IIT-KHARAGPUR LEADS THE WAY FOR BIOFUELS

G Balachandar, Dr Pallavi Sinha, and **Dr Debabrata Das** highlight the role of Department of Biotechnology, IIT-Kharagpur in the development of technologies, such as biohydrogen, biobutanol, BIOHYMET, algal biofuels, and microbial fuel cells for the biofuels.

Our energy requirements are almost fully provided by carbon-containing fossil sources, such as oil, coal, and natural gas. The rapid use of these fossil resources causes an accelerated release of the bound carbon as CO_2. The increased CO_2 concentration in atmosphere is hazardous for the nature and has resulted into global warming. The need of the hour is to switch to an efficient fuel with zero carbon footprint and this path can be achieved by using biofuels.

Role of IIT-Kharagpur in Development of Biofuels

Hydrogen having a highest energy density (143 kJ/g), is a clean and environment-friendly fuel. Fermentative H_2 production using renewable resources (wastes/wastewaters) is a promising way of economical and sustainable energy source. The biological process has been recognized as one of the promising approaches for hydrogen production. The high production cost is still a key issue for the commercialization. Over the years, the group at IIT-Kharagpur has developed a comprehensive and refined expertise in the field of biohydrogen production. IIT-Kharagpur has explored all the domains related to hydrogen production through biological routes. Figure 1 is a schematic diagram of research activities at IIT-Kharagpur in biofuel research.

Amongst the various other processes, dark fermentation appears to be more promising. It is independent of light energy, requires moderate process conditions, and is less energy consuming. Besides, it can also use wastewater as a substrate for hydrogen production. The potential of different substrates for biohydrogen production was identified. Various substrates, such as distillery effluent, starchy wastewater, kitchen waste, and lignocellulosic biomass were used as a substrate for dark fermentative hydrogen production while nitrogen-rich deoiled cake of groundnut and coconut were also found effective and efficient to replace costly nutrient supplement as yeast extract, tryptone, etc. The maximum cumulative hydrogen production and hydrogen yield from groundnut and coconut deoiled cakes were 3.2 and 2.6 L h^{-1} and 11.2 and 9.2 mol H_2/kg $COD_{removed}$, respectively. Groundnut and coconut deoiled cakes were found not only promising substrate but also acted as a nutritional supplement to support hydrogen production process.

The suitability of cane molasses as substrate for continuous biohydrogen production was explored using a 20 L bioreactor. The maximum rate of hydrogen production and yield achieved were 67 L h^{-1} and 18.54 mol H_2/ kg $COD_{removed}$, respectively. Using the logic control system, a high-level automation was achieved in maintaining reduced partial pressure, which in turn was found to enhance the hydrogen yield, purity, and production rate. Dark fermentation of organic wastes at mesophilic and thermophilic temperatures are attractive avenues for biological H_2 production. The dark fermentation at thermophilic temperatures (60°C) is more advantageous. Many industrial organic wastewaters are discharged at elevated temperatures that can be directly used. Moreover, higher temperature condition leads to pathogenic destruction, lower risk of contamination by methanogenic archaea, a higher rate of hydrolysis, and higher H_2 yield. In addition, during fermentation excess heat is generated that requires cooling for mesophilic cultures. Thermophilic biohydrogen production was also explored as an avenue for biological H_2 production. A newly isolated organism, *Thermoanaerobactrum thermosaccharolyticum* ST1 yielded a maximum of 2.7 mol H_2/mol glucose. The lab also focusses biohydrogen production using mixed and co-culture apart from pure cultures to make the process more feasible. One of the current major activities is related to installation and commissioning of 10 m^3 bioreactor for commercial exploitation of biohydrogen production process from organic wastes. The effluent generated from dark fermentation contains metabolites, such as volatile fatty acid which can be used further

