CO_2 Capturing System Utilizing Photobioreactor

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INTRODUCTION

Background

Historical fluctuations in Earth's atmospheric CO_2 levels have been drastically altered since the Industrial Revolution, with current levels exceeding 415 ppm. This unprecedented rise has resulted in significant global warming, extreme weather events, rising sea levels, loss of biodiversity, and ocean acidification, necessitating urgent action.

Problem Statment

Industries contribute significantly to global CO_2 emissions. Our project aims to reduce these emissions through a sustainable and efficient CO_2 capturing system, utilizing algae and solar power, offering an environmentally friendly alternative to traditional methods.

Key Constraints

- Environmental Control: Precise regulation of temperature and pH for optimal algae growth.
- Budget Adherence: Efficient use of resources within set financial limits.
- Durability: Selection of long-lasting materials to ensure system resilience.
- Safety and Public Health: Strict safety protocols to safeguard public health and ensure secure CO_2 containment.

Target Specifications

- Safety compliance for worker and environmental protection
- 95%+ system uptime for reliability
- Scalable for all industrial sizes
- Smooth integration with ongoing operations
- Size-adaptable for various sites
- Solar panels for sustainable energy
- 4%-7% CO_2 concentration for efficient carbon capture

Customers Identification

Industrial Companies seeking innovative operation solutions, and Government Entities focused on sustainability and CO2 level management.

DESIGN

System Design

The final design features algae-filled cylindrical vessels for efficient CO_2 absorption, powered sustainably by integrated solar panels. Advanced sensors maintain optimal conditions for algae growth. Its modular, scalable design allows for easy adaptation across various industrial settings, ensuring seamless integration and cost-effectiveness.

Photobioreactor Process

Microalgae harness sunlight and carbon emissions to perform photosynthesis, converting them into glucose and oxygen. This process is encapsulated in the equation.

$$6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

The system uniquely uses carbon emissions as the carbon source for the algae. As algae absorb CO_2, they grow and produce biomass, which can potentially be converted into biofuel.

Optimizing Quantity and Selection of System Vessels

The objective of this model is to determine the most cost-effective and efficient vessels.

Sets:

$$I = number\ of\ product\ models \in \{1,2,3,4\}$$

Decision Variable:

$$y_i = 1\ if\ the\ product\ model\ i \in I\ is\ selected, 0\ otherwise.$$

$$x_i = \text{Number of units of}\ of\ product\ model\ i \in I.$$

Parameters:

$$v_i = Volume\ of\ one\ unit\ of\ product\ model\ i \in I.$$

$$w_i = Weight\ of\ one\ unit\ of\ product\ model\ i \in I.$$

$$c_i = Cost\ of\ one\ unit\ of\ product\ model\ i \in I.$$

$$W_{max} = Max\ weight = 2000\ Grams$$

$$C_{max} = Max\ cost = 100\$$$

$$V_{min} = Min\ volume = 1200$$

$$M = 100$$

$$\alpha = 0.65$$

$$\beta = 0.12$$

$$\gamma = 0.23$$

Objective Function:

$$Max\ z = \alpha \sum_i (v_i * x_i) - \beta \sum_i (w_i * x_i) - \gamma \sum_i (c_i * x_i)$$

Constraints:

$$\sum_i w_i x_i \le W_{max}$$

$$\sum_i c_i x_i \le C_{max}$$

$$\sum_i v_i x_i \ge V_{min}$$

$$\sum_i x_i \le M y_i$$

$$\sum_i y_i = 1$$

$$x_i \in \mathbb{Z}^+$$

$$y_i \in \{1,0\}$$

Algae Cultivation for Optimal CO_2 Capture

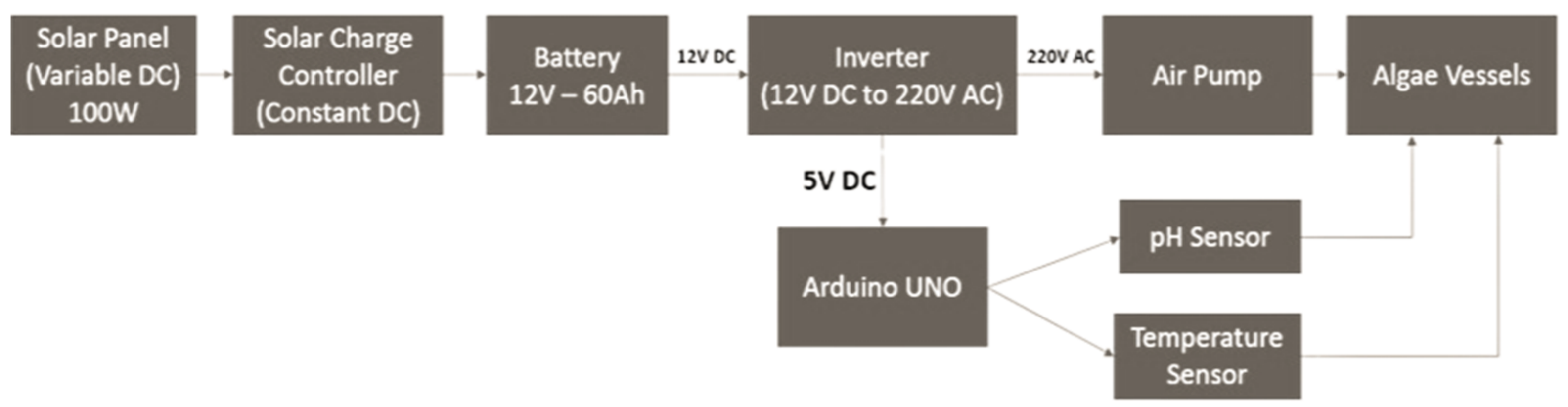
- Species Selection: Chlorella vulgaris, known for its high CO_2 absorption efficiency.
- Growth Environment: Precisely controlled conditions — temperature (20-30°C) and pH (6.5-7.5).
- Medium Composition: Balanced mix of nitrates, phosphates, trace metals, vitamins.
- CO_2 Fixation Measurement: Calculating conversion rates of CO_2 to organic matter to assess system efficiency.
- Growth Rate Monitoring: Utilizing spectrophotometry for accurate measurement of algae growth rates, enabling precise environmental tuning for enhanced CO_2 uptake.

