Design of an Off-Grid Solar-Driven System for Dual-Layer Carbon Capture System Integrating Algae and Seashell

BY

MS. APATCHA SATANYORHIN 63011102

**A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF BACHELOR OF
ENGINEERING IN ENERGY
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
ACADEMIC YEAR 2023**

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

FACULTY OF ENGINEERING
KING MONGKUT’S INSTITUTE OF TECHNOLOGY LADKRABANG
PROJECT CERTIFICATE

Project Title	DESIGN OF AN OFF-GRID SOLAR-DRIVEN SYSTEM FOR DUAL-LAYER CARBON CAPTURE SYSTEM INTEGRATING ALGAE AND SEASHELL
Student Name	Miss Apatcha Satanyothin Student ID. 63011102
Degree	Bachelor of Engineering in energy
Major	Energy Engineering
Project Advisor	Signed: Methawee N. (Methawee Nukunudompanich)

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Project Title	DESIGN OF AN OFF-GRID SOLAR-DRIVEN SYSTEM FOR DUAL-LAYER CARBON CAPTURE SYSTEM INTEGRATING ALGAE AND SEASHELL
Student Name	MISS APATCHA SATANYOTHIN
Degree	Bachelor of Engineering
Major	Energy Engineering
Project Advisor	Dr. Methawee Nukunudompanich, D. Eng
Academic Years	2023

ABSTRACT

The study of the efficiency of CO_2 reduction and PV power generation of the dual-layer carbon capture integrating off-grid solar-driven system for 12 days by culture algae with a volume of 6.0 L of dechlorinated water with nutrient 1.0 g L $^{-1}$ NaCl, air was bubbled into the bottom of the tank with air pump 14 L/min, the ratio of natural light to 6 watts of LED blue lights is 12:12. Combined with layer of 600.5 g of crushed seashell with water to enhance the absorption of carbon dioxide in a working volume of 6.0 L. The study revealed the average CO_2 reduction efficiency of the dual-layer carbon capture system was 54.6%, with the highest efficiency recorded on day 7 at 69.1%, and the lowest on day 12 at 34.6%. The dissolution of calcium carbonate in the shell tank helped buffer CO_2 levels. Additionally, the off-grid solar system provided sufficient power to sustain the experiment throughout the 12 days. The produced power at 10.00 was fluctuated contrasting with at 17.00 that behaved in the stable range. The pH values of both the algae and seashell tanks exhibited notable trends, with the algae tank showing a decrease initially before stabilizing, while the shell tank maintained an alkaline pH attributed to shell dissolution. Observation of the tanks revealed significant algae growth and cleaner water in the shell tank.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

ACKNOWLEDGEMENTS

The thesis of "Design of an Off-Grid Solar-Driven System for Dual-Layer Carbon Capture System Integrating Algae and Seashell" has been successfully completed. I wish to extend my sincere gratitude to all individuals who contributed to this achievement through their assistance, guidance, and support.

I am particularly grateful to Dr. Methawee Nukuludomphannich, Lectuer in the Department of Industrial Engineering, for serving as my thesis advisor. Her invaluable guidance and encouragement were instrumental in overcoming various challenges encountered during the research process.

Also, would like to express my appreciation to Miss. Neeraphat Kunbuala for her expertise, advice, and support, which greatly contributed to the successful completion of this thesis.

Special thanks are due to Mr. Sittichai Boonkit for his assistance in the practical construction of the project's structure and his unwavering support throughout the thesis.

Lastly, I extend heartfelt thanks to my parents and all other supporters for their constant encouragement and assistance in various aspects, which ultimately led to the accomplishment of this thesis. It is my sincere hope that this research will prove beneficial to the field of biological carbon capture and solar cell installation design, as well as to those with an interest in these areas.

Miss. Apatcha Satanyothin

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

TABLE OF CONTENTS

Page

ABSTRACT (i)

ACKNOWLEDGEMENTS (ii)

LIST OF TABLES (iii)

LIST OF FIGURES (ix)

LIST OF SYMBOLS/ABBREVIATIONS (x)

CHAPTER 1 INTRODUCTION

1.1 Background and importance 1

1.2 Objectives of study 4

1.3 Scope 4

1.4 Expected benefits 5

1.5 Research schedule 5

CHAPTER 2 LITERATURE REVIEW 7

2.1 Energy consumption and CO_2 7

2.2 Carbon capture 8

2.2.1 Physical carbon capture method 8

2.2.2 Biological carbon capture method 9

2.3 Microalgae 11

2.4 Mussel shell waste 12

2.5 Shell dissolution 13

2.6 Dry weight and wet weight measurement 15

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

2.7 On-grid and Off-grid solar system 16
2.8 Power performance of solar system 17
2.9 Efficiency of CO_2 reduction 18
2.10 Related research 18

CHAPTER 3 METHODOLOGY 20
3.1 Material 20
3.2 Structural construction 21
3.3 Algae system preparation 22
3.4 Mussel shell system preparation 23
3.5 Water dechlorinating 24
3.6 Off-grid solar-driven system 26
    3.6.1 Load calculation for total energy 25
    3.6.2 PV module sizing 25
    3.6.3 Solar charge controller sizing 26
    3.6.4 Battery sizing 26
    3.6.5 Inverter sizing 27
    3.6.6 Solar system set up 27
3.7 System operation and experiment 28

CHAPTER 4 EXPERIMENTAL RESULT 31
4.1 Data collection results 31
4.2 Algae characterization 34
    4.2.1 Laser microscope analysis 34
    4.2.2 Dry weigh measurement 35
4.3 Shell characterization 36
4.4 The efficiency of CO_2 reduction 36
4.5 The Power performance in off-grid solar system 38
4.6 The pH value of algae and seashell tank 38
4.7 Algae tank and shell tank observation 40
    4.7.1 Algae tank observation 40

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

4.7.2 Shell tank observation 41

CHAPTER 5 CONCLUSION 42

5.1 Summary of experimental results 42

5.2 Suggestion 43

REFERENCES 44

APPENDICES

APPENDIX A 48

APPENDIX B 49

APPENDIX B 50

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

LIST OF TABLES

Tables Page

1.1 The research schedule 5

2.1 Comparative description of different physical carbon capture technologies 9

2.2 Overview of the mechanisms and limitations of biological carbon capture 10

2.3 Configurations of the seven UVic model versions 13

3.1. Electrical appliances and their daily use 25

4.1 Raw collected data for 12-day experiment at 10.00, 17.00 and 22.00 32

4.2 Dry weight and wet weight of 3 samples 35

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

LIST OF FIGURES

Figures Page
1.1 Global emissions from fossil fuels 1
2.1 Simulated time series 14
2.2 Off-grid and on-grid solar system 17
3.1. Drawing of structural system 21
3.2. Drawing of bottom and middle aluminum plates 21
3.3(a). System Drawing 22
3.3(b). Off-Grid solar energy system structure 22
3.4. Flow chart showing the process of algae preparation 23
3.5. Flow chart showing the process of mussel shells preparation 23
3.6. Diagram of off-grid solar power system connecting with loads 28
3.7 Diagram of algae cultivation tank and shell tank operation 29
4.1 The characterization of sample algae compared with some of the algal species 34
4.2 Photo of algae before and after drying 35
4.3 XRD result of mussel shell powder 36
4.4 The CO_2 reduction efficiency of the two-layer carbon capture system 37
4.5 Power produced from an off-grid solar cell system at 10:00 and 17.00 38
4.6 The pH of the algae and shell tank for 12 days 39
4.7 Pictures of algae cultivation in a algae tank over 12 days 40
4.8 Pictures of shells dissolving in a shell tank over 12 days 41

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	**Terms**
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
EPA	The US Environmental Protection Agency
NEPA	The Energy Policy and Planning Office
PV	Photo voltaic
MOFs	Metal-organic frameworks
ALK	Alkalinity
SAT	Surface air temperature
OAE	Ocean alkalinity enhancement
NaCl	Sodium chloride
DCW	Dry cell weight
XRD	X-ray diffraction
DC	Direct current
AC	Alternating current
CO_2	Carbon dioxide
$CaCO_3$	Calcium carbonate
Ca_2^+	Calcium ions
HCO_3^-	Bicarbonate ions
H^+	Hydrogen ion

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

CHAPTER 1

INTRODUCTION

This chapter will discuss the background and importance, objectives, scope, expected benefits, and procedures for carrying out the design of an off-grid solar-driven system for dual-layer carbon capture system integrating algae and seashell research, as shown in the following section

1.1 Background and importance
1.2 Objectives of the study
1.3 Scope of study
1.4 Expected benefits
1.5 Operation procedures

1.1 Background and importance

Global carbon dioxide (CO_2) emissions stemming from fossil fuel sources and cement production over the years. Beginning from 1960 at 9.34 billion metric tons, emissions steadily increased to 36.44 billion metric tons by 2019. This upward trend highlights the significant environmental concern posed by escalating atmospheric carbon dioxide levels, primarily attributed to the combustion of fossil fuels.

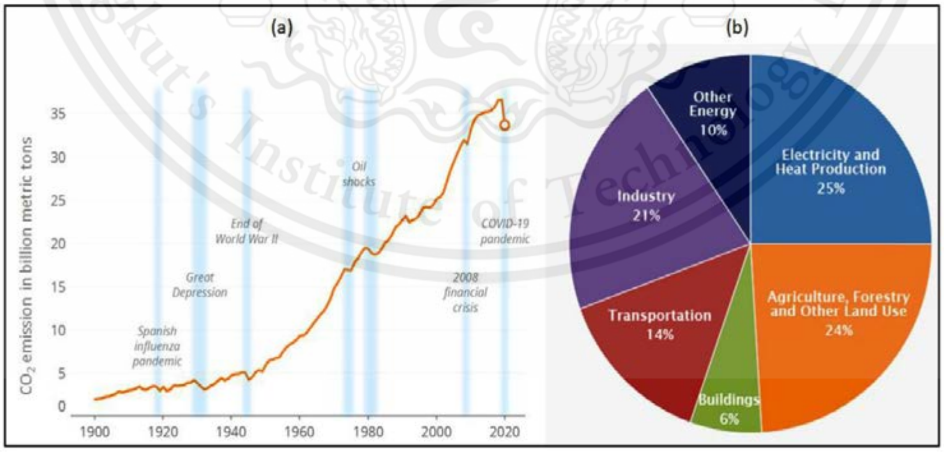


Figure 1.1 Global emissions from fossil fuels: (a) patterns in billion metric tons of CO_2 between 1990 and 2020 [1], and (b) emissions originating from various sectors of the economy [2].

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

The historical data on global CO_2 emissions reveals occasional declines associated with crises such as pandemics, economic downturns, and conflicts, as depicted by vertical blue lines in Figure 1.1a. For instance, during the 1918 Spanish flu pandemic, CO_2 emissions saw a significant 14% decrease, followed by a 15% rebound in 1920. Similarly, the COVID-19 pandemic in 2020 led to a 6.4% drop in global CO_2 emissions (equivalent to 2.3 billion tons), underscoring the temporary nature of emission reductions during crises. According to the US Environmental Protection Agency (EPA) data from 2010, the primary contributors to CO_2 emissions were electricity and heat production, agriculture, forestry, and land use, and industrial activities. Transportation sectors accounted for 14% of global carbon emissions, while emissions from buildings constituted approximately 6%, as illustrated in Figure 1.1b. The global lockdown measures implemented during the COVID-19 pandemic, particularly those restricting transportation, resulted in immediate, short-term environmental benefits, including improved air quality and reduced emissions.

For Thailand, there has been an improvement in economic conditions, leading to increased energy demand. Consequently, CO_2 emissions from energy use in the first half of 2022 rose by 6.7% compared to the same period last year [3]. The Energy Policy and Planning Office (NEPA) reported that CO_2 emissions from energy use in Thailand during this period were at 131.8 million tons, with increases observed in the transportation and industrial sectors, among others, while emissions from the electricity production sector decreased. Over the past years, there has been a consistent upward trend in CO_2 emissions from energy use in Thailand, rising from 145.5 million tons in 1998 to 263.4 million tons in 2018, averaging an annual increase of 3.0%. This trend aligns with the country's average energy consumption growth of 3.7% per year.

Efforts aimed at reducing atmospheric CO_2 levels encounter significant financial and environmental challenges when employing physical and chemical methods. However, carbon capture offers promising opportunities for economic advancement, including incentives within carbon markets, prevention of costly environmental crises linked to unchecked climate change, and the transformation of CO_2 into valuable products and renewable energy sources.

Carbon capture and sequestration technology has emerged as a significant approach with the potential to effectively address carbon emissions to the atmosphere. This technology involves capturing carbon and either storing it or utilizing it for alternative purposes. There are two main categories of carbon capture technologies that have gained attention in recent years: physical and

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

biological. Despite its promise, the physical method of carbon capture and sequestration has been found to have drawbacks, including high operational costs due to substantial energy consumption. For instance, the carbon capture unit at the Shanghai power plant in China incurred energy consumption costs amounting to approximately 40% of the total operational expenses of the power plant itself [4].

In the biological method, green plants are employed to convert carbon into energy necessary for their own survival. Initially, this process primarily involved terrestrial plants like trees. However, recent research indicates that microalgae exhibit greater potential for carbon capture and sequestration compared to terrestrial plants. Overview of the potential of microalgae for CO_2 sequestration, there is reported that microalgae are capable of capturing and sequestering carbon at rates 10 to 50 times higher than those of terrestrial plants [5]. This finding suggests that the use of microalgae for carbon capture and sequestration offers notable advantages over other technologies. Microalgae, a group of photosynthetic microorganisms including both unicellular and multicellular species have garnered increased interest in recent years. Their rapid growth rate relative to terrestrial plants makes them well-suited for carbon fixation through photosynthesis. Furthermore, as microalgae grow, they can serve as feedstock materials for the production of biofuels. This characteristic renders microalgae a sustainable biomaterial for carbon capture and sequestration, contributing minimal pollution to the environment.

