Report - Jawahar Bhawan- Chemical PS

Hydrogen production through photo-bioreactor systems offers a promising pathway for sustainable energy generation, utilizing phototrophic microorganisms to convert wastewater into green hydrogen. Our pipeline aims to design and optimize such a system targeting a production capacity of 0.5-1 kg/day of green hydrogen. Key parameters including reactor volume, residence time, light intensity, and nutrient supply are meticulously examined to maximize hydrogen yield while ensuring economic viability and environmental sustainability.

We propose a pipeline with extensive investigation of wastewater composition, encompassing organic carbon content, nitrogen and phosphorus concentrations, pH, and potential inhibitors, is conducted to assess their impact on hydrogen production efficiency. Optimal reactor volume is determined considering biomass growth rate and light penetration depth.

Light intensity optimization within the reactor is pursued to balance photosynthetic activity with energy consumption. Furthermore, a robust nutrient delivery system is designed to maintain optimal growth conditions for hydrogen-producing microorganisms, accounting for nutrient uptake rates and stoichiometric requirements. The study determines the optimal residence time within the reactor to maximize hydrogen production while minimizing substrate utilization and biomass accumulation.

Various reactor configurations, including tubular, flat-panel, or column, are evaluated based on factors such as light distribution, mixing efficiency, and scalability. Process monitoring and control systems are proposed, integrating sensors and control mechanisms to ensure consistent and reliable hydrogen production.

Economic feasibility is assessed through comprehensive cost analysis, considering capital investment, operating costs, and potential revenue streams from hydrogen sales or carbon credits. By synthesizing these elements, this research aims to contribute to the advancement of photo-bioreactor systems for efficient green hydrogen production, addressing both technical and economic challenges toward a sustainable energy future.

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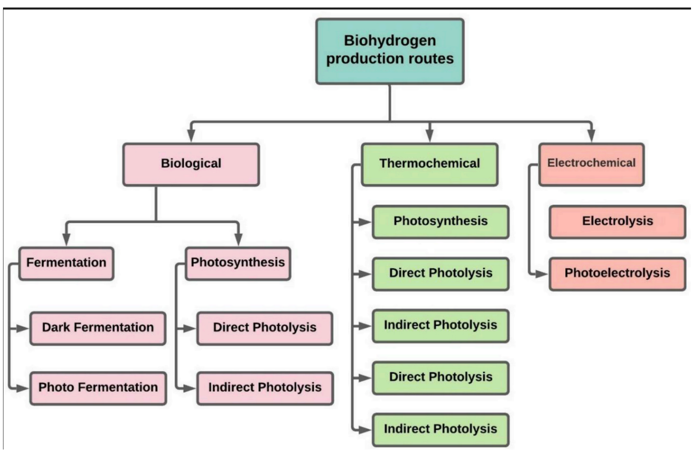
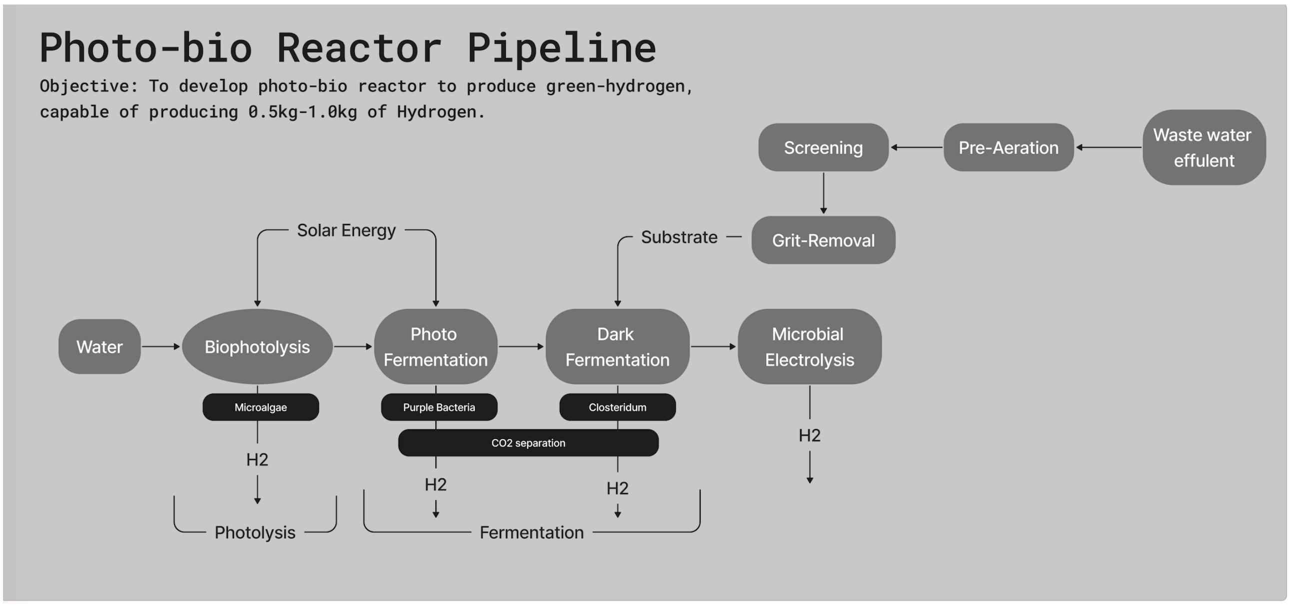