$$CO_2\ Fixation\ Rate = C_{carbon} P \left(\frac{M_{CO_2}}{M_{carbon}} \right)$$

$$\text{Algae Growth Rate}\ \mu = \frac{\ln(\frac{C_2}{C_1})}{t_2 - t_2}$$

Power Management and Sensing

The block diagram shown below demonstrates the electric components and how they are interconnected.



- Solar Power Regulation: A solar charge controller stabilizes the panel's fluctuating DC voltage and protects the battery from overcharging.
- Nighttime Energy Supply: A high-capacity battery provides over 13 hours of operation, ensuring 95% system uptime.
- Power Conversion: An inverter converts DC to AC for the air pump and powers the Arduino UNO, used for sensor programming.
- Energy Efficiency: The system's total power demand is 55.2W, comfortably met by our 100W solar panel.
- Environmental Monitoring: Temperature and pH sensors, crucial for algae growth, are continuously monitored for optimal conditions.

Optimizing System Maintenance

The table presents three tailored maintenance schedules for CO_2 capture systems, categorized by capture rates of 4-6, 6-8, and 8-10 L per day, detailing specific checks and condition-based triggers.

CO_2 Capture Rate	4-6 L per day	6-8 L per day	8-10 L per day
Daily Checks	- Monitor solar panel efficiency; clean if necessary. - Check air pump energy consumption for anomalies.	- Monitor solar panel efficiency; clean if necessary. - Check air pump energy consumption for anomalies.	- Monitor solar panel efficiency; clean if necessary. - Check air pump energy consumption for anomalies.
Weekly Checks	- Measure and record CO_2 capture rate. - Visual inspection of algae health. - Investigate and address drops in CO_2 capture rate or algae health.	- Measure and record CO_2 capture rate. - Visual inspection of algae health. - Investigate and address drops in CO_2 capture rate or algae health.	- Measure and record CO_2 capture rate. - Visual inspection of algae health. - Investigate and address drops in CO_2 capture rate or algae health.
Monthly Checks	- Inspect vessels for damage. - Measure and record vessel volumes. - Initiate maintenance for substantial volume changes or vessel degradation.	- Inspect vessels for damage. - Measure and record vessel volumes. - Initiate maintenance for substantial volume changes or vessel degradation.	- Inspect vessels for damage. - Measure and record vessel volumes. - Initiate maintenance for substantial volume changes or vessel degradation.
Condition-Based Maintenance	- If CO_2 capture rate falls below 4 L per day, initiate maintenance If any vessel volume is above 5.1 L	- If CO_2 capture rate falls below 6 L per day, initiate maintenance If any vessel volume is above 4.9 L	- If CO_2 capture rate falls below 8 L per day, initiate maintenance If any vessel volume is above 4.7 L

To optimize maintenance and monitoring of dispersed CO2 capturing systems, The model below finds the shortest route for maintaining and monitoring scattered CO2 capture devices, reducing travel and resources for technicians.

Sets:

$$\text{n} = \text{number of nodes where each node represents a location} \in \{1,..,..,\text{n}\}$$

Decision Variable:

$$x_{ij} = 1\ if\ a\ path\ from\ node\ i\ to\ node\ j\ is\ selected, 0\ otherwise. i,j \in \{1, \dots, n\}$$

Parameters:

$$d_{ij} = the\ distance\ from\ node\ i\ to\ node\ j. i,j \in \{1, \dots, n\}$$

$$u_i = the\ number\ of\ nodes\ visited\ before\ reaching\ node\ i. i \in \{1, \dots, n\}$$

Objective Function:

$$\min z = \sum_{i \in n} \sum_{j \in n} d_{ij} x_{ij}$$

Constraints:

$$\sum_{j \in n} x_{ij} = 1\ \forall i \in n$$

$$\sum_{i \in n} x_{ij} = 1\ \forall j \in n$$

$$u_i + 1 \le u_j + (n-1)(1 - x_{ij})\ \forall i,j = 2, \dots, n,\ i \ne j$$

$$x_{ij} \in \{1,0\}$$

$$u_i \in \mathbb{Z}^+$$

CONCLUSION

This project represents a significant advancement in reducing industrial CO_2 emissions. By incorporating solar energy, we aim to contribute meaningfully to the global effort against climate change. Our commitment is to provide a solution that aligns with the urgent need for environmental preservation and a reduction in CO_2 emissions.