Especially moss, which is a type of algae that humans often try to remove and clean. Moss is a type of single-celled algae that grows and adheres to areas with flowing water because the flowing water has both oxygen and carbon dioxide and the right temperature combined with the right amount of light, these algae will grow until it clings to a green patch. Some groups tend to stick together in groups, some groups cling to wet area, on the rock, some groups are in the water or underwater, each group has a different color depending on what types of algae there are in moss. In The Use of Alga as Water Quality Indicator in Sansab Canal study [6], when these mosses collected from Sansab Canal were looked at, they found groups of algae that matched the AARL-PP SCORE guide, Including *Chlorella Oscillatoria* sp. and *Monoraphidium* sp.. In addition, from the research results it was found that micro-algae *Monoraphidium* sp. are expected to have the greatest contribution to CO_2 reduction, decreasing from 31.0% to 10.0% [7], while *Oscillatoria* sp. and *Chlorella* sp. have been identified as being equally effective at capturing CO_2 [8]. However, algae are living things that have a limited lifespan. The study and comparison of *Chlorella* sp.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

Scenedesmussp sp. and *Spirulinasp* sp. [9] found that algae had the highest efficiency in fixing carbon dioxide for 10 days, after which the fixation of carbon dioxide tended to decrease with increasing time.

Another solution for biological carbon capture is seashells, primarily composed of calcium carbonate ($CaCO_3$). The shells left after consumption can help reduce carbon through a chemical reaction from the dissolution of the shells (Shell dissolution). Zhang *et al.* [10] found that the dissolution of shells can reduce the amount of CO_2 in the atmosphere, increases the alkalinity of the ocean and increases its ability to absorb carbon. The research also predicts that the seashell melting effect will reduce atmospheric CO_2 levels by 100-437 ppm by 3500, compared to simulations without seashell melting. It would also help reduce the problem in regions with large seafood industries like Thailand of having to contend with large amounts of shell waste from the processing of mussels, clams, and oysters, and help increase the value of this waste into advanced technology.

This study proposes for creative solutions focused on repurposing this waste generated by consumers. The researchers aimed to create a dual-layer carbon capture system by utilizing mussel waste, which is rich in $CaCO_3$, and microalgae. To enhance the reduction of carbon dioxide emissions, an off-grid solar cell system is integrated, enabling installation in any location without requiring connection to electricity.

1.2 Objectives

1.2.1 To create carbon capture system using dual-layer, algae and seashell for CO_2 reduction

1.2.2 To integrate an off-grid solar-driven system for dual-layer carbon capture system with algae and seashell

1.2.3 To study carbon dioxide reduction and PV power generation by dual-layer carbon capture system integrating algae and seashell

1.3 Scope

1.3.1 Seashells: Mussel shells purchased from Thipnaree market, Bang Phli District, Samut Prakan Province, Thailand.

1.3.2 Algae: Algae collected from the pond, Khlong Sam, Khlong Luang, Pathum Thani province, Thailand.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

1.3.3 Parameter: Efficiency of CO_2 reduction and PV power generation from off-grid solar system

1.4 Expected benefits

1. Gives an understanding of the level of efficiency in reducing carbon dioxide together by algae and seashell.
2. Be beneficial in developing the use of waste to biological carbon capture.

1.5 Research schedule

The research schedule of this research study is shown in Table 1.1

Table 1.1 The research schedule

Task	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1. Start and Research	↔						
2. Design and Prototype	↔	↔					
3. Component Preparation	↔	↔					
4. Structural and Component Integration			↔	↔			
5. Set Up Power System				↔	↔		
6. Test and Collect data						↔	
7. Report Preparation							↔

King Mongkut's Institute of Technology Ladkrabang

1.6 Report Outline

The rest of this report is organized as follows:

Chapter 2 reviews the literature in carbon capture system algae, seashell, off-grid solar system, the process of reduction and power generation.

Chapter 3 describes the design and methodology of an off-grid solar-driven system for dual-layer carbon capture system integrating algae and seashell.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

Chapter 4 discusses the data recorded, measurements, or observation.

Chapter 5 closes the report, reviewing the work undertaken and draws conclusions about key parts of the work that was undertaken.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the details, theory, and research involved in Design of an off-grid solar-driven system for dual-layer carbon capture system integrating algae and seashell which following the section below.

2.1 Energy consumption and CO_2
2.2 Carbon capture
2.3 Microalgae
2.4 Mussel shell waste
2.5 Shell dissolution
2.6 Dry weight and wet weight measurement
2.7 On-grid and Off-grid solar system
2.8 Power performance of solar system
2.9 Efficiency of CO_2 reduction
2.10 Related research

2.1 Energy consumption and CO_2

The relationship between energy consumption and CO_2 emissions is a fundamental aspect of the global energy landscape and climate change mitigation efforts. Energy consumption, particularly from fossil fuels such as coal, oil, and natural gas, is a primary driver of CO_2 emissions, contributing to the accumulation of greenhouse gases in the atmosphere. As energy is generated and utilized for various purposes including electricity generation, transportation, heating, and industrial processes, carbon dioxide (CO_2) is released into the atmosphere through combustion and other energy-related activities. The burning of fossil fuels releases carbon dioxide along with other greenhouse gases, leading to the intensification of the greenhouse effect and global warming. The magnitude of CO_2 emissions is directly proportional to the amount of energy consumed, with higher energy consumption levels correlating to increased CO_2 emissions. Consequently, efforts to reduce CO_2 emissions often involve initiatives aimed at improving energy efficiency, transitioning to renewable energy sources, and implementing carbon capture and storage technologies. By reducing energy consumption and decarbonizing the energy sector, societies can

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

mitigate CO_2 emissions, mitigate climate change impacts, and foster a more sustainable and resilient future. [11]

2.2 Carbon capture

Carbon capture technologies play a crucial role in mitigating greenhouse gas emissions and combating climate change by capturing CO_2 emissions from various sources, such as power plants and industrial facilities, before they are released into the atmosphere. Carbon capture involves the process of capturing carbon dioxide (CO_2) emissions generated from industrial processes or combustion of fossil fuels, preventing their release into the atmosphere. Captured CO_2 can then be transported, stored underground, or utilized in various industrial processes to reduce greenhouse gas emissions and mitigate climate change.

This review explores diverse carbon capture methods, encompassing physical, biological method.

2.2.1 Physical carbon capture method

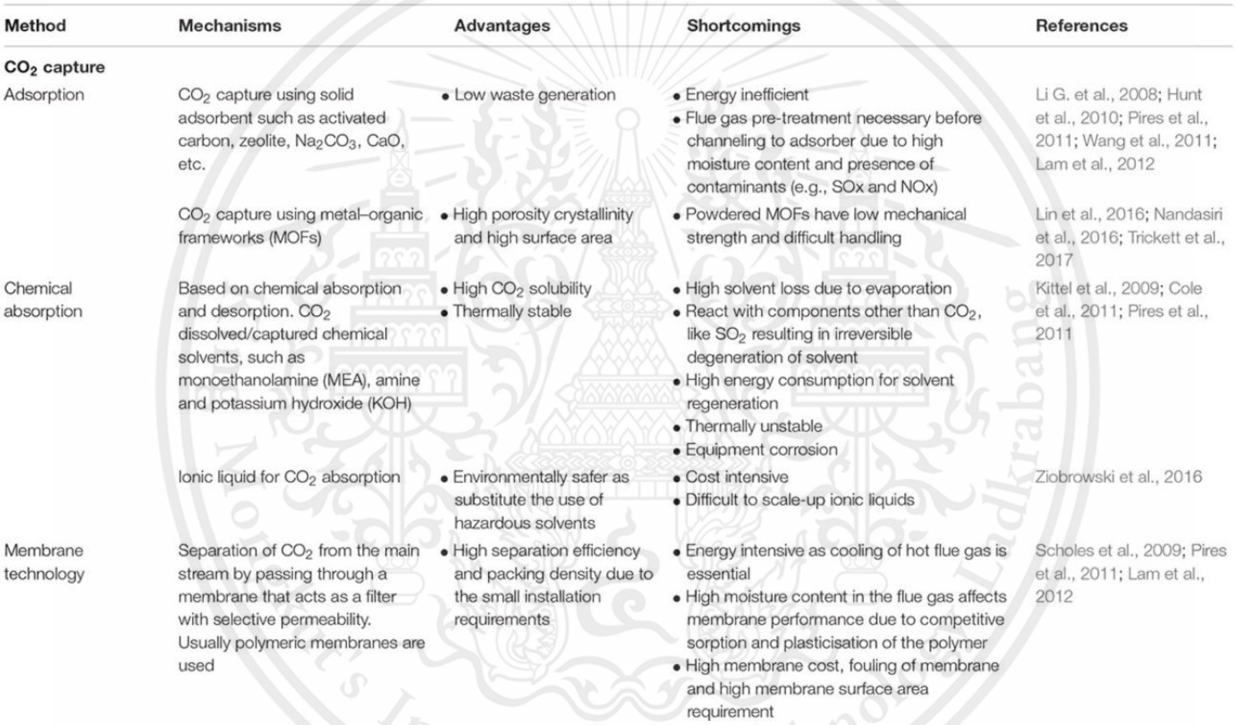
Physical carbon capture techniques are designed to separate CO_2 from industrial emissions through various physical processes, including absorption, chemical adsorption, and membrane-based separation.

1. Absorption involves the dissolution of CO_2 into a liquid solvent, typically using a chemical solvent such as an amine solution. The absorption process occurs when CO_2 in a gas stream comes into contact with the liquid solvent, where it reacts with the solvent to form a stable compound. This compound can then be heated to release the CO_2, allowing for capture and subsequent storage or utilization. Absorption is commonly used in post-combustion capture systems in power plants and industrial facilities.
2. Chemical adsorption, also known as gas-solid adsorption, relies on the physical adsorption of CO_2 molecules onto the surface of a solid material. This process involves the interaction between CO_2 molecules and the adsorbent material, which can be activated carbon, zeolites, or metal-organic frameworks (MOFs). The adsorption capacity and selectivity of the adsorbent determine its effectiveness in capturing CO_2. Chemical adsorption is often employed in pre-combustion capture systems and can offer advantages such as high CO_2 capture efficiency and low energy requirements.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

3. Membrane-based separation utilizes semipermeable membranes to selectively separate CO₂ from gas streams. These membranes allow CO₂ molecules to pass through while blocking other gases such as nitrogen and methane. Membrane-based separation offers advantages such as simplicity, low energy consumption, and scalability. However, challenges such as membrane fouling and limited selectivity for CO₂ over other gases need to be addressed for widespread commercial deployment.

Table 2.1 Comparative description of different physical carbon capture technologies. [12]



Method	Mechanisms	Advantages	Shortcomings	References
CO_2 capture				
Adsorption	CO_2 capture using solid adsorbent such as activated carbon, zeolite, Na_2CO_3, CaO, etc.	• Low waste generation	• Energy inefficient • Flue gas pre-treatment necessary before channeling to adsorber due to high moisture content and presence of contaminants (e.g., SOx and NOx)	Li G. et al., 2008; Hunt et al., 2010; Pires et al., 2011; Wang et al., 2011; Lam et al., 2012
	CO_2 capture using metal–organic frameworks (MOFs)	• High porosity crystallinity and high surface area	• Powdered MOFs have low mechanical strength and difficult handling	Lin et al., 2016; Nandasiri et al., 2016; Trickett et al., 2017
Chemical absorption	Based on chemical absorption and desorption. CO_2 dissolved/captured chemical solvents, such as monoethanolamine (MEA), amine and potassium hydroxide (KOH)	• High CO_2 solubility • Thermally stable	• High solvent loss due to evaporation • React with components other than CO_2, like SO_2 resulting in irreversible degeneration of solvent • High energy consumption for solvent regeneration • Thermally unstable • Equipment corrosion	Kittel et al., 2009; Cole et al., 2011; Pires et al., 2011
	Ionic liquid for CO_2 absorption	• Environmentally safer as substitute the use of hazardous solvents	• Cost intensive • Difficult to scale-up ionic liquids	Ziobrowski et al., 2016
Membrane technology	Separation of CO_2 from the main stream by passing through a membrane that acts as a filter with selective permeability. Usually polymeric membranes are used	• High separation efficiency and packing density due to the small installation requirements	• Energy intensive as cooling of hot flue gas is essential • High moisture content in the flue gas affects membrane performance due to competitive sorption and plasticisation of the polymer • High membrane cost, fouling of membrane and high membrane surface area requirement	Scholes et al., 2009; Pires et al., 2011; Lam et al., 2012

2.2.2 Biological carbon capture method

Biological carbon capture encompasses a range of methods that utilize photosynthetic organisms to sequester CO₂ from the atmosphere or industrial emissions. These are examples of biological method.

1. Microalgae, are microscopic, single-celled organisms that thrive in diverse aquatic environments, ranging from freshwater to seawater. They possess photosynthetic pigments, such as chlorophyll, which enable them to capture CO₂ from the surrounding environment and convert it into organic matter, primarily through the process of photosynthesis. Microalgae

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

exhibit rapid growth rates and high CO_2 fixation capacities, making them promising candidates for biological carbon capture applications.

