Development and Assessment of Integrated System for Promotion of Biomass Utilization

（バイオマス利活用の促進に向けた
複合型システムの開発および評価）

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Abstract

論文内容の要旨　(博士)

Title of Thesis 博士学位論文名	Development and Assessment of Integrated System for Promotion of Biomass Utilization （バイオマス利活用の促進に向けた複合型システムの開発および評価）

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The rapidly growing population and urbanization are accompanied by the increase of waste generation, which is well beyond the nature's assimilative capacity. Green technologies, namely anaerobic digestion and composting are among the emerging approaches to utilize the organic fraction of the waste, in order to achieve energy and nutrients recovery, as well as to establish a sustainable society. However, the application of such green technologies are not as wide as anticipated. Among the common constraints, such as technical, political and economic, the lack of public interest is considered as the most vital factor. Currently most of the studies focused on improving the performance or efficiency of each technology. But if the technologies do not attract, or benefit the public in a more direct way, the public's perspectives towards the biomass utilization may remain the same. A different approach, which can serve as a stimulus for the public interest, is therefore essential.

The main objective of this thesis is to propose an integrated system that not only utilizes the biomass but also results into the production of crops using the by-products from the biomass utilization. Differ from typical approach such as anaerobic digestion, where the main concern is to produce biogas as the result, under the integrated system the CO_2 that contains inside the biogas and emits during the combustion of biogas is used for CO_2 enrichment in seaweed cultivation and greenhouse, respectively. The latter is hence presented as an extra value for implementation of anaerobic digestion. The crops produced can be served as the direct benefit back to the public, who generate the biomass at the first

place. It is anticipated that the awareness towards the benefits of biomass utilization can be improved under such integrated system.

This thesis consists of 3 main parts, with the first and second part discussed about the integration of anaerobic digestion with land-based seaweed cultivation and greenhouse, respectively. The CO_2, as a result of purification or combustion of biogas, is usually discharged into atmosphere without further utilization. By introducing land-based seaweed cultivation to be integrated with anaerobic digestion, the CO_2 that dissolved in the water upon purification of biogas, can be used to promote the seaweed growth. In the case of commercializing the land-based seaweed cultivation, the cost of transporting seawater was estimated to be a major concern.

In the second part, the greenhouse was introduced to be integrated with anaerobic digestion, in which the CO_2 emitted during the combustion of biogas was utilized as the source of CO_2 enrichment in greenhouse. Based on the investigations, the injection of such CO_2 into the greenhouse did not only enhance the plants growth, but also could be served as the solution to prevent CO_2 depletion that would instead affect the plants growth in typical greenhouse approach. All in all, instead of discharging the CO_2 into the atmosphere it is certainly more beneficial to direct the CO_2 into the greenhouse.

The third part focused on verifying the vacuum-type aeration system as the efficient composting method to overcome conventional problems faced by composting. Odor control and the difficulty in monitoring are the two major concerns regarding composting. By using the vacuum-type aeration system, the gases, including the odorous gases that emitted during the composting process are collected and directed to a chemical scrubber. Apart from reducing the odor emission to the air, as reported in other studies, the composition as well as concentration of those gases can be monitored easily, as showed from the investigations in this thesis. On the other hand, quinone profile analysis, which can effectively quantify the changes in microbes, was introduced as a supportive monitoring method. These would certainly help to manage the composting process in a more efficient and comprehensive way, and even can be the breakthrough point for beginners to utilize the biomass through composting.

Overall, the proposed integrated system presented a shift of perspectives towards waste management in this coming era. The concept of such integrated system is to not only dispose of the biomass safely but also creates straight and direct values, namely crops production, to the public simultaneously. By implementing the integrated system, as proposed in this study, the biomass treatment will no longer be seen as a public nuisance that brings no benefits at all. The idea of utilizing by-products particularly CO_2, which conventionally discharged into atmosphere, can certainly change the perspectives towards current approach of biomass treatment. It is highly anticipated that this concept could be the benchmark for further innovative prospects, where the possibility as well as the potential of biomass can be fully utilized, and hence promoting the biomass utilization especially in developing countries.

(769 words)

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CHAPTER 1
GENERAL INTRODUCTION

1.1 Background

According to United Nation, the world population is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and exceed 11 billion in 2100 [1]. On the other hand, in 2014, 54% of the world's population is residing in urban areas, and by 2050, 66% of the world's population is projected to be urban, particularly in Africa and Asia [2]. The rise of population and urbanization, however, has been accompanied by huge concern particularly in terms of environmental disturbances. These environmental disturbances include changes in landscape, impacts on biophysical environments, shortage of natural resources, as well as emission of an enormous amount of waste. In contrast to ages ago, where any environmental disturbances caused by people were local and usually well within the environment's capacity to absorb them, the environmental disturbances nowadays come in larger scale and thus beyond nature's assimilative capacity [3]. And hence the waste management has been the shared task for every region and countries, in order to protect the environment, as well as the interest of public health. For the discussion to follow, this study would focus on the organic fraction of the waste, which will be stated as biomass, as it is the major part of the waste discharged in any region, and would one of the main cause of environmental disturbances if treated improperly.

Most of all, the expectations regarding the waste management nowadays are concluded to at least meet the following main principles: secure of public health and environmental impacts, energy and nutrients recovery, and contribution towards sustainable society. For these principles, green technologies, namely anaerobic digestion and composting, are gaining focus as the alternative methods to treat the organic fraction of the waste. Many studies have been conducted, regarding the utility as well as improvement of each process, as reviewed elsewhere [4-7]. Nevertheless, overall the application of such green technologies is not as significant as anticipated, even though the public is well aware of their advantages and potentials. Therefore, a different approach, or addition of extra values that differs itself to current state is needed, in order to promote the implementation of the green technologies in waste treatment.

1.2 Motivation and Objectives

As mentioned above, the world nowadays is becoming more urbanized and developed. The rapidly increasing populations each year have resulted into a historically high level of consumption level. An inevitable consequence of this growing consumption trend is the rapid increase in the amount of waste produced. In order to regulate the waste disposal, and also help to alleviate the environmental disturbances, an effective and sustainable waste management system is very much needed.

Various green technologies, such as anaerobic digestion and composting, are emerging as the alternative methods to dispose of the organic waste. Numerous studies and investigations have been conducted to introduce their potential as well as improve their performance and efficiency. Yet, the application of the green technologies is not as wide as anticipated, especially in the developing countries. A number of constraints, namely technical, financial, institutional, economic, and public interest, are often discussed as the reasons behind [8]. Among them, the public interest is perhaps the most vital, as the public awareness and attitude about waste can affect the whole waste management [9-10]. The need to improve public awareness of, and community participation in, waste management has been widely recognized by researchers as necessary to create sustainable waste systems and to promote environmental citizenship amongst community members. It is argued that people of lower socio-economic groups tend to have less regard for environmental issues on the basis that employment and housing are their main priorities [11]. The issues of public acceptance, changing value systems, public participation in planning and implementation stages, and changes in waste behavior are equally as important as the technical and economic aspects of waste management [12]. As the integration between socio-economic and environmental studies is essential [13], the participation of the community in the production and use of scientific knowledge is considered the best approach to environmental management of waste.

Therefore, a different approach, which can serve as a stimulus for the public interest, and at the same time assure the concerns regarding the green technologies, is essential for the promotion of the implementation of green technologies in the organic waste treatment. In this thesis, an integrated system that combines the treatment of organic waste with production of crops was proposed. It is a concept that starts from treating organic waste with anaerobic digestion or composting, in which energy and nutrients can be recovered. Then the CO_2, emitted as a result of purification or combustion of biogas, is utilized for CO_2 enrichment in seaweed cultivation and greenhouse, respectively. As for the composting process, a vacuum-type aeration system was introduced to overcome the conventional concerns of composting, namely odor control and process monitoring. Such integrated system would not only treat the organic waste with energy and nutrients recovered, but also produce crops that can be viewed as an innovative output for waste treatment.

The main objective of this thesis is to propose the integrated biomass utilization system mentioned above to the public in the aim for the promotion of biomass utilization. In order to archive this objective, several sub objectives, as stated below, are set:

1) To investigate the utilization of biogas' CO_2 in land-based seaweed cultivation;
2) To investigate the CO_2 enrichment in greenhouse using the CO_2 emitted from the combustion of biogas;
3) To introduce and verify the utility of vacuum-type aeration system in monitoring composting process.

1.3 Structure of Thesis

The structure of this thesis can be described as Figure 1.1 below.

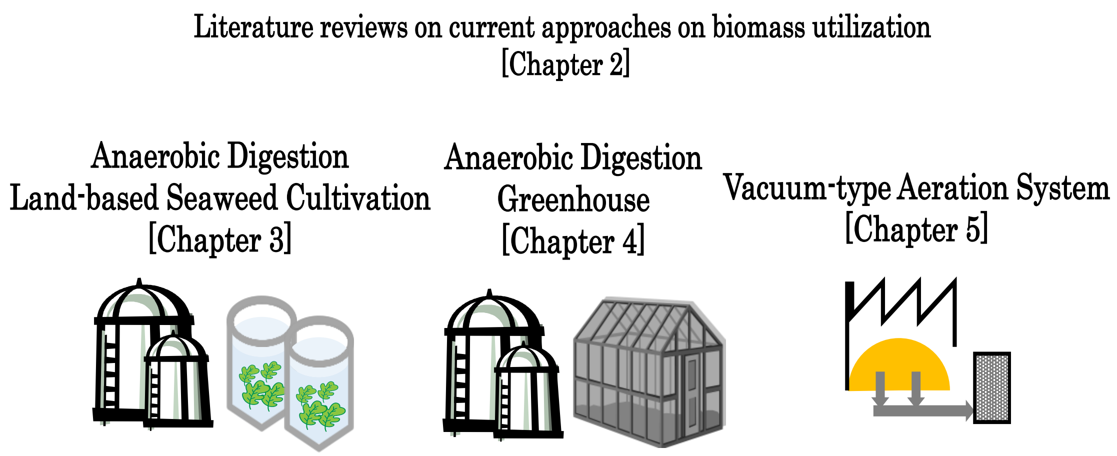

Figure 1.1 Brief description of thesis structure

Contents of each chapter are as followed:

Chapter 1: Introduction of the general background, motivation and objectives, and the structure of this thesis.

Chapter 2: Literatures review was carried out, focusing on the current studies and strategies regarding the waste management, biomass utilization approaches, anaerobic digestion, composting, etc.

Chapter 3: Biogas' c, which is lack of utilization currently, was applied as CO_2 enrichment in land-based seaweed cultivation. The commercial-scale was discussed with operating costs estimated.

Chapter 4: The integration between anaerobic digestion and greenhouse was discussed, with focus on the changes in CO_2 concentration in the greenhouse atmosphere. The amount of CO_2 necessary was estimated as well, based on the greenhouse scale used in the study.

Chapter 5: Oily sludge, which is the residue upon treatment of grease trap waste, was composted using vacuum-type aeration system. The composting conditions were investigated, with the utilities of vacuum-type aeration system as the next era composting method evaluated.

Chapter 6: Conclusions of all chapters and the future prospects that the proposed integrated system were stated.

CHAPTER 2

LITERATURES REVIEW

2.1 Overview of Waste

Waste is any substance that is discarded after primary use. It is unwanted and sometimes unstable as well as hazardous materials, which need to be treated before discharge. Although the definition and category of waste are different in each region and country, it is broadly classified into organic and inorganic. The organic fraction includes animal by-products, food scraps, agricultural waste, sewage sludge, and etc., while the inorganic fraction mostly consist of metal, glass, plastic and others. Waste generation and waste composition varies between and also within regions and countries, primarily caused by the differences in economic development, the degree of urbanization, and also the local culture and climate, population. In terms of municipal solid waste (MSW), the generation levels are approximately 1.3 billion tons per year, and are expected to increase to approximately 2.2 billion tons per year by 2025 [14]. Waste generation rates have been positively correlated to per capita energy consumption GDP and final private consumption [15], and hence it is certain that the overall waste generation in a global scale would only increase, as a result of population and economic growth.

Figure 2.1 showed the global solid waste composition. Although the waste composition is influenced by many factors, almost half of the global solid waste composition consists of organic matter. The percentage of organic matter is particular high in countries other than high-income countries. Figure 2.2 showed the difference of waste composition by country income. Overall, low- and middle-income countries have a high percentage of organic matter (40-85%) in the urban waste stream, whereas the middle- and high-income countries' saw increase in inorganic matter, such as plastic and metal [14]. As the major part of the waste discharged in any region is in fact organic matters, therefore it is very important to assure that the disposal or treatment of organic matters in the regions are properly practiced. For the discussion to follow, this study would focus on the organic fraction of the waste, which will be stated as biomass. Figure 2.3 showed the common biomass sources.

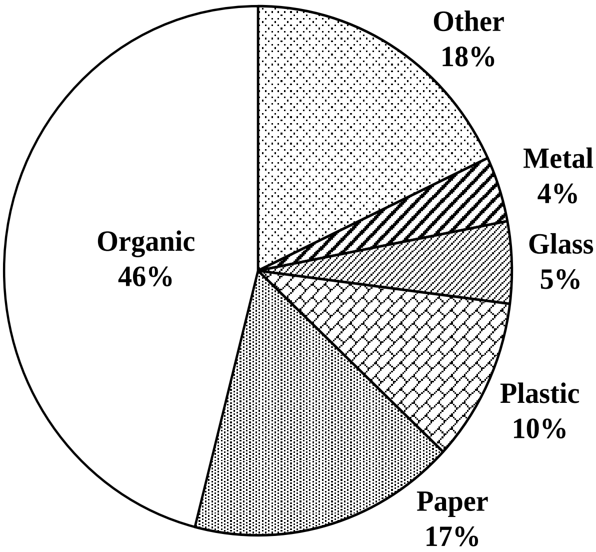

Figure 2.1 Global solid waste composition [14].

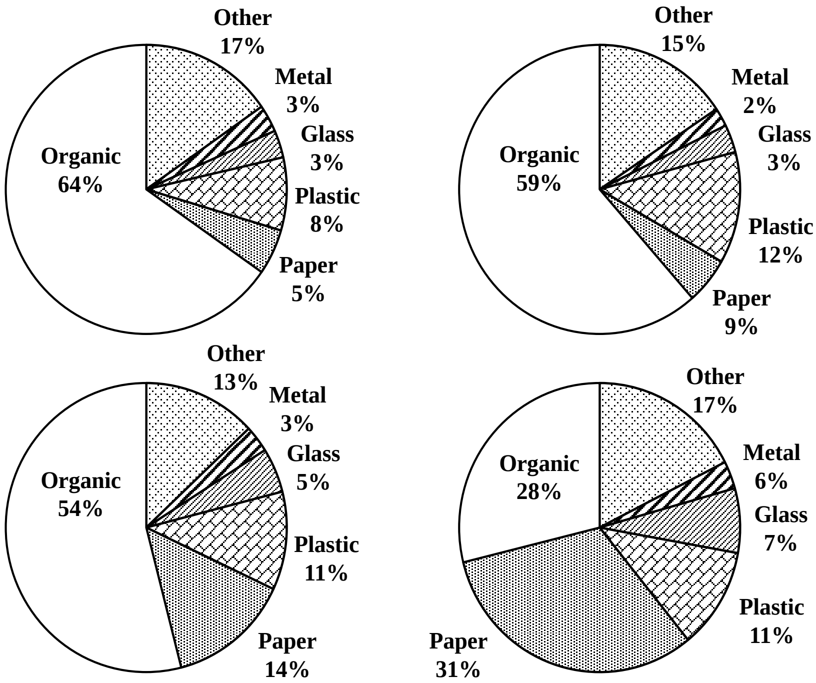

Figure 2.2 Difference of waste composition by country income [14].

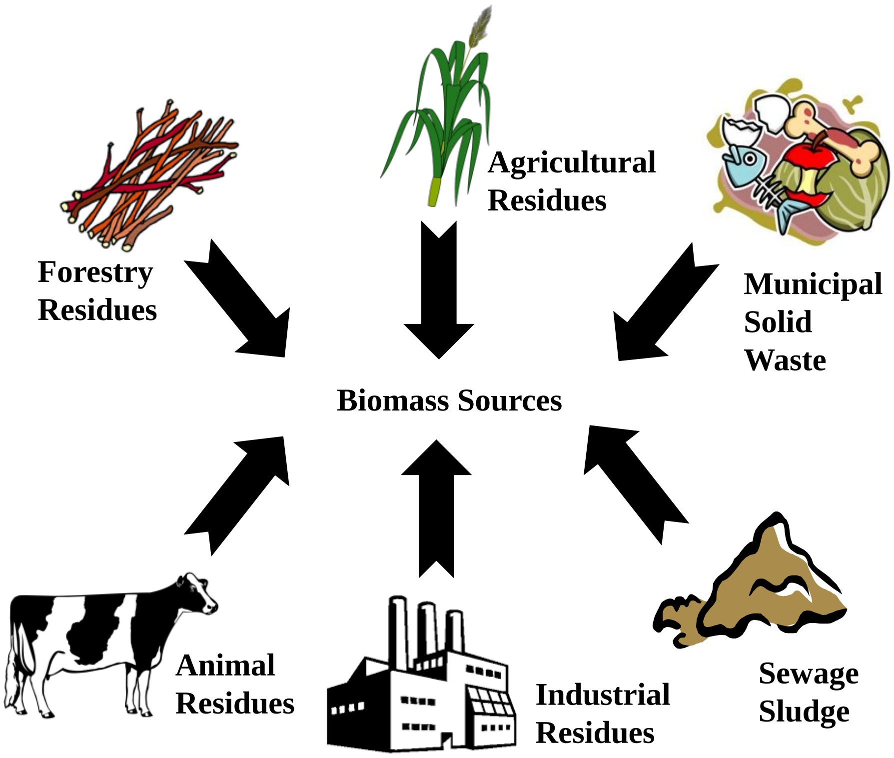

Figure 2.3 Common biomass sources.

2.2 Waste Hierarchy Concept

As the waste continues to increase, the waste management or waste treatment has become more and more crucial for every region. The waste hierarchy concept is the most common principle in waste management. Figure 2.4 showed the common concept of waste hierarchy. It is often showed as a pyramid, with the basic premise being the prevention of waste generation. This is followed by reduction or reuse, and then recycle. The next level is material recovery or waste-to-energy. And the last but least desired is disposal, which is occurred without any benefits recovered. As so, the waste hierarchy classifies the waste management strategies according to their desirability in terms of waste minimization. The aim of the waste hierarchy is to extract the maximum practical benefits from the waste itself and also to generate the minimum amount of the waste eventually.

Since the introduction of the waste hierarchy, it has become the backbone of waste management in most of the regions. However, there are arguments that there are limitations regarding the waste hierarchy, as summarized elsewhere [16]. Mostly it is concluded that social and economic local aspects may invalidate the function of waste hierarchy. It is also believed that waste reduction requires a cultural and social transformation toward a change in demand by consumers [17].One study has suggested that the adoption of a value-based conception of waste can improve the implementation of waste hierarchy [18]. All in all, the search for a better approach to improve the current waste treatment state is an ongoing challenge.

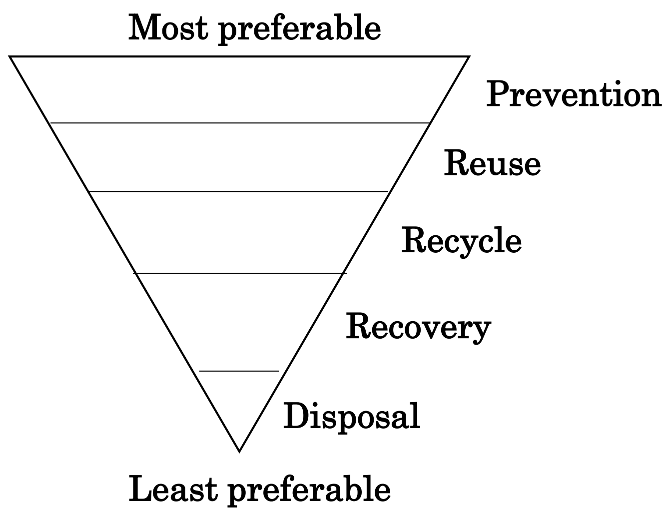

Figure 2.4 Common concept of waste hierarchy [19].

2.3 Current Waste Treatment Methods

Figure 2.5 showed the annual global municipal solid waste as differed by treatment options. Table 2.1 showed in further detail of how municipal solid waste is disposed by country income. The data are, however, only approximate values collected by World Bank. This is because the waste disposal data are the most difficult to collect, as many countries do not collect waste disposal data at the national level, making comparisons across income levels and regions difficult [14]. Nevertheless, the most practiced disposal option is clearly landfill, followed by recycled and then waste-to-energy (WTE). WTE is the process of generating energy in the form of electricity and/or heat through combustion (incineration), or production of a combustible fuel commodity, such as methane, methanol, ethanol or synthetic fuels.

Of the many methods to treat the waste, the major methods, namely landfill and incineration are elaborated here. The target of this study is the organic fraction of the waste, or in other word, the biomass. Therefore the green technologies, namely anaerobic digestion and composting, which can biologically degrade the organic fraction and turn into energy and nutrients, are stated here as well, with emphasis on the tasks they faced.

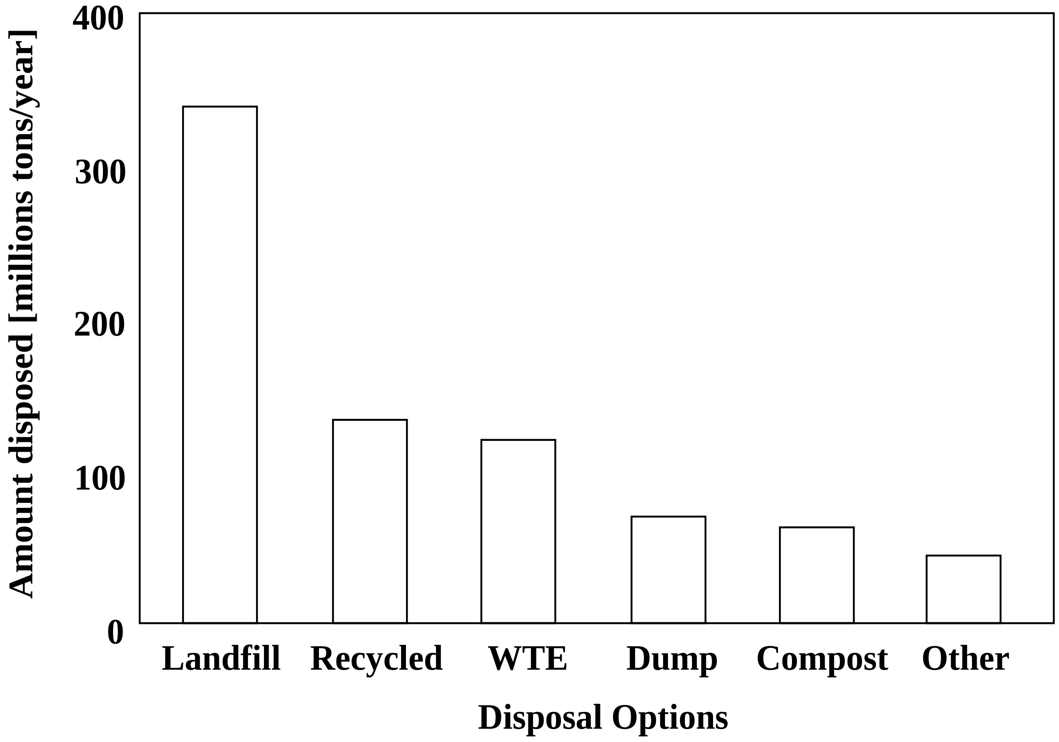

Figure 2.5 Annual global municipal solid waste as differed by treatment options [14].

Table 2.1 Municipal solid waste disposal methods by country income (million tonnes) [14].

High Income		Upper Middle Income	
Dumps	0.05	Dumps	44
Landfills	250	Landfills	80
Compost	66	Compost	1.3
Recycled	129	Recycled	1.9
Incineration	122	Incineration	0.18
Other	21	Other	84
Low Income		**Low Middle Income**	
Dumps	0.47	Dumps	27
Landfills	2.2	Landfills	6.1
Compost	0.05	Compost	1.2
Recycled	0.02	Recycled	2.9
Incineration	0.05	Incineration	0.12
Other	0.97	Other	18

2.3.1 Landfill

From the earliest times, disposal of waste into open dumps was the standard practice. However, this resulted to a lot of problems, such as odors, water pollution and diseases, which led to the concept of burying the waste. The sanitary landfill, which compacts the waste in layers and covers it with earth after one operation, was first used in California in 1934. Since then, many improvements, such as leachate collection and gas recovery have taken place. Some general guidelines have been proposed regarding the design criteria for sanitary landfill [20], as stated below:

- The site should be on inexpensive land within economical hauling distance, have year-round access, and be at least 1500m downwind from residential and commercial neighbors.
- The area should be reasonably clear, level and well drained.
- Soil of low permeability, well above the groundwater table, is desirable for protection of underground water supplied and as cover material.

- A detailed hydro-geological investigation is necessary.

However, there are various problems with land filling, especially when it is poorly operated. Odors and insects are the most evident shortcomings, as well as the leachate and greenhouse gases (GHG) emission during the decomposing of the organic waste [21-22]. While the waste is decomposed, liquid from the waste, seepage from the groundwater, and water from precipitation and surface runoff percolate through the refuse, producing a contaminated liquid called leachate. The leachate would contaminate the groundwater and soil, causing a serious environmental problem both in short and long terms. All in all, bearing such shortcomings, as well as being considered as the least desired option in waste management, landfill would continue to be the predominant method for regions where cost is the determining factor.

