ANNEXURE-I

SYNOPSIS

1. Introduction

The increase in global scale urbanization has resulted in significant energy demand and material consumption as well as the anthropogenic generation of waste in large quantities. The major source of our fuel needs is the petroleum-based refinery, which has a grave impact over energy-environment nexus. Consequently, alternative and renewable energy sources should be explored to gain sustainability. It is estimated that in the next eight years, the average per capita waste generation rates per person, will increase from 1.2 to 1.42 kg per day in low and middle economic countries. The intrinsic advantage of waste is its biodegradable organic fraction associated with inherent net positive energy that could be converted to economically useful energy forms, to meet the world's energy demand. The regulatory requirement for the treatment of waste prior to disposal makes waste as renewable feedstock for sustainable renewable energy generation. Considerable improvements are required to the existing bioprocess and also efforts should be made towards practical applicability at commercial scale.

2. Statement of Problem

Waste has potential to meet the world's growing energy demand, by employing several bioprocesses. Dark fermentation, being one of the green and eco-friendly process, received significant interest in the recent decade owing to the fact that biohydrogen production through renewable waste feedstock can address today's two most important concerns: energy security, climate change through waste remediation. This process of biological hydrogen production will compete with conventional hydrogen production in a sustainable and economical way. Yet, the process parameters and reactor configuration need to be optimized to increase the production rate and yield with diverse wastes at a pilot scale before commercialization. Besides, biohydrogen, an additional sustainable option is biodiesel production from waste. Converting solar energy to high energy bio-molecules during microalgae cultivation is referred as photo-bioproducts and can be cultivated by open pond and specially designed closed systems called photobioreactors.

Employing mixed microalgae to utilize waste (liquid or gaseous) for biodiesel production is more feasible to apply at commercial scale to mitigate gaseous (CO_2, CO)

and liquid wastes (effluents). Prior to commercialization, mixed microalgae require optimization towards higher biomass and lipid productions to overcome the limitations.

Moreover, photo-bioproducts an additional sustainable bioelectricity can be generated from photosynthesis process. Photosynthetic conversion of solar energy to chemical energy and further to electrical energy using rhizosphere microorganisms of plant root is referred as bioelectrogenesis and the system used is plant microbial fuel cell (P-MFC). Based on the application requirement, P-MFC can be designed as an eco-electrogenic engineered system (EES) specifically used to remediate waste in natural water bodies which are polluted. Yet, it is necessary to optimize electrode material, distance of anode to cathode and operation with real field effluents for efficient power output and waste remediation before scaling up.

3. Scope and Objectives of the Research

The scope of the thesis was designed to study acidogenic and photosynthetic processes for the production of biobased products viz., biohydrogen, biodiesel and bioelectricity through waste utilization encompassing process upscaling as final objective. Hydrogen production through fermentation process is technically simpler, requires low operating costs, is more robust and makes it feasible and sustainable to upscale the processes for mass production. Microalgae cultivation for biobased products is more advantageous than other biological routes due to rapid doubling time of cells, harvesting solar energy and CO_2 sequestration capabilities with less land use. Rhizosphere mediated electrogenesis employing photosynthetic fuel cell with terrestrial and aquatic plants through the photosynthetic process is generating considerable interest in applied research in recent times and is also considered important in the context of the biorefinery. Furthermore, integrated strategies address the unused carbon in one process to serve as the substrate for another process in a cascading biorefinery pathway. In response to finding solutions to the challenges and for process understanding, different strategies have been adopted to harness bioenergy and value-added products through sustainable biological processes addressing the waste remediation (Fig 1).