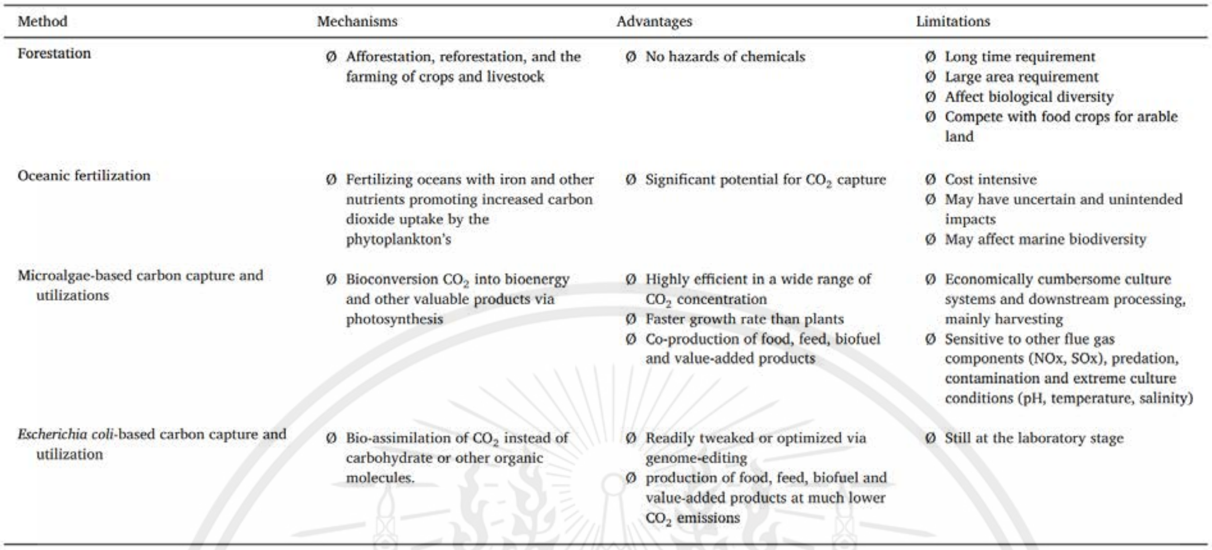
2. Macroalgae (Seaweed) commonly known as seaweed, are multicellular algae that grow in marine environments. Like microalgae, macroalgae are capable of photosynthesis and can efficiently capture CO_2 from the surrounding water. Macroalgae cultivation, particularly in coastal areas or offshore environments, offers opportunities for large-scale carbon sequestration. Seaweed can be harvested for various purposes, including biofuel production, animal feed, and fertilizer, providing additional economic incentives for seaweed cultivation as a carbon capture strategy.
3. Terrestrial Plants, including trees, shrubs, and grasses, play a crucial role in carbon sequestration through photosynthesis. Forests, in particular, serve as significant carbon sinks, absorbing CO_2 from the atmosphere and storing it in biomass and soil organic matter. Afforestation (planting trees on previously non-forested land) and reforestation (replanting trees in areas where forests have been cleared) are effective strategies for enhancing biological carbon capture on land. Agroforestry practices, which integrate trees with agricultural crops or livestock, also contribute to carbon sequestration while providing additional benefits such as soil conservation and biodiversity enhancement.

There are more of biological carbon capture methods, including forestation, ocean fertilization, and microalgae cultivation, offer viable options for mitigating climate change by sequestering CO_2. Forestation, in particular, has been recognized as an effective means of absorbing carbon and mitigating climate change.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Table 2.2 presents an overview of the mechanisms and limitations of biological carbon capture and storage (CCS) [12].



Method	Mechanisms	Advantages	Limitations
Forestation	Ø Afforestation, reforestation, and the farming of crops and livestock	Ø No hazards of chemicals	Ø Long time requirement Ø Large area requirement Ø Affect biological diversity Ø Compete with food crops for arable land
Oceanic fertilization	Ø Fertilizing oceans with iron and other nutrients promoting increased carbon dioxide uptake by the phytoplankton's	Ø Significant potential for CO_2 capture	Ø Cost intensive Ø May have uncertain and unintended impacts Ø May affect marine biodiversity
Microalgae-based carbon capture and utilizations	Ø Bioconversion CO_2 into bioenergy and other valuable products via photosynthesis	Ø Highly efficient in a wide range of CO_2 concentration Ø Faster growth rate than plants Ø Co-production of food, feed, biofuel and value-added products	Ø Economically cumbersome culture systems and downstream processing, mainly harvesting Ø Sensitive to other flue gas components (NOx, SOx), predation, contamination and extreme culture conditions (pH, temperature, salinity)
Escherichia coli-based carbon capture and utilization	Ø Bio-assimilation of CO_2 instead of carbohydrate or other organic molecules.	Ø Readily tweaked or optimized via genome-editing Ø production of food, feed, biofuel and value-added products at much lower CO_2 emissions	Ø Still at the laboratory stage

2.3 Microalgae

Microalgae represent a promising solution for carbon capture, overcoming challenges associated with traditional carbon capture and storage (CCS) methods such as high energy consumption, logistical issues, and potential leakage risks. Their exceptional CO_2 fixation efficiency positions them as a viable third-generation bioenergy feedstock, offering a cost-effective and environmentally friendly alternative to conventional CCS technologies. Through photosynthesis, microalgae convert CO_2 into biomass feedstock, which can be utilized for various bioenergy production processes such as fermentation, gasification, and anaerobic digestion. Research underscores the superior carbon capture capabilities of microalgae compared to terrestrial plants, making them an appealing choice for CO_2 capture. Furthermore, microalgae-based integrated bio-refineries enable the production of valuable products beyond bioenergy, including pharmaceuticals, cosmetics, and fine chemicals.

Microalgae comprise diverse forms, including cyanobacteria and eukaryotic algae like green algae and diatoms. Their CO_2 concentrating mechanism facilitates efficient photosynthesis even at low atmospheric CO_2 concentrations [13]. Despite their potential, the economic viability of microalgae remains a challenge, especially for producing low-value bulk products like proteins and fatty acids. Nonetheless, integrated bio-refinery systems offer a pathway to unlock their full production potential.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Among microalgae species, Chlorella stands out for its ability to thrive in high CO_2 environments, making it suitable for capturing CO_2 from combustion gases [14]. Studies have demonstrated that Chlorella cultivation not only captures CO_2 but also reduces other harmful components like NOx and SOx present in combustion gases. Moreover, large-scale microalgae cultivation holds the potential to sequester substantial amounts of CO_2, contributing to global emission reductions.

By harnessing photosynthesis, microalgae convert solar energy and CO_2 into chemical fuels, presenting a sustainable solution for both atmospheric and industrial CO_2 capture

2.4 Mussel shell waste

Mussel shell waste refers to the discarded shells of mussels, which are often generated as a byproduct of the seafood industry. These shells are primarily composed of calcium carbonate ($CaCO_3$), along with small amounts of proteins and organic matter. Rather than disposing of mussel shells as waste, there are various beneficial uses and applications for this abundant resource. [15]

1. Soil Amendment: Mussel shells can be crushed into a fine powder and used as a soil amendment to improve soil structure and fertility. The calcium carbonate content helps to neutralize soil acidity and provide essential nutrients such as calcium for plant growth. Additionally, mussel shell powder can enhance soil water retention and promote beneficial microbial activity.
2. Aquaculture: Mussel shells can be utilized in aquaculture systems as substrate material for growing algae or as a component of feed formulations for shellfish and finfish. The rough texture of the shells provides a suitable surface for algae attachment and growth, supporting a healthy aquatic ecosystem. Incorporating mussel shell powder into aquafeed can also enhance calcium intake and shell formation in shellfish species.
3. Construction Materials: Mussel shells can be processed into calcium carbonate-based materials such as lime or cement for use in construction applications. These materials can serve as alternatives to traditional cement and concrete, offering environmental benefits such as reduced carbon emissions and lower energy consumption during production.
4. Water Treatment: Crushed mussel shells can be used in water treatment processes to remove contaminants such as heavy metals and organic pollutants. The high surface area and porosity

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

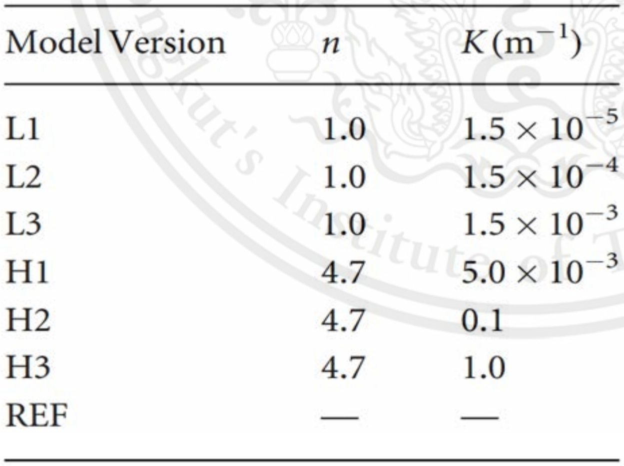
of mussel shell particles make them effective adsorbents for capturing and immobilizing pollutants in water bodies and wastewater treatment facilities.

5. Environmental Remediation: Mussel shell waste can be employed in environmental remediation efforts to restore degraded habitats and mitigate coastal erosion. Mussel shell reefs and barriers can provide habitat for marine organisms, stabilize shorelines, and enhance biodiversity in coastal ecosystems.
6. Reduce CO_2 in seawater: primarily composed of calcium carbonate ($CaCO_3$), can be deployed in marine environments to enhance the alkalinity of seawater, thereby facilitating the absorption and storage of CO_2 from the atmosphere. This process involves the dissolution of calcium carbonate particles from mussel shells in seawater, resulting in the release of calcium ions (Ca_2^+) and bicarbonate ions (HCO_3^-) into the water column.

2.5 Shell dissolution

Another solution for biological carbon capture is seashells, primarily composed of calcium carbonate ($CaCO_3$). The shells left after consumption can help reduce carbon through a chemical reaction from the dissolution of the shells (Shell dissolution)

Table 2.3 Configurations of the seven UVic model versions. [16]



Model Version	n	$K\,(\mathrm{m}^{-1})$
L1	1.0	1.5×10^{-5}
L2	1.0	1.5×10^{-4}
L3	1.0	1.5×10^{-3}
H1	4.7	5.0×10^{-3}
H2	4.7	0.1
H3	4.7	1.0
REF	—	—

Zhang et al. (2023) [16] conducted model simulations to investigate how the dissolution of calcium carbonate ($CaCO_3$) affects climate change dynamics and the ocean carbon cycle. By integrating six different parameterizations of the dissolution effect into the UVic model, they

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

assessed its impact using the SRES A2 CO_2 scenario, which includes total emissions of 5,462 PgC. The findings suggest that the dissolution effect leads to an increase in seawater alkalinity (ALK) and strengthens the ocean carbon sink, thereby providing a negative feedback mechanism that counteracts the rise in atmospheric CO_2 levels and mitigates global warming. Compared to the reference simulation outlined in Table 2.3, the simulations incorporating the dissolution effect predict a decrease in simulated atmospheric CO_2 concentration ranging from 100 to 437 parts per million (ppm) by the year 3500, as indicated in Figure 2.1.

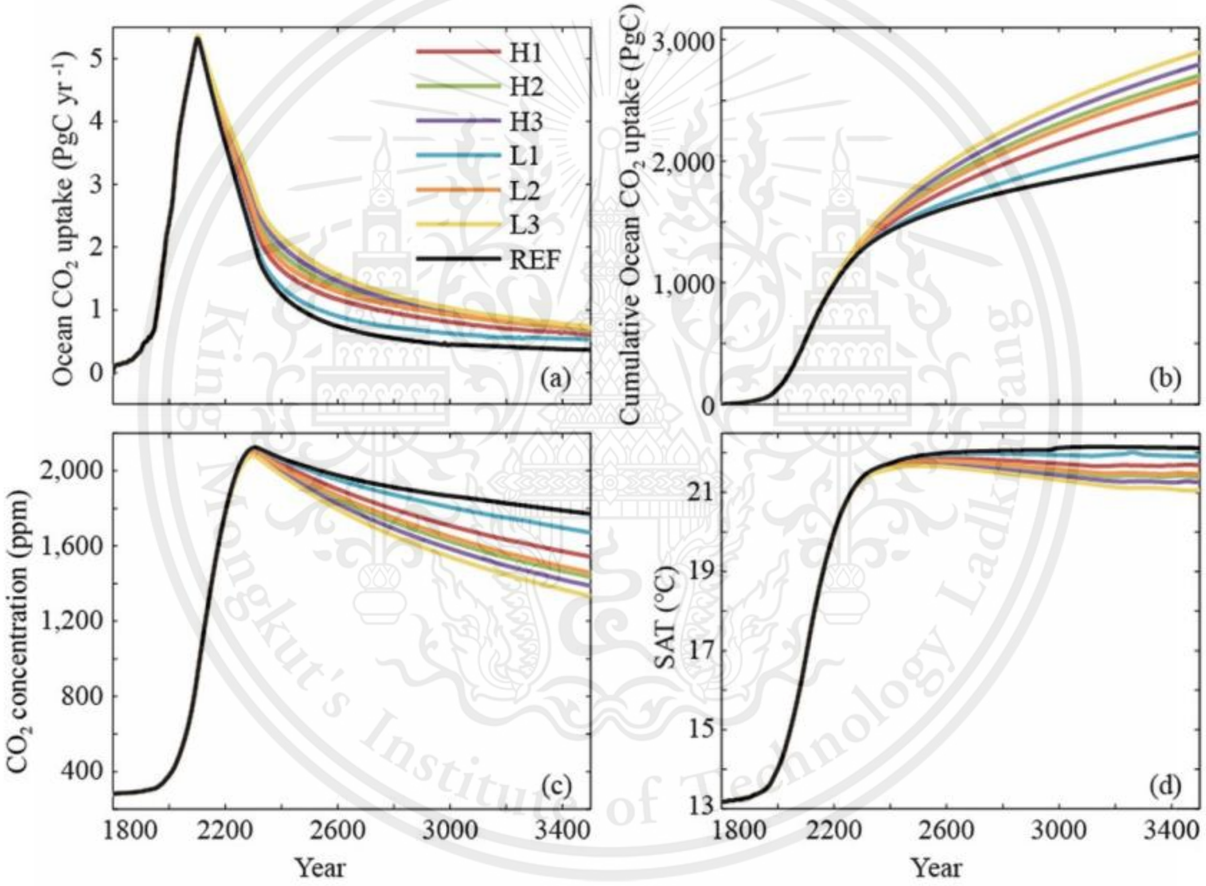


Figure 2.1 Simulated time series of (a) oceanic CO_2 uptake, (b) cumulative oceanic CO_2 uptake, (c) atmospheric CO_2 concentration, and (d) SAT (surface air temperature). Annual and global mean value are showed. Refer to Table 2.3 for the seven model versions. [16]

The impact of the dissolution of calcium carbonate ($CaCO_3$) on the global carbon cycle varies depending on the specific parameterization of the dissolution-ΩC relationship, highlighting

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

the importance of addressing parameter uncertainty in influencing carbon cycle dynamics. This dissolution effect, while enhancing the ocean carbon sink, also mitigates seawater acidification, primarily through the increase in alkalinity (ALK). For instance, simulation L3 indicates a rise in surface mean pH by 0.17 by the year 3500, corresponding to a 48% decrease in hydrogen ion concentration ($[H^+]$) compared to the reference simulation. Notably, the Pacific-Indian Ocean experiences more significant acidification compared to the Arc-Atlantic Ocean, leading to stronger dissolution effects and feedbacks on ocean carbon sink and acidification in the former.