Waste Water Treatment (Pre-Treatment)

Pre-treatment Steps used in our pipeline to treat the wastewater:

1. **Pre-Aeration:**
   - **Purpose**: The first step in pre-treatment is pre-aeration, where raw sewage undergoes aeration to keep solid contaminants in suspension. This is achieved using air diffusers.
   - Aeration helps in the oxidation of organic matter and enhances the removal of volatile compounds, improving the efficiency of subsequent treatment processes.
2. **Screening:**
   - **Purpose:** Screening is employed to remove solid particles larger than 3 mm from the wastewater.
   - Screens with appropriate mesh sizes are utilised to capture large debris, such as rags, plastics, and other solids, preventing them from entering the MBR system and causing clogging or damage.
3. **Grit Removal:**
   - **Purpose:** Grit removal aims to eliminate heavier particles like sand, gravel, and grit, as well as fats and grease.
   - Various mechanisms, such as settling tanks or grit chambers, are employed to allow these heavier particles to settle out, preventing abrasion and damage to downstream equipment.

Need for Pre-Treatment- Pre-treatment is essential to ensure the effective operation of subsequent treatment processes and the longevity of membrane filtration units. By removing large solids, grit, and odorous compounds, pre-treatment safeguards the integrity of the membranes and enhances overall treatment performance.

Fermentation of refined waste to produce hydrogen

We proposed a two step fermentation idea, for maximum yield of green hydrogen-

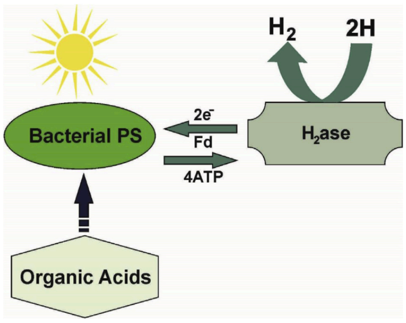
1. Photofermentation (using Purple Bacteria)

2. Dark Fermentation (using Clostridium)

Photofermentation

		minerals
Photo fermentation	$CH_3COOH+2H_2O$ + light $\rightarrow 4H_2+2CO_2$ $N_2+8H^++8e\_+16ATP \rightarrow 2NH_3+H_2+16ADP+16P_i$	It has no activity for O_2 evolution Ability to use a long light spectrum Ability to consume organic substrates derived from waste Ability to use a wide spectrum of light

Photofermentation is the fermentative transformation of organic substrate into hydrogen by Purple Bacteria. Photofermentation is represented as one of the most efficient modes without high risk for BioH2 production. The main process of microbial hydrogen production is defined by the pyruvate anaerobic metabolism and degradation of pyruvate is catalyzed by one of two enzyme systems shown in the equations:

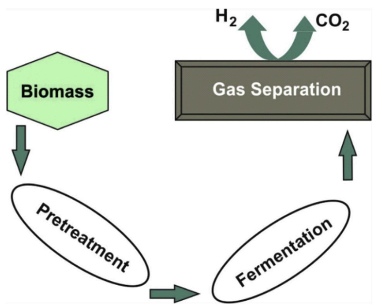


Pyruvate + CoA → acetyl – CoA + formate

Dark Fermentation

Dark fermentation	Pyruvate + CoA $\rightarrow$ acetyl-CoA + formate $C_6H_{12}O_6+6H_2O \rightarrow 12H_2+6CO_2$	Requires no illumination Does not depend on O_2 (anaerobic process) It produces by-products with organic acids having commercial value Wide variety of carbon sources as substrate

Dark fermentative green-hydrogen production provides a cost-effective and environmentally friendly process. This is an aggregate process revealed by bacterial diverse groups, implying a series of biochemical reactions using several steps similar to anaerobic transition. Dark fermentation is used primarily with anaerobic bacteria, although some algae are also used, on carbohydrate rich substrates grown without the need of light energy



Reaction involved: C6H12O6 + 6H2O → 2H2 + 6CO2

Photolysis of refined waste water to produce hydrogen

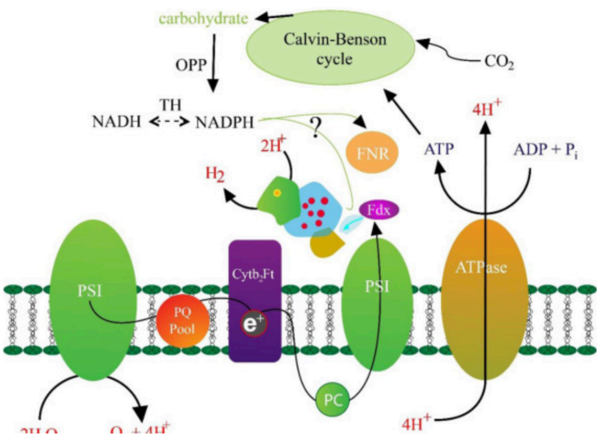
BioPhotolysis for H2 production

Direct biophotolysis	$2H_2O + Fd_{(ox)}$+light→O_2+4H + $Fd_{(red)}$ (4e^-); $4H^+$+$Fd_{(red)}$ (4$e^{-)}$→$2H_2$+$Fd_{(ox)}$	High theoretical efficiency There is no requirement of adding the substrate nutrients Water is the substrate and solar energy is the Source of energy It is not necessary to produce ATP

Direct biophotolysis is a biological and chemical process resembling photosynthesis, involving microalgae to produce molecular hydrogen directly from water using solar energy.

The reaction is: 2H2O + solar energy → 2H2 + O2

Microalgae such as Microalgae are used ion this process. During this process, photosystem II (PSII) splits water molecules, and the electrons are transferred to ferredoxin (Fd) using solar energy. It's crucial to maintain low oxygen levels to sustain hydrogen production, as hydrogenase enzyme is oxygen-sensitive.



Calculation of design parameters for the reactor

Sample Calculation

Surface area for algal growth = $2*2 = 4m^2$

hydraulic residence time (HRT) (θ):

$$V = \frac{Q \times t}{\text{Hydrogen production rate}}$$

using $Q = 0.0075\ m^3/h$ & hydrogen production rate to be = 0.5 kg/day

$$V = \frac{0.075\ m^3/h \times 24}{0.5} = 11.4\ m^3$$

New hydraulic residence time(θ) = $\frac{V}{Q}$

$$\theta = \frac{11.4}{0.075} \simeq 152 \text{ hours}$$

light attenuation & Intensity

$$I(0.1) = I_0 \times e^{-\alpha \times z}$$

& Biomass growth

$$\mu = \mu_{max} \times \frac{S}{K_s + S}$$

$$\mu = 0.2 \times \frac{3}{0.5+3} \approx 0.0286\ h^{-1}$$

$$J = -D \times \frac{\partial C}{\partial z}$$

$$J = -(2 \times 10^{-6}) \times (0.1 g/m^3 \times 0.1) = -2 \times 10^{-7}\ g/m^2 s$$