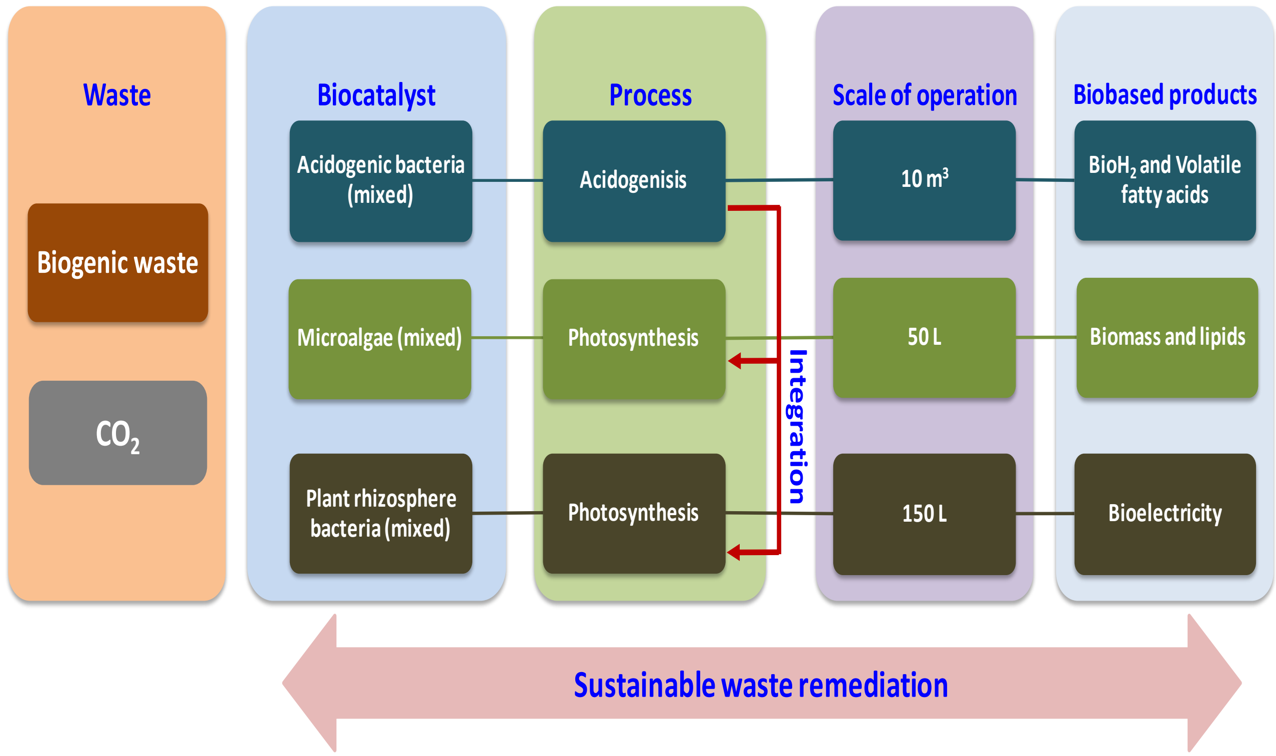

Fig 1: Flow chart depicting the scope of research

With the existing scope in the literature, the thesis was designed and discussed with the following broad objectives

- To enumerate the potential of different waste/wastewaters as feedstock for acidogenic biohydrogen production.
- To comprehend and optimize the critical parameters of the acidogenic process towards upscaling and techno-economical feasibility
- To evaluate photosynthetic process for higher biomass and lipid productivity through selective-optimization strategy and process upscaling
- To design and evaluate the rhizosphere mediated bioelectricity production using terrestrial and aquatic plants towards process upscaling
- To integrate acidogenic and photosynthetic processes in cascading mode to produce biobased products with simultaneous waste remediation in a biorefinery framework

4. Structure of the Thesis

The thesis is divided into six chapters. Chapter 1 presents a general introduction and review of literature covering different topics of the thesis; Chapter 2 presents acidogenic biohydrogen production optimizing physicochemical parameters, reactor configuration and upscaling the process assessing techno-economic feasibility for commercial application; Chapter 3 deals with photosynthetic mixed microalgae cultivation by optimizing physicochemical parameters and scaling up in an efficiently designed flat-panel photobioreactor for higher production of biomass and lipids; Chapters 4 presents rhizobial catalyzed bioelectrogenesis from terrestrial and aquatic plants through photosynthetic CO_2 sequestration; Chapter 5 depicts integration strategies of acidogenic process with photosynthetic process for bio-based production (biomass, biodiesel and bioelectricity) with simultaneous waste remediation; Chapter 6 summarizes research output and future scope of the research.