Observational studies validate the simulated results, with modeled export flux of $CaCO_3$ at a depth of 130 m in the mid-1990s falling within the observed range. Additionally, simulated $CaCO_3$ production and dissolution rates align with observational data, confirming the accuracy of the model in capturing large-scale ocean $CaCO_3$ cycle fields. The findings suggest a potentially substantial feedback of the dissolution effect on atmospheric CO_2, with varying estimates reported in previous modeling studies. Under the SRES A2 CO_2 scenario, simulations predict a noticeable decline in atmospheric CO_2 concentration by 100–437 ppm by the year 3500, emphasizing the significance of dissolution effect representations.

Moreover, the study evaluates the potential implications of the dependence of $CaCO_3$ dissolution on ΩC for the global carbon cycle, particularly in the context of marine carbon dioxide removal (mCDR) geoengineering strategies such as ocean alkalinity enhancement (OAE). By elucidating the role of the dissolution effect in the ocean carbon sink and climate system, the results contribute valuable insights for future modeling studies and geoengineering endeavors.

2.6 Dry weight and wet weight measurement

Dry weight and wet weight measurements are fundamental techniques used in various scientific disciplines, including biology, environmental science, and materials science, to quantify the mass of a substance or sample under different conditions. [17]

1. Wet Weight Measurement

Wet weight refers to the weight of a sample when it is in its natural, hydrated state. This measurement includes the mass of both the sample material and any water or other fluids present within it. Wet weight measurements are typically conducted using a balance or scale capable of accurately measuring the mass of the sample in grams or kilograms.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

In biological and environmental studies, wet weight measurements are commonly used to assess the biomass of living organisms, such as plants, animals, and microorganisms. For example, wet weight measurements of aquatic plants or algae can provide insights into their growth rates and productivity in aquatic ecosystems.

2. Dry Weight Measurement

Dry weight refers to the weight of a sample after all moisture and water content have been removed through drying. This measurement specifically quantifies the mass of the sample material itself, excluding any water or other volatile substances.

To determine the dry weight of a sample, it is first placed in an oven or desiccator at a controlled temperature for a specified period to remove all moisture. Once the sample is completely dried, it is weighed using a balance or scale. The difference between the initial wet weight and the final dry weight represents the amount of water that was present in the sample. Dry weight measurements are particularly important in environmental studies, where they are used to assess the organic matter content of soil, sediment, or biomass samples. By removing water, dry weight measurements provide a more accurate representation of the organic material present in the sample, which is essential for calculating nutrient content, carbon storage, and other ecological parameters.

2.7 On-grid and Off-grid solar system

On-grid and off-grid solar systems represent two distinct approaches to harnessing solar energy for electricity generation. On-grid systems, also known as grid-tied or grid-connected systems, are integrated with the local utility grid. Comprising solar panels, inverters, and occasionally batteries, these systems convert sunlight into electricity, which is synchronized with the grid's voltage and frequency and supplied directly into it. On-grid systems often utilize net metering, allowing excess electricity to be exported to the grid for credit against the owner's electricity bill.

In contrast, off-grid solar systems operate independently of the utility grid and are designed for standalone facilities or remote locations. These systems include solar panels, batteries for energy storage, charge controllers, inverters, and backup generators. Off-grid systems provide energy autonomy by storing excess solar energy in batteries for use during periods of low sunlight or at night. While on-grid systems offer cost savings and support grid stability, off-grid systems

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

provide autonomy and reliability, making them suitable for remote areas where grid connection is impractical. Both system configurations offer unique advantages and are chosen based on factors such as location, energy requirements, and grid accessibility.

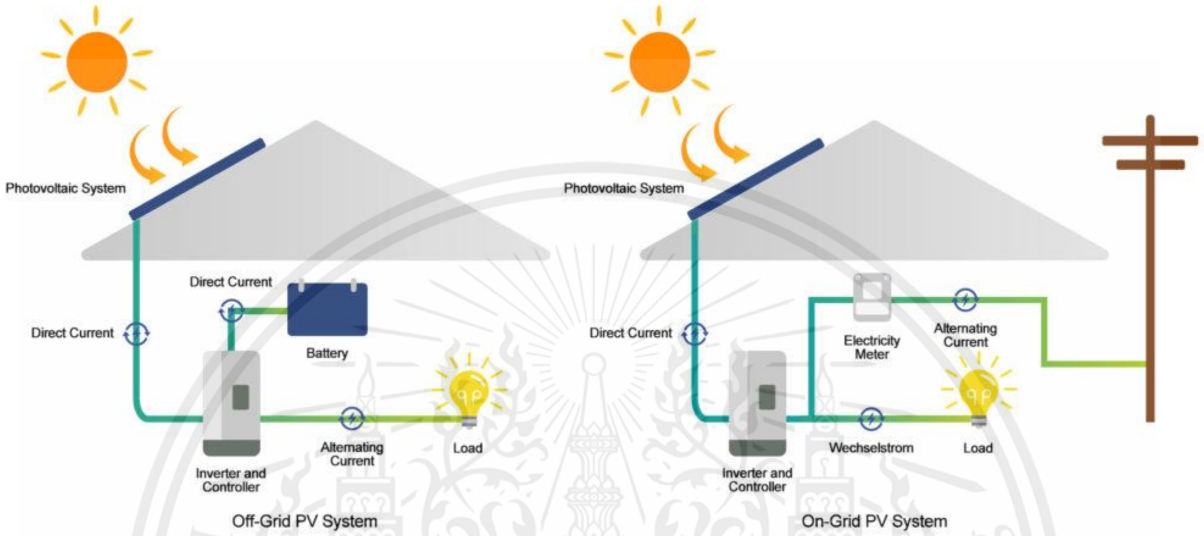


Figure 2.2 Off-grid and on-grid solar system [18]

2.8 Power performance of solar system

Power performance from solar systems is a critical aspect of assessing the effectiveness and reliability of solar energy generation. It encompasses a range of factors that influence the efficiency and output of solar panels in converting sunlight into electricity. One key factor is sunlight intensity, which directly affects the amount of energy captured by solar panels. Higher sunlight intensity leads to increased electricity generation, while lower intensity results in reduced output. Solar panel efficiency is another crucial consideration, representing the ability of panels to convert sunlight into electricity. Higher efficiency panels can generate more power for a given amount of sunlight, making them desirable for maximizing power performance.

Additionally, the angle and orientation of solar panels relative to the sun play a significant role in power performance. Optimal positioning ensures maximum sunlight exposure throughout the day, enhancing electricity generation. Factors such as shading from trees, buildings, or other

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

obstructions can significantly impact power output by reducing the amount of sunlight reaching the solar panels. Minimizing shading is essential for optimizing power performance.

Temperature also affects solar panel efficiency, with higher temperatures typically leading to reduced performance. Monitoring and managing panel temperature through proper ventilation or cooling systems can help maintain optimal efficiency. Furthermore, the quality and condition of system components, including inverters, wiring, and mounting hardware, are crucial for ensuring consistent power performance. Well-maintained and properly installed components contribute to overall system efficiency and reliability.

System size is another important consideration, as larger solar systems have the capacity to generate more electricity than smaller ones. However, even smaller systems can achieve high power performance with efficient design and operation. Monitoring and analyzing the electricity output of the solar system over time are essential for assessing power performance. Metrics such as capacity factor, efficiency ratio, and degradation rate provide insights into system performance and help identify any issues or opportunities for improvement.[19]

2.9 Efficiency of CO_2 reduction

The efficiency of CO_2 reduction is a pivotal measure used to assess the effectiveness of carbon capture and utilization (CCU) processes in diminishing CO_2 emissions. This metric gauges the percentage of CO_2 that is successfully captured or converted in relation to the initial CO_2 input. The formula typically employed to compute CO_2 reduction efficiency can be calculated by

$$\text{Efficiency of CO}_2\text{ reduction (\%)} = \left(\frac{\text{Influent of CO}_2 - \text{Effluent of CO}_2}{\text{Influent of CO}_2}\right) \times 100$$

Efficiency calculations may vary based on the specific CCU technology and process objectives. For instance, in carbon capture and storage (CCS) systems, efficiency could pertain to the percentage of CO_2 captured from industrial emissions and permanently stored underground. Conversely, in carbon utilization technologies like carbon capture and utilization (CCU) or carbon capture and utilization (CCU), efficiency might denote the percentage of CO_2 converted into value-added products such as fuels, chemicals, or building materials.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

2.10 Related research

This thesis studies design of an off-grid solar-driven system for dual-layer carbon capture system integrating algae and seashell. The related research comprises the following.

Suktalord at al.[6] studies the use of alga as water quality indicator in Sansab Canal, when these mosses collected from Sansab Canal were looked at, they found groups of algae that matched the AARL-PP SCORE guide, Including *Chlorella* sp. *Oscillatoria* sp. and *Monoraphidium* sp..

Juškaite at al.[7] The research results it was found that micro-algae *Monoraphidium* sp. are expected to have the greatest contribution to CO_2 reduction, decreasing from 31.0% to 10.0%,

Anguselvi at al.[8] shows that Oscillatoria and Chlorella have been identified as being equally effective at capturing CO_2.

Ngen Kum Kong at al. [9] studies and compares of *Chlorella Scenedesmus* sp. and *Spirulina* sp. found that algae had the highest efficiency in fixing carbon dioxide for 10 days, after which the fixation of carbon dioxide tended to decrease with increasing time.

Zhang et al. [10] highlight the potential of shell dissolution to reduce atmospheric CO_2 levels, enhance ocean alkalinity, and augment carbon absorption capacity. Their findings suggest a significant decrease in atmospheric CO_2 by 100-437 ppm by 3500 through shell dissolution. This approach offers a solution to regions with substantial seafood industries.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

CHAPTER 3

METHODOLOGY

In methodology is presenting the material used (section 3.1), structural construction (section 3.2), algae system preparation (section 3.3) seashell system preparation (section 3.4), water dechlorinating (section 3.5), off-grid solar-driven system (section 3.6) and system operation and experiment (section 3.7).

3.1 Material

3.1.1 Structural material

a) Ten of 30x30mm Aluminum profiles (1 meter each)
b) Two of 5mm Aluminum plates
c) Four of wheels
d) Brackets and Connection equipments
e) A plasma cutting machine

3.1.2 Preparation material

a) An X-ray diffractometer, Rigaku, MiniFlex
b) A digital weighing scale, Sartourius, BSA2245-CW
c) A heating Oven, Memmert
d) A 3D Measuring laser microscope, Olympus, LEXTOLS5000

3.1.3 Solar driven material

a) A 370W Monocrystalline half-cut cell, EMP
b) An 12V 500W Off grid inverter, TBE
c) A 30A MPPT Solar charger, SUOER
d) A 12V 100Ah Battery, 3K

3.1.4 Experimental and Operation material

a) An air pump no.1, 9W, flow rate 14 L/min
b) An air pump no.2, 6W, flow rate 10 L/min

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

c) An air pump no.3, 4W, flow rate 6.6 L/min
d) Two of 6W LED Blue Bulb, Horse Power, HP-350
e) Three of Air detector (sensor no.1, sensor no.2, sensor no.3), H8 Plus

3.2 Structural construction

Aluminum-sized 3x3 mm was used as the main component for building the supported structure due to its strength. The design included two levels for placing objects, with a solar panel placing on a stand at 13.5 degrees, as shown in Figure 3.1. In the section of 5 mm thick aluminum sheets, apply them by cutting with Plasma cutting machine and drilling holes according to the drawing in Figure 3.2.

