and soil health (Canellas and Olivares, 2014). Unlike traditional systems, this platform prioritizes digestate quality over biogas yield.

### **3.4 Supplemental Fuel Generation**

Methane and hydrogen generated during digestion are utilized as supplemental fuels and combined with syngas for energy recovery, improving overall system efficiency (Weiland, 2010).

## **4. Functional Role of Microfine Biochar**

### **4.1 Process Intensification via Electron Transfer**

Biochar has been shown to enhance anaerobic digestion through facilitation of direct interspecies electron transfer (DIET), improving microbial syntrophy and metabolic efficiency (Lovley, 2017; Chen et al., 2014).

### **4.2 Influence on Humic Substance Formation**

Humic substances are formed through complex microbial and abiotic processes involving the transformation and recombination of organic matter (Stevenson, 1994). Biochar may influence these processes through:

- Catalytic surface interactions (Lehmann and Joseph, 2015)
- Adsorption of organic intermediates (Ahmad et al., 2014)
- Electron shuttle behavior (Lovley, 2017)
- Microbial community modulation (Lehmann et al., 2011)

These mechanisms may enhance the formation of humic and fulvic acids within the digestate.

## **5. Energy and Resource Integration**

The integration of thermal and gaseous outputs across the TCR and ABR establishes a closed-loop system in which energy, carbon, and water are continuously recycled. Such integrated systems have been identified as critical for advancing circular bioeconomy models (Zhang et al., 2017).

## 6. Discussion

The system demonstrates a shift toward **biology-centric processing**, where thermochemical and biological pathways are co-optimized. The incorporation of biochar and thermal control enables enhanced microbial performance, while carbon recycling improves overall sustainability.

## 7. Conclusion

This thermally integrated platform represents a novel approach to carbon utilization and agricultural input production. By prioritizing biostimulant generation and leveraging synergistic interactions between thermochemical and biological processes, the system offers a scalable pathway toward regenerative agriculture and circular carbon economies.

## 8. Author Bio

Michael Smith is the founder of REGENiTECH LLC, headquartered in Whitefish, Montana. With over 40 years of experience in computational physics, artificial intelligence, and systems modeling, his work has spanned animation, simulation, and behavioral modeling across industries including aerospace, gaming, and scientific research. His current work focuses on biomimicry-driven biorefinery systems and regenerative soil technologies. Smith's groundbreaking biorefinery innovations are featured in the award-winning documentary 'The Need To Grow', highlighting scalable solutions for soil regeneration, carbon sequestration, and sustainable agriculture.

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