2.3.2 Incineration

Incineration is used as a treatment for a very wide range of waste. Basically it is the oxidation of the combustible materials contained in the waste. The combustion of the waste results into production of ashes, flue gases and heat. The inorganic constituents of the waste mostly form into the ashes. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. The objective of incineration is to reduce the waste volume and also destroy the hazardous materials. Approximately 130 million tons of waste is incinerated across 35 countries [23]. Japan, Demark and Luxembourg treated >50% of the waste stream through incineration [23].

Although the incineration sector has undergone rapid technological development over the last few decades, including the energy recovery, debates remain regarding the incineration. Several main issues are stated below [24-26]:

- Disposal of the ashes, which may contain heavy metals
- Control of the emissions to air
- Removal of the fine particulates and toxic gases
- High initial investment and operating costs, which are not favorable for low- and middle-income countries

2.3.3 Anaerobic Digestion

Anaerobic digestion is generally considered to be an economic and environmental friendly technology for treating various organic waste. Under strict anaerobic conditions, the organic waste is decomposed by microorganisms and produced biogas as a result. Biogas, which is a mixture of methane and carbon dioxide, can be used for energy generation, and hence has also been seen as one of the major renewable energy resources. Since the introduction of both commercial and pilot plant designs during the early 1990s, anaerobic digestion of municipal waste (MW) has gained worldwide attention [27]. Most of the anaerobic digestion plants are located in Europe, where more than 7 million tons of municipal waste per year are treated by 212 plants in the EU. Countries having the largest annual capacity installed are Germany and Spain, with 2 and 1.6 million tons of capacity, respectively [28].

Anaerobic digestion is a complex process, which can be divided into 4 main phases of degradation, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Figure 2.6 showed the basic biochemistry process of anaerobic digestion. In the first phase, water-soluble compounds (long-chain carbohydrates, proteins, fats) are broken down. The monomers formed in the hydrolytic phase are then degraded in the second phase, forming into short-chain organic acids, alcohols, nitrogen oxide, hydrogen sulfide, hydrogen and carbon dioxide. In the final phase, the methane formation takes place under strictly anaerobic conditions. Thereby, the carbon in the raw materials is converted into carbon dioxide and methane.

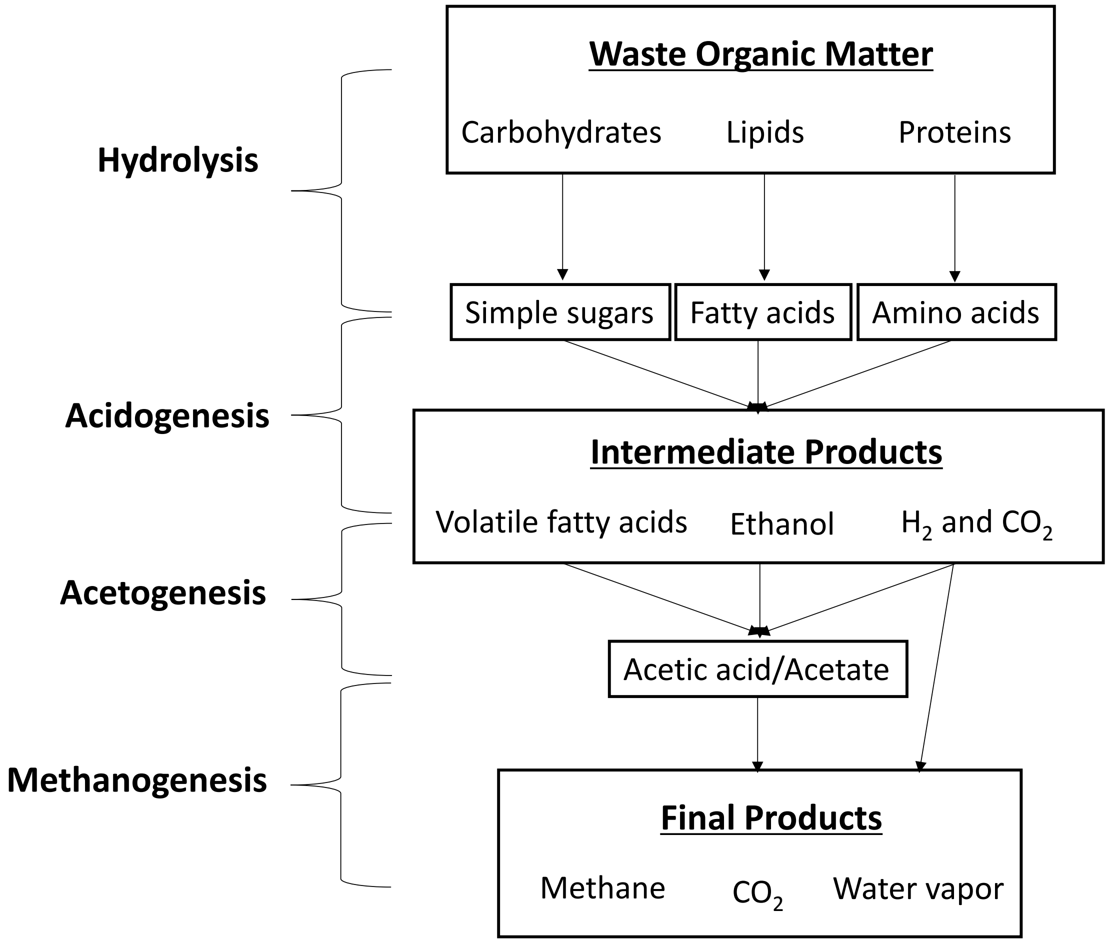

Figure 2.6 Basic biochemistry process of anaerobic digestion [29].

2.3.3.1 Parameters for Optimum Anaerobic Digestion

The microbial metabolism processes in anaerobic digestion are dependent on many parameters. Table 2.2 summarized the common parameters for anaerobic digestion. It is, however, to be noted that the parameters vary according to the concentration and composition of the substrates. In general, the energy balance of anaerobic digestion is better in the mesophilic range than in the thermophilic range. The thermophilic mode of operation results in about a 50% higher rate of degradation, and thus a shorter hydraulic retention time (HRT) and a higher biogas yield. However, in the thermophilic mode, thermophilic methanogens are more temperature sensitive than mesophilic, and hence even small variations in temperature would cause a substantial decrease in activity.

The optimum pH for the methane-forming microorganisms is 6.7-7.5. A fall in the pH value and a rise in the CO_2 in the biogas are an indication of a disturbance of the digestion process. A first sign of the acidification is an increasing propionic acid concentration. Therefore the monitoring of volatile fatty acids, which include propionic acid, is important to understand the process’s condition. Dilution by water, addition of neutralizing substances (sodium carbonate, caustic soda solution), or reduction of the organic loading rate (increase in HRT), are the common prevention of excessive acidification.

Table 2.2 Common parameters for anaerobic digestion [30]

Parameter	Hydrolysis/acidogenesis	Methane formation
Temperature [℃]	25-35	Mesophilic: 32-42
		Thermophilic: 50-58
pH value [-]	5.2-6.3	6.7-7.5
C/N ratio [-]	10-45	20-30
DM content [%]	<40	<30
Required C:N:P:S ratio	500:15:5:3	600:15:5:3
Trace elements	No special elements	Essential: Ni, Co, Mo, Se

2.3.3.2 Utilization of Biomass using Anaerobic Digestion

In general, all types of organic waste, or biomass, that contains carbohydrates, proteins, fats, cellulose and hemicellulose as main components, can be used as substrates for anaerobic digestion. With the introduction of both commercial and pilot anaerobic digestion plant designs during early 1990s, anaerobic digestion of organic waste has received worldwide attention, with various types of organic waste utilized, as reviewed elsewhere [4, 31-33].

Recent research trends saw the increase of anaerobic co-digestion, in which different substrates are mixed and treated together. It has been observed that co-digestion can lead to many advantages. For example, dilution of toxic compounds, increased load of biodegradable organic matter, improved balance of nutrients, synergistic effect of microorganisms and better biogas yield are the potential benefits that are achieved in a co-digestion process. Co-digestion of an organic waste also provided nutrients in excess, which accelerates biodegradation of solid organic waste through bio-stimulation [34]. Additionally, digestion rate and stabilization were increased [35]. It was reported that between 2010 and 2013 the studies about using fats, oils and greases (FOGs) and algae as co-substrate have increased [36]. The interest on FOGs most probably is caused by the growing enforcement of grease trap in restaurants and food industry, while the algae has gained popularity due to its growing potential as a biomass resource.

The research trends also saw focuses on 4 topics, namely (i) the identification of the microbial community dynamics during digestion, (ii) the extension of the existing anaerobic digestion models by inclusion of microbial community data, (iii) the further development and optimization of pre-treatment methods to enhance the anaerobic degradability of the biomass and waste and (iv) the upgrading and purification of the obtained biogas (including its transformation into more value-added components), as summarized elsewhere [37]. The design of digester, the parameters or monitoring approaches for anaerobic digestion performance are the focuses of study as well, as reviewed elsewhere [33, 38].

Table 2.3 summarized the biogas yield obtained from anaerobic digestion based on solid organic waste. Biogas is generally composed of 48–65% methane, 36–41% carbon dioxide, up to 17% nitrogen, <1% oxygen, 32–169 ppm hydrogen sulfide and traces of other gases [39]. Unlike fossil fuel, biogas does not contribute much to the greenhouse effect, ozone depletion or acid rain [40]. This is one of the main reasons that anaerobic digestion may play a very crucial role in meeting energy challenges of the future generation. As the biogas is not only composed of methane, the purification of biogas, or in other words, the separation of CO_2 and other trace components is essential for better combustion performance of biogas. Biogas can be purified from CO_2 using pressure swing adsorption, membrane separation, physical or chemical CO_2 absorption, as reviewed elsewhere [41]. However, not much have been reported about the utilization of CO_2 after it was removed. Any innovative approach targeting the biogas' CO_2 is believed to add extra value as well as advantage on the anaerobic digestion.

Table 2.3 Biogas yield obtained from anaerobic digestion of different solid organic waste [38]

Substrate	Methane yield (l/kg VS*)
Municipal solid waste	360
Fruit and vegetable wastes	420
Municipal solid waste	530
Fruit and vegetable waste, and abattoir wastewater	850
Swine manure	337
Municipal solid waste	200
Food waste leachate	294
Rice straw	350
Maize silage and straw	312
Jatropha oil seed cake	422
Palm oil mill waste	610
Household waste	350
Lignin-rich organic waste	200
Swine manure and winery wastewater	348
Food waste	396

*VS: Volatile solids.

2.3.3.3 Concerns regarding Anaerobic Digestion

In most of the cases, the primary motive behind the installation of anaerobic digestion is to produce biogas for alternative power generation. In those cases, the energy balance and biogas production efficiency are among the main priorities. In order to achieve stable production biogas, not only the quality but also the quantity of the substrates are crucial. In some cases, pretreatments on the substrates are required for improvement of the digestion process, yet the utility of some pretreatments is still under studied [42-43]. This only adds further concern regarding the energy balance as well as the economic feasibility to install and run anaerobic digestion. On the other hand, the anaerobic digestion of organic waste results into not only biogas but also digestate, the material remaining after the digestion process. The digestate can be used as a soil amendment, or organic fertilizer after composting. But there are reports that stated that the application of digestate as fertilizer, may pose health risks for animals and humans, particularly in cases where the digestate contains high level of heavy metals [44]. It is therefore the use of digestate as fertilizer is usually governed by strict regulations and standards that protect public health. The regulations and standards, however, are getting stricter in recent years, and in some regions the use of digestate in agriculture field is not a practice at all [45-46]. For this reason, the disposal of the digestate has been one of the major concerns when considering the installation of anaerobic digestion.

2.3.4 Composting

Composting is the aerobic decomposition of organic matter by microorganisms into a nutrient-rich, stable humus material known as compost. Compost is primarily used as soil amendment, as well as organic fertilizer for crops production. It is, however, not a relatively new method but being practiced since ancient times. The concept of large-scale composting in a methodical manner started only after the 1900s [47]. In the past few decades, it has evolved into a more sophisticated technology with greater emphasis on environmental and public health aspects.

In general, the composting process starts with gathering the organic waste, mixing and then formation into a pile. There are several essential factors that affect the composting, as stated below [47]:

- Nutrients – The nutrients contain the organic material, in the form of carbon and nitrogen, are essential for the activity of microorganisms. Carbon and nitrogen levels vary with each organic material. Carbon-rich materials tend to be dry and brown such as leaves, straw, and wood chips. Nitrogen materials tend to be wet and green such as fresh grass clippings and food waste. Generally, a C/N ratio ranging between 25:1 and 30:1 is the optimum combination for rapid decomposition. If the ratio is more than 30:1, the heat production would drop and the decomposition become slow.
- Air – The composting is an aerobic process, and hence the microorganisms need oxygen to stay active for the decomposition of the organic materials. If the air supply is not enough, it

may reach an anaerobic condition, in which not only the microorganisms would become inactive, but also the odors would be released. Turning, addition of bulking agents, and regular aeration are the common ways applied for the control of air factor in the composting.

- Moisture – Microorganisms need water to survive. The optimum moisture content for a compost pile should range from 40 to 60%. The ideal percentage of moisture will depend on the raw materials' structure and composition. A low moisture content would slow down the microorganisms' activity. On the other hand, if the moisture content is too high, it would force the air out of pile pore spaces, which would suffocate the aerobic microorganisms. As a result, the anaerobic microorganisms will take over, resulting in production of unpleasant odors.
- Temperature – Temperature is an important factor in the composting process and is related to air and moisture levels. As the microorganisms decompose the organic materials, heat is produced which in turn increases the temperature within the compost pile. It is typical for the temperature to gradually rise and peak within the thermophilic range, and then gradually fall as the compost enters the maturation phase.

Compost can be utilized as a soil amendment or organic fertilizer. In addition to returning nutrients to the soil and thus permitting the reduction of artificial fertilizers, compost is also a waste that does not have to be landfilled. When it is used as daily cover at landfills, it replaces other materials that would otherwise be used for that purpose. However, there are concerns on the environment associated with making as well as using compost. These impacts depend both on the technical approach used and the waste composition of the input streams. Mixed MSW and sewage sludge composting pose greater risks because these materials typically contain higher levels of heavy metals than the kitchen or yard wastes. Meanwhile, when the compost piles are not properly aerated, or the process itself is improperly maintained, anaerobic microorganisms would flourish and hence produce methane gas as well as odors. The unpleasant odors are one of the main concerns regarding the promotion and application of composting [48]. In many cases, the composting firms are shut down due to the complaints from nearby neighbor. Therefore the reduction or control of the odor emission is often the first priority when considering treatment of waste using composting.

Another main concern regarding the composting is the evaluation of the stability or maturity of the compost. Finished compost should be both stable (resistant to decomposition) and mature (ready for a particular end-use) so that it can safely be packaged and transported, and not cause adverse effects during its end use. An unstable or immature compost may lack of a balance of available nutrients that often does not meet the relative nutrient requirements of the crop [47, 49], or contain potential pathogens that would harm the crops [47]. Therefore it is very important to monitor the progress and evaluate the state of compost. A variety of methods for evaluating stability and maturity are available, yet there are no universally accepted standards for the evaluation of compost stability [50-51]. Table 2.4 showed the list of methods used to assess compost stability and maturity. Most of the time the on-site experience plays the vital role in such evaluation, as well as making and monitoring the composting process. In order to effectively produce good quality compost, and also control the negative impacts caused by the process, it is suggested that the methods should be simple, unsophisticated and easy to use.

Table 2.4 List of methods used to assess compost stability and maturity [47].

	Methods
Chemical parameters	Carbon/nitrogen ratio
	Nitrogen species
	pH
	Cation exchange capacity
	Organic chemical constiuents
	Acetic acid
	Starch-iodine
	Reactive carbon
	Humification parameters
	- Humification index
	- Relative concentrations of fulvic acid to humid acid
	- Humic substances
	- Functional groups
	Optical density
Physical parameters	Temperatures
	Color, odor, specific gravity
	Fluorescence
Plant Assays	Cress seed
	Wheat and rye grass germination
	Root color
Microbiological tests and activity	Respiration – oxygen depletion
	Respiration – carbon dioxide evolution
	Microbial changes – content of fungi, actinomycetes, etc.
	Enzyme activity

2.4 Integrated System as an Approach

Managing waste is a complex task that requires appropriate technical solutions, sufficient organizational capacity, and co-operation between a wide ranges of stakeholders [52]. However, the conventional waste management approach is reductionist, not tailored to handle complexity; interacting systems and their elements are divided into ever-smaller parts. System processes, such as waste generation, collection, and disposal operations, are considered independently, though each is interlinked and influenced by the others [53]. Consequentially, one waste problem can be solved, but other waste problems, or residues, are often generated with each compartmentalized 'solution' [54]. This led to growing demand for waste management approaches that recognize the social, cultural, political, and environmental spheres; that engage with a broad community of stakeholders; and that consider the larger system through holistic, integrating methodologies [55]. To reduce environmental impacts and drive costs down, a system should be integrated (in waste materials, sources of waste, and treatment methods), market oriented (i.e. energy and materials have end uses), and flexible, allowing for continual improvement [56].

Integrated solid waste management (ISWM) is the current waste management paradigm that has been widely accepted and applied in the developed countries. The U.S. Environmental Protection Agency (EPA) defines ISWM as a complete waste reduction, collection, composting, recycling, and disposal system, while the United Nations Environment Programme refers ISWM to "the strategic approach to sustainable management of solid wastes covering all sources and all aspects, covering generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximizing resource use efficiency". All in all, ISWM strives to strike a balance between 3 dimensions of waste management: environmental effectiveness, social acceptability and economic feasibility [55]. By having a comprehensive waste management system for efficient waste collection, transportation, and systematic waste disposal—together with activities to reduce waste generation and increase waste recycling—, the typical environmental concerns regarding the waste generation can be significantly reduced. While nothing new, the ISWM approach provides the opportunity to create a suitable combination of existing waste management practices to manage waste more efficiently.

Despite the fact that the ISWM is a holistic ideal, in which considerable efforts are being made by many governments and entities to confront the waste problems, major gaps still exist in real practices [55]. After taking good consideration of reduction, recycle, recovery, etc., most of the studies regarding the ISWM, however, often end with disposal, such as landfill. Although this is corresponded well to the waste hierarchy, most of the cases the final residues can still be utilized for further usage. A well-function waste management should consist of a sound sustainable material cycle, where the waste, as well as the by-products or residues during the waste treatment, are to be utilized into products again. The next step for ISWM, or the waste management in general, should involve components that could not only serve as an incentive for the public, but also provide a comprehensive approach towards the utilization potential.

CHAPTER 3

INTEGRATION OF ANAEROBIC DIGESTION AND LAND-BASED SEAWEED CULTIVATION: UTILIZATION OF BIOGAS' CO_2

Summary

The utilization of biogas' CO_2, which makes of 40% of biogas generally, was targeted as part of the proposed integrated system. It is well-known that biogas can be used for power generation through the combustion of CH_4, but not many studies have been reported on the utilization of CO_2 after separated from biogas. The purpose of this study was to investigate the utilization of biogas' CO_2 in seaweed cultivation, which was proposed to be integrated with anaerobic digestion. Land-based seaweed cultivation was selected as the method, and the seaweed cultivated was *Ulva prolifera*. The biogas' CO_2 was dissolved into water using the water scrubbing method. The initial conditions for the cultivation of *Ulva prolifera*, including CO_2 concentration, were determined using bench-scale cultivation (500ml). Pilot-scale cultivation (100L and 1000L) were then performed, and the economic feasibility under commercialized scale was evaluated. Results showed that the addition of CO_2 can enhance the production yield by almost 50%. The evaluation of economic feasibility indicated that currently the operating costs were high, which mainly caused by the cost of sea water. All in all this study showed that the CO_2 separated from biogas could be utilized in seaweed cultivation. The integration of anaerobic digestion and seaweed cultivation can be presented as a new approach, in which not only biogas can be produced but seaweed as food or products to be sold also obtained in one place.

3.1 Introduction

The biogas produced through anaerobic digestion can be used for power generation. Although depends on anaerobic digestion's conditions as well as the raw materials, the composition of biogas mainly consists of 60% of methane gas (CH_4) and 40% of carbon dioxide (CO_2), along with some trace gases such as water vapor, hydrogen sulfide (H_2S), etc. [57]. In order to enhance the energy value of the biogas, the CO_2 is removed generally. Based on the concept of Zero Emission [58], in which no waste is produced in one production process, and everything emitted has its use, the removed CO_2 from biogas is no exception. Whereas various studies have been reported on the methods to remove CO_2 from biogas [59-60], very few are focused on the utilization of the removed CO_2.

CO_2 is an essential component for photosynthesis. Applications of CO_2 on plant especially in a controlled environment such as greenhouse have long been discussed. Results have shown that the plant growth can be enhanced, and the practical use has been well established in Netherland [61]. Whereas in Japan, application of CO_2 on crops such as strawberry, cucumber and tomato have been studied and put in practice since the 1960s [62-65]. Nevertheless, in most of the cases, the CO_2 is provided through the gas cylinder [66].

In this study, the CO_2 removed from biogas is proposed to be used in cultivating seaweed. The reason is that the one of the simplest methods to purify or separate the CO_2 from biogas is water scrubbing, which would result into production of CO_2 enriched water [59-60]. Seaweeds are harvested for use as food, feed for aquaculture, fertilizer for agriculture, and in industrial and pharmaceutical applications [67]. Therefore instead of discharging the CO_2 enriched water without further utilization, it is certainly beneficial to use it for cultivation of seaweed. The effects of CO_2 enrichment on various species of seaweeds have long been studied [68-70]. On the other hand, it is reported that the CO_2 of biogas was successfully dissolved into water using a gas dissolving equipment [66] [71-72]. This has led to the possibility of applying the CO_2 dissolved water as a CO_2 source in seaweed cultivation. To date, there are very few literatures regarding the utilization of biogas' CO_2 in seaweed cultivation.

The cultivation used in this study was a land-based cultivation. The land-based cultivation is the contrast to the conventional method, where the seaweed is cultivated on land using tanks. In

2004, a research group from Kochi University developed a new "germling cluster" method, in which a higher daily growth rate (DGR) of *Ulva prolifera* was achieved [73-74]. In this study the initial cultivation conditions were first determined based on bench-scale cultivation (500mL). The effects of biogas' CO_2 on the seaweed growth was then evaluated under pilot-scale cultivation (100L, 1000L). Based on the results obtained, the economic feasibility of utilizing biogas' CO_2 in a commercial scale was discussed, in which a current commercialized land-based cultivation plant in Kochi Prefecture was compared.

3.2 Experimental Section

3.2.1 Seaweed

The seaweed used in this study is *Ulva prolifera* (seed provided by Kochi University). *Ulva prolifera* is known to have high rates of nutrient uptake, as well as tolerant to changes in temperature, salinity, light and desiccation [75].

3.2.2 Bench-scale cultivation

Figure 3.1 showed the schematic diagram of bench scale cultivation, while Figure 3.2 showed the cultivation vessels used. An artificial climate incubator (LH-60/80CCFL-DT, Nippon Medical & Chemical Instruments Co., Ltd.) was used to control the cultivation environment. The temperature was set at 25℃, and the lightness was set at 26000Lx (12 hours on-off). The sea water for cultivation was artificially made, by dissolving LIVESea Salt (Delphys Inc.) in purified water. Table 3.1 showed the initial cultivation conditions of each cultivation section. The optimum condition for salinity and the CO_2 concentration of artificial sea water were examined in Section A1-A4 and Section B1-B4, respectively. 3 cultivation vessels (500mL) were prepared in each section. All vessels and artificial sea water were sterilized using autoclave before cultivation. The salinity of sea water was adjusted using LIVESea Salt (Delphys Inc.). CO_2 was installed into the artificial sea water by bubbling CO_2 from a gas cylinder. The concentration of CO_2 was adjusted by checking through the pH meter and portable carbon dioxide meter (CGP-31, DKK-TOA Co.) simultaneously. The bubbling of CO_2 was stopped when the pH of artificial sea water reached the desired CO_2 concentration. The CO_2 enriched artificial sea water was directed and circulated into the cultivation vessels using a perista pump. The stirring of the cultivation vessels was conducted using stirrers and aeration, as showed in Figure 3.1. The changes of pH were checked from time to time, to ensure that the concentration of CO_2 was consistent during the cultivation. The essential nutrients needed for cultivation was referred to study elsewhere [76]. After the initial cultivation conditions were determined, the effects of CO_2 on *Ulva prolifera* was evaluated by comparing 3 cultivation experiments, namely Standard (artificial sea water only), Nutrients (artificial sea water and nutrients added) and CO_2 (artificial seawater, nutrients and CO_2 added). The results were compared based on the average wet weight and daily growth rate (DGR) after 7 days of cultivation [77]. The calculation for DGR is showed as followed:

$$a = (y/x)^{(1/(b-1))} \quad (1)$$

a: Daily growth rate

b: Cultivation days

x: Initial weight

y: Final weight

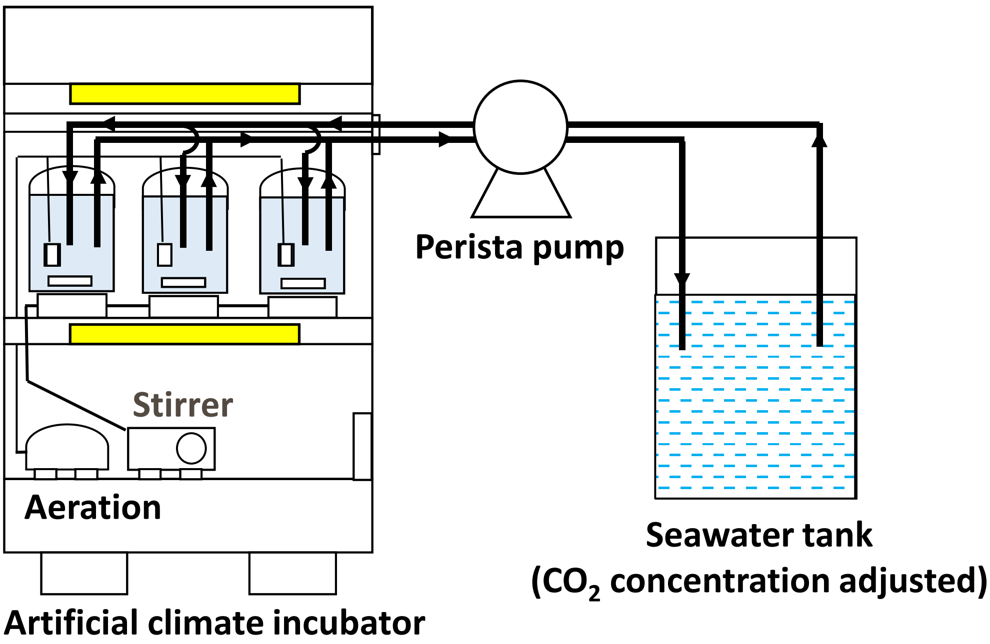

Figure 3.1 Schematic diagram of bench0scale cultivation.

