Abstract of the problem (Max. 1000 words)

Cassava processing industries generate substantial quantities of high-strength wastewater and solid residues characterized by elevated chemical oxygen demand (COD), biological oxygen demand (BOD), starch-rich suspended solids, and rapid acidification potential. Improper management of this waste leads to severe environmental concerns including odor emission, methane leakage, groundwater contamination, and high treatment costs. Although conventional anaerobic digestion (AD) systems are currently used for biogas generation, these systems primarily focus on methane (CH_4) production and are associated with several technical and operational limitations. Methane-dominant biogas (60–70% CH_4) exhibits a narrow flammability range, slow flame propagation speed, high ignition temperature, longer combustion duration, and relatively lower heat efficiency, limiting its industrial fuel performance. In addition, conventional single-stage AD processes often suffer from low organic loading efficiency, metabolite accumulation (volatile fatty acids), extended hydraulic retention times (HRT), process instability, and incomplete energy recovery from cassava waste substrates. These constraints reduce overall system efficiency, economic feasibility, and energy recovery potential for cassava-based industries. There is therefore a pressing need for an improved, scalable, and industrially viable waste-to-energy technology that enhances fuel quality while maximizing energy recovery and minimizing environmental impact.

Biohythane, a renewable gaseous fuel comprising 5–25% hydrogen (H_2) blended with 75–95% methane (CH_4), presents a promising alternative to conventional methane-rich biogas. The addition of hydrogen significantly enhances combustion characteristics, including improved flammability range, higher burning velocity, shorter ignition delay, reduced quenching distance, and increased thermal efficiency. Furthermore, biohythane offers higher theoretical energy recovery and lower greenhouse gas (GHG) emissions due to its improved hydrogen-to-carbon (H/C) ratio compared to methane alone. Despite these advantages, current cassava industry AD systems are not optimized for biohythane production, particularly with respect to controlled hydrogen enrichment, metabolite management, and enhanced microbial electron transfer mechanisms. Cassava wastewater contains complex carbohydrates and organic polymers that hinder efficient hydrolysis and fermentation, limiting hydrogen generation and subsequent methanogenic integration. The imbalance in pyruvate metabolism pathways and insufficient activity of key enzymes such as hydrogenase and nitrogenase further constrain hydrogen yield and overall process efficiency.

The industrial challenge, therefore, is to develop and implement a two-stage anaerobic digestion process specifically optimized for biohythane production from cassava industrial waste. The proposed system must enhance hydrolysis and acidogenesis in the first stage to maximize hydrogen generation while stabilizing methanogenesis in the second stage for controlled methane integration. Key technical barriers that need to be addressed include slow decomposition rates, accumulation of inhibitory metabolites, inefficient interspecies electron transfer (IET), and suboptimal organic loading rates. Innovative pretreatment strategies- including alkali, acid, and enzymatic processes- must be evaluated and optimized to break down complex starch-based and fibrous components, thereby improving microbial accessibility and substrate conversion efficiency. Additionally, advanced catalytic interventions such as biomass-derived hydrochar-supported bimetallic nanoparticles (HSBNP) are required to enhance intracellular and interspecies electron transfer, act as catalytic cofactors at enzyme active sites, and promote balanced formate lyase and ferredoxin oxidoreductase activity to facilitate improved pyruvate conversion and hydrogen generation. These catalytic

materials should support microbial consortia stability, accelerate fermentation kinetics, and ultimately increase biohythane yield and energy recovery.

The desired industrial solution must demonstrate enhanced gas yield and improved hydrogen-to-methane ratios under high organic loading conditions while maintaining operational stability and reducing hydraulic retention time. It should enable higher theoretical energy recovery compared to conventional methane-only systems, reduce greenhouse gas emissions, and improve plant-level energy self-sufficiency. The process should be economically viable, scalable for industrial implementation, and compatible with existing cassava processing infrastructure. Ultimately, the industry seeks a closed-loop biorefinery model that transforms cassava industrial waste from an environmental liability into a high-value renewable energy resource through optimized biohythane production. Successful development of such a system will support sustainable waste valorization, regulatory compliance, reduced carbon footprint, and improved economic returns for cassava processing industries while contributing to broader renewable energy and circular economy goals.