Factors affecting efficiency (Hyperparameters)

1. Microalgae species - For the microalgae to be able to synthesize hydrogen, it is critical that the required environmental conditions are met so as to induce the specific metabolic pathways in the species. Also, a newly screened biohydrogen production by green microalga, i.e., Chlorella sp. was researched with its new strain showing higher biohydrogen

2. Light intensity: Bio-photolysis, as is, can be considered similar to that of photosynthesis with the presence and amount of light during the hydrogen production process having a major effect

The microalgae undergo photosynthesis in the presence of light (first stage) and amass starch and lipids. As for the dark stage (second stage), the initial high-intensity light/sunlight exposure to cells establishes an anaerobic condition because it damages the PSII, thus inhibiting PSI. The condition further assists the hydrogenase enzyme to maximize activity sooner by increasing the sulphur and oxygen consumption rate of the culture and degrading the stored starch and proteins

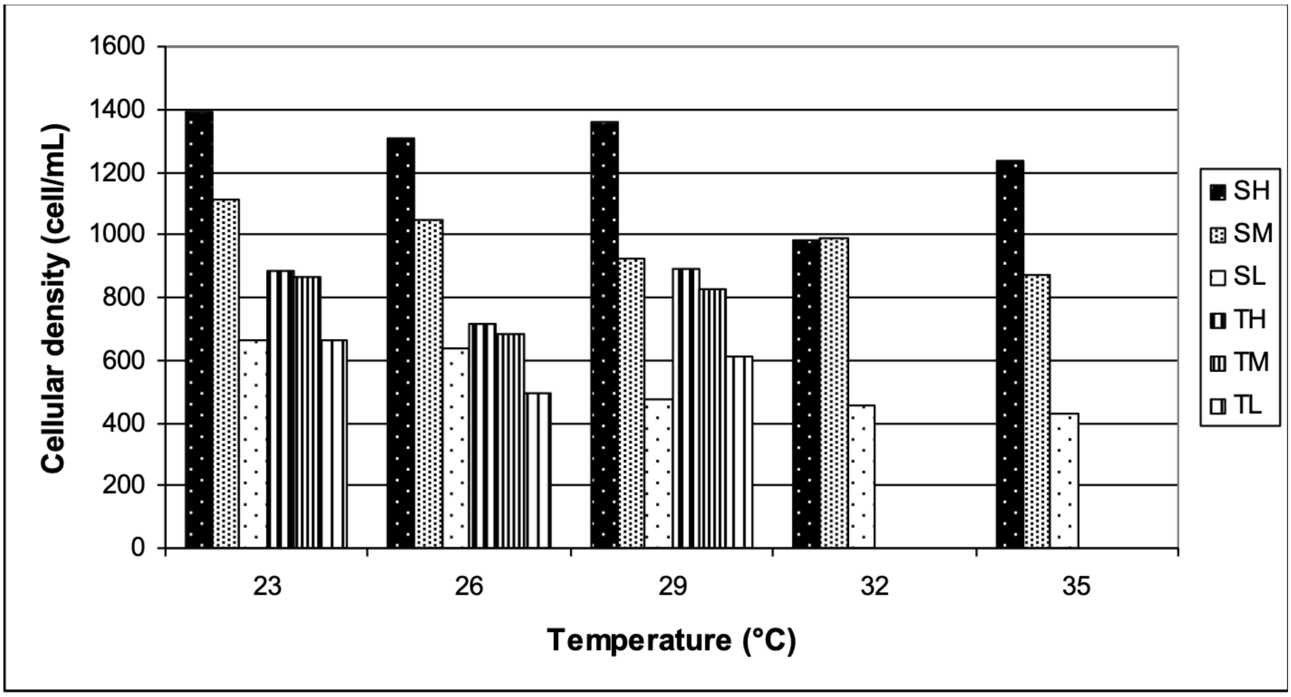
In short, the generation of H2 can be maximized depending on the amount of exposure to light during the anaerobic phase.