5. Summary of the Research

Comprehensive efforts were made towards up-scaling the biohydrogen production process for practical application. Biohydrogen production is assessed by a methodical two-phase rapid protocol/methodology developed to know the potential of diverse waste/wastewater varying different process parameters [inoculum (pretreated and untreated), redox condition and organic loading] crucial for biohydrogen production. During these experiments, it was noticed that acidogenic redox condition with pretreated inoculum at high organic loading with food waste and design synthetic wastewater as substrate showed good results for biohydrogen production. In addition, experiments were carried out to enhance biohydrogen production with two reactor configurations (biofilm and suspended) with above-optimized conditions. Enhanced biohydrogen production with biofilm configured bioreactor was observed due to adherence of robust microbes (developed during exposure to different microenvironment) on biofilm matrix. Further, the optimized configuration was incorporated in the 10 m^3 acidogenic biohydrogen pilot plant design and was evaluated with food waste as feedstock for biohydrogen production with the optimized conditions. Finally, techno-economic analysis for biohydrogen process was performed with real field data which showed positive results in socio-economic aspects and is environmentally friendly towards practical application of commercial plant.

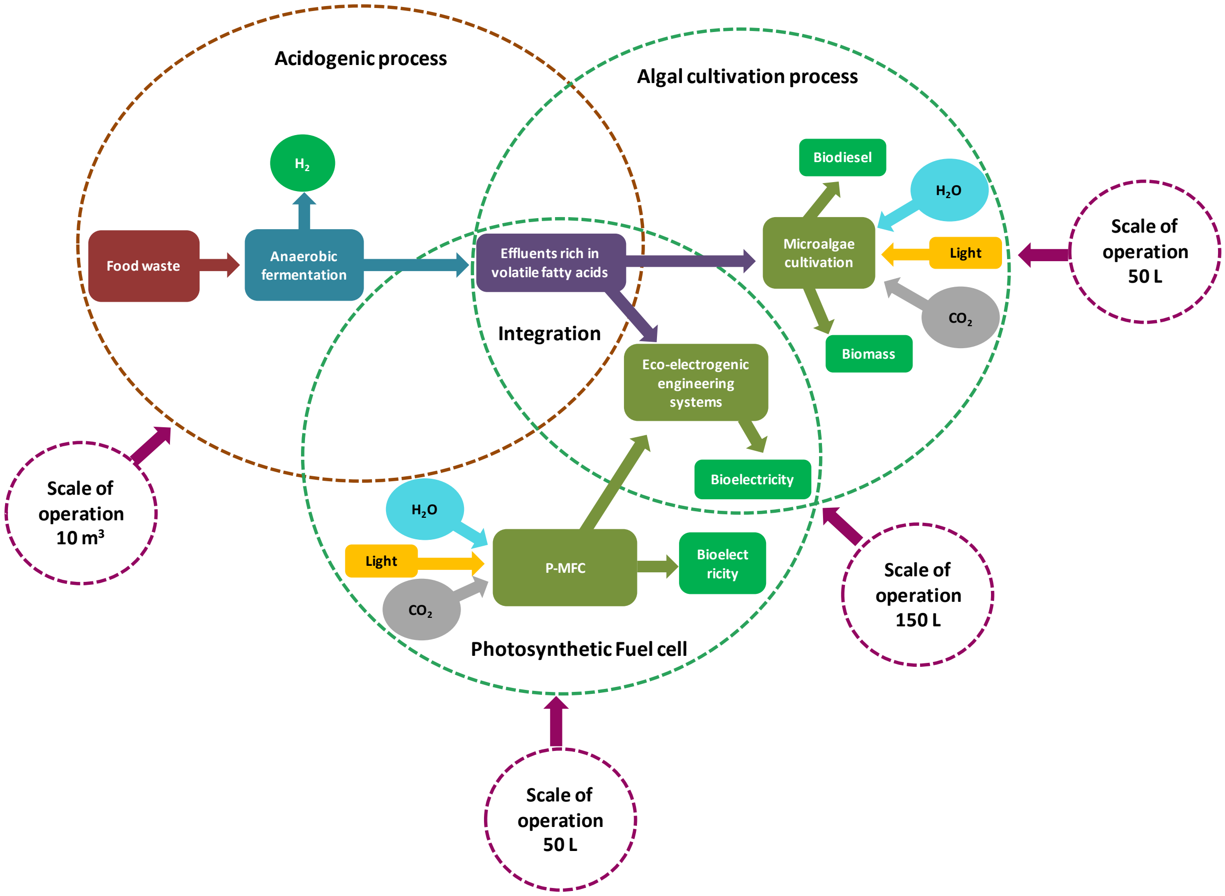

Fig 2: Flow chart depicting biohydrogenesis, photosynthesis and bioelectrogenesis integration and scale up operations during research work

Further research extended with the photosynthetic process includes cultivation of mixed microalgae by optimizing physicochemical parameters that show positive influence on biomass and lipid productivity with Taguchi method. Among the eight factors, carbon concentration individually showed significant positive influence on the biomass productivity (5.26 g/l) followed by nitrates, light, temperature, pH, carbon source, Magnesium, and Phosphates. Among the four parameters, pH, salinity, and carbon concentration showed significant influence on maximizing the lipid synthesis (55% of total lipids). The broader understanding of biomass production and lipid biosynthesis for biodiesel production