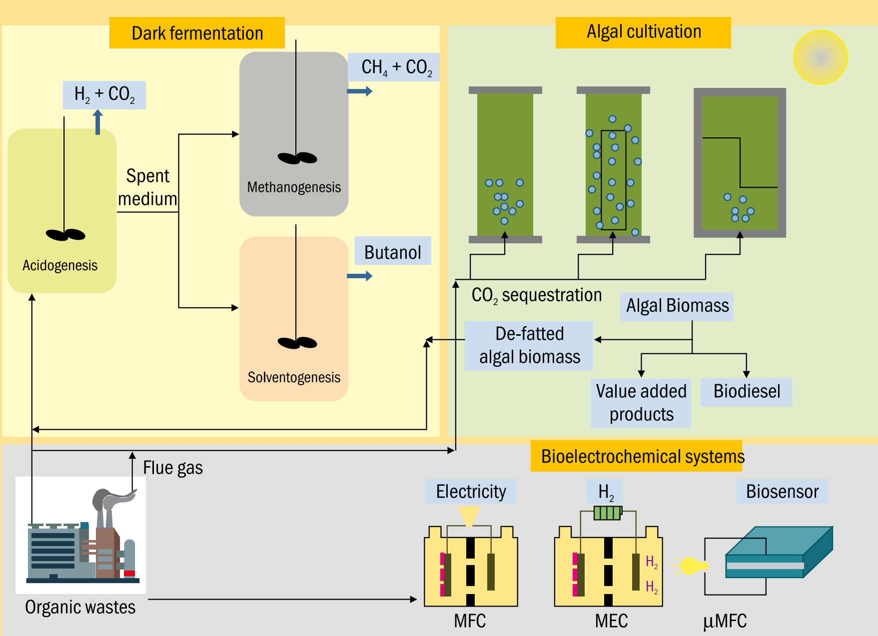

Figure 1: Schematic diagram of research activities at IIT-Kharagpur in biofuel research

A substantial research has been carried out on the development of continuous hydrogen production process especially in customized bioreactors. IIT-Kharagpur has successfully designed and commissioned pilot plant for biohydrogen production using an 800 L reactor. a prototype 20 L packed bed reactor has also been developed for continuous hydrogen production. Such type of packed bed reactor uses cheaper environment-friendly lignocellulosic biomass as a matrix for whole cell immobilization. Our endeavour with large-scale biohydrogen production has motivated us to commercialize biohydrogen production process for decentralized energy solution.

for biomethanation and biobutanol production for maximum energy recovery. Integration of biohydrogen production with biomethanation (BIOHYMET) makes the process overall more economical and sustainable. BIOHYMET production by such integrated process permits an increase in conversion efficiency of biomass to gaseous energy. An integrated two-stage anaerobic microbial dark fermentation process was also developed to produce biohydrogen gas (H_2) and butanol using obligate anaerobe *Clostridium acetobutylicum* MTCC 11274. The strain is known to produce hydrogen along with volatile fatty acids in acidogenesis phase and butanol in solventogenesis phase using accumulated volatile fatty acid. A substantial research has been carried out on the development of continuous hydrogen production process especially in customized bioreactors. IIT-Kharagpur has successfully designed and commissioned pilot plant for biohydrogen production using an 800 L reactor. A prototype 20 L packed bed reactor has also been developed for continuous hydrogen production. Such type of packed bed reactor uses cheaper environment-friendly lignocellulosic biomass as a matrix for whole cell immobilization. Our endeavour with large-scale biohydrogen production has motivated us to commercialize biohydrogen production process for decentralized energy solution. Intensive research work on improvement of hydrogen production using different organic wastes/residues and scale up of the process up to 10 m^3 is in progress for the commercial exploitation of the production process (Figure 1).

Picture 1: 10 m^3 capacity of pilot plant facility under construction for biohydrogen production from different organic wastes in IIT-Kharagpur

Another area of research in the laboratory on microalgal biotechnology focusses on the algal biorefinery concept. The efforts are concentrated on high rate algal biomass generation in controlled photobioreactors with subsequent use of the obtained biomass as a source of food, feed, biofuels and bioactive compounds. In the continuous mode of operation with *Chlorella sorokiniana*, the maximum biomass productivity of 0.11 g L^{-1} h^{-1} was observed at an optimum dilution rate of 0.05 h^{-1} when 5 per cent air–CO_2 (v/v) gas mixture was used. Biological fixation of CO_2 was also studied using industrial flue gas. The flue gas emitted from the oil producing industry contains mostly CO_2 and H_2S (15.6 per cent v/v and 120 mg L^{-1}, respectively) along with nitrogen, methane, and other hydrocarbons. The highest reduction in the CO_2 content of inlet flue gas was 4.1 per cent (v/v). *Cyanobacteria* were also used for CO_2 sequestration study. *Anabaena* sp. PCC 7120 was grown in customized airlift photobioreactors. Higher light utilization efficiency and a higher rate of CO_2 biofixation were observed with maximum biomass concentration of 0.71 g L^{-1} using BG11 medium under aerated conditions. Another new approach for CO_2 sequestration was microbial carbon capture cells (MCCs). *Cyanobacteria* were grown in photobiocathode in dual-chambered flat plate mediator-less MFCs separated by an anion exchange membrane.