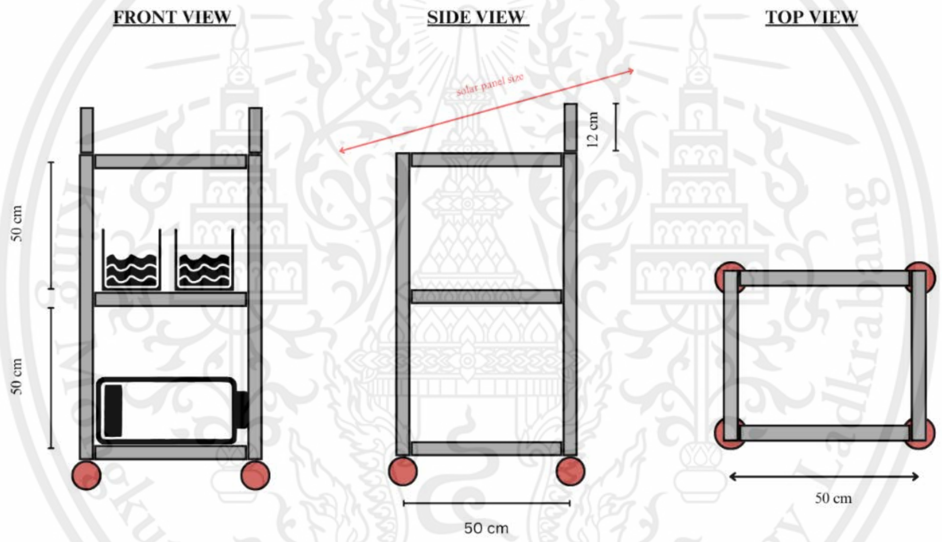


Figure 3.1. Drawing of structural system

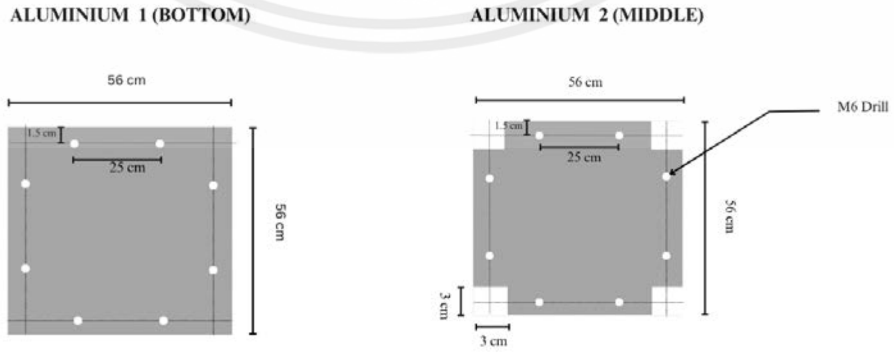


Figure 3.2. Drawing of bottom and middle aluminum plates

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

The solar panel was installed on top. Off-grid system components are placed on the bottom plate. Tanks of algae and seashell were placed on the upper plate as shown in Figure 3.3.

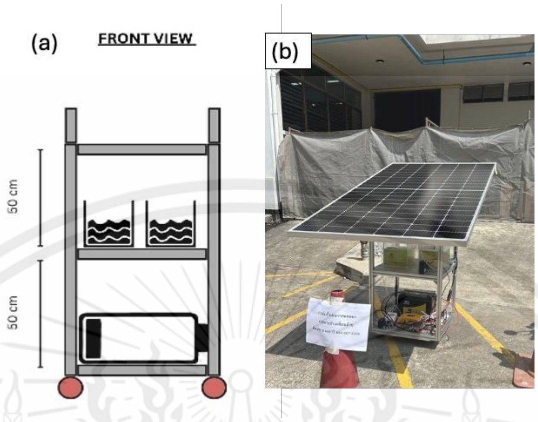


Figure 3.3. (a) System Drawing. (b) Off-Grid solar energy system structure for a two-layer carbon dioxide capture process with algae and mussel shells.

3.3 Algae system preparation

The algae used in the experiment were collected from a still pond, Khlong Sam, Khlong Luang, Pathum Thani Province, Thailand, and dried at 50-60 °C for 3 hours to obtain 3 grams of algae dry weight. The shape and size of the algae were then observed under a 3D Measuring laser microscope (Olympus, LEXTOLS5000). Use a culture tank size 20x20x20 centimeters, add 6.0 liters of chlorine-free water containing the nutrient sodium chloride (NaCl) 1.0 grams per liter, supply air to the bottom of the tank with an air pump at 14 L/min, 24 hours a day. 12 days to raise seaweed The ratio of natural light to 6 watts blue LED lights was 12:12. After cultivation, average biomass productivity was calculated with equation (1) to analyze the rate at which algae accumulated over 12 days in grams per liters per day

$$\text{Biomass productivity}(\mathrm{g\,L^{-1}d^{-1}}) = 2 \times \frac{\mathrm{DCW2-DCW1}}{\mathrm{t2-t1}} \qquad (1)$$

DCW1 and DCW2 are the dry weights of algae before and after cultivation at times t1 and t2, respectively.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

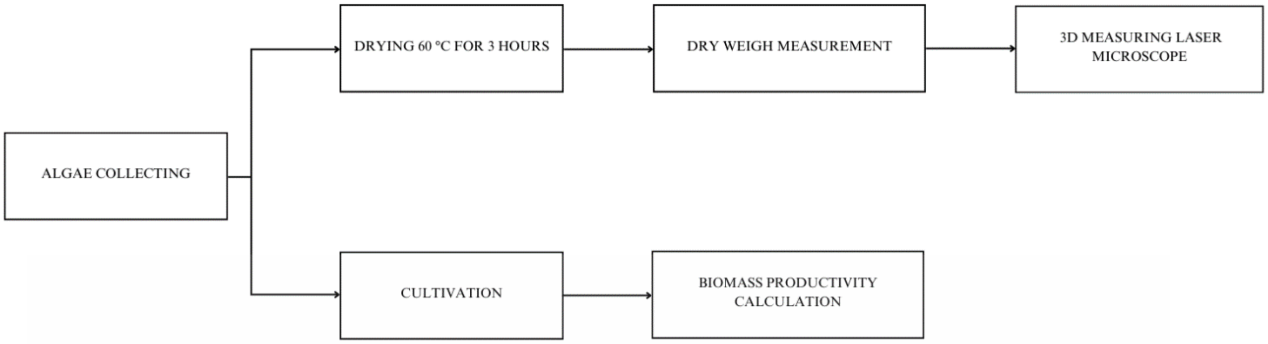


Figure 3.4. Flow chart showing the process of algae preparation

3.4 Mussel shell system preparation

Considering a 1:1 shell to water ratio, the mass of shells required was calculated from the molecular weight of $CaCO_3$ multiplied by the number of moles of $CaCO_3$. Therefore, 600.5 grams of crushed shells were dissolved in 6 liters of water. For shell preparation steps in Figure 3.5, The mussel shells were collected from the Thipnaree market, Bang Phli District, Samut Prakan Province. Mussel shells were cleaned by washing with acetic acid at a concentration of 5 M, and then the samples were washed with distilled water. They were dried at 100–200°C for 5 h and ground into crushed shell, respectively.

The crushed shell powder was then analyzed by X-ray diffraction (XRD; Miniflex600, Rigaku) using Cu-Kα, 40 kV and 30 mA. Each specimen was scanned. from 20° to 80° (2θ) with a scanning speed of 6° per minute. Then 600.5 g of crushed peel was combined with prepared dechlorinated water to increase carbon dioxide absorption in a 20x20x20 tank with volume. Working 6.0 liters

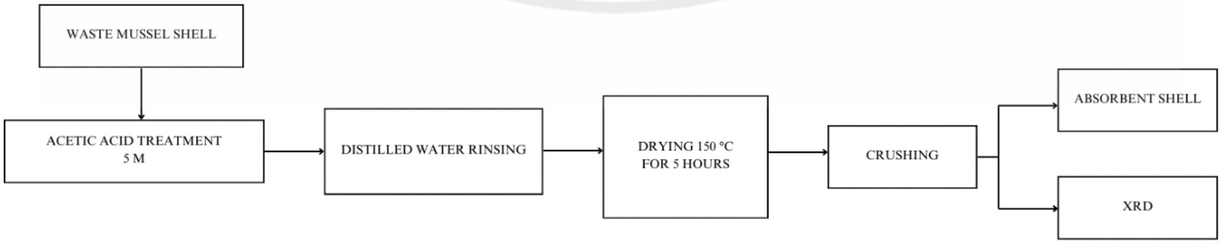


Figure 3.5. Flow chart showing the process of mussel shells preparation

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

3.5 Water dechlorinating

To prepare water as a culture medium for shell and algae, tap water was aerated with air bubbles using a 9W air pump for 1 hour to evaporate chlorine. The water was then incubated and left exposed to open air for 48 hours.

3.6 Off-grid solar-driven System

The utilized energy system is based on solar power, which is renewable. An off-grid solar system was integrated to power the experiment for 12 days 20 hours of autonomy. Key components of a solar PV system include the solar charge controller, inverter, battery, and electrical loads (appliances).

1. PV module: converts sunlight into direct current (DC) electricity.
2. Solar charge controller: regulates the voltage and current from the PV panels to the battery, preventing overcharging and extending battery life.
3. Inverter: converts the DC output from the PV panels into clean alternating current (AC) suitable for powering AC appliances.
4. Battery: stores excess energy generated by the PV system for use when there is demand, ensuring continuous power supply to electrical appliances.
5. Load: these are the electrical appliances connected to the solar PV system, for this research the considered loads are shown in Table 3.1.

All of components was designed and calculated the size and specification for having most efficiency to power the whole system as detailed below

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

3.6.1 Load calculation for total energy (Wh/day)

Table 3.1. Electrical appliances and their daily use

Appliances	Quantity	Rating (W)	Time of use (hr)	Daily use (Wh/day)
LED blue bulb	2	6	12	144
Air pump No. 1	1	9	24	216
Air pump No. 2	1	6	24	144
Air pump No. 3	1	4	24	96
Sensor	2	0.25	24	12
Total				612

3.6.2 PV module sizing

The first method to determine the size of PV module is to multiply the total daily energy use with 1.3, extra losses for all problems such as lost in system, wire loss, etc., to get the Watt-hours per day required by panel.

$$\text{Total energy requirement from panel} = \text{Total energy} \times 1.3$$
$$\text{Total energy requirement from panel} = 612 \times 1.3$$
$$\text{Total energy requirement from panel (Wh/day)} = 795.6$$

Divide total energy requirement from panel to the panel generation factor following equation (2) to get the size of panel needed

$$\text{Panel size (watt)} = \frac{\text{Total energy requirement from panel}}{\text{Panel generation factor}} \qquad (2)$$

Panel generation factor (PGF) is used while calculating the size of solar cells. it is a varying factor depending upon the climate of the site location (depending upon global geographic location). For Thailand PGF is 3.43.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

$$\text{Panel size (watt)} = \frac{795.6\text{W}}{3.43}$$

$$\text{Panel size (watt)} = 231.95\ \text{W}$$

The result of 231.95 W is the peak energy required from panel. Therefore, for the safety margin, the solar panel used to install in this research is a 370W Monocrystalline half-cut cell, EMP.

3.6.3 Solar charge controller sizing

This research is using MPPT type of Solar charge controller due to their ability to adjust voltage to match the battery bank's voltage and boost current to compensate for power loss.

To calculate the amperage, use the equation (3),

$$\text{Solar charge controller size (A)} = \frac{\text{Watt of solar panel}}{\text{Battery voltage}} \tag{3}$$

Because a 370 watts solar panel is used and the battery voltage is 12 volts, the size of the Solar charge controller can be calculated according to equation (3). In this research, a 30 amps MPPT SUOER solar charge controller is used.

3.6.4 Battery sizing

Designing battery is important, the battery needs to be sufficiently sized to store enough energy for running the appliances during periods of both nighttime and cloudy days. Equation (4) is used to calculate battery capacity (Ah) using a battery loss coefficient of 0.85. Depth of discharge is 0.6 for lead-acid and storage batteries. (Day of autonomy) 1 day.

$$\text{Battery Capacity (Ah)} = \frac{\text{Total energy per day used by appliances} \times \text{Days of autonomy}}{\text{Battery loss} \times \text{Depth of discharge} \times \text{nominal battery viltage}} \tag{4}$$

$$\text{Battery Capacity (Ah)} = \frac{618 \times 0.83}{0.85 \times 0.6 \times 12}$$

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

$$\text{Battery Capacity (Ah)} = 84.15 \text{ Ah}$$

Therefore, A 12V 100Ah Battery, 3K, is used in this research for ability to store excess energy.

3.6.5 Inverter sizing

In stand-alone systems, the inverter needs to have sufficient capacity to manage the total wattage utilized simultaneously and should be 25% bigger than total watt of appliances. From data in Table 3.1 shows that the total watt of appliances is 25.25 watts. Thus, the chosen inverter in this research is an 12V 500W Off grid inverter, TBE. This ensures that the inverter can accommodate the surge current experienced during the startup phase.

3.6.6 Solar system set up

After designing and calculating the size of the main components. It was concluded that in this research the following components were used

1. A 370W Monocrystalline half-cut cell, EMP
2. A 30A MPPT Solar charger, SUOER
3. A 12V 100Ah Battery, 3K
4. An 12V 500W Off grid inverter, TBE
5. Load appliances
    a) An air pump no.1, 9W, flow rate 14 L/min
    b) An air pump no.2, 6W, flow rate 10 L/min
    c) An air pump no.3, 4W, flow rate 6.6 L/min
    d) Two of 6W LED Blue Bulb, Horse Power, HP-350
    e) Three of Air detector (sensor no.1, sensor no.2, sensor no.3), H8 Plus

All 5 of these components were connected together as in Figure 3.6. Using SOLAR PV CABLE, Black, Red, 4.0 mm², TUV EN50618 wires.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