3. Cellular density

Cell density affects the culture of microalgae and its capacity for hydrogen production as it controls the amount of light that passes through the cell

The nature of the cultivation process determines the cell density which in turn affects the H2 productivity of microalgae.

It is extremely important to maintain cell density as the respiration in a culture with low cell concentration would not allow the uptake of the dissolved oxygen into the culture.



4. Subtracts (nutrient intake)

In a culture, additive subtracts such as biotin, cyanocobalamin, and thiamine need to be supplemented to support maximum cell growth and hydrogen production by the microalgae As the culture requires a balance of carbohydrate-based substrate, organic nitrogen and phosphate, which are required for optimal hydrogen production, are vital. Additionally, a carbon source is important for the microalgae to flourish, unless the cultured algae are under photoautotrophic conditions

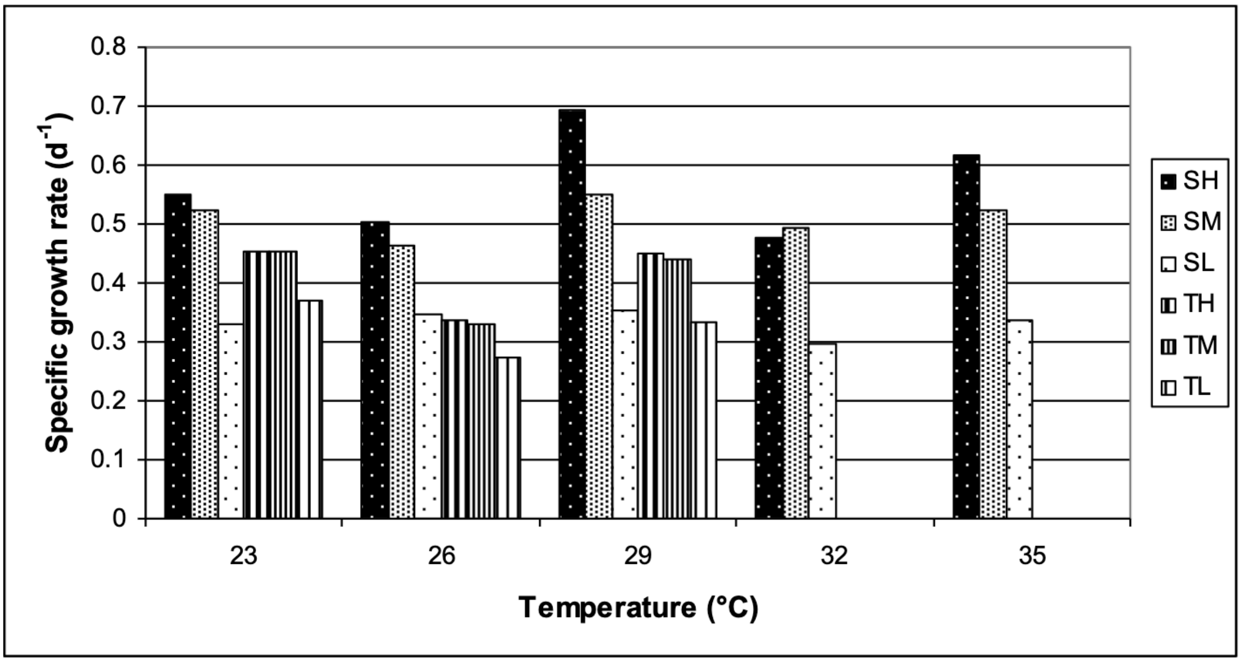
5. pH

pH is an important physical factor that influences the metabolic pathways and thereby the H2 production by a microalgae

Maximum appropriate pH values depend on the microalgae species in use. however, the functional and appropriate pH level is around 5.2 and 6.0.