Figure 3.2 Cultivation vessels used in bench-scale cultivation.

Table 3.1 Initial cultivation conditions of each cultivation section.

<table>
<tr><th>Unit</th><th>Salinity [%]</th><th>Ammonium sulfate [mg/L]</th><th>Monocalcium phosphate [mg/L]</th><th>Urea [mg/L]</th><th>Clewat 32* [mg/L]</th><th>CO_2 concentration [mg/L]</th></tr>
<tr><td>A1</td><td>2.0</td><td rowspan="8">20.0</td><td rowspan="8">4.0</td><td rowspan="8">2.0</td><td rowspan="8">5.0</td><td>-</td></tr>
<tr><td>A2</td><td>2.5</td><td>-</td></tr>
<tr><td>A3</td><td>3.0</td><td>-</td></tr>
<tr><td>A4</td><td>3.5</td><td>-</td></tr>
<tr><td>B1</td><td rowspan="4">3.5</td><td>71（pH8.0）</td></tr>
<tr><td>B2</td><td>83（pH7.5）</td></tr>
<tr><td>B3</td><td>95（pH7.0）</td></tr>
<tr><td>B4</td><td>107（pH6.5）</td></tr>
</table>

3.2.3 Pilot-scale cultivation

Based on the results obtained from 3.2.2, a pilot-scale cultivation using "germling cluster" method was conducted. Figure 3.3 and 3.4 showed the schematic diagram and view of cultivation tanks used in pilot-scale cultivation. The cultivation was conducted using the facilities plant under The Advanced Creative Technological Development Grant from the Ministry of Education, Culture, Sports, Science and Technology, Japan [78].

Previous study reported that the seaweed would stop growing when its density reaches the cultivation tank capacity. In order to have a better assessment regarding the feasibility of commercialization, 2 types of cultivation tank, namely 100L and 1000L, were used in this pilot-scale cultivation, Before the cultivation in pilot scale was started, a pre-cultivation was held using 500mL (7-10 days) and 1L (1-2 weeks) cultivation vessels. The seaweed was moved when it had grown until certain density, in which the cultivation tank was difficult to be see through based on eyes observation and photos. Surface seawater (water temperature 7-12℃) taken from the Mikawa Bay was used as the sea water for pilot-scale cultivation. The sea water was circulated throughout the system, passing by an ultraviolet germicidal irradiation equipment. The circulation rate of sea water for 100L and 1000L cultivation tanks were 500mL/min and 5000mL/min, respectively. The stirring of the cultivation tanks was conducted using aeration. The necessary amount of nutrients were added.

A gas dissolving equipment (OD-110, Taiei Seisakusho Co. Ltd.) was connected to one side of external 1t tank, to produce CO_2 dissolved water, with operating conditions of 17L/min for sea water flow rate and 2L/min for gas flow rate. Figure 3.5 showed the gas dissolving equipment used in this study. 2 types of CO_2, namely pure CO_2 from gas cylinder and CO_2 from biogas, were examined in pilot-scale cultivation. Biogas was generated from anaerobic digestion of sewage sludge and the properties of anaerobic digestion are showed in Table 3.2. The anaerobic digestion tank were implemented nearby to the pilot-scale facilities. Under on-off mode, in which the pH of sea water was controlled to remain within 6.8-7.2, CO_2 from the gas cylinder was supplied for 24 hours, and biogas from anaerobic digestion was supplied for 5 hours during daytime. Both cultivations were conducted during the winter season (pure CO_2: 2013/12/13-2013/12/28, biogas' CO_2: 2014/1/8-2014/1/23). The temperature and lightness during the cultivations were not controlled.

Figure 3.3 View of cultivation tanks used in pilot-scale cultivation.

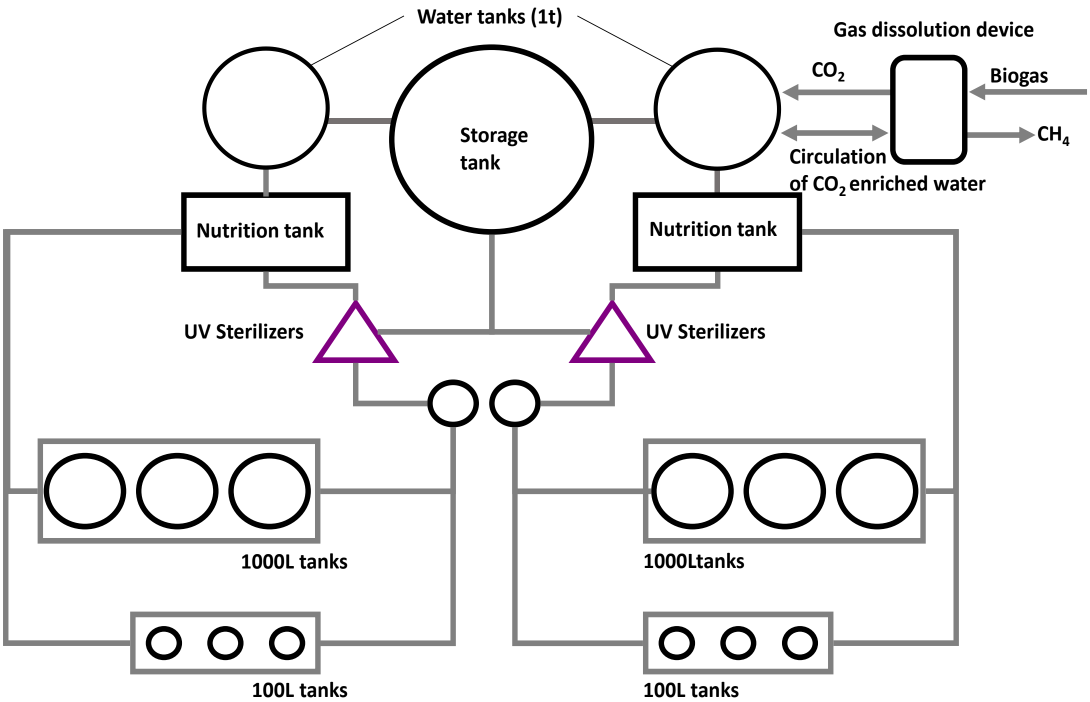

Figure 3.4 Schematic diagram of cultivation tanks used in pilot-scale cultivation.

Figure 3.5 Gas dissolving equipment (OD-110, Taiei Seisakusho Co. Ltd.)

Table 3.2 The properties of anaerobic digestion.

Substrate	Sewage sludge
Input	100 L/day
Concentration	11%-TS*
Temperature	38℃
Capacity	2 m^3
Hydraulic retention time (HRT)	20 days
Average biogas composition	CH_4 54%, CO_2 47%

*TS: total solids

3.3 Results and Discussion

3.3.1 Initial Cultivation Conditions and Effects of CO_2

Figure 3.6 showed the DGR of each cultivation section. Regarding the salinity, section A4, which had the same salinity (3.5%) as regular sea water, obtained the highest DGR. On the other hand, every section of B1-B4 obtained high DGR, and it was higher than section A4. This clearly showed the effect of CO_2, which resulted in increasing of seaweed growth. The DGR was especially high in both section B2 and B3. As the circulation of sea water would be performed during pilot-scale cultivation, in which the fluctuation of pH is expected to occur, therefore pH7 was set as the basis of CO_2 concentration.

Figure 3.7 showed the average wet weight and DGR of Standard (artificial sea water only), Nutrients (artificial sea water and nutrients added) and CO_2 (artificial seawater, nutrients, and CO_2 added) section. The salinity of all 3 sections was set as 3.5%, based on the results obtained previously. Results showed that both Nutrients and CO_2 section obtained higher average wet weight and DGR when compared to Standard section. This indicated that nutrients are certainly essential for cultivation. There was not much difference of DGR between Nutrients and CO_2 section, but it was clear that the average wet weight obtained in the CO_2 section was 1.2 times higher than Nutrients section. Based on these results, it can be estimated that the application of CO_2 on seaweed cultivation would lead to the increase of the final yield.

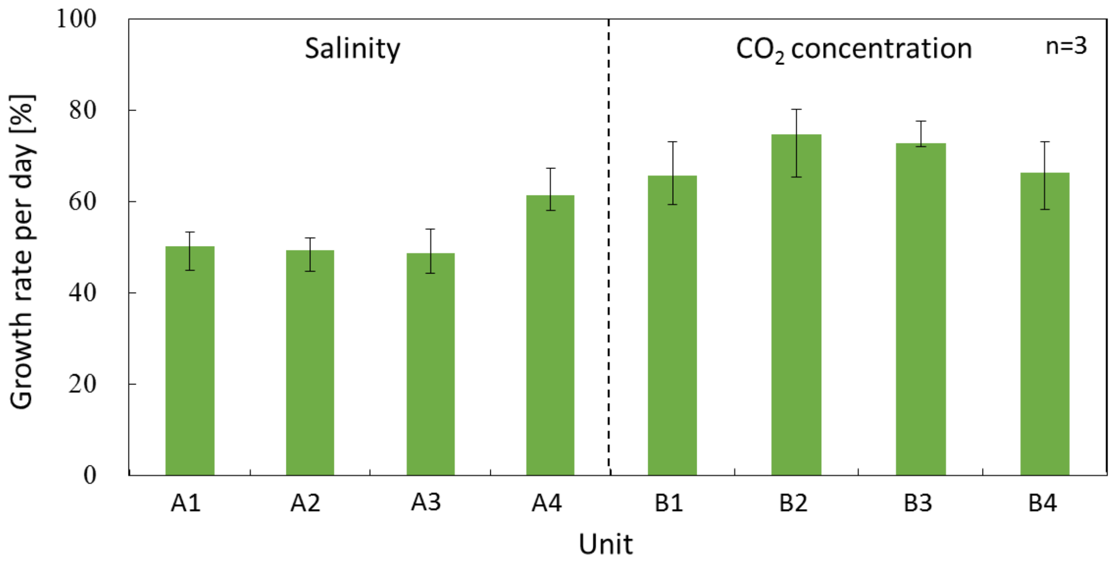

Figure 3.6 The daily growth rate of each cultivation section.

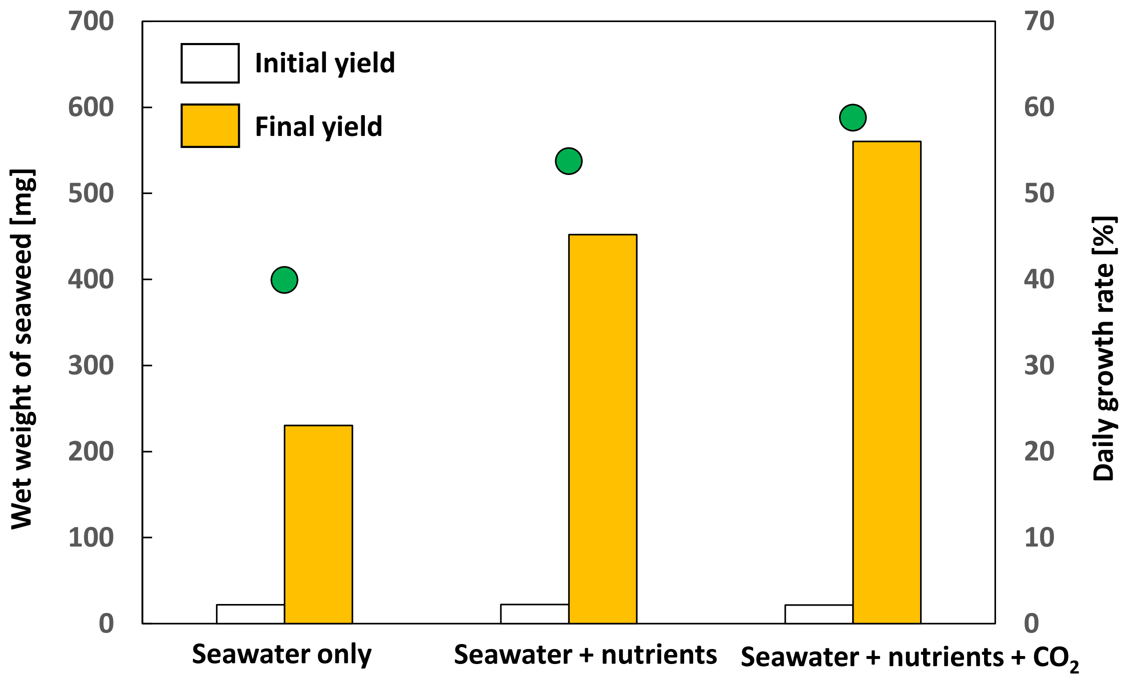

Figure 3.7 The average wet weight and daily growth rate of Standard (artificial sea water only), Nutrients (artificial sea water and nutrients added) and CO_2 (artificial seawater, nutrients, and CO_2 added) section.

3.3.2 Effects of Biogas' CO_2 in Pilot-scale Cultivation

Figure 3.8 showed the seaweed growth in pilot-scale cultivation, with (1) showing the results obtained using pure CO_2 and (2) showing the results obtained using biogas' CO_2, respectively. When the regular cultivation is compared with the CO_2 applied cultivation, both (1) and (2) showed a similar growth in 10 days. In order to further evaluate the practical use of CO_2 in seaweed cultivation, the experiments were continued, as the seaweed was removed from 100L cultivation tanks to 1000L cultivation tanks. In the case of (1), the remove was conducted on day 10, and 2 times higher of growth was obtained in 15 days with CO_2 applied. A different pattern was showed in the case of (2), in which the remove of seaweed was conducted on day 15, and the growth of seaweed when CO_2 applied was only half time higher than regular cultivation. These were probably caused by the shorter time of CO_2 supply when compared to (1), as well as other differences in terms of temperature and lightness. Overall, the effects of applying CO_2 in seaweed cultivation, especially biogas' CO_2, were notable. The seaweed in cultivation using biogas' CO_2

is expected to have similar growth with the regular cultivation after removing into 1000L cultivation tanks, due to the changes in density. Figure 3.9 and Figure 3.10 showed the comparison based on eye-view of cultivation tanks and seaweed between regular cultivation and CO_2 applied cultivation.

However, currently, this study is considered as the basic test to examine the utilization of biogas' CO_2 in land-based seaweed cultivation. Further investigations, such as the optimum CO_2 supply time, the correlation between seaweed growth and cultivation tank's capacity, as well as the stirring method and the cultivation conditions under different season, are necessary in order to establish a highly efficient seaweed cultivation with biogas' CO_2 applied.

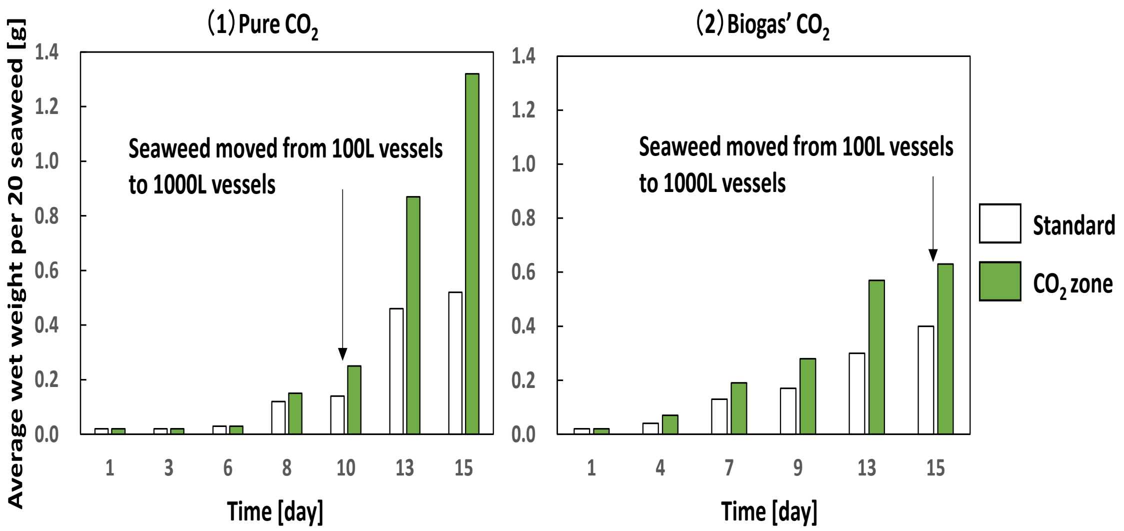

Figure 3.8 The seaweed growth in pilot-scale cultivation, with (1) showing the results obtained using pure CO_2 and (2) showing the results obtained using biogas' CO_2, respectively.

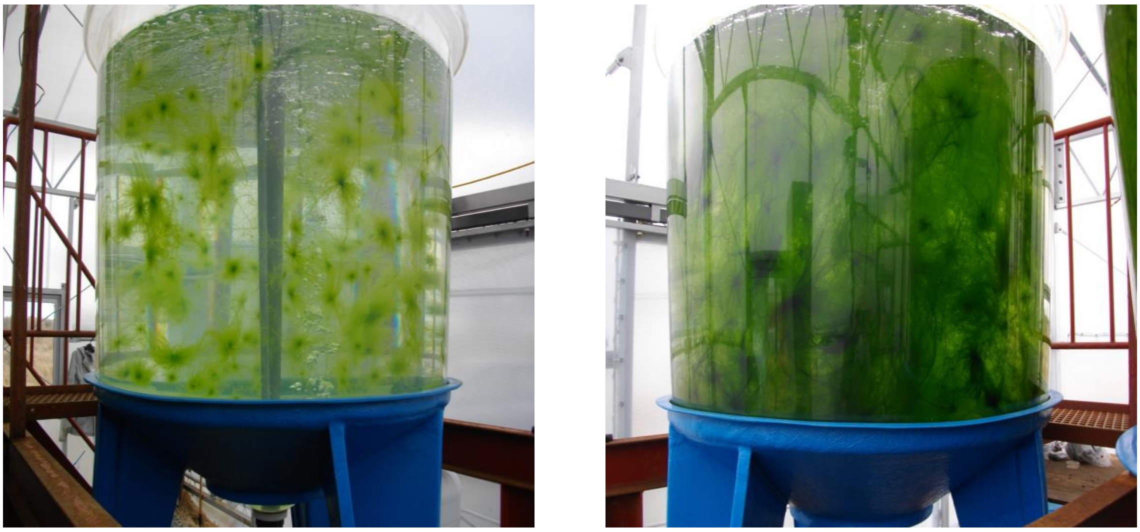

Figure 3.9 Comparison based on eye-view of cultivation tanks

(Left: Regular cultivation; Right: CO_2 applied cultivation)

Figure 3.10 Comparisons of seaweed between regular and CO_2 applied

(Above: CO_2 applied; Bottom: Regular)

3.3.3 Economic Feasibility Assessment for Application of Biogas' CO_2 in Land-based Seaweed Cultivation

Based on the results obtained in the pilot-scale cultivation, the operating cost, which consists of expense for sea water, labor, utilities, seed and miscellaneous expense, was estimated. The miscellaneous expense was set as 30% from the sum up of sea water, utilities, labor, and seed. Table 3.3-3.8 showed the values used for the estimation, while Table 3.9 showed the operating cost of different cultivation systems, and Figure 3.11 showed the operating cost per weight of each cultivation system. The Kochi System is a currently operating land-based seaweed cultivation plant located in Kochi Prefecture, and its actual harvest yield (0.0143kg/day per 1 ton of cultivation tank) was used as the basis for calculation. The market price for *Ulva prolifera* in Kochi Prefecture was selected as the basis for comparison (¥10000 per kg). The pilot-scale cultivation conducted in this study was named as Biogas' CO_2 System. As seen from Table 3.9, the expense for sea water in the Biogas' CO_2 System accounted for the most part of the total operating cost. For this reason, the reuse of sea water, with the aim to reduce the total operating cost, was considered. Furthermore, by taking references from Kochi System, the commercialization of Biogas' CO_2 System was estimated as well. All estimations under Biogas' CO_2 System was presumed to harvest 2 times higher of seaweed yield, based on the results obtained in the pilot-scale cultivation.

Results, as seen from Figure 3.11, showed that the Kochi System's operating cost was well below than the market price. In contrast, the operating cost of current Biogas' CO_2 System was 1.5 times and 1.7 times higher, when compared to the market price and Kochi System, respectively. The smaller scale of Biogas' CO_2 System was one of the reasons that led to higher operating cost. It must be noted that the Kochi System used deep water, which was relatively suitable for seaweed cultivation and also cheaper in cost (¥7 per 1 ton of cultivation tank). The Biogas' CO_2 System, however, used sea water (¥2500 per 1 ton of cultivation tank) that was supplied by a local company, in which most of the expense consisted of transportation fee. In the case of reusing the sea water for 5 times under current cultivation conditions, as well as presuming a 2 times higher of seaweed yield is obtained, the estimation showed that the final operating cost was, in fact, lower than the market price. Under commercialized scale, in which the Kochi System was referred, the total operating cost could be further reduced by almost half of original cost.

As a conclusion, the estimation in this study showed that the sea water is a concern in the case of land-based seaweed cultivation. The total operating cost can be reduced when the sea water is reused, although further investigations, for example, the filtering of sea water after cultivation, as well as the changes of nutrients composition, are necessary. It is also noteworthy that biogas' CO_2 can be utilized in seaweed cultivation, which would lead to increase of the seaweed yield, and eventually further reduce the operating cost.

Table 3.3 Seaweed market price in Kochi Prefecture and the market value of seaweed produced based on Kochi System [74]

Market price for 1 kg-dry of *Ulva prolifera* in Kochi Prefecture [¥]	10000
Harvest yield of 10 tonne cultivation tank per week in Kochi System [kg-dry]	1
Market value of *Ulva prolifera* harvested from 1 tonne cultivation tank per day [¥]	143

Table 3.4 Seawater cost per 1 tonne cultivation tank

Kochi System	
Deep ocean water [¥]	7
Operating cost per day (3 times replacement) [¥]	21
Pilot-scale in this study	
Surface seawater [¥]	2500
Operating cost per day (Replace every 2 week) [¥]	178

Table 3.5 Seaweed seed cost per 1 tonne cultivation tank

Kochi System	
Seaweed seed [¥]	10
Pilot-scale in this study	
Seaweed seed [¥/g]	210
Initial seaweed weight [g]	0.1
Seaweed seed cost per 1 tonne cultivation tank [¥]	21

Table 3.6 Utilities cost per 1 tonne cultivation tank

Kochi System	
Cost per day [¥]	9,600
Utilities cost per 1 tonne cultivation tank [¥]	16
Pilot-scale in this study	
Electricity used for 2 weeks cultivation [kWh]	18.61
Electricity fare per month based on value set by Chubu Electric Power Co. [¥/kwh]	1,307.3
Electricity fare per day for 1 tonne cultivation tank [¥]	58

Table 3.7 Labor cost per 1 tonne cultivation tank

Kochi System	
Total labor cost per day [¥]	27,400
Labor cost per 1 tonne cultivation tank [¥]	46
Pilot-scale in this study	
Minimum salary per hour in Aichi Prefecture [¥]	780
Working time per 1 tonne cultivation tank [min]	5
Labor cost per 1 tonne cultivation tank [¥]	65

Table 3.8 Electricity used for pilot-scale cultivations [kWh]

	Cultivation tanks		
	100L	1000L	Total
1. Injection of seawater into the cultivation tanks	0.007	0.047	0.053
2. Circulation of seawater	0.002	0.024	
(× operating time)	0.396	3.957	4.352
3. Aeration	0.024	0.060	
(× operating time)	4.013	10.033	14.047
4. Dissolving of CO_2	0.159		0.159
Regular cultivation (1+2+3)			18.452
CO_2 applied cultivation (1+2+3+4)			18.612

Table 3.9 The operating cost of different cultivation systems.