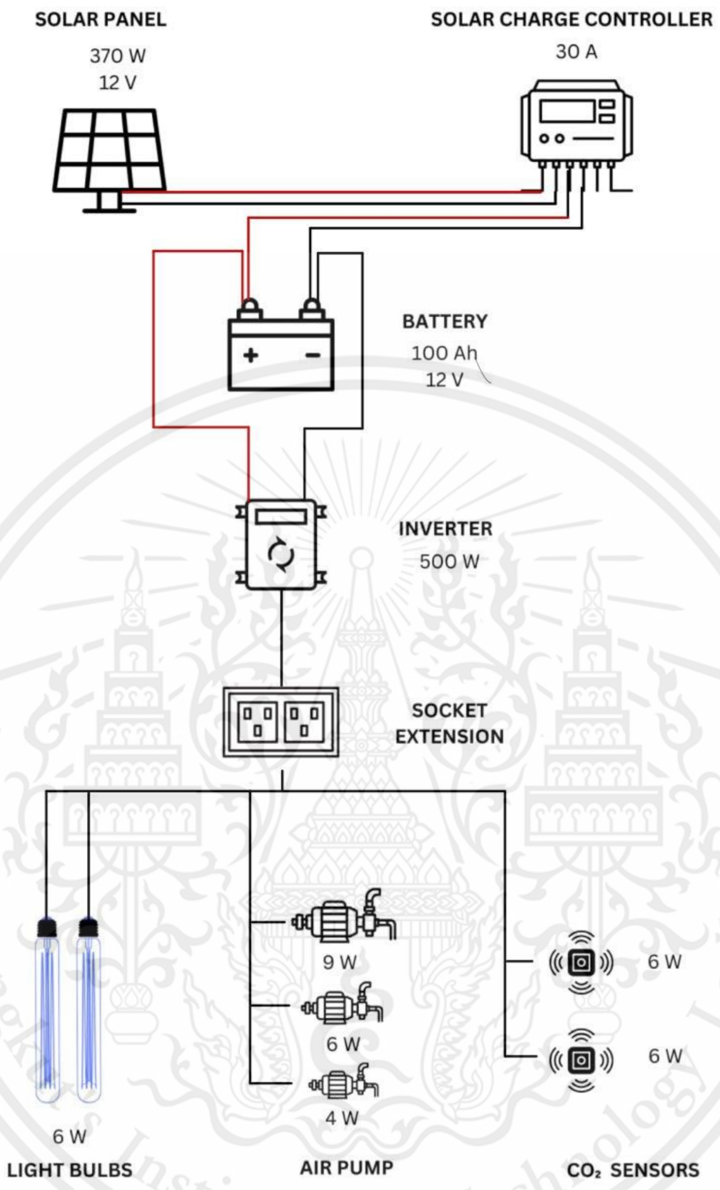


Figure 3.6. Diagram of off-grid solar power system connecting with loads

3.7 System operation and experiment

The two-layer carbon capture system combines the preparation of the algae system in 3.3 and the preparation of the mussel shell system in 3.4. Picture 3.7 shows that the air is sucked in by Air pump no.1 for 14 L/min, which has Sensor no. 1 model H8 Plus to measure CO_2 before bringing air through the pipe to System 1 (Algae tank). In this tank, CO_2 was captured through the process of photosynthesis. Air that has absorbed carbon will be pumped through Air pump 2 at a flow rate

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

of 10 L/min through pipes connected to System 2 (Shell tank). Crushed shells mixed with water will help store CO_2 by dissolving the shell. Then the air from the shell tank was sucked out of the tank by Air pump no.3. The value of the CO_2 that passed was measured by Sensor no.2, model H8 Plus, attached to the shell tank.

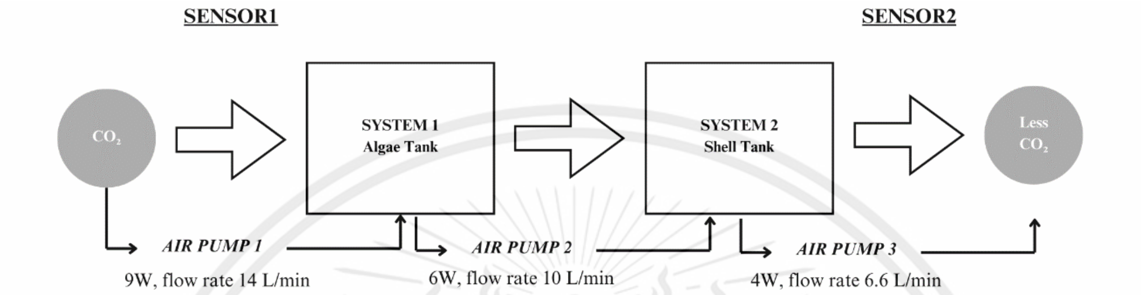


Figure 3.7 Diagram of algae cultivation tank and shell tank operation

The experiment lasted 12 days. Algae samples were collected before and after to assess algae growth in the culture. By collecting data every day at 10.00, 17.00 and 22.00 by leaving the data collection period for 3 minutes and using the average data. The data collected was as follow

1. Carbon dioxide (PPM) of 2 sensors
2. Temperature of 2 sensors
3. Humidity of 2 sensors
4. pH water of the algae tank and shell tank
5. Current of PV generation
6. Voltage of PV generation
7. Picture of algae and shell tanks

After the experiment, the obtained values were calculated to find the efficiency of reducing carbon dioxide of the algae and seashell. Calculated from equation (1) [20]

$$\text{Efficiency of CO}_2\text{ reduction (\%)} = \left(\frac{\text{Influent of CO}_2 - \text{Effluent of CO}_2}{\text{Influent of CO}_2}\right) \times 100 \qquad (5)$$

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

Where Efficiency of CO_2 reduction is the efficiency in reducing CO_2 (%) for the system, Influent of CO_2 is the amount of CO_2 incoming (PPM) and Effluent of CO_2 is the amount of CO_2 outgoing (PPM).

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

CHAPTER 4
EXPERIMENTAL RESULT

In this chapter, we present results of 12 days experiments of design of an off-grid solar-driven system for dual-layer carbon capture system integrating algae and seashell. The sections in this chapter are as follows

4.1 Data collection results
4.2 Algae characterization
4.3 Shell characterization
4.4 The efficiency of CO_2 reduction
4.5 The Power performance in off-grid solar system
4.6 The pH value of algae and seashell tank
4.7 Algae tank and shell tank observation

4.1 Data collection results

Table 4.1 shows the results of the data collected during the 12-day experiment at 10.00, 17.00 and 22.00. The variables used to collect in this table are carbon dioxide (PPM) of 2 sensors, temperature of 2 sensors, humidity of 2 sensors, pH water of the algae tank and shell tank, current of PV generation, voltage of PV generation. Also, these data will be used for calculation in section 4.4, 4.5 and 4.6.

Table 4.1 Raw collected data for 12-day experiment at 10.00, 17.00 and 22.00

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

		Sensor1			Sensor2			pH Seashell		pH Algae		PV generation		
Day	**Time**	**CO_2 (PPM)**	**Temp of SS no.1**	**Humidity (%)**	**CO_2 (PPM)**	**Temp of SS no.2**	**Humidity(%)**	**pH Seashell**	**av. PH shell**	**pH Algae**	**av. PH algae**	**Voltage (V)**	**current (I)**	**Power (W)**
1	10	1897	33	61	765	32	61	8.8	8.75	8.7	8.7	12.9	2.1	26
	17	1080	33	58	560	33	59	8.73		8.73		13.3	1.8	23.4
	22	871	28	78	576	28	78	8.71		8.67		0	0	0
2	10	1563	30	66	590	30	67	8.75	8.76	8.59	8.56	13.5	3.7	48.5
	17	1190	31	66	690	30	67	8.75		8.56		14.4	3.9	54.18
	22	1663	29	74	590	29	74	8.79		8.53		0	0	0
3	10	1053	31	64	375	32	63	8.79	8.77	8.57	8.59	12.5	2.4	29.6
	17	1223	30	65	480	31	63	8.75		8.59		14.8	3.6	52.8
	22	1039	28	75	485	28	75	8.78		8.61		0	0	0
4	10	907	31	66	368	32	63	8.89	8.85	8.64	8.67	12.5	2.4	29
	17	998	31	66	364	31	66	8.84		8.69		12.7	2.3	28
	22	1034	28	78	455	28	78	8.83		8.68		0	0	0
5	10	1146	33	61	440	34	60	8.85	8.85	8.69	8.6866667	12.6	3.6	56.9
	17	1276	33	56	584	34	55	8.85		8.68		13.3	2	27
	22	981	29	72	324	29	72	8.86		8.69		0	0	0
6	10	1753	37	69	574	37	69	8.86	8.86	8.69	8.6866667	13.5	5.6	74.8
	17	1848	34	58	583	34	58	8.84		8.68		12.5	2.4	29.7
	22	814	28	78	275	28	78	8.89		8.69		0	0	0

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

Day	Time	CO₂ (PPM)	Temp of SS no.1	Humidity (%)	CO₂ (PPM)	Temp of SS no.2	Humidity (%)	pH Seashell	av. PH shell	pH Algae	av. PH algae	Voltage (V)	current (I)	Power (W)
7	10	1188	31	66	477	32	64	8.91	8.90	8.69	8.69	12.4	2.5	32
	17	1848	31	70	475	31	67	8.91		8.69		13.6	2.5	33.4
	22	954	29	70	256	30	70	8.87		8.69		0	0	0
8	10	1534	31	67	475	32	64	8.84	8.89	8.69	8.69	13.5	3.4	45
	17	1828	34	37	603	34	38	8.88		8.69		13.4	1.6	20.9
	22	1020	29	72	466	30	70	8.94		8.69		0	0	0
9	10	1353	39	53	467	38	52	8.89	8.90	8.69	8.69	13.2	9.4	124.1
	17	1201	36	51	509	36	49	8.9	8.87	8.69		12.5	1.5	18.6
	22	1005	28	75	545	28	75	8.92		8.69		0	0	0
10	10	1732	32	71	785	32	68	8.86		8.7	8.693 3333	13	1.5	20.6
	17	1056	34	71	658	34	71	8.87		8.69		12.8	3.3	41.5
	22	830	28	78	598	28	75	8.89		8.69		0	0	0
11	10	1047	32	61	690	34	57	8.81	8.89	8.69	8.68	12.6	3.4	41.6
	17	1201	36	51	563	36	49	8.9		8.67		13.8	3.6	49.3
	22	1157	28	76	754	28	74	8.95		8.68		0	0	0
12	10	1342	39	52	765	40	53	8.97	8.97	8.69	8.69	13.4	9.5	125.6
	17	1065	34	59	664	34	59	8.97		8.69		12.2	3.3	39.8
	22	1273	28	78	980	28	76	8.98		8.69		0	0	0

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

4.2 Algae Characterization

4.2.1 Laser microscope analysis

The algae samples were analyzed using a laser microscope (Olympus, LEXTOLS5000) at 20× magnification. In Figure 4.1 the texture and color of the algae are shown. The algae were found to have a normal green color indicating growing cells. It can be said that these algae are ready to photosynthesize and produce chlorophyll.

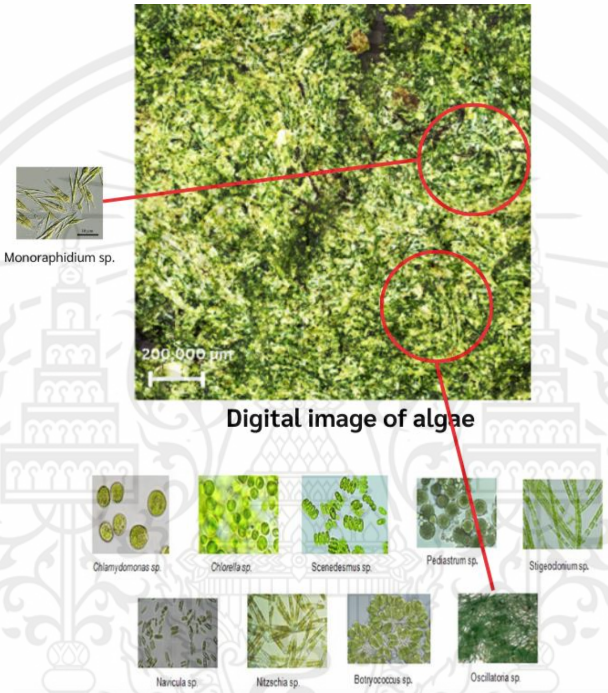


Figure 4.1 The characterization of sample algae compared with some of the algal species being used in wastewater treatment [21]

Figure 4.1 also shows a comparison of the characteristics of species of algae that can be found in wastewater. The red circles that the researcher can observe are similar to *Monorphidium* sp. and *Oscillatoria* sp., it can be assumed that the sample of algae has the part on these species.

4.2.2 Dry weigh measurement

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

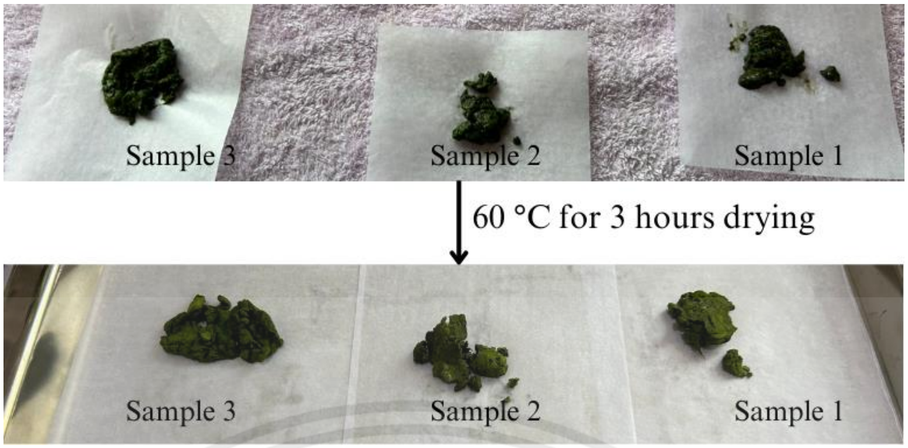


Figure 4.2 Photo of algae before and after drying

Figure 4.2 shows pictures of algae before and after drying. In order to determine the dry weight of algae. The researcher conducted an experiment by drying 3 samples of wet algae by the same condition and weighing them to find the average dry weight of the three algae. The results are shown in Table 4.2.