The performance of the MCC with *Anabaena* purged with CO_2–air mixture was compared with that of a conventional cathode purged with air only. A maximum power density of 57.8 mW/m^2 was observed when 5 per cent (v/v) CO_2-air mixture was used. Algal biomass was also used as substrate in biohydrogen production. Acid-heat pretreated *Chlorella sorokiniana* biomass gave maximum hydrogen production of 2.68 mol mol^{-1} of hexose under thermophilic dark fermentation. Algal biomass from two-stage cultivation was used for biodiesel production. Under mixotrophic growth, maximum lipid content obtained was 58±0.34 per cent w/w of DCW. Phycocyanin and related phycobilin proteins were found to have antioxidant, anti-inflammatory, anti-viral, anti-cancer, cholesterol lowering effects, neuroprotective and hepatoprotective properties and are present in *Cyanobacteria*. An effort was made to extract these value-added products that have an industrial application from *Nostoc* sp. Under green light regime and suitable nitrate concentration, the maximum yield of phycobilin protein (0.132 mg/mg of dry cell mass) was observed.

In recent years, microbial fuel cell (MFC)-based technologies have turned out to be promising technologies for direct energy production from various wastewaters. However, numerous hurdles need to be overcome to make this technology economically feasible and suitable for field applications. In this regard, IIT-Kharagpur has focussed on improving the performance, reducing the construction cost, and expanding the application scopes of MFC-based technologies collectively known as bioelectrochemical systems. Low-cost materials for the anode, cathode, and membrane in MFCs were studied to increase the power performance using complex wastewaters as substrate. Catalytic enhancement with $MnCO_2O_4$ in the presence of polypyrrole (PPy) on carbon cloth cathode showed maximum potential reaching power densities of 10.2 W m^{-3} using low-cost KOH doped PVA-PDDA anion exchange membrane. The IIT-Kharagpur team has also exploited MFCs as a secondary stage treatment process by linking it with dark fermentation processes for enhanced energy recovery. Their experimental results indicated overall energy recovery of 33 per cent. Feasibility of power generation and hydrogen production in a microbial electrolysis cell was also studied using wastes like sewage sludge. The maximum hydrogen yield of 4.5 mmol H_2 g^{-1} $COD_{reduced}$ was achieved at 1.0 V. Using MFCs as portable power sources will need development of cost-effective, self-sustainable, small sized MFCs with lower start-up times, which can generate sustained power for longer periods of time. Although micro-sized MFCs are already developed, the requirement of syringe pumps or other flow distribution systems makes it unpractical to be used in remote locations to power devices. Hence, a paper based air-breathing microbial fuel cell was developed using *Shewanella putrefaciens* as biocatalyst which has an instant start-up. The developed device could generate a maximum power of 3.5 μW indicating the potential of the device as a power source in remote locations. IIT-Kharagpur also developed microbial carbon capture cells (MCCs) with *Cyanobacteria* as photobiocathode and achieved power densities 100.1 mW m^{-2} thereby providing simultaneous power generation, carbon dioxide sequestration, and wastewater treatment. Currently, the group is focussing on scale-up studies broadening the outlook of this technology.

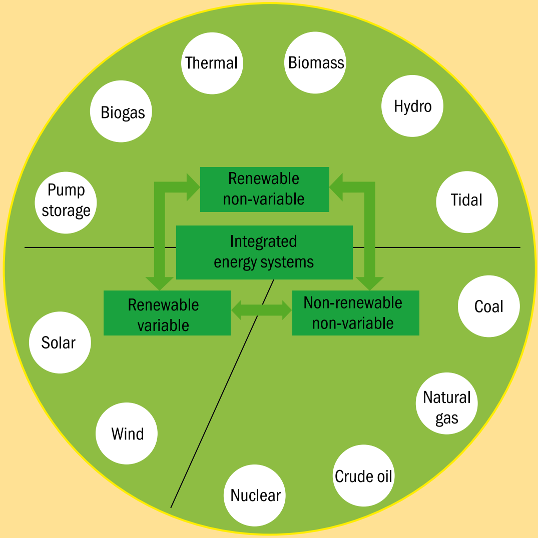

Figure 2: Integration of various forms of energy systems

Integrated Energy Systems: The Way Ahead

Energy generation and pollutants emission scenarios can play a vital role for understanding many issues directly or indirectly related to energy supply and demand, as well as environmental issues such as climate change. In the face of resource scarcity and climate change, the world energy system is going to encounter a major transformation. The world is going to have a very distinct energy system in future from the one that exists currently. It is necessary to develop a new energy system that is exclusively based on the extended use of renewable energies in order to reduce or balance CO_2 emissions to a great extent. Today, one of the greatest challenges with humanity is finding a way to access safe, clean and sustainable energy. Around the world, researchers, policymakers and investors have been struggling for answering to the questions on the future energy system. It is very important to identify the energy reserves based on their availability and sustainability that can lead to develop a sustainable energy generation process. The primary goal is to integrate the various form of renewable energy (Figure 2) in order to achieve the maximum extraction of energy and supplies. We hope that all of us working together are able to achieve this goal for the future generations of the world. AU

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