	Kochi Commercialized Plant [¥]	Pilot-scale in this study [¥]	Pilot-scale in this study (5 times seawater reuse) [¥]	Commercialized of pilot-scale in this study based on Kochi Commercialized Plant (5 times seawater reuse) [¥]
Seawater	21	178	36	36
Seaweed Seed	10	21	21	10
Utilities	16	58	58	16
Labor	46	65	65	46
Others	28	97	54	32
Total	121	419	234	140

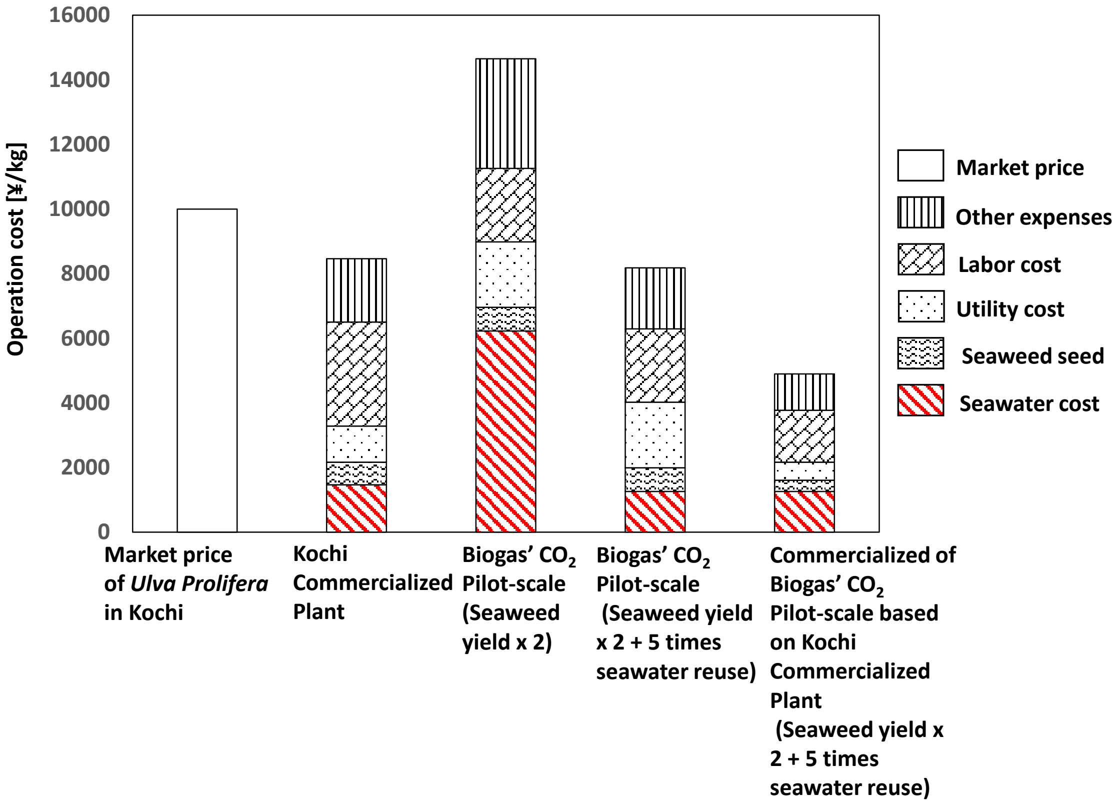

Figure 3.11 Operating cost per weight of each cultivation system.

3.4 Conclusions

The feasibility of utilizing biogas' CO_2 in land-based seaweed cultivation was examined in this study. The seaweed yield can be doubled by applying the biogas' CO_2 dissolved seawater. This opens up a new approach to utilization of biogas from anaerobic digestion. On the other hand, the estimation of operating cost based on the pilot-scale cultivation showed that the expense of sea water is a concern that should be addressed beforehand in case of land-based seaweed cultivation. Reuse of sea water is suggested as a solution to reduce the cost, but further investigations are needed. In addition, as this study is considered as an initial investigation regarding the application of biogas' CO_2 in seaweed cultivation, the optimum cultivation conditions such as lightness, sea water temperature, stirring method, etc., are yet to be examined. The initial cost which includes the facilities and equipment have to be taken into account for the better assessment of feasibility.

CHAPTER 4

INTEGRATION OF ANAEROBIC DIGESTION AND GREENHOUSE: UTILIZATION OF CO_2 EMITTED FROM COMBUSTION OF BIOGAS

Summary

The idea of enriching the CO_2 concentration inside the greenhouse to enhance the photosynthesis by plants has long been studied and conducted since many years ago. However, most of the studies or cases applied gas cylinder or combustion of carbon-based fuels to supply CO_2 into the greenhouse. Gas cylinder sometimes can be expensive when the greenhouse scale is large. On the other hand, in regions where the heat is less needed to keep the greenhouse warm, the combustion of fuels is rather unnecessary. In this chapter, the CO_2, as a result from the combustion of anaerobic digestion's biogas, was used as the CO_2 source to enrich the CO_2 concentration inside a greenhouse. The effects of such enrichment was investigated based on the cultivation of tomatoes. The changes of CO_2 concentration during the CO_2 enrichment were determined. Results from the CO_2 enrichment increased the overall growth yield of tomatoes, but the concentration was not able to be maintained at desired level once the ventilation of the greenhouse was turned on. Nevertheless, in terms of preventing the depletion of CO_2, which is a common phenomenon in greenhouse, the utilization of CO_2 emitted from the combustion of biogas can certainly be used. Instead of discharging the CO_2 into the atmosphere, as showed in this study, it can be used for CO_2 enrichment for tomatoes growth, or a solution for prevention of CO_2 depletion in greenhouse. Similar to the previous chapter, the integration of anaerobic digestion and greenhouse as shown in this study is anticipated to be the new approach as well as showcase to the public, which could lead to a shift of perspectives towards biomass utilization.

4.1 Introduction

Greenhouses are used extensively by botanists, commercial plant growers, and dedicated gardeners. Particularly in cool climates, greenhouses are useful for growing and propagating plants because they both allow sunlight to enter and prevent heat from escaping. This allows a longer growing season as well as a year-round stable supply of plants, especially for the season-limited crops. The forms of greenhouse include tunnels and houses. In recent years, there are also greenhouses that have advanced environmental control functions [79]. All in all, the greenhouses serve as a shield between the nature and the plants, and thus allow growing seasons to be extended as well as possibly improved.

Carbon dioxide (CO_2) is an essential component of photosynthesis. Photosynthesis is a chemical process that uses light energy to convert CO_2 and water into sugars in green plants. These sugars are then used for growth within the plant, through respiration. The normal atmospheric CO_2 concentration is between 300 and 340 ppm, and in case of greenhouse it can be quickly drawn down to 200 ppm, due to the CO_2 uptake by the plants [80]. The photosynthesis can be halted when the CO_2 concentration approaches 200 ppm [80]. Therefore it is worth enriching with CO_2 to maintain a 350 to 400 ppm concentration, to avoid the detrimental effects of CO_2 depletion and thus potentially increasing yields.

The benefits of CO_2 supplementation, or enrichment, on plant growth and production within the greenhouse environment have been well understood for many years [81]. Studies have reported that the CO_2 concentration up to 1000 ppm in the greenhouse can enhance the growth of plants [82-83]. In general, the CO_2 resulted from combustion of hydrocarbon fuels, such as propane gas and kerosene, is the most common source for CO_2 enrichment for many years. Usually these fuels are employed in dedicated burners to provide CO_2 while a separate heating system provides most of the heat to the greenhouse [84]. However not every region, particularly the warmer region, needs the heat and hence it is unnecessary for burners to be applied. The other popular source for CO_2 enrichment is the compressed, or bottled CO_2, but the major drawback is the expense, especially in a large greenhouse [83].

This study targeted the exhaust gases produced by the combustion of anaerobic digestion's biogas, which is free, as the source supply for CO_2 enrichment in greenhouse. The benefits of CO_2

enrichment from exhaust gases over pure CO_2 has already been discussed elsewhere [85]. A numbers of studies have promoted the possibility of using the landfill's biogas [86-87], and even the CO_2 emitted from a composting process that was held in the greenhouse [88]. As there is no literature regarding the application of combustion of anaerobic digestion's biogas, the effects of the emitted CO_2 on plants growth, in this case tomato, was investigated. Focus on the phenomenon of CO_2 depletion in greenhouse during the enrichment process was evaluated as well. The challenge, however, is how best to distribute CO_2 into the greenhouse, particularly in southern greenhouses where ventilation is more frequent [80]. As the CO_2 is heavier than air and it does not easily mix into the greenhouse atmosphere by diffusion, normally the CO_2 is injected into the greenhouse above the plant canopy and carried by the circulating air. The frequent ventilation would then affect the CO_2 concentration inside the greenhouse. Therefore, in this study, in contrast to the injection from the above, the CO_2 was distributed near to the plant canopy through a transparent vinyl duct with holes. The changes in CO_2 concentration and the CO_2 volume needed were estimated. This study aimed to be the practical showcase of integrating anaerobic digestion and greenhouse in one place.

4.2 Experimental Section

4.2.1 Growing Conditions

The study was carried on tomatoes (CF Momotaro Haruka, TTM017). The cultivations were conducted in parallel using a separated greenhouse (125 m^2), with one side set as Standard Area, and the other side as CO_2 Enrichment Area. Figure 4.1 showed the schematic structure of the greenhouse. The greenhouse was part of the facilities under The Advanced Creative Technological Development Grant from the Ministry of Education, Culture, Sports, Science and Technology, Japan [78]. 915 tomato trees were planted in each area, with 4 runs conducted at different period of time. Figure 4.2 showed some photos taken during the cultivation. The cultivations were conducted with "low node-order pinching and high density planting" [89], using hydroponics under nutrient film technique [90]. The nutrients of the cultivation solution were referred to "Yamasaki Formula", which is generally served as the standard for hydroponics [91]. The electrical conductivity (EC) and pH of the solution were set to be maintained at 1.1 and 6.3, respectively.

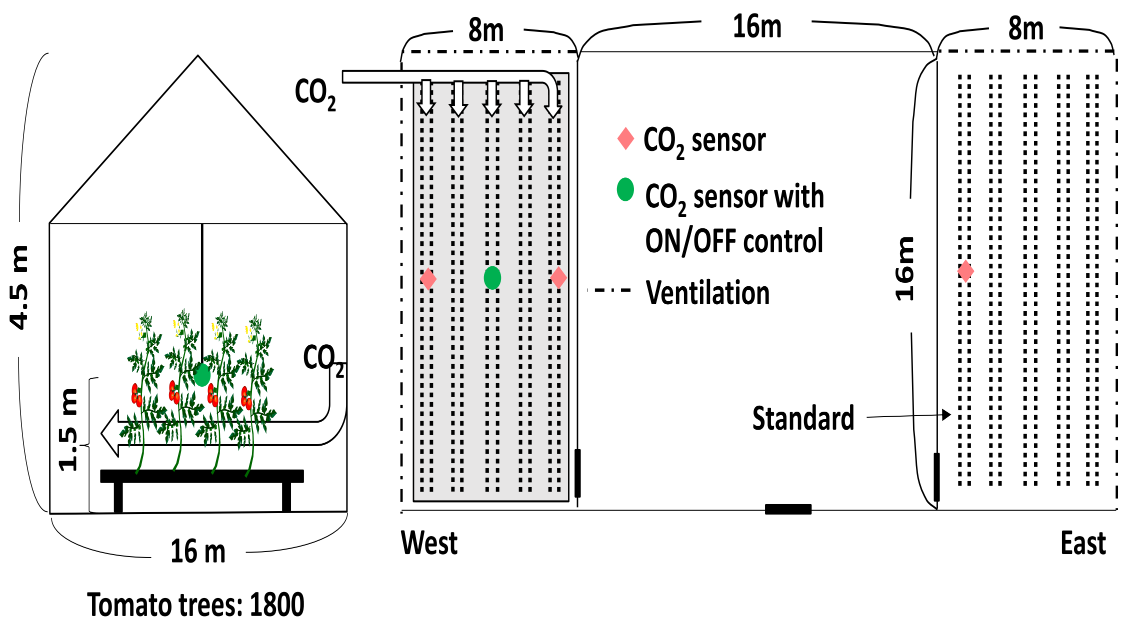

Figure 4.1 Schematic structure of greenhouse

Figure 4.2 Greenhouse and tomato cultivation

4.2.2 CO_2 Enrichment

CO_2, as a result from the combustion of anaerobic digestion's biogas using a cogeneration system (Aisin Seiki Co., Ltd.), was injected into the greenhouse through a transparent vinyl duct using a blower. Figure 4.3 showed the photo showing the transparent vinyl duct used in this study. Table 4.1 showed the digestion conditions of anaerobic digestion. The anaerobic digestion tank and cogeneration system were implemented nearby to the greenhouse. The CO_2 concentration was controlled as 1000 ppm using an ON/OFF mode sensor. The sensors were placed near to the tomato leaves, as showed in Figure 4.1. The CO_2 concentration was continuously monitored using data logger (Graphtec, GL820) to determine the changes in CO_2 concentration under ventilation. The injection of CO_2 was started after the fruits at the first stage started to grow. Injection time was 10 hours, starting from the sun rise time. Tomato yield was determined by picking and weighing marketable fruit from each plant. The average tomato yields (estimation based on 10 a greenhouse per year) after each cultivation were determined to evaluate the effects of CO_2 enrichment.

Figure 4.3 Transparent vinyl duct for CO_2 enrichment.

Table 4.1 The properties of anaerobic digestion.

Substrate	Sewage sludge
Input	100 L/day
Concentration	11%-TS*
Temperature	38℃
Capacity	2 m^3
Hydraulic retention time (HRT)	20 days
Average biogas composition	CH_4 54%, CO_2 47%

*TS: total solids

4.3 Results and Discussions

4.3.1 Effects of CO_2 Enrichment on Tomato Yields

Figure 4.4 showed the average tomato yields of each run under different period of time. Whereas Run1 and Run2 did not see very much difference between Standard Area and CO_2 Enrichment Area, Run3 and Run4 obtained a significant increase in terms of tomato yields under CO_2 enrichment. The flow rate for Run3 and Run4 was actually increased upon seeing the less obvious results from Run1 and Run2. Run1 and Run4, which both were conducted around February to June, obtained higher tomato yield when compared to Run2 and Run3, which conducted around May to August and October to January, respectively. Nevertheless the CO_2 enrichment, in which in this case the CO_2 source was origin from the combustion of anaerobic digestion's biogas, can certainly enhance the tomato growth, and thus improve the overall yield. Typically the CO_2 emitted from the combustion is discharged into the atmosphere. Instead of discharging into the atmosphere, it can be utilized as an enrichment to plants in greenhouse.

The results obtained from this study also indicated that the distribution of CO_2 using a transparent vinyl duct, which was placed near to the plants, did not bring opposite effects to the plants growth. However, there was one study suggested that the exposure of the whole plant to elevated CO_2 concentration is crucial for the acclimation of plant to the high CO_2 concentration [92]. The distribution method suggested in this study might not been able to ensure the exposure of CO_2 enrichment to the whole plant, and hence further investigations are essential. Besidees that, the environment inside the greenhouse is actually affected by many parameters, namely temperature, photoperiod, relative humidity, nutrients and irrigation schedule [93]. It was said that the beneficial effects of CO_2 enrichment strongly depend on the interrelationship between those parameters, in which many studies have been conducted to optimize the levels and control strategies of CO_2 injection in greenhouses [83, 85, 94]. Therefore tasks remain in order to effectively utilize the CO_2 in greenhouse to ensure higher efficiency of CO_2 enrichment.

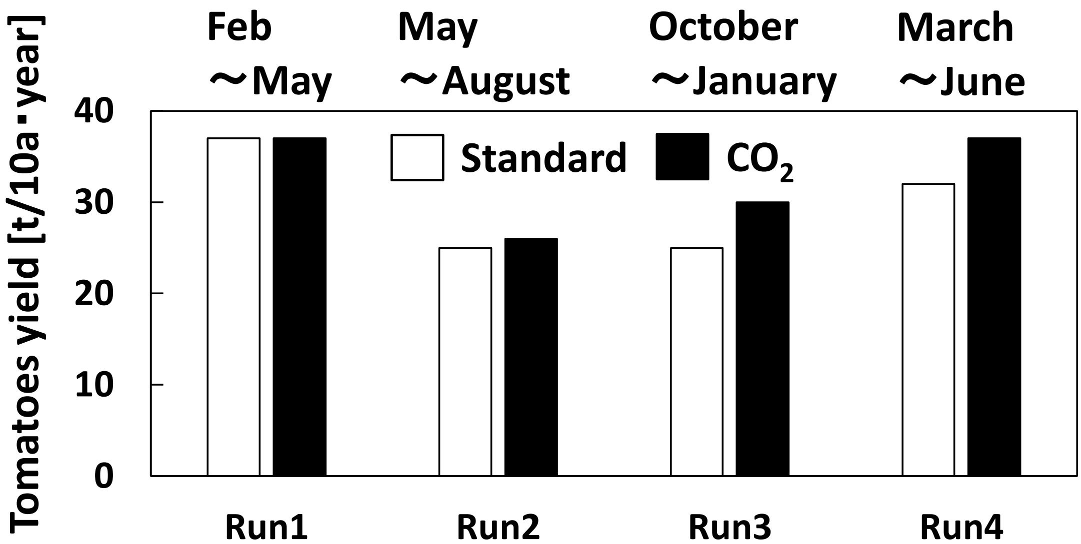

Figure 4.4 Average tomato yields in each run under different period of time.

4.3.2 Changes in CO_2 Concentration during CO_2 Enrichment

Figure 4.5 showed the changes in CO_2 concentration in Standard Area and CO_2 Enrichment Area. Firstly, regarding the Standard Area, the CO_2 concentration was constant within the range of 560 to 580 ppm from 7pm to 7pm. This was seen as the result of respiratory of plants during night time when there is no photosynthesis occurred. After the sun rose (7pm), the CO_2 concentration started to decrease, indicating the starting of photosynthesis. It decreased as low as nearly 200 ppm, which could affect the plants growth [80]. This indicated that under normal circumstance, in which there is no extra CO_2 injected, the CO_2 within the greenhouse might be not enough and hence lead to lower than expected of tomato yield [80]. The turn on of ventilation at 10am, can be served as a way to prevent the CO_2 depletion, as the CO_2 concentration slightly increased after that.

On the other hand, the CO_2 concentration in CO_2 Enrichment Area from 7pm to 6am was almost the same as the CO_2 concentration in Standard Area. When the CO_2 was started to be injected at 6am, it increased significantly and it reached as high as nearly 1200 ppm at some points. It was kept above 1000 ppm for some hours before started to decrease around 9am and continued downfall after the ventilation was turned on at 10am. These changes indicated that the CO_2

enrichment in terms of concentration can only be maintained for a short time. When the ventilation is turned on, the CO_2 injection can still enrich the CO_2 concentration in the greenhouse, even though it may not be within the range of desired concentration (1000 ppm). Studies have proposed that it is uneconomic to maintain a constant level of 1000 ppm of CO_2 in the day time as the ventilation is frequently required [95]. In terms of preventing the CO_2 depletion, the emitted CO_2, as showed in this study, can certainly be considered as the supply source instead of the normally applied hydrocarbon fuels or liquid CO_2. This is indeed corresponded to a study that suggested that one effective strategy in terms of CO_2 enrichment is to inject CO_2 only to prevent depletion, thus remaining at atmospheric levels, while benefiting from some yield improvements and lower costs [90].

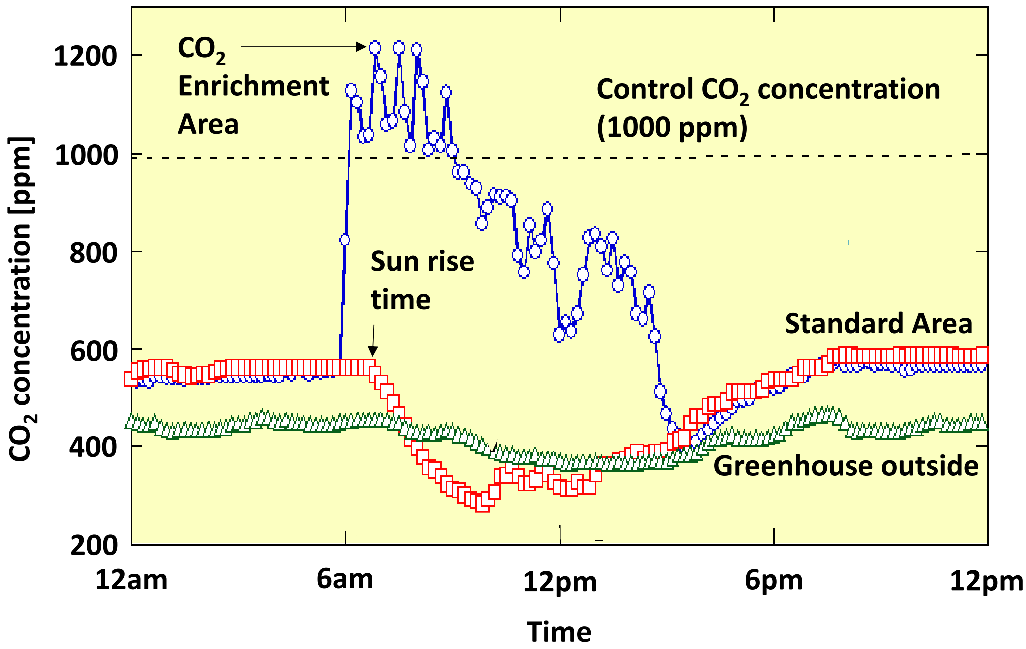

Figure 4.5 Changes in CO_2 concentration in Standard Area and CO_2 Enrichment Area.

4.3.3 Estimation of CO_2 Necessary for CO_2 Enrichment

In previous 2 sections, the effects of CO_2 enrichment as well as the changes in CO_2 concentration have been discussed. Based on the greenhouse scale and the basic CO_2 conditions, namely flow rate and concentration used in this study, the amount of CO_2 needed per day was estimated. Instead of distributing the CO_2 evenly to the greenhouse, only one role of the plant canopy was targeted for the CO_2 enrichment. Figure 4.6 showed the schematic diagram regarding the partly CO_2 enrichment area. The changes in CO_2 concentration at the partly CO_2 enrichment area, as well as the Standard Area, was monitored simultaneously. The flow rate for CO_2 during injection was 0.9 Nm^3/min. The injection time was set as 10 hours (5am-5pm). The wind speed during the experiment was monitored, with an average value of 5 m/s recorded. Figure 4.7 showed the raw data of data logger showing the changes in CO_2 concentration at the partly CO_2 enrichment area. As similar to Figure 4.5, the CO_2 concentration increased instantly when the injection of CO_2 was started. The downfall that followed every increase was considered to be the result of photosynthesis. In contrast to section before, where the CO_2 could not be maintained around 1000 ppm, Figure 4.6 showed that it can be maintained throughout the injection time. The highest recorded CO_2 concentration, which was between 11am to 12pm, was selected to be the basis for estimation of CO_2 needed per day under such scale of greenhouse. It was estimated that at least 0.96 kg/m^2 per day was necessary to ensure that the CO_2 enrichment remains at 1000 ppm, which is the desired concentration to enhance the plants growth. In case of utilizing the emitted CO_2 from the combustion of biogas, the carbon flow, which starts from the input of anaerobic digestion to the biogas combustion, is a vital part that must be evaluated beforehand.

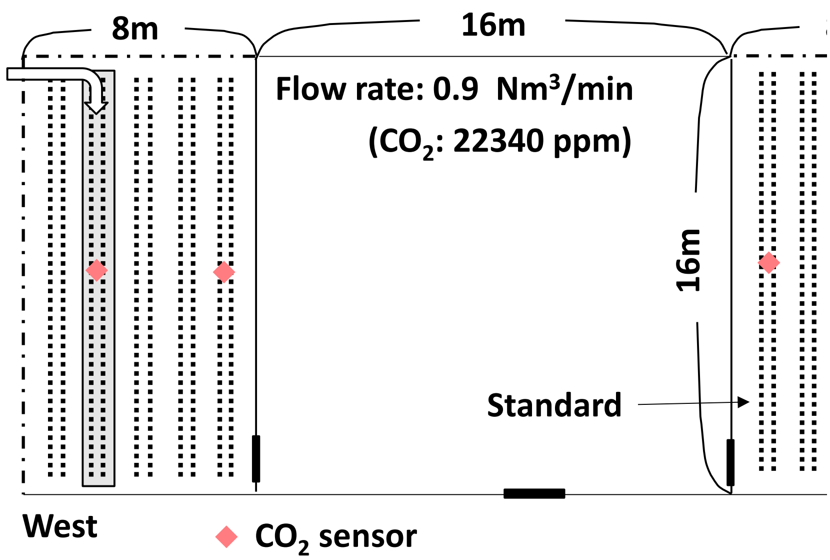

Figure 4.6 Schematic diagram regarding the partly CO_2 enrichment area.