6. Temperature

The optimum temperature at which sustainable growth of the microalgae influencing the optimal hydrogen production is around 15–85 °C in a mixed culture



7. Oxygen sensitivity

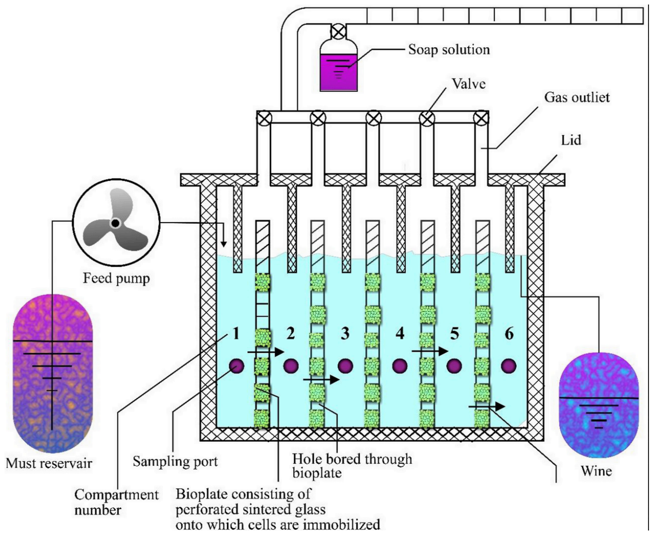
Oxygen sensitivity is regarded as the most common and most problematic challenge for many bio-hydrogen production technologies. Oxygen molecules are highly sensitive towards hydrogenase, causing inhibition of the functions of the hydrogenase enzyme.

This occurs due to the oxygen's binding potential to the active site of the hydrogenase. Such bonds are totally irreversible making it even more difficult to extract hydrogen and oxygen molecules from this complex compound

Usually very low levels of hydrogen production are noticed at around 15% atmospheric oxygen level.

Multi-stage bioreactors (MSR)

Scientists have favored multi-stage bioreactors over single-stage photobioreactors due to their capability for large-scale biohydrogen production. Multistage bioreactors utilize a combined setup with different reactions occurring in consecutive stages. This setup enhances overall production yield. Typically consisting of three to four stages, these bioreactors maximize production. In the first stage, blue-green algae utilize visible light, while unfiltered infrared light is harnessed in the second stage by photosynthetic microbes in the photo-fermentative reactor. The third stage, in a dark fermentative reactor, yields hydrogen and organic acids. Finally, the fourth stage, controlled by MEC, ensures continuous organic acid production, independent of light, operating 24/7.



Cost-economics

Cost Category	Amount (Rupees)
Capital Costs	
Reactor vessel	4,72,000
Photobioreactor Panels	1,30,000
Lighting System	1,00,000
Temperature Control Equipment	1,50,000
Infrastructure and Site Prep	3,00,000
Installation and Commissioning	4,00,000
Pumps, piping, monitoring	21,000
Fire Pump	90,000
Total Initial Investment	**16,63,000**
Operational Costs	
Electricity (per year)	2,79,225
Maintenance	3,20,000
Feedstock (per year)	3,80,000
Total Operational Costs/yr	**9,79,225**
Hydrogen Sales Revenue/yr	**13,41,375**
ROI	**21.73%**

1. **Total Initial Investment (Capital Costs)**:
   - Sum of all individual capital costs: Reactor vessel, Photobioreactor Panels, Lighting System, Temperature Control Equipment, Infrastructure and Site Preparation, Installation and Commissioning, Pumps, piping, and monitoring equipment, and Fire Pump.
2. **Total Operational Costs per Year**:
   - Electricity: Electricity cost per year = Electricity cost per unit × Total electricity consumption per year

     Electricity cost per year=Electricity cost per unit × Total electricity consumption per year
   - Maintenance: Total routine maintenance cost + Total labor costs + Total spare parts and supplies cost
   - Feedstock: Total cost of wastewater acquisition, pretreatment, transportation, and storage and handling.
3. **Hydrogen Sales Revenue per Year**:
   - Total revenue in 1 year = Selling price of hydrogen per kg * Total production of hydrogen per year.
4. **Return on Investment (ROI)**:
   - ROI = (Annual Revenue−Total Annual Operational Cost / Total Capital Cost)×100