Internet Journal of Society for Social Management Systems Vol.10 Issue 2 sms15-4529
ISSN: 2432-552X
ORIGINAL ARTICLE

Multiple Biowaste Recycling Systems linked with Organic/ProbioticAgro-production

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ABSTRACT: The multiple recycling systems for degradable biowaste streams are expected to improve waste management and link it with value-added organic/probiotic agro-production. Analysis of effective ways to formulate the links based on best practices in Japan (two thermal/material recycling models) and Taiwan (one material recycling model). The main conclusions of this work are: (1) From a socioeconomic viewpoint, measures are needed to promote biowaste separation-at-source and encourage a shift in the agro-sector; (2) From a technical viewpoint, the introduction of innovative core technology is desired to make such recycling links more acceptable to the agro-sector through the production of high-quality fertilizer with probiotic effects. Based on these findings, an additional case study was conducted to clarify the applicability of a multiple biowaste recycling system to Bandung, Indonesia, where the municipality is struggling with the burden of waste disposal.

Key Words**:** Multiple Biowaste Recycling System, Innovative Core Technology, Socio-economic Schemes

1. INTRODUCTION

(1) Background of the Study

The amount of biowaste generated in all Asian countries is estimated at 2.6 billion ton/year, including 260 million ton/year in Japan [NEF, ABU, 2012]. With Asian countries making wide use of landfill systems of disposal, it is desirable that models for biowaste recycling systems should be developed in order to mitigate current environmental degradation.

In Japan, on the other hand, incineration technology has been widely adopted in the wake of the so-called ‘Tokyo Garbage War’ in the 1960s, when municipal waste being used to reclaim land around Tokyo Bay caused a public nuisance. As a result, most domestic waste and approximately 60% of sewage sludge are now incinerated (after digestion in case of sewage sludge), although those measures are costly and the end-product is non-recyclable.[Jun Matsushita and Suharyanto, 2013], [MLIT (2), 2013].

In the wake, Multiple biowaste processing and recycling systems integrated with value-added agriculture (referred to here as simply ‘multiple biowaste recycling systems’) are desirable, since we will face global shortages of phosphate minerals in the near future and have to guarantee sustainable agro-production without them. Integration with agriculture could also contribute to inhibiting one-way chemical fertilizer use [Steven J. Van Kauwerbergh, et al., 2010], which accelerates eutrophication of public waters due to nutrient runoff from farmland.

Therefore, the formulation of multiple biowaste recycling systems can be seen as crucial for restructuring current waste management modes while integrating further with value-added probiotic agro-production throughout the world.

Received:2015.9.20 / Accepted: 2017.07.11

Internet Journal of Society for Social Management Systems Published Date: 2017.7.11

(2) Purpose of this Study

Figure 1 is a diagram of such a multiple biowaste recycling system that incorporates modal shifts in both waste disposal and agro-production. Although

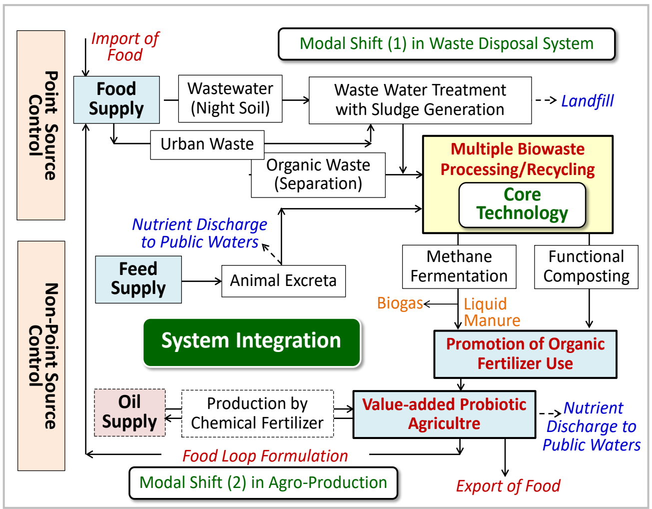


Figure 1 Diagram of Multiple Biowaste Processing and Recycling Link

such ideas exist, it is widely recognized in Japan that consensus building among relevant stakeholders who would have to play key roles in formulating the various links in a system has barely begun. Thus, the Japanese government has introduced schemes known as "Biomass Town" projects and "Bistro Sewage" as a way to smooth the way to full multiple biowaste recycling models based on implementing subsidiary measures. By learning lessons from these schemes, we can materialize individual links and disseminate them more promptly, although few have been verified as effective and successful thus far. [Jun Matsushita, Tomonao Miyashiro, et al., 2014]