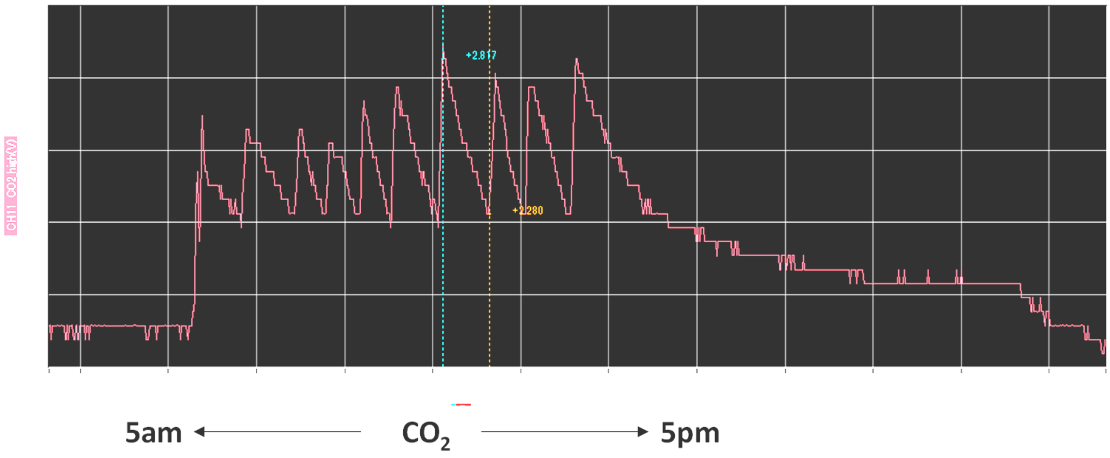

Figure 4.7 Raw data of data logger showing the changes in CO_2 concentration at the partly CO_2 enrichment area.

4.4 Conclusions

Although the CO_2 enrichment in a greenhouse is a well-studied approach in horticulture field, the case in which the greenhouse is considered as a combination with anaerobic digestion, so that the CO_2 resulted from the combustion of biogas can be utilized as the CO_2 source for CO_2 enrichment, is rarely reported. In this study, not only the emitted CO_2 had been proven to have the same enrichment effects as other CO_2 sources, but it also can be used as a way to avoid further CO_2 depletion. The different approach in terms of distribution of CO_2, where the CO_2 was distributed through a transparent vinyl duct near to the plant canopy, did not show significant effects as the concentration decreased once the ventilation was started. In cases where the greenhouse scale is smaller, or the overall expectation is not the main motive, a partly distribution of CO_2 can be considered, as results obtained in this study showed that the concentration can in fact be maintained at the desired concentration throughout the day time. Nevertheless, in case of integration of anaerobic digestion and greenhouse, the carbon flow as well as material flow should be evaluated carefully to design the suitable scale or capacity so that the necessary amount of CO_2 can be ensured. All in all the idea of having a greenhouse implemented beside an anaerobic digestion system can certainly change the typical perspectives regarding the current approaches on horticulture as well as biomass utilization.

CHAPTER 5

APPLICATION OF VACUUM-TYPE AERATION SYSTEM ON OILY SLUDGE COMPOSTING: APPROACH FOR BETTER PROCESS ASSESSMENT

Summary

Whereas the previous two chapters discussed about the utilization of CO_2 upon the integration of anaerobic digestion and crops production, this chapter focused on promoting the utility of composting process in biomass utilization. Odor emissions and difficulty to monitor are the common concerns regarding the composting process. In order to control the odor emissions, a research group from National Agriculture and Food Research Organization (NARO) developed the vacuum-type aeration (VTA) system in 2003. This VTA system is a composting technology that combines negative aeration with a chemical scrubber, in which the gases emitted during the composting process can be collected and treated. By using the VTA system, odor emission to the atmosphere can be reduced, and it is highly anticipated that the emission gases can be well monitored. In this study, the advantages of using VTA system for monitoring the composting progress were evaluated based on the composting of oily sludge (OS), which is a dewatered residue from grease trap waste. The changes of flow rate within the compost pile, as well as CO_2 and NO_3 gases, which were emitted during the composting, were monitored. Furthermore, quinone profile analysis, which is used to quantify the amount of microbes, was introduced as an additional monitoring method. This study aimed to verify the VTA system' advantages in helping to monitor the progress of composting, and also propose a comprehensive monitoring approach towards a better composting process.

5.1 Introduction

Composting is one of the most widely used methods to utilize organic waste into a stable amendment by decomposition through the activities of microbes. It is an environmentally friendly way to reduce the volume of organic waste by 40-50%, as well as produce organic fertilizer or soil conditioner to improve soil quality and fertility [47]. Various organic waste has been utilized through composting, such as animal manures, municipal solid waste and sewage sludge [96-98]. Yet the gases emitted during the composting process, for example, ammonia (NH_3), remain a concern as they would become an odor problem if the process was not managed well [99-100]. It would then lead to neighbor complaints as well as a lack of acceptance of the facility [100].

In order to control odor emission, Abe *et al.* developed a vacuum-type aeration (VTA) system (Figure 5.1) [101]. In contrast to the conventional method that forces air from the bottom of the compost pile to the compost surface (positive aeration), the VTA system withdraws air from the compost surface to the bottom of the compost pile (negative aeration), in which the air is then led to a chemical scrubber to be treated. It is reported that the NH_3 emitted from the compost surface was reduced under the VTA system when compared with a conventional positive-pressure aeration system [102]. With the VTA system, not only can air be provided for the microbes, but also the emitted gases, such as NH_3 and carbon dioxide (CO_2), as well as flow rate, can be collected in one place and be well-monitored throughout the process. These features would be helpful in managing the composting process, as the generation of NH_3 and CO_2 are considered as one of the parameters to evaluate the state of composting [47, 103]. It is also suggested that the NH_3 and the heat collected at the chemical scrubber can then be utilized as liquid fertilizer and a heat source for a greenhouse [104-105]. To date, the number of studies that discussed negative aeration is far less when compared to the conventional method. Besides, studies regarding the application of the VTA system in composting organic waste are focused only on animal manure. In order to extend the application of the VTA system in the composting field, further discussions, for example, its utility on monitoring the composting progress, as well as investigations that involve organic waste other than animal manure, are necessary [106].

In this study the composting of oily sludge (OS), which is the dewatered residue resulted from the treatment of grease trap waste, was conducted using the VTA system. Generally, the majority of OS is disposed through direct land application or landfill, but this could affect the soil [107]. Although composting would disinfect the pathogens and contaminants contain inside the OS, in which a stable and safe organic fertilizer can be produced, no research has been performed to assess the composting conditions [107]. For this reason, two common bulking agents, namely sawdust and cattle manure compost, were used to examine the effects of bulking agent volume in OS composting. In addition to conventional monitoring methods to evaluate the state of compost, quinone profile analysis was carried out in this study as well. Quinone profile analysis, which is one of the microbiological analysis methods, has been used for the characterization of microbes in environmental samples such as sludge [108], soil [109-110], as well as compost [111-113]. Tang *et al.* discussed the potential of quinone profile analysis to assess the composting state [114], however, to date there are none reported about the practical use of quinone profile analysis as a monitoring method. Therefore, the aims of this study are to accumulate knowledge regarding the composting of OS using the VTA system, and also examine the feasibility of VTA system as well as quinone profile analysis in terms of monitoring approach in a composting process.

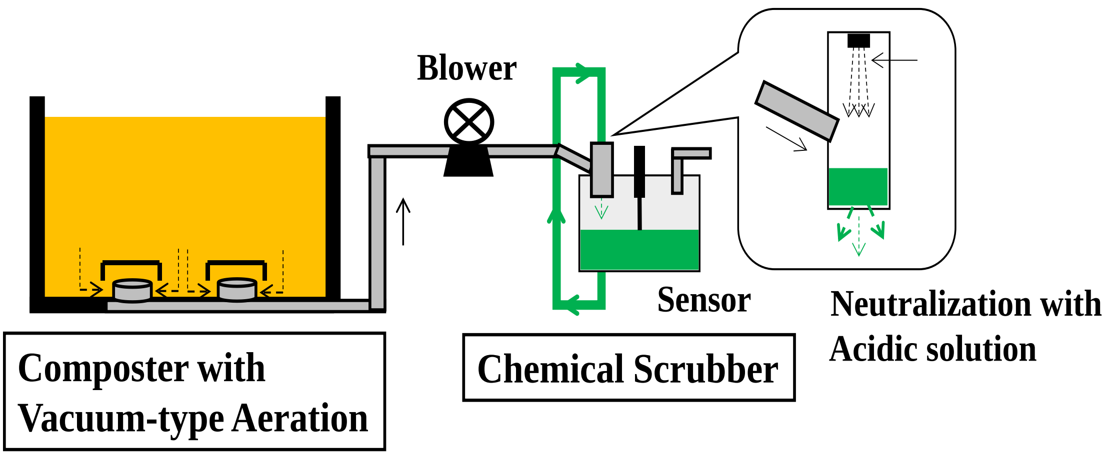

Figure 5.1 Vacuum-type aeration system (adapted from Abe *et al.*) [101]

5.2 Experimental Section

5.2.1 Composting Materials

The oily sludge (moisture content 73%, C/N ratio 20, oil content 12%) was obtained from a local company who collects and treats grease trap waste. The grease trap waste was treated using activated sludge system, and the dewatered sludge was used as the raw material in this study. Cattle manure compost (moisture content 55%) was obtained from a local cattle farm. Two runs were conducted: Run1 as the control and Run2 with more volume of bulking agents added. Table 5.1 shows the initial properties of each run. Run1 and Run2 were conducted for 4 weeks and 5 weeks, respectively. The initial moisture content of both runs was adjusted to 60%. Water was added to maintain the moisture content of the composting at approximately 50%.

Table 5.1 Initial properties of each run

Run	Volume of oily sludge [kg]	Volume of bulking agents [kg]	Initial moisture content [%]	Bulk density [kg/m^3]
Run1	527	287	61	678
Run2	472	374	60	601

5.2.2 Vacuum-type Aeration System and Conditions

Figure 5.2 and Figure 5.3 showed the schematic diagram of VTA system and compost container. The compost was turned by hand once a week and samples were taken during turning. As there is no reference on composting OS using VTA system, the ventilation rate was set as 23〜100 L/min/m^3, as referred to report elsewhere [101]. The air permeability within the compost pile would affect the flow rate as recorded by flowmeter. Therefore, based on the flow rate recorded through flowmeter, the frequency of blower was adjusted during turning to maintain the desired ventilation rate. Samples were freeze-dried in a vacuum freeze dryer for 24 hours and stored at -30℃ until further analysis.

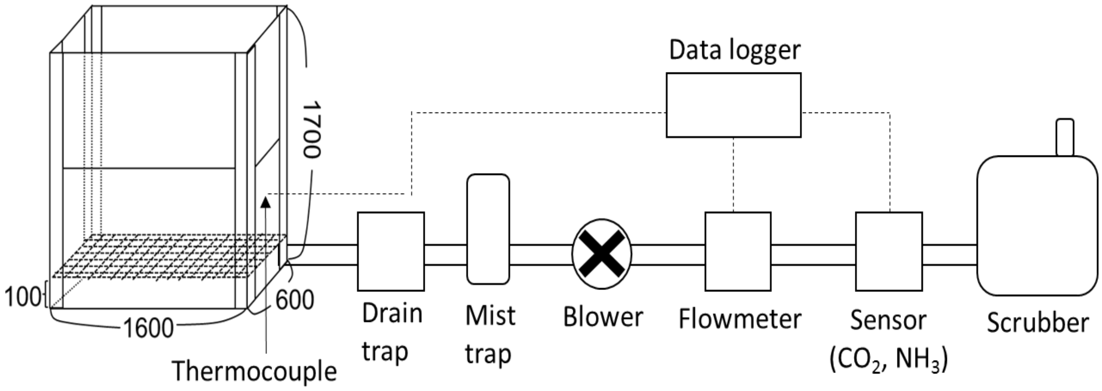

Figure 5.2 Schematic diagram of the vacuum-type aeration system.

Figure 5.3 Compost container.

5.2.3 Analytical Methods

The temperature of the composting was monitored every day with a time interval of one minute using a THERMO RECORDER. The concentration of CO_2 and NH_3 were data logged, using Vaisala GMT 220 Series CO_2 Transmitters (interval of 2 hours) and a Honeywell Manning EC-P2 Gas detector (interval of 1 hour), respectively. For the analysis of C and N to determine the C/N ratio, the freeze-dried sample was analyzed with a CHN analyzer (Elementar Analytical, Vario EL III).

Quinone profile analysis was performed by methods described elsewhere [115-116], with some modifications upon pre-studies. 0.3 g of freeze dried compost samples were placed in an extraction vessel (1 mL internal volume, SUS 316, Jasco) with supercritical CO_2 as solvent and methanol as modifier. The extraction conditions under supercritical CO_2 were as follows: an extraction vessel temperature of 55°C, a pressure of 25 MPa, a CO_2 flow rate of 2.7 ml/min, and a methanol flow rate of 0.3 ml/min for 30 min. The extracted quinone was re-extracted by hexane and followed by purification using Sep-Pak Plus Silica Cartridges (Waters) before analysis using ultra-performance liquid chromatograph (UPLC). The Waters Acquity UPLC system (Milford, MA, USA) was equipped with a binary solvent delivery manager, a sample manager and a photo-diode array detector (PDA- 2996, Waters). The analytical column was a Waters Acquity UPLC™ BEH C18 column (1.7 µm, 2.1 mm × 50 mm). The mobile phase consisted of 97% methanol containing 3% v/v di- isopropyl ether and was pumped at a flow rate of 0.5 mL/min. Chromatography was performed at 35±1 °C with a chromatographic run time of 35 min. The auto-sampler temperature was set at 4.0±1 °C and the sample injection volume was 10 µL.

The total quinone (TQ) content, which is the sum of the detected quinone contents of different species in a compost sample, was determined. The nomenclature of the quinone is designated as follows: ubiquinones (UQ) and menaquinones (MK) with n isoprene units in their side chain were abbreviated as UQ-n and MK-n, respectively [116]. The UQ and MK species were identified based on the retention time on the column and the spectrum of each peak observed in the PDA detector at 270 nm for MKs and at 275 nm for UQs. The linier correlation between the logarithm of retention time of quinones and an equivalent number of isoprenoid units (ENIU) was used to identify the quinones species [117]. UQ-10 and MK-7 were used as quantitative standards for UQ and MK, respectively. The ENIU can be approximated by the following equation:

$$ENIU_k = a + b\log\left(\frac{ET_k}{ET_{std}}\right) + c\left[\log\left(\frac{ET_k}{ET_{std}}\right)\right]^2 \qquad (2)$$

where ET_k represents the elution time of a quinone species k and ET_{std} represents the elution time of standard quinone. The constants are shown as a, b, and c, which are empirically obtained for each UPLC system [117]. The amounts of quinones were calculated from the peak area based on the mole absorption coefficients (ubiquinone 14.4 mM^{-1} cm^{-1}, menaquinone 17.4 mM^{-1} cm^{-1}) [118]. The quinone mole fraction was calculated as a ratio of the quinone content in the species *k* to the total quinone content.

5.3 Results and Discussion

5.3.1 Changes in Temperature and C/N ratio

Figure 5.4 shows the changes in temperature and C/N ratio for the composting process in each run. Both Run1 and Run2 reached thermophilic range within 1 week. The temperature dropped significantly when the compost pile was turned, but all in all the temperature remained at the thermophilic range throughout the run. In general, the temperature rises within the first few days of composting to the thermophilic range, and when it gradually decreases to a constant state near ambient, it is widely considered as the state of compost stability [47]. As seen from Figure 5.3, the temperature of both Run1 and Run2 still remained high at the thermophilic range at the end. This suggested that the degradation process in each run might still be under progress, and yet to become stable. For this reason, under current conditions, a longer composting time (more than 5 weeks) would be necessary for the composting of OS to become stable.

Regarding the changes in C/N ratio, as seen from Figure 5.4, Run1 was relatively small, whereas Run2 showed a more rapid decrease throughout the run. The rapid decrease in Run2 showed that the degradation of OS was in progress. C/N ratio is commonly used as a parameter to reflect the degradation rate of organic waste in composting, as well as an indicator of stability, in which a C/N ratio lower than 20 is assumed to be indicative of a stable compost generally [47, 119]. However, the initial C/N ratio of Run1 was below 20, while the C/N ratio in Run2 dropped to below 20 at week 1. This was contradictory to observation based on changes in temperature, in which the thermophilic range indicated that the OS compost in both runs was not yet stable. For this reason, the general perspective of compost stability based on C/N ratio might not be suitable in the case of OS composting. This is corresponded to study elsewhere, where more than two parameters are necessary to determine composting state [120], and thus it is appropriate to conclude that OS composting is no exception either.

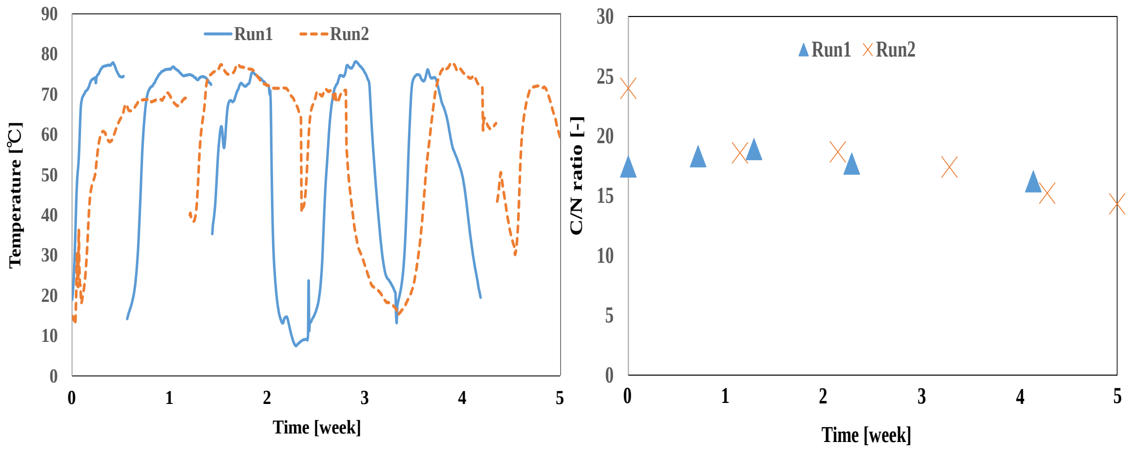

Figure 5.4 Changes in temperature and C/N ratio of oily sludge composting.

5.3.2 Changes in Flow Rate, CO_2 and NH_3 Volume in the Withdrawn Gas

Under the VTA system, the air as well as the gases emitted during the composting process were withdrawn into one place and hence the contents could be monitored. Figure 5.5 shows the changes in flow rate, CO_2 and NH_3 yield of the withdrawn air in each run. Even though the ventilation rate of the blower was the same in both runs, the flow rate as recorded was different. Overall Run1 was relatively inconsistent compared to Run2, especially between week 2 and week 3, where the flow rate recorded was as high as 15 m^3/h, and as low as 0 m^3/h. As OS contains a large fraction of lipids generally [121], the lipid fraction might lead to difficulty for air to flow smoothly within the composting pile. As composting is an aerobic process, air, or oxygen, is very important for the activity of microbes during composting. The lack of air, or low air permeability, would affect the respiratory activity of microbes, and eventually the composting process [122]. The effect can be seen from the changes in CO_2 yield, as showed in Figure 5.5 (b). Overall Run1's CO_2 yield was low compared to Run2, indicating that the microbes were not active in Run1. The CO_2 yield was only high between week 2 and week 3, where the flow rate was high. In the case of Run2, the CO_2 yield dropped to a low level around week 3 and lasted for several days before it gradually increased after the turning was conducted. It is widely suggested that the turning frequency should be done routinely [123]. However, as showed by the changes of CO_2 yield in

Run2, the timing for turning needs to be brought forward when the CO_2 yield, or the microbes' activity, would be below average for a certain period. This does in fact correspond to a study that argued that the turning of compost pile has to be delayed or done more frequently depends on the state of composting process [124]. VTA system can certainly be the effective method to monitor the composting state and hence adjustments can be made in real time.

In the case of the NH_3 yield, Run1 recorded higher NH_3 yield compared to Run2, especially between week 2 and week 4, as shown in Figure 5.5 (c). The low air permeability may have caused an anaerobic state within the compost pile, which led to the production of NH_3 [45]. Nevertheless, since the gases emitted during the process were withdrawn from the surface to the bottom of compost pile using the VTA system, the odor concern caused by NH_3 is less than the conventional method [102]. The addition of a bulking agent as shown by the results obtained in Run2, or adjustment of the ventilation rate would improve air permeability, and hence maintain the microbes' activity.

Overall, it is notable that by using the VTA system, the air permeability of the compost pile, as well as the composting state based on the emitted gases, can be well monitored. The idea of effectively collecting the emission gases into one place had actually been developed under a technique called dynamic chamber system, in which the compost is conducted in an enclosed chamber and the emission gases are collected from the top of the compost pile [125]. It is, however, difficult to apply in a large scale compost pile, with higher initial costs expected. Therefore the VTA system is anticipated to be the breakthrough for composting sector, it is not only useful for reducing odor emission but also helpful in monitoring and controlling the composting process.

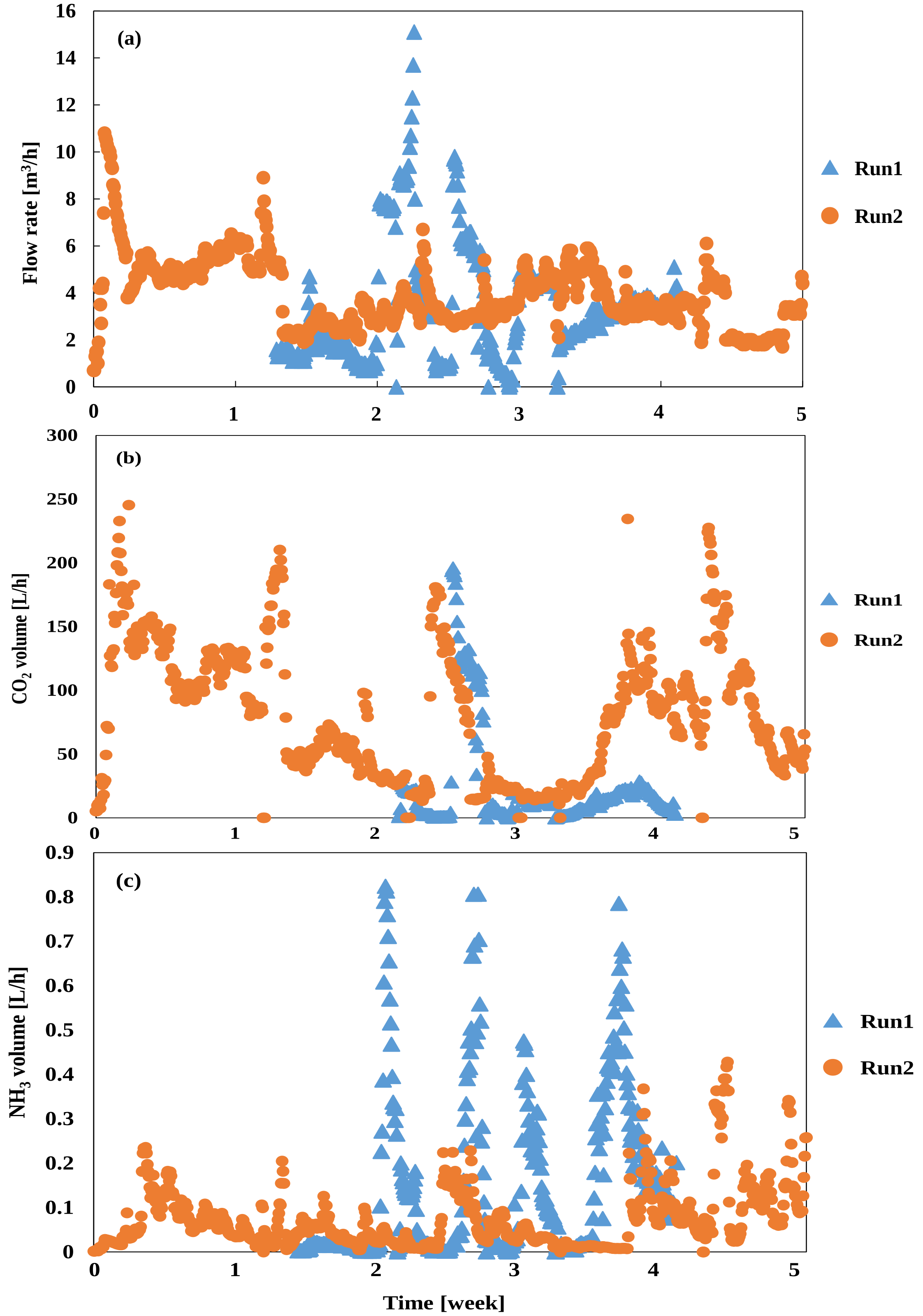

Figure 5.5 Changes of (a) flow rate, (b) CO_2 and (c) NH_3 volume in the withdrawn gas.

5.3.3 Changes in Microbial Properties based on Quinone Profile Analysis

Figure 5.6 shows the changes of total quinone (TQ) contents in both runs. The TQ in both runs were seen increasing gradually, but overall the TQ in Run 1 was lower than Run 2. As TQ is correlated with microbial biomass and total bacterial count [126], the results obtained corresponded with the CO_2 concentration results shown in Figure 5.5 (b). The TQ indicated that the microbes in Run1 were, in fact, inactive, due to a lack of oxygen caused by low air permeability. This showed that the application of quinone profile analysis can be used as a support with other monitoring methods for a more comprehensive understanding of the composting process.

As mentioned before, quinone profile analysis has been mostly applied to identify the species of microbes in various samples. Various studies have reported that MK-7, which is known to be the dominant quinone of *Bacillus* spp., is the major quinone found in composting process [111, 127-128]. As seen from Figure 4, the dominant quinone in Run2 was MK-7, and hence MK-7 is suggested to be the fundamental quinone in OS composting as well. Other than MK-7, UQ-6, which is the dominant quinone of *Saccharomyces cerevisiae* [129], was significantly found in Run 2 after week 2. This indicated that the microbe of UQ-6 could be a specific and vital species in OS composting as it was hardly detected in other studies.