and recovery of bio-based products lead to the design of 50 l flat panel photobioreactor (FPBR) for microalgae cultivation operated with optimized biomass and lipid conditions towards practical applicability. High biomass and lipid production during operating FPBR with optimized biomass condition is best suitable for outdoor cultivation of mixed microalgae to produce high value-added photosynthetic products.

Photosynthetic fuel cells were explored to tap their potential for power generation with *Pennisetum setaceum,* a perennial grass plant by placing anodes at different regions of the rhizosphere. The study concluded that the maximum power was observed with the anode placed nearer to the root zone due to maximum plant-microbial and electrode interactions. Subsequently, another study was carried out to evaluate the power production by exploring the photosynthetic CO_2 sequestration by native macrophytes in designed ecological engineering system (EES). The power production enumerated the specific advantage of EES as self-sustainable technology by means of a photosynthetic process with the potential of real field applications.

Integration of acidogenic and photosynthetic processes in a biorefinery framework towards maximum resource recovery with simultaneous waste treatment is the sustainable practice for process upscaling in an economically viable route (Fig 2). In this direction, acid rich effluents from biohydrogen reactor were used as a substrate for microalgal cultivation. Apart from gaseous energy (H_2) production in the first stage, the integration facilitated liquid energy production in the form of biodiesel in the second stage with simultaneous wastewater treatment. In the similar way, the effluent from biohydrogen process was also fed to EES embedded with fuel cell assemblies. The study made a comprehensive evaluation of photosynthetic hydrophytes, abiotic cathode and biotic anode along with microbes (present in sediment and rhizosphere of the aquatic plant) with concurrent power generation and wastewater treatment. Biorefinery is emerging as a potential route, where a range of products can be valorized from non-edible feedstock/biogenic waste. The research output deliberates on ‘waste as a prime target substance in the biorefinery that shows a broad range of opportunities for commercial interests’.