2. MATERIALS AND METHODS

In this study, we assume that scheme-specific measures can be coupled with core technology to effectively start-up these subsidiary link projects. The core technology should be innovative enough to enable biowaste to be processed into organic fertilizer endowed with probiotic effects, making it more acceptable to the agro-sector. With the aim of verifying this assumption, three model projects are selected for evaluation from technical and socioeconomic viewpoints, as summarized in **Table 1**.

Whereas, two of them are thermal/material recycling links based on methane fermentation technology and the other is a material recycling link based on the application of a brand-new subcritical water technology developed in Japan [G8 International Trading Ltd., 2015].

Analysis is conducted from technical and socioeconomic viewpoints to clarify best practice for materializing these approaches. Further, a case study on the possibility of materializing these links in Bandung, Indonesia, is carried out, anticipating that the results would be indicative of how to effectively implement multiple biowaste recycling systems elsewhere in the world.

Table 1 Comparison of Biowaste Recycling System Models from Technical/Socioeconomic Aspects

Classification	Biowaste Recycling Model	Technical Aspects	Socio-economic Aspects
[Biomass Town] Thermal/Material Recycling Link	Ohki-cho Model (Fukuoka-ken, Japan) ･Raw garbage (separated) ･Night soil & sewage sludge [Total: 40 ton/day]	･Methane fermentation ･Biogas generation [750 kWh/day] ･fertilization of liquid manure [6,000 ton/year]	･Free-of-charge fertilization of liquid manure in the wake of cost reduction of raw garbage disposals ･Public assistance for sales of Ohki-brand organic crops by the municipality
[Bistro Sewage] Thermal/Material Recycling Link	Saga-shi Model (Saga-ken, Japan) ･Dehydrated sewage sludge after methane fermentation [Total: 18 ton/day]	･Biogas generation [7,500 kWh/year] ･Functional composting by high-temp. Bacillus ferment. [3,000 ton/year]	･Low cost supply of functional compost ･Public promotion of sewage sludge originated compost jointly with 'Bistro Sewage Alliance' in Japan
[Private Business] Material Recycling Link	Yilan Model (Yelan Province, Taiwan) ･Food residues ･Chicken excreta [Total: 20 ton/year]	･Japan's brand new subcritical water processing technology ･Functional composting by actinomycete fermentation [6,000 ton/year]	･Public licensing of organic fertilizer ･Sales of organic fertilizer with probiotic effects to local farmers ･Sales of value-added agri-products to local market

Note: *Biomass Town and Bistro Sewage* are the subsidiary measures to promote bio-waste recycling by national government in Japan.

3. RESULTS OF THE ANALYSIS

(1) Thermal/Material Recycling Model in Ohki-cho (Fukuoka-ken, Japan)

Outline

Ohki-cho is a rural town located in southwest Fukuoka prefecture in western Japan. It has a population of about 15 thousand people. The town used to rely on a neighboring town for its waste incineration and final landfill disposal. However, operational costs had become a serious financial burden on the municipality, particularly as available landfill sites diminished in number and the discharge of sludge into the sea was forbidden in 2009 under the London Treaty.

Against this background, the town urgently needed to develop a biowaste thermal/material recycling system. The links in this multiple biowaste recycling system, which are shown in **Figure 2**, are as follows: (1) Domestic organic waste is segregated at source and collected with sewage sludge by the municipality; (2) The two streams are mixed together and fed into a newly installed methane fermentation plant; (3) The resulting biogas is used for power generation and the digested liquid remaining after methane extraction is utilized as liquid manure by the agro-sector in local paddy fields. [Osamu Nakamura and Haruna Endo, 2011]

Technical Analysis

The aim here is to clarify that the application of methane fermentation technology to mixed biomass waste processing is a practical means of formulating this link.