As mentioned previously, there is nothing reported about the practical use of quinone profile analysis as a monitoring method. Tang *et al.* reported that TQ is initially low but gradually increases as the composting process progresses, and then it would start to decrease after reaching a peak [114]. It is suggested that the stage where the microbes' activity starts to decrease is an indication of compost stability [130-132]. In this study, the TQ in Run1 slightly increased after week 3, whereas Run2 showed a significant rise from week 3. The decrease of TQ was not seen in both runs, indicating that the composting process was not yet stable, as suggested also from the results based on the changes in temperature. Nevertheless, by determining the TQ using quinone profile analysis, the effects caused by the composting conditions on the microbes, for example, the inconsistent flow rate as showed in Run1, could be assessed and adjusted quickly. In order to fully establish quinone profile analysis as a supportive parameter to manage the composting process, further investigations that correlate the quinone profile to other parameters are necessary.

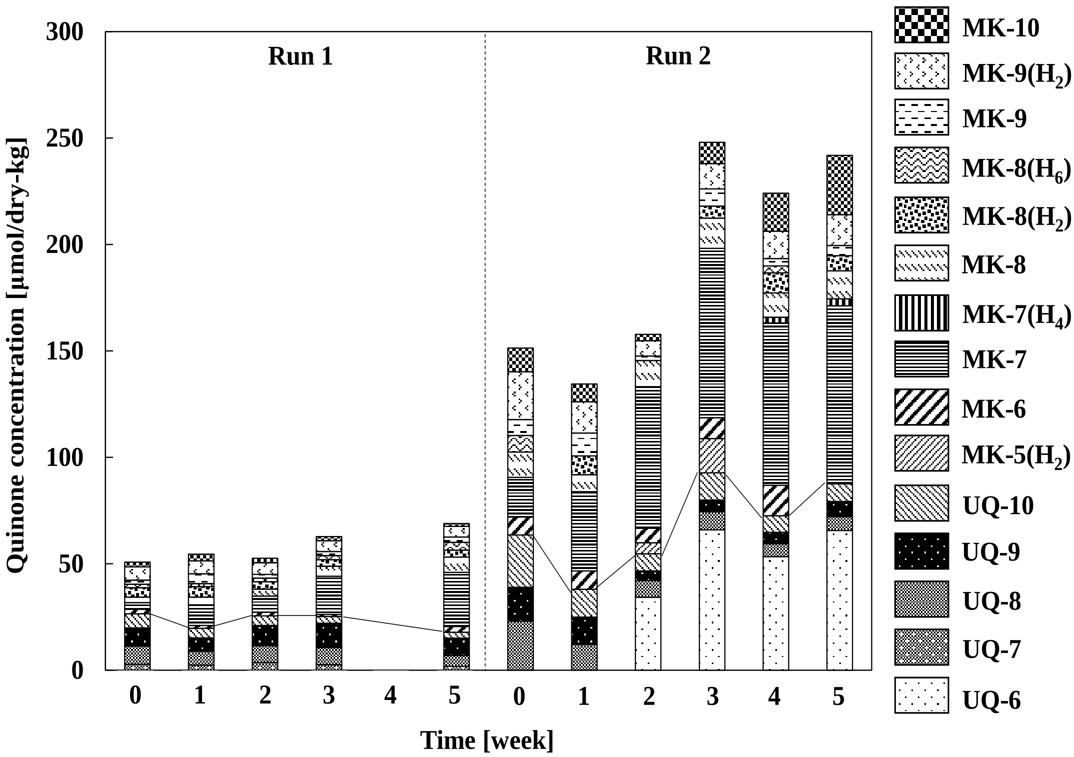

Figure 5.6 Changes of total quinone contents of each run.

5.4. Conclusions

In this study, OS was composted using the VTA system, with sawdust and cattle manure compost used as the bulking agent. The changes in flow rate and CO_2 concentration, as monitored by the VTA system, indicated that the volume of bulking agent is vital in improving air permeability in composting OS. Under current composting conditions, more than 5 weeks of composting time would be necessary for the OS compost to reach a stable state. All in all, it is clear that the VTA system is able to determine the progress of the composting process, such as the flow rate and that the composition of emitted gases can be well monitored.

On the other hand, the application of quinone profile analysis as an alternative monitoring method was able to support the observations obtained based on conventional parameters. As microbes would be affected directly by any improper conditions, for example the lack of air as shown in this study, the perspectives or information that are obtained through the quinone profile analysis would lead to better awareness of the actual state of the composting process. Significant results that corresponded to previous studies were not obtained through this study, due to the short experimental period, but a combination with a conventional parameter, for example, C/N ratio, is highly anticipated. In order to assess the utility of OS composting, further investigations that include the optimum volume of bulking agent, as well as the effects on crops when applied, will have to be studied apparently. At the same time, the correlation of quinone profile analysis with conventional parameters in composting needs to be addressed further in order to establish it as a practical monitoring method.

CHAPTER 6

CONCLUSIONS AND FUTURE PROSPECTS

6.1 Overall Conclusions

This thesis proposed the concept of integrated system that adds extra values, namely crops production and utilization of by-products to the present approaches. The aim is to impact the public's perspectives towards biomass utilization so that more involvement can be generated through a more straightforward benefit to the public itself. Several aspects of fundamental development and assessment regarding the concept of integrated system were investigated and the following conclusions can be drawn:

1. In the first attempt to use biogas' CO_2 for CO_2 enrichment in land-based seaweed cultivation, the effect was significant, in which the growth yield was improved by almost 50%. Seaweed itself is famous for its health benefits, thus the increase of seaweed yield through the biogas' CO_2 enrichment can certainly attract more involvement from the public. The location of such integrated system, however, is crucial, as the cost for transporting seawater in the case of land-based cultivation was estimated to be a major part of economic feasibility.

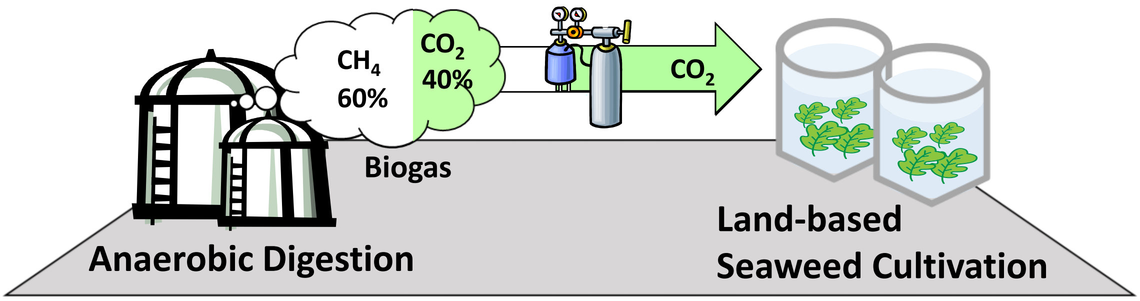

Figure 6.1 Integration of anaerobic digestion and land-based seaweed cultivation.

2. Instead of discharging the emitted CO_2, which is a residue of biogas combustion, to the atmosphere, it was connected and injected into the greenhouse for CO_2 enrichment of tomatoes. The growth yield was enhanced, but the more important part was that that CO_2 can be used for prevention of CO_2 depletion in greenhouse. Instead of using propane gas or liquid CO_2 as the

sources of CO_2 enrichment, the integration of anaerobic digestion with the greenhouse might provide a cheaper yet effective approach for the CO_2 concerns regarding the greenhouse.

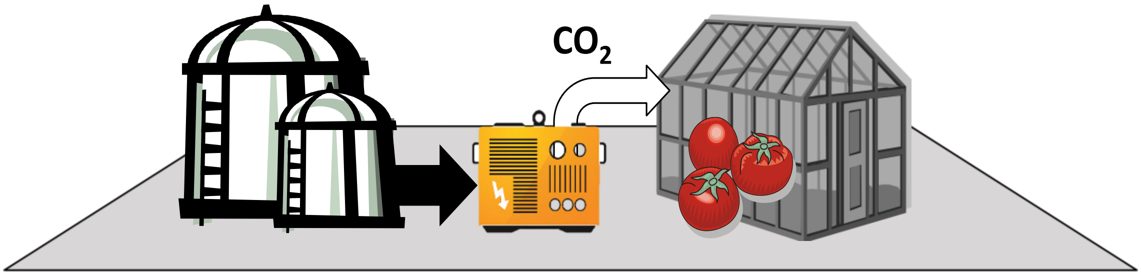

Figure 6.2 Integration of anaerobic digestion and greenhouse

3. The vacuum-type aeration system (VTA system), which withdraws the air from the bottom of compost pile, was introduced as the potential solution to monitor the composting. In contrast to conventional method, where the gases emitted from the composting process are diffused into the atmosphere, this VTA system collects the gases (CO_2, NH_3) in one place and hence the composition and concentration can be monitored accurately. Quinone profile analysis was introduced as the supportive assessment method to the conventional approaches. Based on the changes in microbes, which are the main reason of decomposition, the progress as well as the effects caused by the composting conditions, such as air permeability and turning timing, can be determined. The VTA system can be the breakthrough approach for composting biomass with less odor and higher monitoring capability.

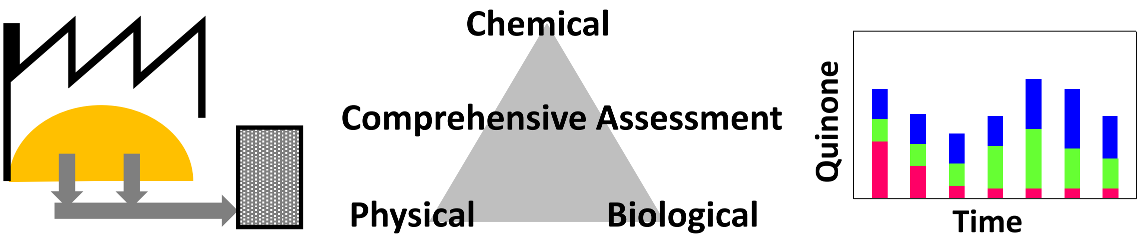

Figure 6.3 Vacuum-type aeration system and quinone profile analysis as the monitoring approach for composting process.

The integrated system, in which the main concept is to fully utilize the every products as well as by-products that result into crops production, is a practical showcase of how different sectors can and should work together. The current approach towards biomass is rather largely depended on local authorities or stakeholders. Mostly the actions or methods taken are rather independent, with not-strong involvement from other sectors, including the public. By implementing the integrated system, as proposed in this study, the biomass treatment will no longer be seen as a public nuisance that brings no benefits at all. The integrated system that involves aquaculture, horticulture and agriculture with biomass treatment will only strengthen the linkage between various sectors of the public. Consequently it can create new employment opportunities, with the promise of ensuring the proper treatment of biomass, and hence contribute to the implementation of sustainable society.

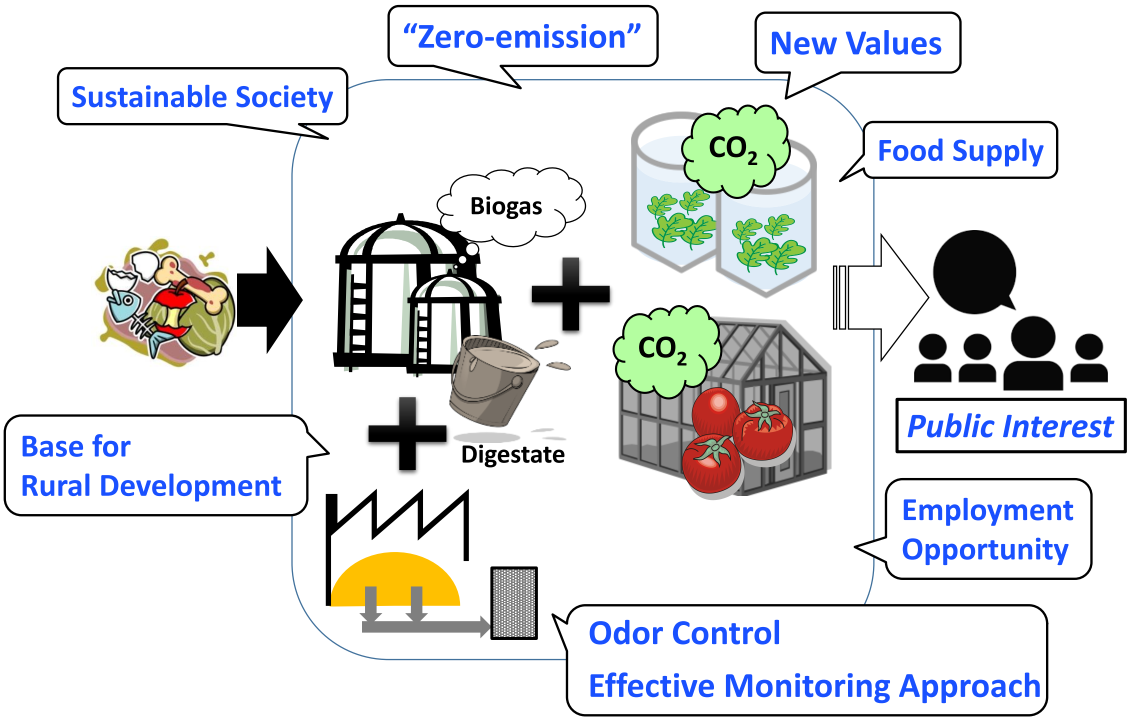

Figure 6.4 Potentials of integrated system.

6.2 Future Prospects

Although some fundamental parts of the integrated system have been investigated and discussed in this thesis, the full potential of such integrated system remains to be studied. Figure

6.5 showed the comprehensive concept of integrated system for the promotion of biomass utilization. The biogas produced by anaerobic digestion can be used for power generation and seaweed cultivation, as showed in this thesis. Other than the CO_2, the heat that is generated during the combustion of biogas can be used for heating up the greenhouse during cold season. Then the digestate, which is a major residue of anaerobic digestion, can be used as substrate for composting, or liquid fertilizer for hydroponics in greenhouse after certain intermediate treatment. The vacuum-type aeration system, on the other hand, can capture the CO_2 and heat emitted from the composting process. Similar to the integration between anaerobic digestion and greenhouse, the CO_2 and heat from the composting process can be utilized for CO_2 enrichment and warming of greenhouse. One of the specialty of VTA system is the generation of liquid fertilizer, as a result of NH_3 treatment inside the chemical scrubber by acidic solution. This liquid fertilizer can certainly be used for hydroponics inside the greenhouse, or even common farm cultivation. The idea of integrated system is to fully maximize the potential of biomass in terms of utilization, while creating the straightforward value that the public can see and be benefited. The conditions and situation of biomass treatment are varied according to regions, cultures, economic activities, and so not all parts of the system can be implemented. Nevertheless, the concept of integrated system can be the stimulus to engage the current lack of public interest in most part of the world.

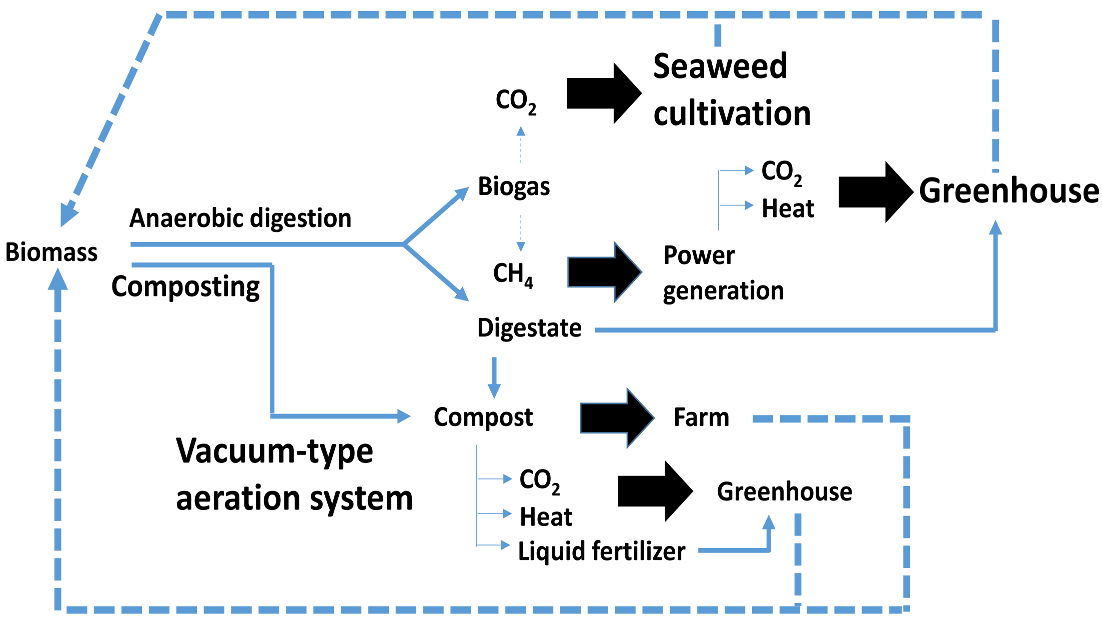

Figure 6.5 Comprehensive concept of integrated system.

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Lee Chang Yuan
Toyohashi, January 2017.

ACHIEVEMENTS

Author's Publications

1. Ni Luh Gede Ratna Juliasih, Lee Chang Yuan, Yuki Sago, Yoichi Atsuta, Hiroyuki Daimon, Supercritical Fluid Extraction of Quinone from Compost for Microbial Community Analysis, Journal of Chemistry, vol. 2015, Article ID 717616, 7 pages, 2015.
2. Ni Luh Gede Ratna Juliasih, Lee Chang Yuan, Yoichi Atsuta, Hiroyuki Daimon, Development of Coupled Supercritical Fluid Extraction-high Performance Liquid Chromatography for Quinone Analysis in Activated Sludge, Separation Science and Technology, 51(3), 439-446, 2016.
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Domestic Conference

1. Lee Chang Yuan，佐合悠貴，鈴木邦彦，熱田洋一，大門裕之，キノンプロファイル法を用いた堆肥製造過程における微生物群集構造の変化，化学工学会第 45 回秋季大会, 2013 年 9 月 16 日，岡山大学.

International Conference

1. Ni Luh Gede Ratna Juliasih, Lee Chang Yuan, Yuki Sago, Yoichi Atsuta, Hiroyuki Daimon, Microbial Community Dynamics during Composting Process and Cultivation of Komatsuna, International Symposium on EcoTopia Science 2013 (ISETS'13), No. 15-5-6 (1184), Nagoya, December 13-15, 2013.
2. Lee Chang Yuan, Hirotsugu Kamahara, Yoichi Atsuta, Hiroyuki Daimon, Pilot-scale anaerobic digestion system in Toyogawa Wastewater Treatment Plant, International Conference of Global

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3. Hirotsugu Kamahara, Lee Chang Yuan, Yoichi Atsuta, Hiroyuki Daimon, Development of Biomass, CO2, Heat Utilization System in Sewage Treatment Plant: Concept Study, International Conference of Global Network for Innovative Technology, 168-171, 15th-16th December 2014, Malaysia.
4. Hirotsugu Kamahara, Lee Chang Yuan, Hamidi Adbul Aziz, Hiroyuki Daimon, Prospect of Wet Biomass Utilization in Penang, Malaysia, International Conference of Global Network for Innovative Technology, 172-174, 115th-16th December 2014, Malaysia.
5. Ni Luh Gede Ratna Juliasih, Lee Chang Yuan, Yoichi Atsuta, Hirotsugu Kamahara, Hiroyuki Daimon, Effect of static extraction on extraction efficiencies using on-line supercritical fluid extraction-high performance liquid chromatography for lipoquinone analysis in activated sludge, The 5th Annual International Conference in conjunction with The 8th International Conference of Chemical Engineering on Science and Applications, No.20, 130-136, 9th-11th September 2015, Indonesia.
6. Motoki Nishimura, Lee Chang Yuan, Yoichi Atsuta, Hirotsugu Kamahara, Kunihiko Suzuki, Kei Takeda, Hiroyuki Daimon, Determination of Anaerobic Digestibility of Food Waste based on Neutral Detergent Solubles using Near Infrared Reflectance Spectroscopy, International Conference of Global Network for Innovative Technology, 74, 27th-29th January 2016, Malaysia.
7. Lee Chang Yuan, Yoichi Atsuta, Hiroyuki Daimon, Application of Vacuum-type Aeration System to Grease trap Sludge Composting, 3, 11th International Forum on Ecotechnology, 25th-26th December 2016, Malaysia.
8. Lee Chang Yuan, Hirotsugu Kamahara, Yoichi Atsuta, Hiroyuki Daimon, Towards a New Social System: Biomass Park in Wastewater Treatment Plant, 14, 11th International Forum on Ecotechnology, 25th-26th December 2016, Malaysia.

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1. Lee Chang Yuan, Hirotsugu Kamahara, Hamidi Abdul Aziz, Hiroyuki Daimon, Treatment of Sewage Sludge using Anaerobic Digestion in Malaysia: Current State and Challenges, Renewable and Sustainable Energy Review.
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2. Lee Chang Yuan, 蒲原弘継, 熱田洋一, 大門裕之, 水熱反応を用いた液状飼料製造法のライフサイクル分析, 廃棄物資源循環学会.
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3. Lee Chang Yuan, Hirotsugu Kamahara, Yoichi Atsuta, Hiroyuki Daimon, Towards a New Social System: Biomass Park in Wastewater Treatment Plant.
   (In progress)
4. Lee Chang Yuan, 佐合悠貴, 蒲原弘継, 熱田洋一, 大門裕之, コマツナ水耕栽培におけるメタン発酵消化液の利用.
   (In progress)

APPENDIX

Presentation Slides

Open Defense for Doctoral Program
23th February 2017

Development and Assessment of Integrated System for Promotion of Biomass Utilization

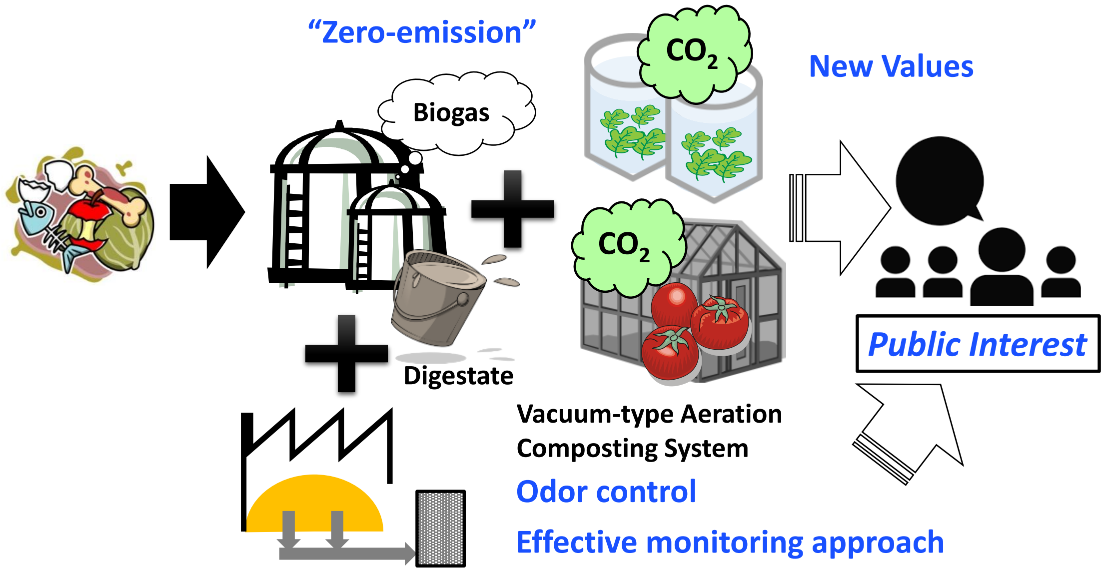
バイオマス利活用の促進に向けた複合型システムの開発および評価

Lee Chang Yuan

Department of Environmental and Life Sciences
Toyohashi University of Technology

Integrated System for Promotion of Biomass Utilization

Integration of Biomass Treatment and Crops Production



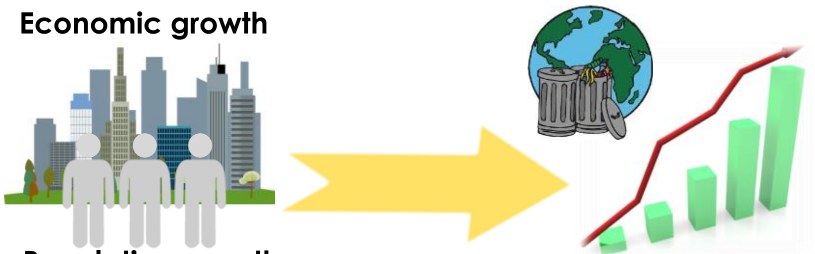
- Development and assessment of fundamental parts
- Evaluation of potentials and challenges of the system

General Background

Biomass Resources

Forestry/Agricultural Residues | Animal Residues | Municipal Solid Waste *2.2 billion tons in 2025 | Sewage Sludge

Economic growth

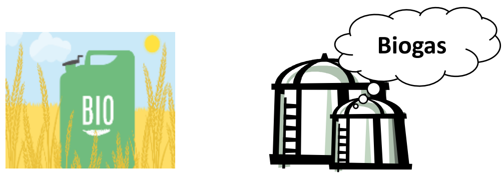


Population growth

*The World Bank, 2012

- ☐ Secure of public health & environmental impacts
- ☐ Energy and nutrients recovery
- ☐ Contribution towards sustainable society

Current Approach towards Biomass



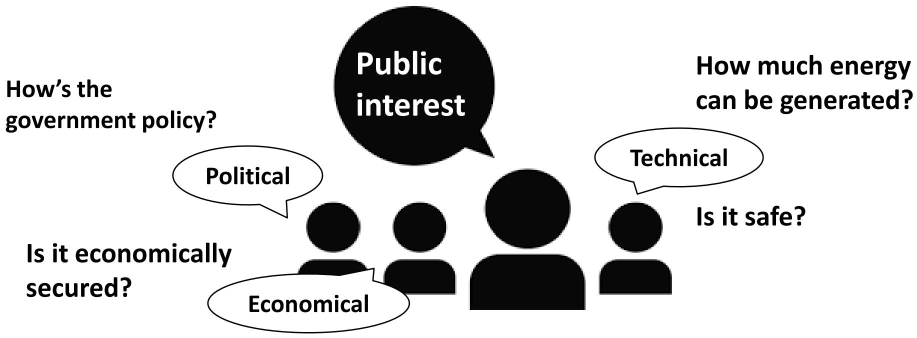
Conversion into biofuels | Production of biogas through anaerobic digestion | Composting into soil amendment or organic fertilizer | Power generation through combustion

Open dumping | Landfill | Incinerator

- Mostly in low and lower middle-income countries
- Mostly in high-income countries

Interest of biomass utilization is high but lack of application

Questions regarding the Biomass Utilization



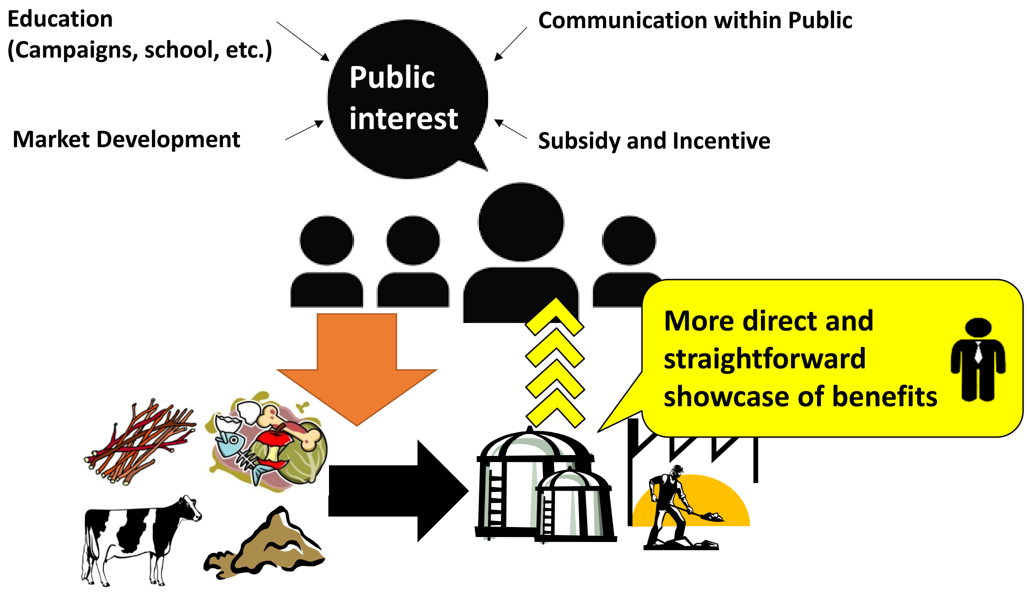
What is the use of waste? → Waste is waste

What do I get? → Energy is not priority

The public interest is equally as important as the technical aspect.