Table 4.2 Dry weight and wet weight of 3 samples

Sample	Wet weight (g)	Dry weight (g)	Dry/wet
1	5.8233	1.8348	31.5
2	3.3850	1.1018	32.5
3	3.8475	1.512	39.3
Average			34.5

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

4.3 Shell characterization

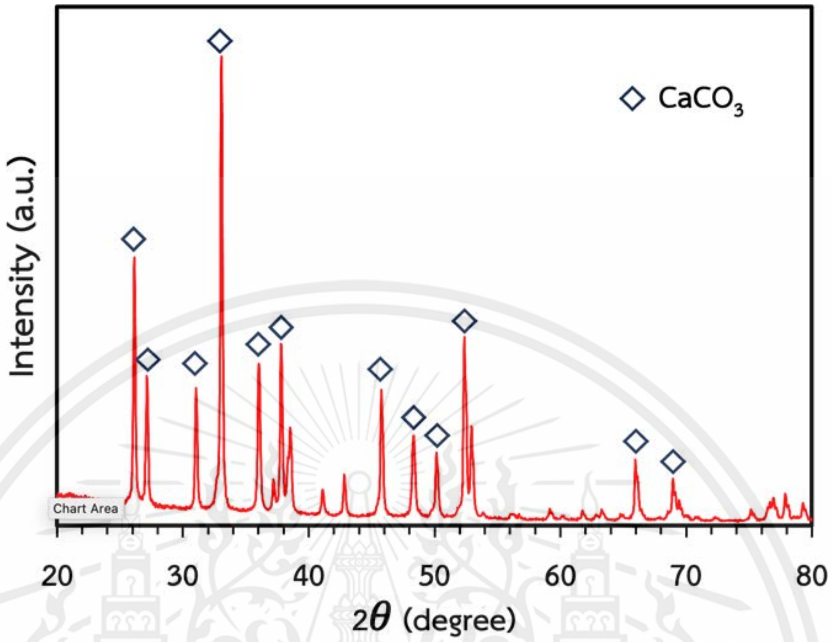


Figure 4.3 XRD result of mussel shell powder

From the XRD results of crushed mussel shell powder as shown in Figure 4.3, it was found that the XRD peak of aragonite ($CaCO_3$) (JCPDS 01-075-9985) was the location of the peak of most shells. In positions 26°, 27.23°, 33.09°, 37.84°, 45.81°, 48.36°, 50.21°, 52.38°, 66.09° and 68.93° they were found to be very similar. Therefore, it can be concluded that the mussel shells used in the experiment were mainly composed of argonite or calcium carbonate ($CaCO_3$).

4.4 The efficiency of CO_2 reduction of 2-layer carbon capture

It was found that from day 1 to day 12, the average CO_2 reduction efficiency of algae and shellfish was 54.6%, and the highest CO_2 reduction efficiency was 69.1% on day 7, while the CO_2 reduction efficiency was the least on day 1. 12 is at 34.6%. From Figure 4.4, it can be seen that the efficiency in reducing CO_2 will gradually increase and at a certain point it will begin to be less effective in reducing CO_2 due to the early stages of the algae experiment. It grows well by using the nutrients available at the beginning, making it highly effective in reducing CO_2. But as time

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

passes, the algae grow more but the amount of nutrients decreases [22] due to being used. already in the first period Therefore, when the growth rate of algae decreases, CO_2 fixation decreases as well.

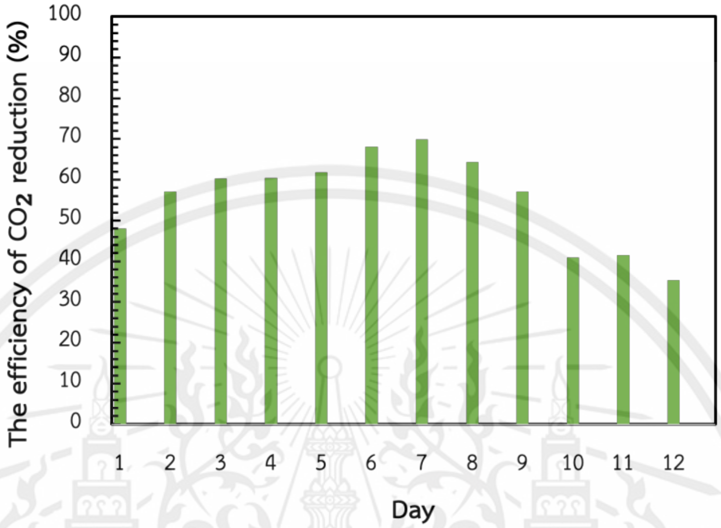


Figure 4.4 The CO_2 reduction efficiency of the two-layer carbon capture system

From the shell dissolution reaction as shown in the chemical equation below [23]

$$\mathrm{CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca^{2+} + 2HCO_3^-} \qquad (6)$$

When water and CO_2 mix with calcium carbonate ($CaCO_3$) contained in mussels, Calcite will dissolve until calcium ions (Ca^{2+}) and bicarbonate ions (HCO_3^-) are dissolved, which makes the water more alkaline. As the water absorbs more CO_2, the water may end up buffered by dissolving carbonate to reverse the reaction and produce CO_2 again. To prevent excessive CO_2 suction from the algae tank into the shell tank causing the reaction to reverse, air pump 2 will have a lower flow rate than air pump 1. Therefore, after reducing the efficiency of reducing CO_2 of only the algae tank, the efficiency in reducing CO_2 of both systems has not decreased much.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

4.5 The power performance in off-grid solar system

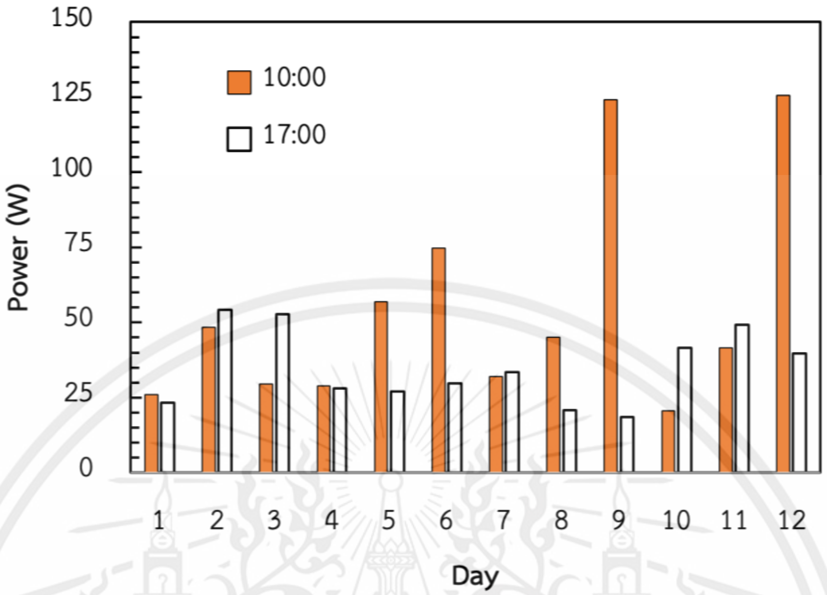


Figure 4.5 Power produced from an off-grid solar cell system at 10:00 and 17.00

Figure 4.5 shows the power production of the double-layer CO_2 capture solar power system at 10.00 and 17.00. It was found that the overall efficiency of power production at 10:00 was higher production efficiency at 17.00. The highest power that can be produced is on day 9 (124.1W) and day 12 (125.6W) and the least was on day 10 (21.9W). From the observation that on the 9th and 12th day, there was strong sunshine. There was also rain in the morning of the 10th, with the power production range between 18.6W - 54.2W.

4.6 The pH value of algae and seashell tank

From Figure 4.6, it was found that on the first day, the pH of the algae tank decreased slightly to 8.56 by blowing air into the system (14 L/min) in the same direction as the research. 'Algae to reduce global warming' (2017) [24] that studied the addition of carbon dioxide in farming Chlorella sp. algae found that the pH value would decrease from 7.35 to 6.92. After that, when the algae were able to adjust, they would begin to use some carbon dioxide in order to increase photosynthesis, the pH value will decrease. After that, the pH value will start to stabilize [25].

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

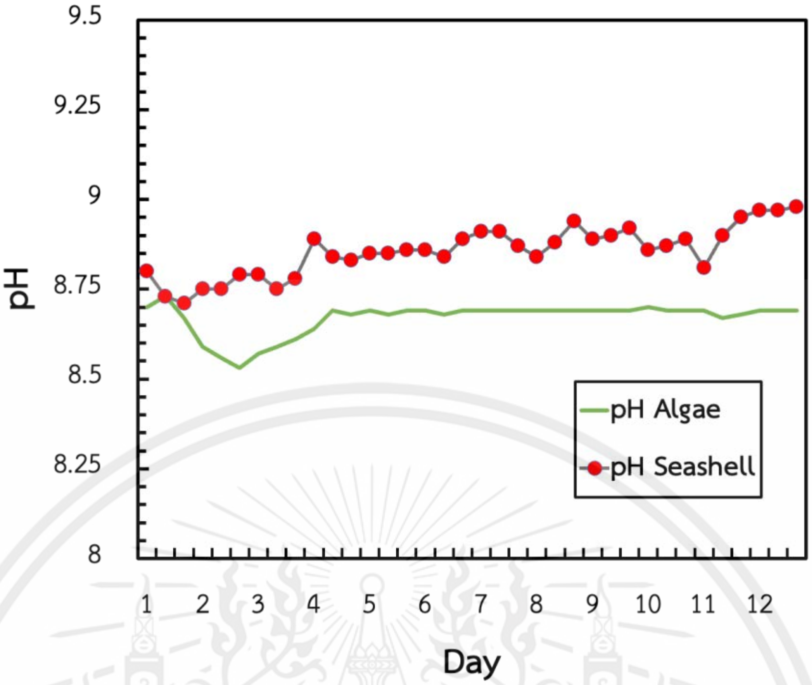


Figure 4.6 The pH of the algae and shell tank for 12 days

Meanwhile, it can be observed that the pH value of the shell tank in Figure 4.6 tends to be more alkaline in the range between 8.71 and 8.98, meaning that the shell dissolves through reaction (6). The dissolution process increases the alkalinity of seawater. (ALK), which increases the ability of water to absorb carbon. It acts as an antagonist against increasing CO_2 levels in the atmosphere, also related to the CO_2 reduction efficiency of the double-layer carbon capture system because the alkalinity of the shell water means that it has the ability to reduce CO_2.

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

4.7 Tanks observation

4.7.1 Algae tank observation

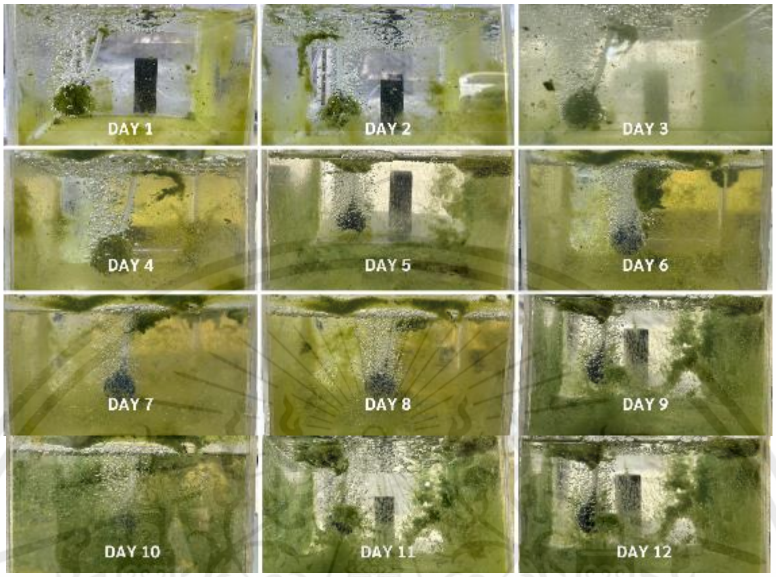


Figure 4.7 Pictures of algae cultivation in a algae tank over 12 days

Observations of the algae tank in Figure 4.7 from day 1 to day 12 were clearly different. The culture contained 1.0 g of sodium chloride per liter on the first day. Algae in this closed system can use sunlight to grow during the day. At night, algae can use light from a 6-watt blue LED bulb (Horse Power, HP-350) for optimal growth under a limited period of time. All photos were taken at 17.00 every day. From the first day, algae could be seen clinging to the oxygen concentrators and beginning to multiply. On day 4, the water became cloudy from growing algae fragments. On day 8, algae began to float on top of the water. Some clung to the edges and walls of the tank, and on day 12, large amounts of dark green algae gathered in large clumps. More will fall off the walls of the tank and float in the tank, turning the water a darker green. This may indicate old or dead cells of the algae [26].

To calculate the biomass productivity from day 1 to day 12 (12 days), it was calculated by equation (1) where DCW1 equals 3 grams, DCW2 is 30.7 grams. Biomass productivity of the algae is 4.619 $g\ L^{-1}d^{-1}$.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

4.7.2 Shell tank observation

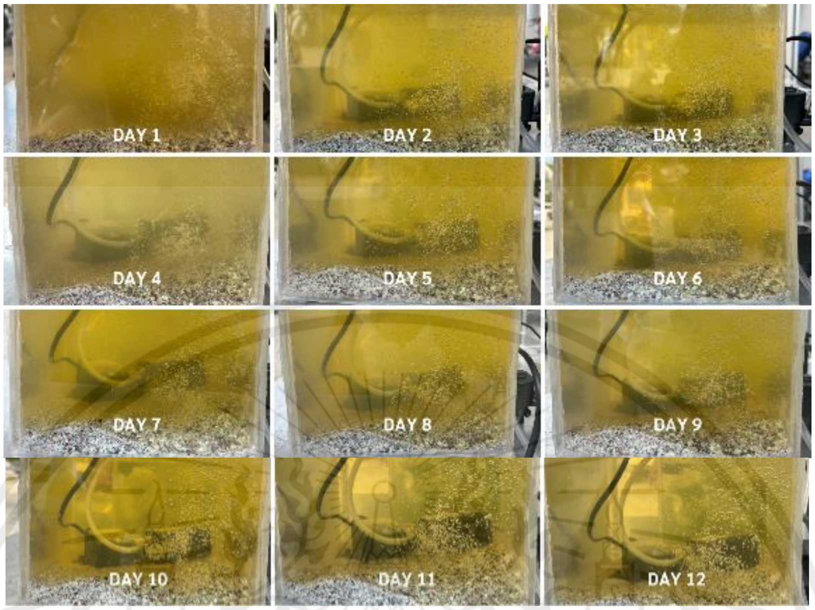


Figure 4.8 Pictures of shells dissolving in a shell tank over 12 days

All photos of the shell tank in Figure 4.8 were taken at 17.00 each day with air pumped with air pump 2 from day 1 to day 12. It is noticeable that the water in the tank is cleaner and clearer.