(1) The core methane fermentation technology, although quite conventional, is well able to drive a thermal/material recycling system in this town; (2) This multiple biowaste recycling system contributes to reducing waste incineration and disposal costs by about 20%, from USD 0.2/kg to about USD 0.16/kg, enabling the municipality to sustain the new processing system and support the free-of-charge supply of liquid manure for local organic farming as an alternatives to chemical fertilizer use; (3) Research and development on paddy field distribution methods for liquid manure has been helpful because it gives incentive for farmer involvement in developing recycling links under the direction of experts [Kohji Iwashita and Akihide Iwata, 2010].

Socioeconomic Analysis

Various measures have been introduced to support links in the multiple biowaste recycling system, as

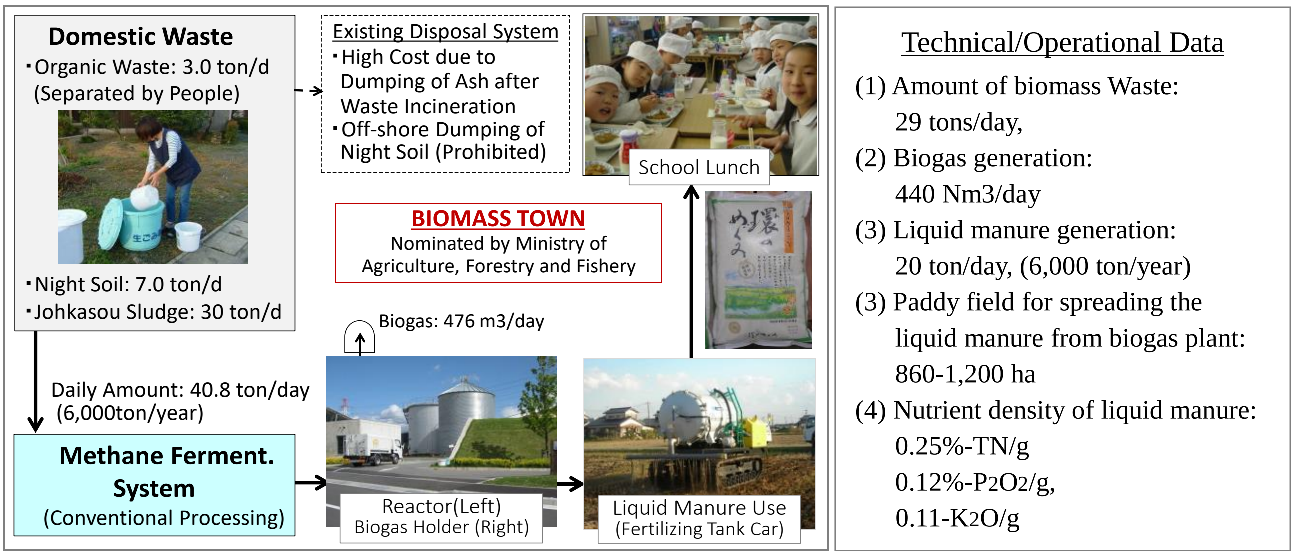


Figure 2 Multiple Biowaste Recycling Link at Oki-cho, Fukuoka-ken, Japan

Note: Data were obtained by the Courtesy of Haruna Endo.

Internet Journal of Society for Social Management Systems Vol.10 Issue 2 sms15-4529
ISSN: 2432-552X

follows:

(1) Organic waste separation at source has been introduced, coupled with an award scheme to strongly encourage the public to take part; (2) Liquid manure from the biogas plant is provided to local farmers at no charge, supported by the reduced cost of waste handling; (3) Farmers' outgoings on fertilizer are reduced by 90%, from USD 120 per 10 acres (chemical fertilizer use) to only USD 10 per 10 acres; (4) Local organic crops are provided for school lunches and sold at "Michino-eki" (local service area shops), giving local farmers a guaranteed market for their products strongly motivating them to continue supporting the link.