R.E. Marshall et al., *Waste Management*, 2013.

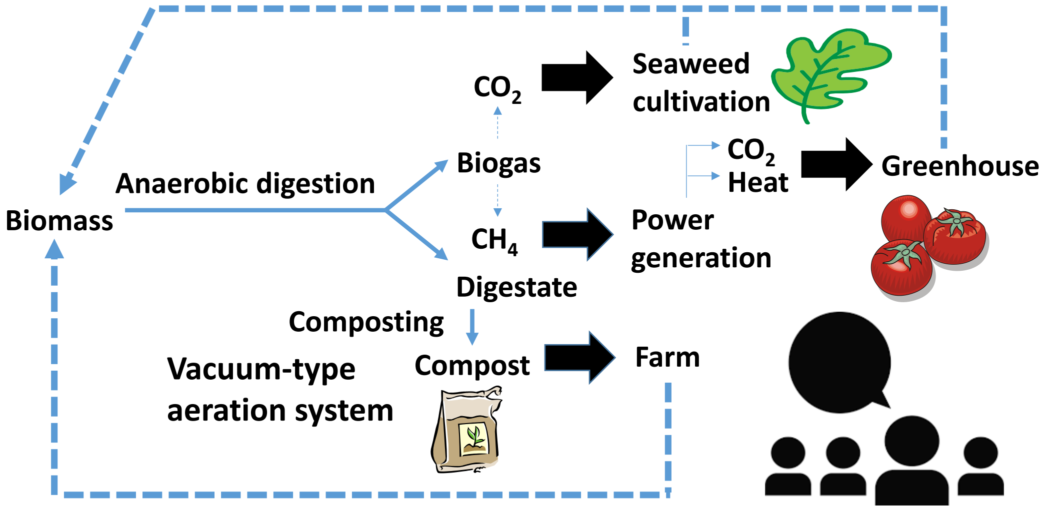
What are the Strategies to increase the Public Interest?



The participation of the public is the best approach on waste management.

Al-Khatib et al., *Waste Management*, 2009.

Integrated System – Combination of Treatment and Production

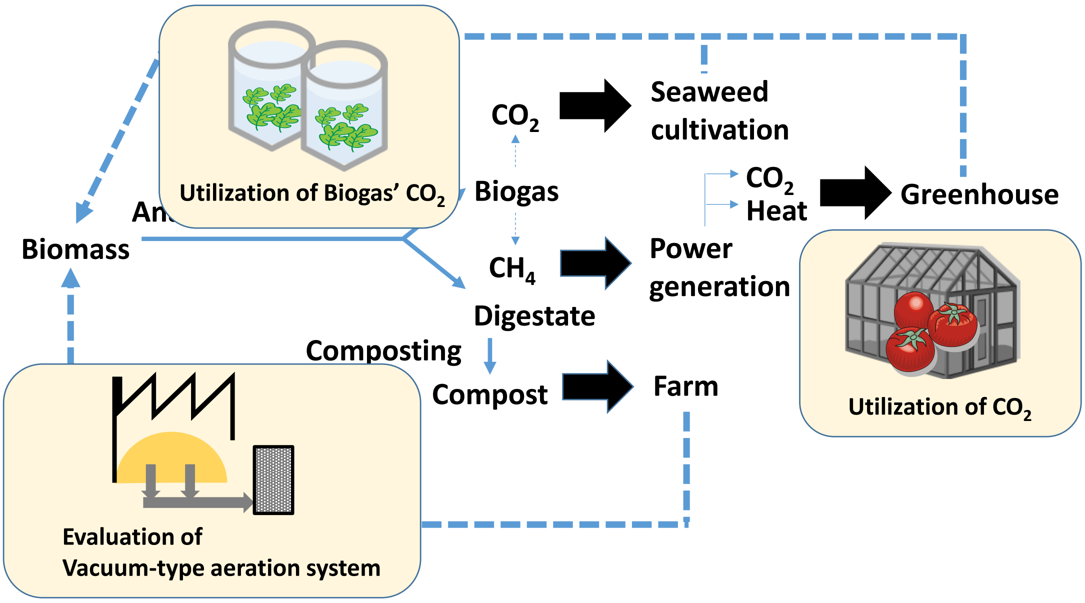


✓ A System to Connect Different Sectors

✓ A Showcase of What Biomass Utilization can do

Promotion of the Biomass Utilization

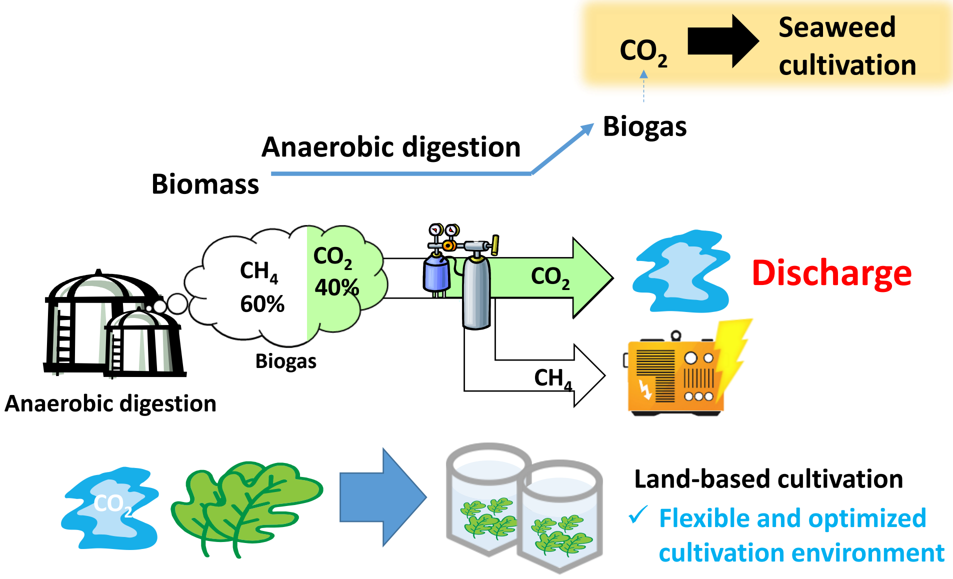
Motivations and Objectives



- ➢ Development and assessment of fundamental parts
- ➢ Evaluation of potentials and challenges of the system

Chapter 3

General Background and Objective



Objective

Investigate the utilization of biogas' CO_2 in land-based seaweed cultivation

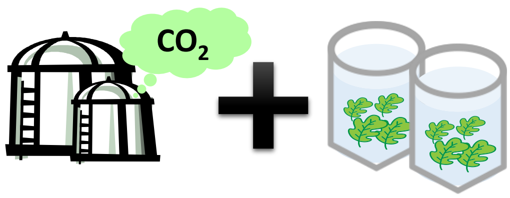
Previous Studies and Approaches of Current Study

CO_2 enrichment in seaweed cultivation

- ✓ Mostly in batch-scale
- ✓ CO_2 from gas cylinder
- ✓ Enclosure needed in situ

Land-based seaweed cultivation

- ✓ Salty groundwater*
- ✓ Deep ocean water**

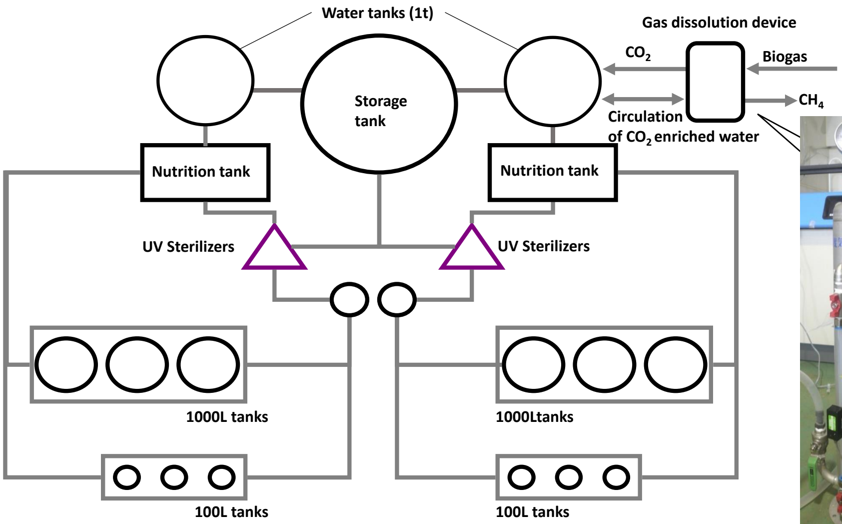


1. Pilot-scale cultivation
2. Estimation of commercial scale

*H. Ebata *et al.*, *Bulletin of the Society of Sea Water Science*, 2006.

** M. Hiraoka, *Journal of the Japan Institute of Energy*, 2012.

Application of Biogas' CO_2 under Pilot-scale



OD-110 (Daiei Seisakusho Co., Ltd.)

Seaweed: *Ulva prolifera*

Cultivation method: Germling Cluster method**

Cultivation vessels: 100ℓ, 1000ℓ

Seawater: Mikawa Bay's surface seawater (water temperature 7～12℃)

CO_2 enriched water concentration: pH6.8～7.2

Effects of CO_2 Enrichment

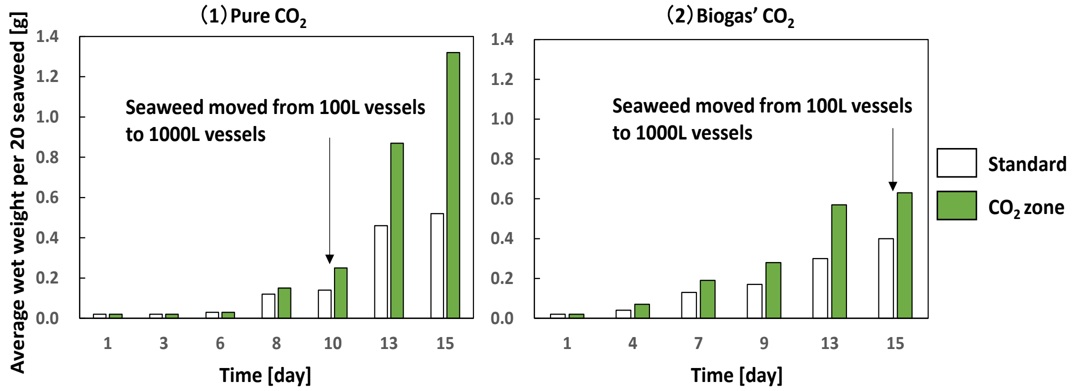
Regular Cultivation

CO_2 Enrichment Cultivation

CO_2 Enrichment Cultivation

Regular Cultivation

Results - Effects of CO_2 Enrichment in Pilot-scale



CO_2 supply:
on-off mode 24 hours

Biogas' CO_2 supply:
on-off mode 5 hours during daytime

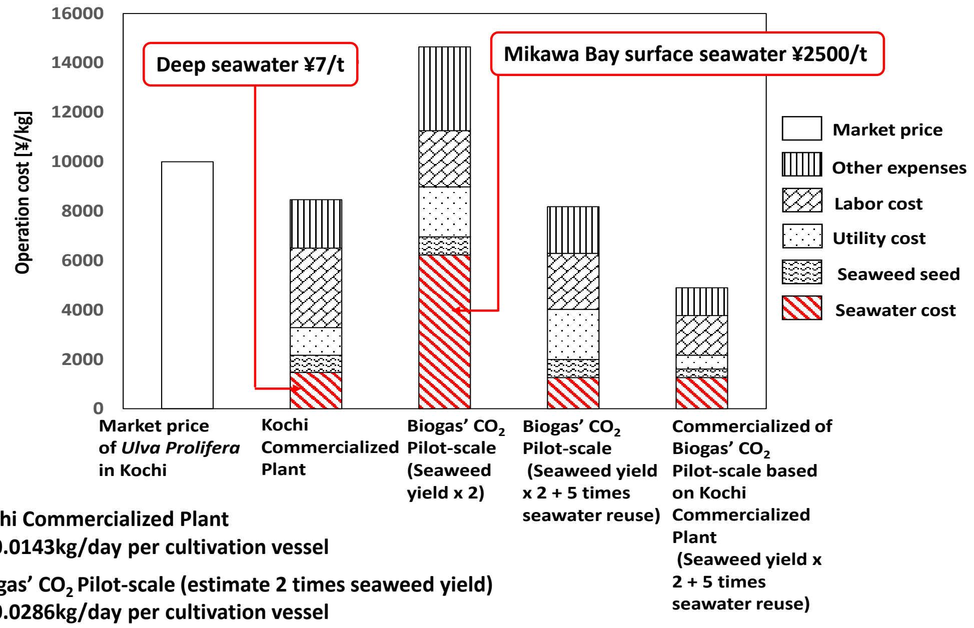
Estimated CO_2 consumed: 0.33 kg/m³/day

Difference between (1) and (2) were caused by CO_2 supply time

Until seaweed was moved from 100L to 1000L, growth pattern was similar

✓ The effects of applying CO_2 in seaweed cultivation, especially biogas' CO_2 were notable → 2 times higher of growth

Economic Feasibility Study based on Pilot-scale



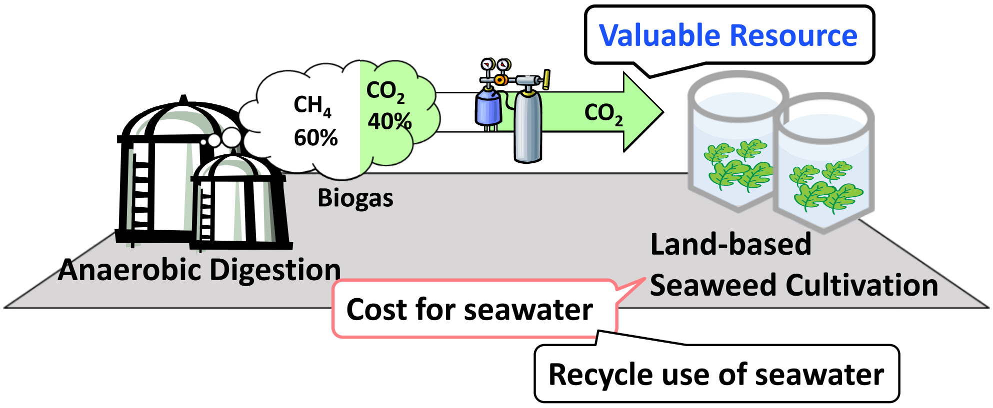
Kochi Commercialized Plant
→ 0.0143kg/day per cultivation vessel

Biogas' CO_2 Pilot-scale (estimate 2 times seaweed yield)
→ 0.0286kg/day per cultivation vessel

Current operation cost is high due to seawater cost

✓ Reuse of seawater as well as the commercialization would lead to profit

Summary for Chapter 3



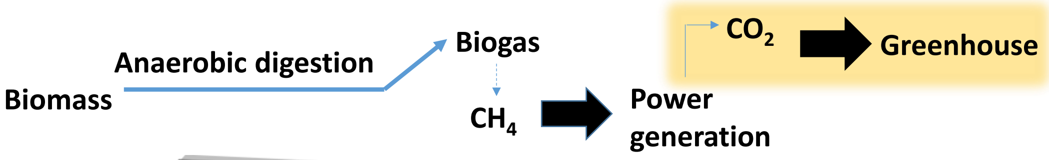
□ **Integration of anaerobic digestion and land-based seaweed cultivation**

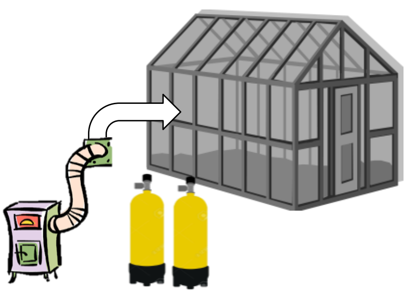
✓ **Treatment of biomass** ✓ **Energy recovery by CH_4** ✓ **Higher production yield of seaweed by CO_2**

From "Waste" to Seaweed ➡ Attract Public's Interest

Chapter 4

General Background and Objectives



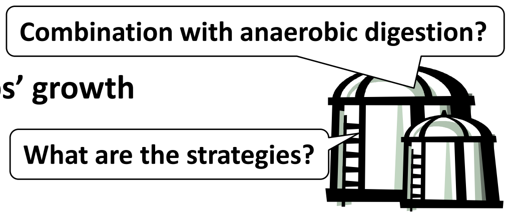


Control over growing environment

Longer growing season

Better protection from insects and diseases

Well-established especially in Netherlands



CO_2 Enrichment → Enhance the crops' growth

- Combustion of carbon-based fuels
- Liquid or bottled CO_2 gas

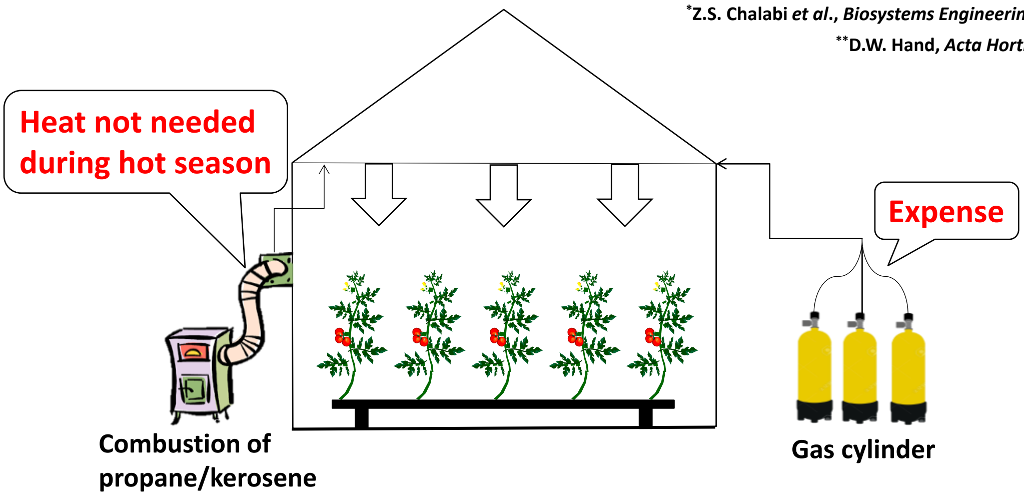
Objectives

Investigations of integration of anaerobic digestion and greenhouse

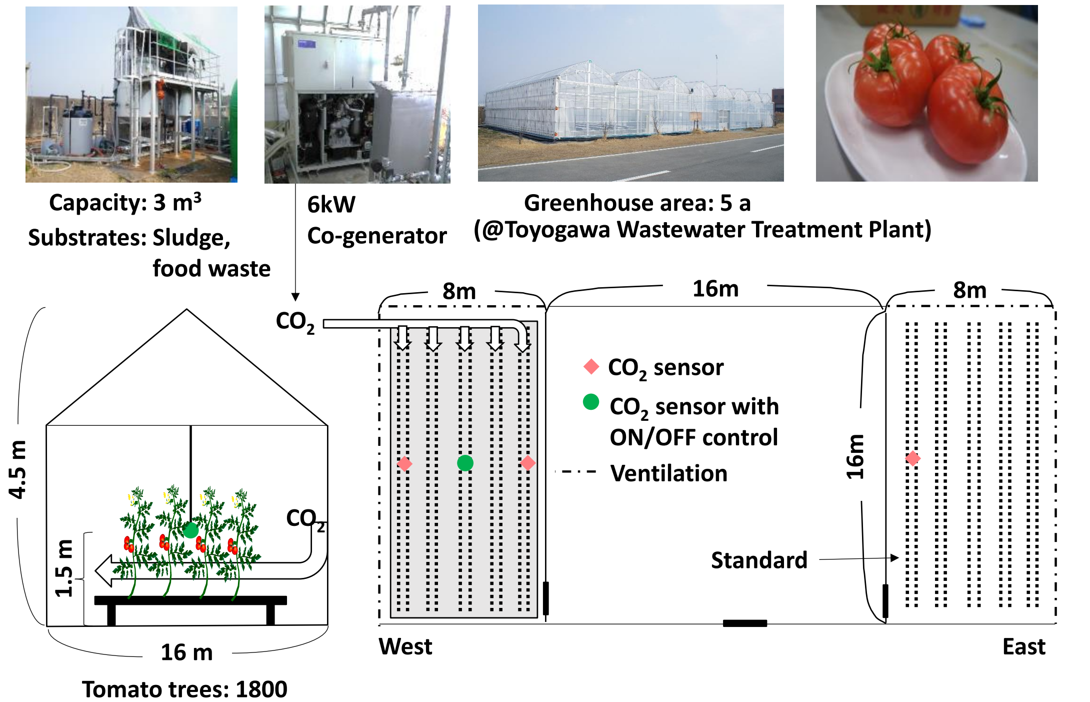
Previous Studies and Approaches of Current Study

- ✓ In general CO_2 enrichment in the range of 1000 to 1500 ppm*
  - → >1500 ppm brings harm to plants
- ✓ Concentration varies under ventilation
  - → Mostly enclosed greenhouse in country like Netherlands
- ✓ Important to keep CO_2 level constant at ambient level (300〜340ppm)**

*Z.S. Chalabi *et al.*, *Biosystems Engineering*, 2002.
**D.W. Hand, *Acta Hortic*, 1984.