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use

CHAPTER 5

CONCLUSION

This chapter will discuss the summary of the experimental results and suggestions for improving the design of an off-grid solar-driven system for dual-layer carbon capture system integrating algae and seashell, which is shown in the following topic

5.1 Summary of experimental results

5.2 Suggestions

5.1 Summary of experimental results

Off-Grid solar power system design for a 2-layer carbon dioxide capture process with algae and mussel shells for 12 days by growing the algae with 6.0 liters of chlorine-free water with 1.0 sodium chloride (NaCl) nutrient g/L. Air is sucked in with an air pump 1 (14 L/min). The ratio of natural light to 6W blue LED lights is 12:12. Mix a layer of 600.5 grams of crushed mussel shell with water to increase the absorption of carbon dioxide in the working volume of 6.0 liters.

The results show the average CO_2 reduction efficiency of the two-layer carbon capture system was 54.6%, with the highest efficiency recorded on day 7 at 69.1% and the lowest on day 12 at 34.6%, with a correlation. by dissolving calcium carbonate in shell tanks to help reduce CO_2 levels. In addition, the off-grid solar cell power system provided enough power to run the experiment for 12 days. The power produced at 10.00 fluctuated and the power produced tends to depend on weather conditions, contrast to the constant range at 17.00. The pH values of both the algae and shell tanks showed a clear trend. The algae tanks initially decreased in value before stabilizing. Meanwhile, the shell tank maintains an alkaline pH, which is caused by the dissolution of the shells, which increases the CO_2 reduction efficiency. Observation of the algae tank and shell tank. It revealed significant algae growth and a biomass yield of 4.619 $g\ L^{-1} d^{-1}$. Meanwhile, in the shell tank, it was found that the water was clearly cleaner.

Overall, the findings indicate the potential of algae and shell to alleviate carbon dioxide levels and highlighting the ability to capture carbon and produce sustainable solar energy.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

5.2 Suggestion

The off-grid solar energy system design is able to provide power for 12 days continuously to a two-layer carbon dioxide capture process using algae and mussel shells, which has an average efficiency in reducing carbon dioxide of 54.6% which is the efficiency of the whole system. But, the performance of the algae tank and the seashell tank cannot be determined separately.

Researcher suggests that the sensors should be installed between the algae tank and the shell tank as an alternative for determining the efficiency of reducing carbon dioxide in each tank.

In addition, the information obtained can be developed into science activities that focus on creating solar energy production sources or conserving water sources by reusing waste to reduce carbon dioxide. Raise awareness of the use of mussel shells and algae for their intended purpose.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

REFERENCES

[1] Boden, T.A., Marland, G., Andres, R.J. (2017). Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory, U.S. Department of Energy. https://doi.org/10.3334/CDIAC/00001_V2017

[2] EPA. (2021). Global Greenhouse Gas Emissions Data. Retrieved from https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

[3] Green Network. (2022). Carbon Dioxide Emissions from the Energy Sector in Thailand's First 6 Months of 2565 BE. https://www.greennetworkthailand.com/CO_2-energy-q2-2565/

[4] Xu, X., Gu, X., Wang, Z., Shatner, W., & Wang, Z. (2019). Progress, challenges and solutions research on photosynthetic carbon sequestration efficiency of microalgae. Renewable & Sustainable Energy Reviews, 110, 65–82. https://doi.org/10.1016/j.rser.2019.04.050

[5] Bhola, V., Swalaha, F. M., Kumar, R. R., Singh, M., & Bux, F. (2014). Overview of the potential of microalgae for CO_2 sequestration. International Journal of Environmental Science and Technology, 11(7), 2103–2118. https://doi.org/10.1007/s13762-013-0487-6

[6] Suktalord, P., Pratsaphan, R., Rakchad, S., Petchpool, T., Kerdsombat, P., & Laloknam, S. (2016). The Use of Algae as Water Quality Indicator in Sansab Canal. Research Unit of Science, Technology, and Environment for Learning, Faculty of Science, Srinakharinwirot University. https://doi.org/10.14456/jstel.2016.2

[7] Juškaite, L., & Zagorskis, A. (2020). Microalgae strains monoraphidium griffithi and chlorella sp. for the carbon dioxide capture from biogas. The 11th International Conference ENVIRONMENTAL ENGINEERING 11th ICEE SELECTED PAPERS. https://doi.org/10.3846/enviro.2020.720

[8] Anguselvi, V., Masto, R. E., Mukherjee, A. K., & Singh, P. P. (2019). CO_2 capture for industries by algae. In IntechOpen eBooks. https://doi.org/10.5772/intechopen.81800

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

[9] เงินคำคง, ค., ชื่นบาล, ศ., ชื่นบาล, ฐ., & เงินคำคง, น. (2017). The Efficiency of Carbon Dioxide Capture by Green Microalgae. https://ph01.tci-thaijo.org/index.php/rmu tijo/article/view/96537

[10] Zhang, H., Kuo, W., Gao, F., Li, Z., Yu, Z., Jiang, J., Lian, T., & Feng, G. (2023). Feedbacks of $CaCO_3$ dissolution effect on ocean carbon sink and seawater acidification: a model study. Environmental Research Communications, 5(2), 021004. https://doi.org/10.1088/2515-7620/aca9ac

[11] Li, J., Irfan, M., Samad, S., Ali, B., Zhang, Y., Bădulescu, D., & Bădulescu, A. (2023). The Relationship between Energy Consumption, CO2 Emissions, Economic Growth, and Health Indicators. International Journal of Environmental Research and Public Health, 20(3), 2325. https://doi.org/10.3390/ijerph20032325

[12] Singh, J., & Dhar, D. W. (2019). Overview of Carbon capture Technology: Microalgal Biorefinery concept and State-of-the-Art. Frontiers in Marine Science, 6. https://doi.org/10.3389/fmars.2019.00029

[13] Wang, Y., Stessman, D., & Spalding, M. H. (2015). The CO_2 concentrating mechanism and photosynthetic carbon assimilation in limiting CO_2: how Chlamydomonas works against the gradient. Plant Journal, 82(3), 429–448. https://doi.org/10.1111/tpj.12829

[14] Ighalo, J. O., Dulta, K., Kurniawan, S. B., Omoarukhe, F. O., Ewuzie, U., Eshiemogie, S. O., Ojo, A. U., & Abdullah, S. R. S. (2022). Progress in microalgae application for CO2 sequestration. Cleaner Chemical Engineering, 3, 100044. https://doi.org/10.1016/j.clce.2022.100044

[15] Popović, N. T., Lorencin, V., Strunjak-Perović, I., & Čož-Rakovac, R. (2023). Shell Waste Management and Utilization: Mitigating organic pollution and enhancing sustainability. Applied Sciences, 13(1), 623. https://doi.org/10.3390/app13010623

[16] Zhang, H., Kuo, W., Gao, F., Li, Z., Yu, Z., Jiang, J., Lian, T., & Feng, G. (2023). Feedbacks of $CaCO_3$ dissolution effect on ocean carbon sink and seawater acidification: a model

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

study. Environmental Research Communications, 5(2), 021004. https://doi.org/10.1088/2515-7620/aca9ac

[17] Measurements of cell biomass concentration. (n.d.). Retrieved from https://user.eng.umd.edu/~nsw/ench485/lab9c.htm

[18] Brian. (2022). Off-Grid or On-Grid PV systems: Which to choose? Professional Distributed PV Module Manufacturer. https://www.maysunsolar.com/off-grid-or-on-grid-pv-systems/

[19] Vidyanandan, K. (2017). An Overview of Factors Affecting the Performance of Solar PV Systems. Power Management Institute, NTPC Ltd., NOIDA, India.

[20] Kao, C. Y., Chiu, S. Y., Huang, T. T., Dai, L., Hsu, L. K., & Lin, C. S. (2012). Ability of a mutant strain of microalgae Chlorella sp. to capture carbon dioxide for biogas upgrading. Applied Energy, 39, 76-183.

[21] Vinod, K., Richa, K., Sonika, K., & Pankaj, K. (2020). Sustainable approaches towards wastewater treatment using algal technology along with management of post-harvest biomass.

[22] Sumardiono, S., Yono, B., Syaichurrozi, I., & Sasongko, S. B. (2014). Utilization of biogas as carbon dioxide provider for Spirulina platensis culture. Biological Sciences, 6(1), 53-59.

[23] Sea, M. A., Hillman, J. R., & Thrush, S. F. (2022). The influence of mussel restoration on coastal carbon cycling. Global Change Biology, 28(17), 5269–5282. https://doi.org/10.1111/gcb.16287

[24] Zhou, W., Wang, J., Chen, P., Ji, C., Kang, Q., Lu, B., Li, K., Liu, J., & Ruan, R. (2017). Bio-mitigation of carbon dioxide using microalgal systems: Advances and perspectives. Renewable & Sustainable Energy Reviews, 76, 1163–1175.

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

[25] Suktalord, P., Pratsaphan, R., Rakchad, S., Petchpool, T., Kerdsombat, P., & Laloknam, S. (2016). The use of algae as water quality indicator in Sansab Canal. หน่วยวิจัยวิทยาศาสตร์ เทคโนโลยี และสิ่งแวดล้อมเพื่อการเรียนรู้คณะวิทยาศาสตร์มหาวิทยาลัยศรีนครินทรวิโรฒ.

[26] Brittany.Chesser. (2020). Planktonic Algae Die-off - Aquaculture, Fisheries, & Pond Management. Aquaculture, Fisheries, & Pond Management. https://fisheries.tamu.edu/2020/12/02/planktonic-die-off/

King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

APPENDIX A
COMPLETED STRUCTURE

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

APPENDIX B

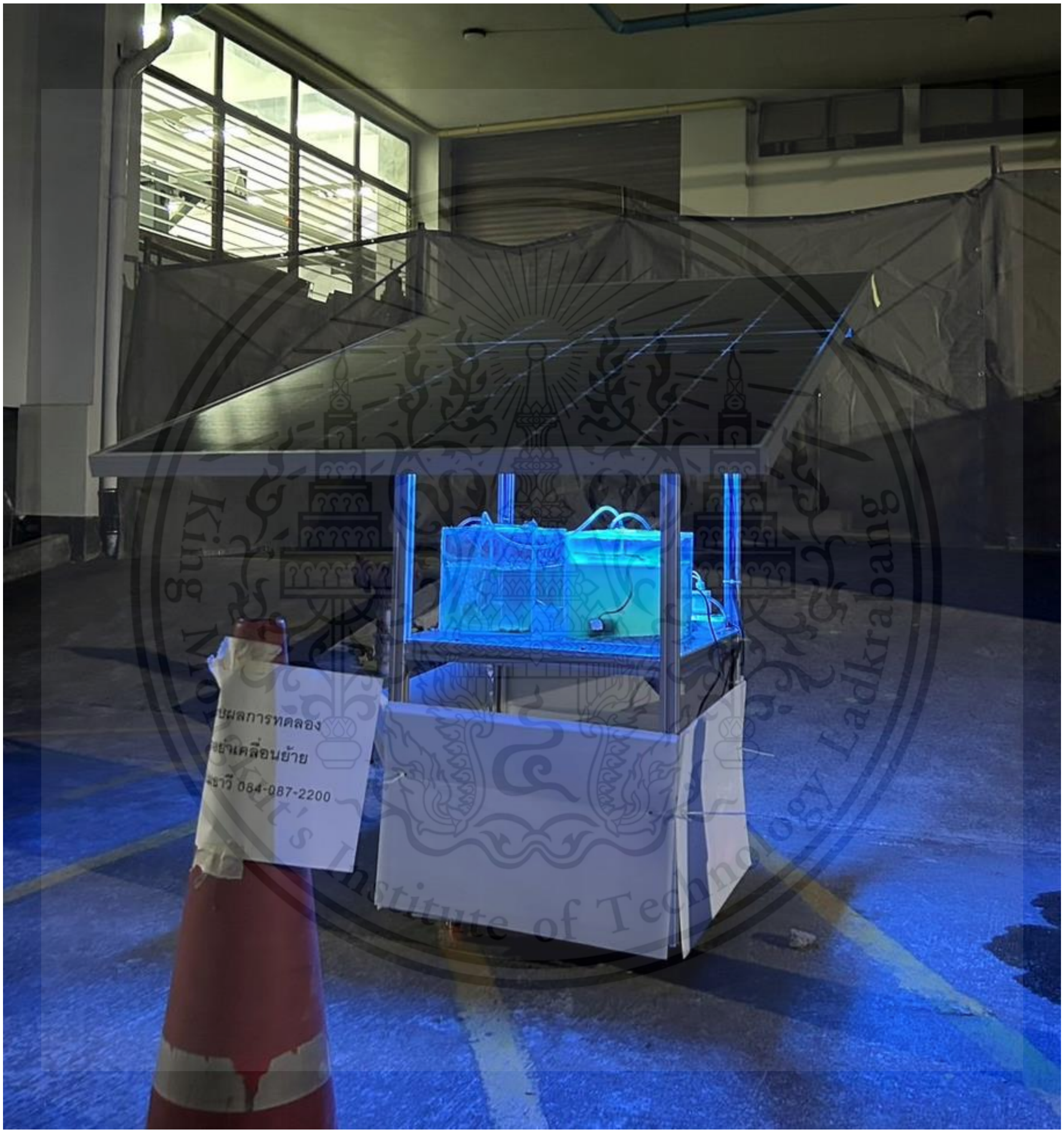
THE SYSTEM AT DAY TIME

This material is reserved for educational use only, not allowed for commercial use.

Forbidden to modify the content, and cite the document when use

APPENDIX C

THE SYSTEM AT NIGHT TIME



King Mongkut's Institute of Technology Ladkrabang

This material is reserved for educational use only, not allowed for commercial use.
Forbidden to modify the content, and cite the document when use