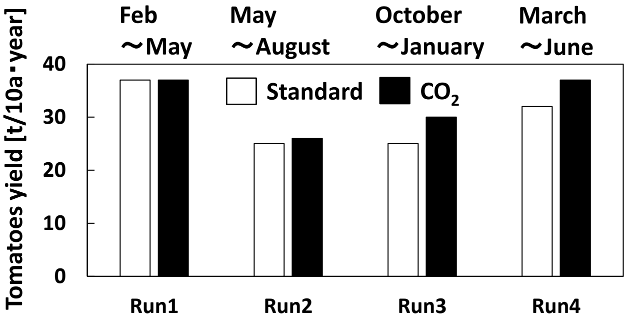


Integration of Anaerobic Digestion and Greenhouse



Effects of CO_2 Enrichment on Tomatoes Yield

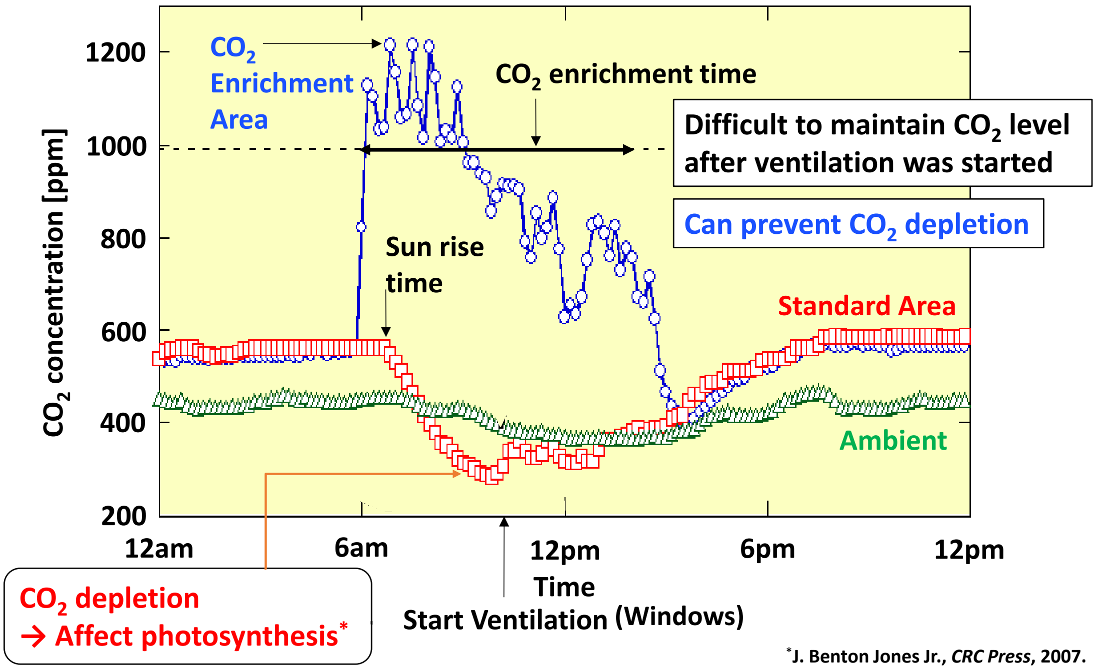




Average weight: 0.12 kg/tomato Average yield: 6000 tomatoes/cold season

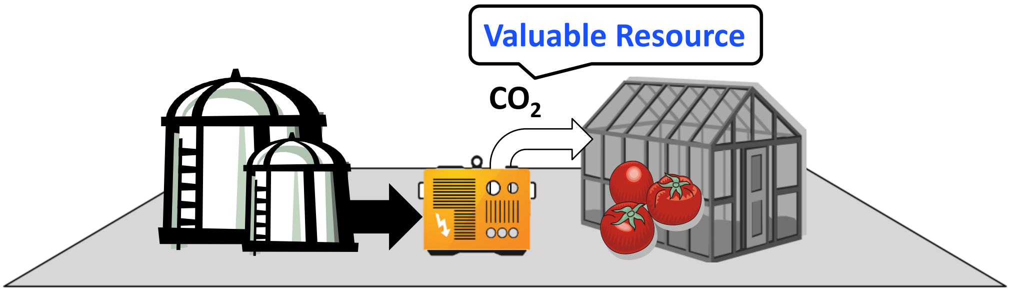
✓ CO_2 enrichment origin from anaerobic digestion biogas

Changes in CO_2 Concentration



*J. Benton Jones Jr., *CRC Press*, 2007.

Summary for Chapter 4



☐ **Integration of Anaerobic Digestion and Greenhouse**

- ✓ Treatment of biomass
- ✓ Energy recovery by CH_4
- ✓ Free CO_2 enrichment for growth yield or prevention of CO_2 depletion

From "Waste" to Tomatoes ➡ Attract Public's Interest

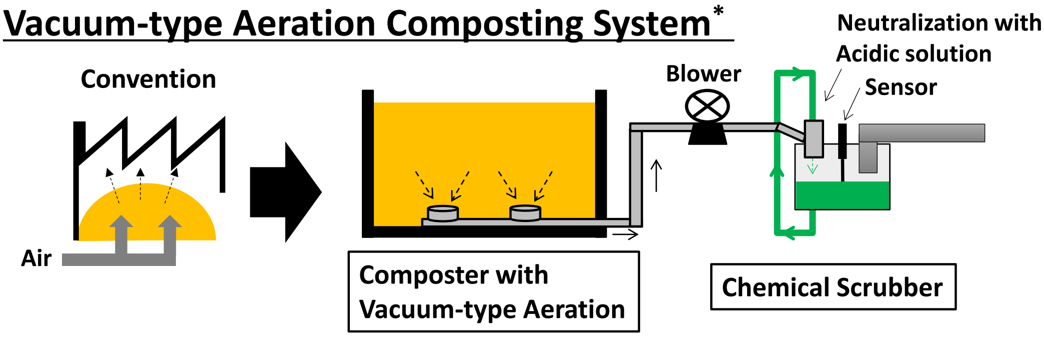
Chapter 5

General Background

- ✓ Organic Fertilizer
- ✓ Soil Amendment
- ◆ Odor Emission
- ◆ Reply on on-field experience

*Abe et al., *The Society of Agricultural Structures*, 2003.

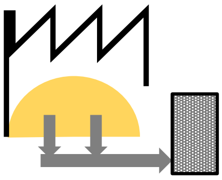
Vacuum-type Aeration Composting System*



Air absorbed from the bottom
and directed to a chemical scrubber

- ✓ Reduce odor to atmosphere
- ✓ Potential of efficient monitoring

Previous Studies and Objectives of Current Study



Vacuum-type Composting Aeration System (VTA system)

~ Designed to reduce the odor emission during composting of animal manures

✓ Most studies focused on odor reduction

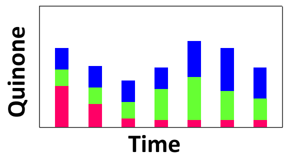
How about its advantages in helping to monitor the process?

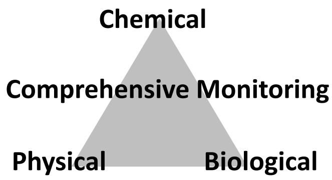
Objective 1

Investigate the utilities of VTA system in monitoring composting process

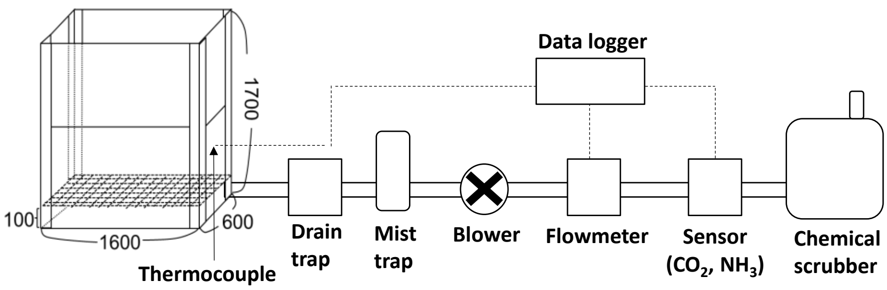
Objective 2

Introduction of quinone profile analysis as a supportive monitoring method





Composting of Oily Sludge using Vacuum-type Aeration Composting System



Oily sludge (originally from grease trap)

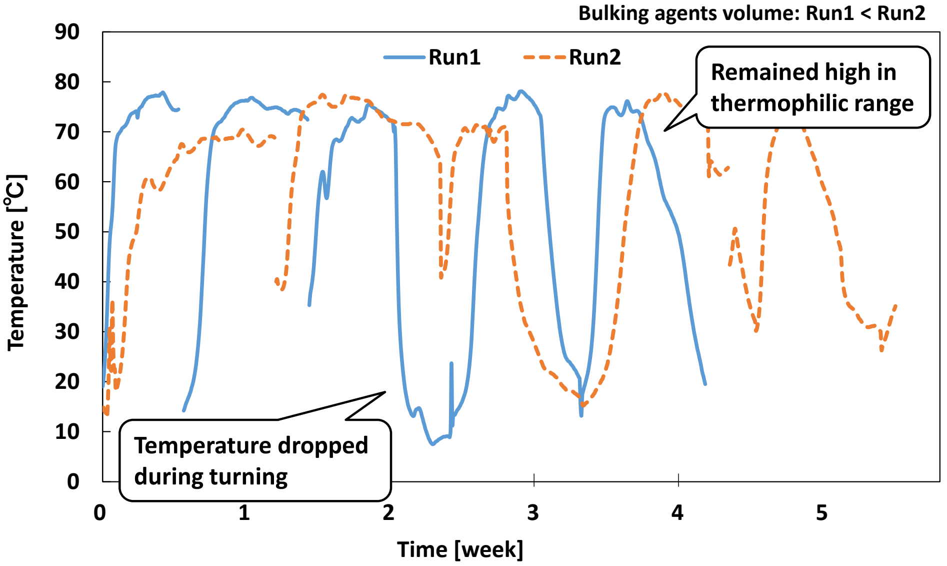
Run	Oily sludge [kg]	Bulking agents [kg]	Initial moisture content [%]	Bulk density [kg/m³]
Run1	527	287	61	678
Run2	472	374	60	601

Bulking agents: Sawdust & cattle manure

●Temperature ●C/N ratio ●Flow rate ●CO_2 & NH_3 concentration

Result - Changes in Temperature

Changes in Temperature ～ A conventional monitoring tool

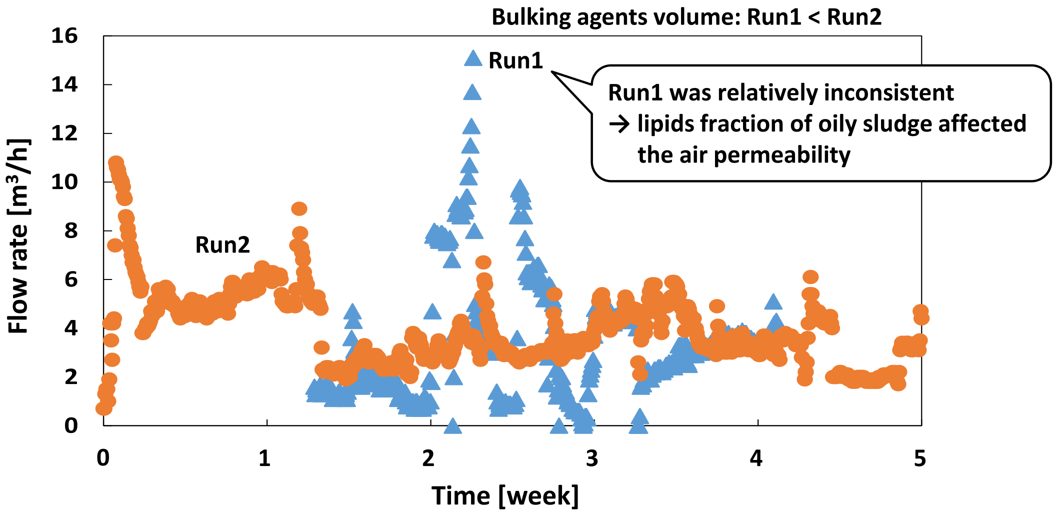


Changes in temperature showed no differences

Degradation process in both run was still under progress → not yet stable

Result - Changes in Flow Rate as Captured by VTA System

Changes in Flow Rate ～ Difficult to monitor under conventional approach



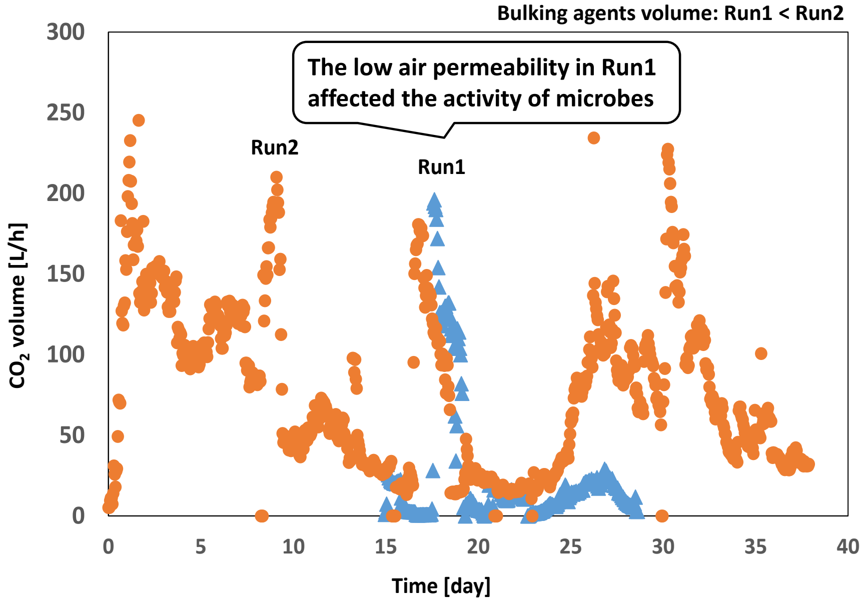
✓ **Bulking agents volume is essential for better air permeability in oily sludge composting**

✓ **VTA system captured changes in flow rate effectively**

→ **Adjustment of flow rate** → **Determination of optimum conditions**

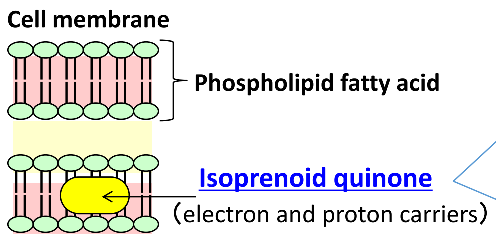
Result - Changes in CO_2 as Captured by VTA System

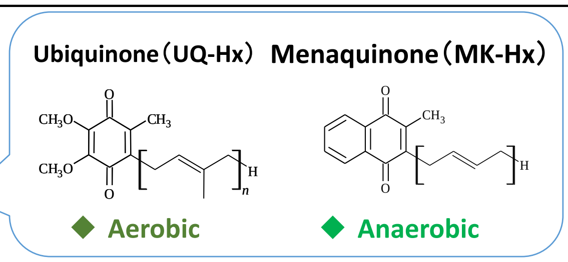
Changes in CO_2 ~ Difficult to monitor under conventional approach



✓ **VTA system effectively captured the changes in CO_2 → Turning, increase of air supply, etc.**

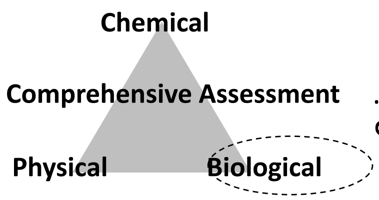
Quinone Profile Analysis

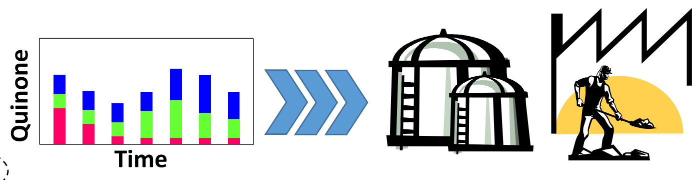




Quinones as biomarkers for microbial community analysis

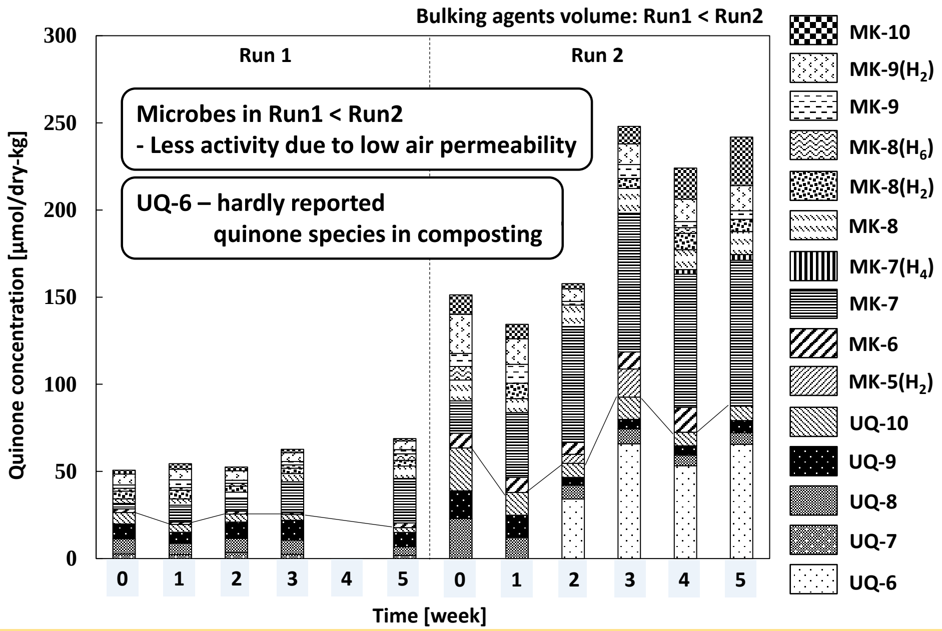
- **Quinone exist in almost all bacteria**
- **One species or genus of bacteria has one dominant type of quinone**
- **Quinone content shows the index of biomass**





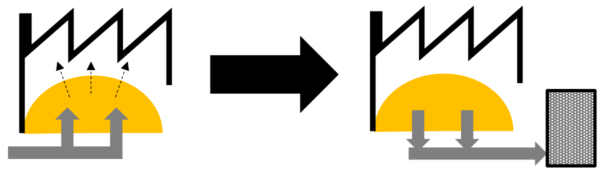
Introduce quinone profile analysis as a supportive monitoring tool for comprehensive assessment of biological process

Result - Quinone Profiles of Oily Sludge Composting



Quinone profile analysis as a supportive monitoring tool for conventional approaches

Summary for Chapter 5



Vacuum-type Aeration Composting System

✓ **Odor Control** ✓ **Efficient Monitoring** ✓ **Comprehensive Assessment**

小桝屋グループ Komasuya group

Tobishima Factory, Aichi (since 2016)

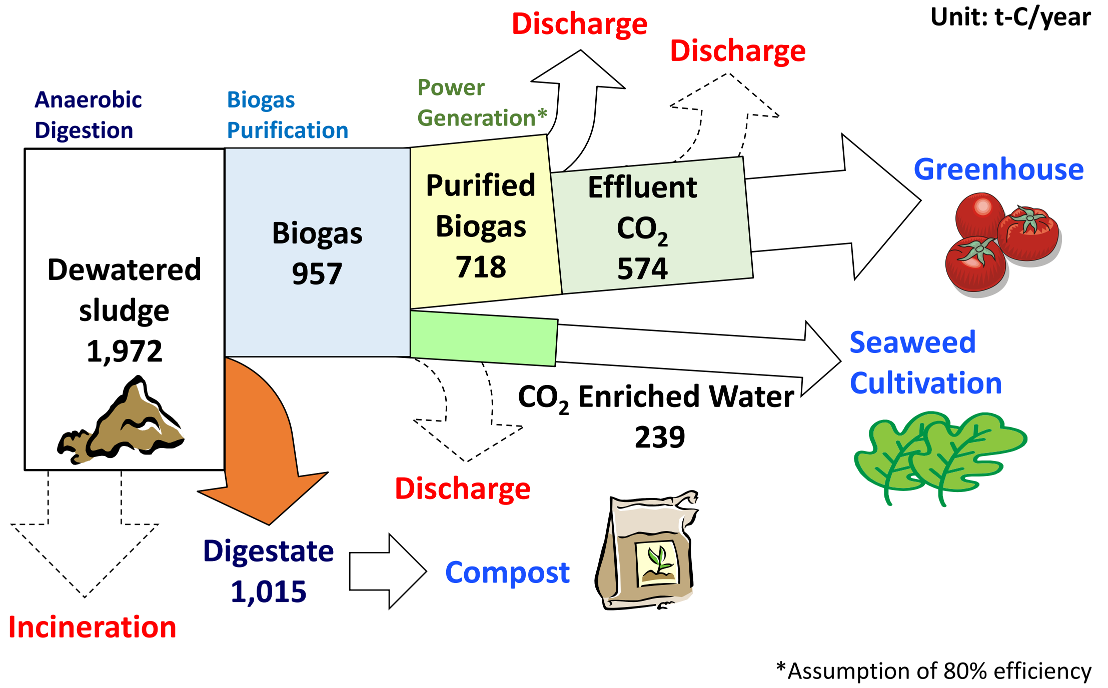
Raw materials: dewatered sludge (origin from food factory), vegetable scraps, tea stains, sawdust, etc.

Production: 3,300 tons per year

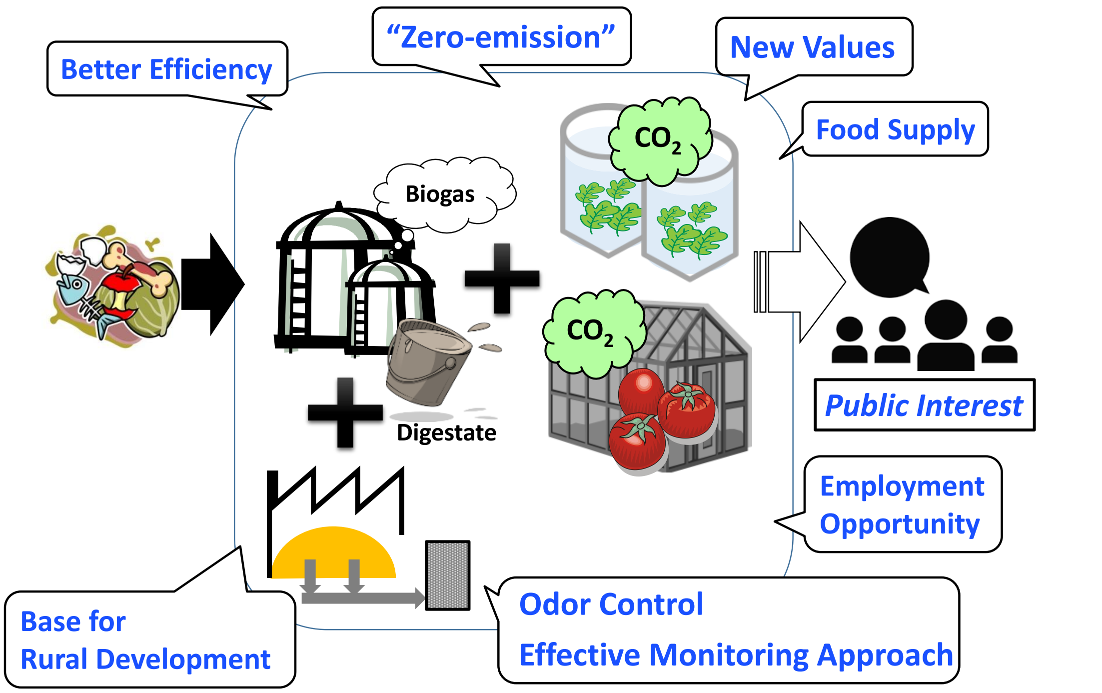
✓ **Higher nitrogen in compost** ✓ **Significant odor reduction**

✓ **Shorter composting period**

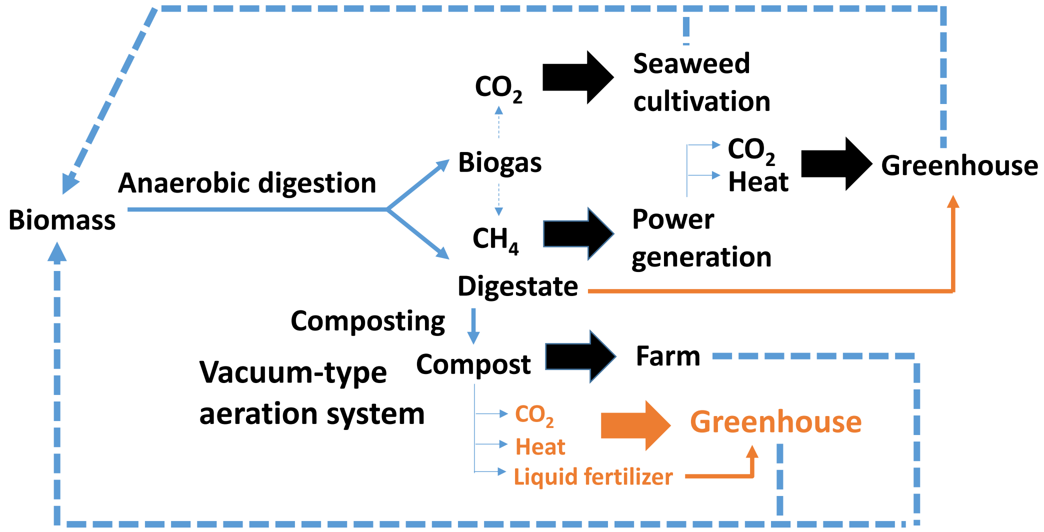
Conclusions – Carbon Flow of Integrated System



Conclusions – Potentials of Integrated System



Future Prospects – Comprehensive Integrated System



→ Make full use of every products and by-products

→ Create stronger linkage between various sectors

Biomass Utilization for a Better Tomorrow