On the basis of this project, the national government has designated Ohki-cho as a 'Biomass Town' and provides the municipality with financial assistance to develop associated facilities [MAFF, 2015].

(2) Thermal/Material Recycling Model in Saga-shi (Saga-ken, Japan)

Outline

Saga-shi is the prefectural capital of Saga, a prefecture in western Japan, and has a population of about 200 thousand people. The city used to rely on an incineration system for the disposal of sewage sludge from its wastewater treatment plant. The costs of operating this system had become a serious financial burden for the municipality, so engineers at the treatment plant proposed a low-cost replacement plan for the aging incinerator.

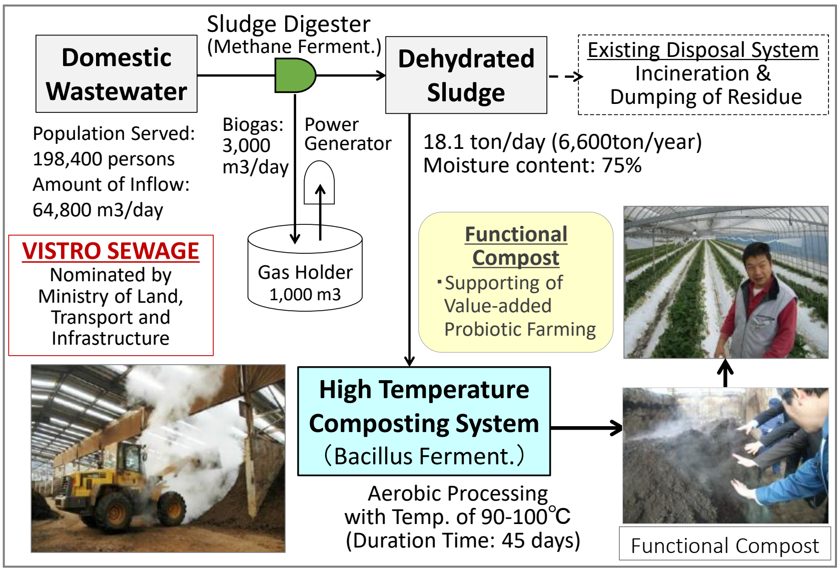
A biowaste recycling system coupled with sludge digestion was recognized as a sophisticated technical alternative to incineration, and a multiple biowaste recycling system with the links shown in **Figure 3** was developed. The main links in the system are as follows:

(1) A sludge digester is used to recover energy from the raw sludge; (2) A particular bacillus fermentation technology is selected to treat dehydrated sludge after digestion with high-temperature aerobic processing; (3) The functional compost thus produced is recognized by the local agro-sector as stimulating crop growth and increasing sugar content.

Technical Analysis

The aim here is to clarify that the application of a particular bacillus fermentation technology to dehydrated sewage sludge processing is workable in formulating this link.

(1) The high-temperature bacillus fermentation technology is a solid foundation for thermal/material



Technical/Operational Data

(1) Amount of biomass waste (dehydrated sewage sludge): 18.1 ton/day, (6,600 ton/year)

(2) Amount of functional compost after bacillus fermentation: 15 ton/day, (5,500 ton/day)

(3) Farmland for spreading the functional compost: 275-500 ha

(3) Nutrient density of the compost: 3%-TN, 1.5%-P_2O_2, 2.5%-K_2O

Figure 3 Multiple Biowaste Recycling Link at Saga-shi, Saga-ken, Japan

Note: Data were obtained by the courtesy of Kyowa-kako Ltd.

recycling in the wastewater treatment plant; (2) The multiple biowaste recycling system contributes to reducing sludge incineration/disposal costs highly by 44%, from USD 1 million per year to about USD 0.56 million per year; (3) The resulting compost is verified to be functional by the local agro-sector in promoting crop growth and increasing sugar content.

Socioeconomic Analysis

Introduction of this bacillus fermentation technology has promoted this biowaste recycling link as follows: (1) It contributes to reduced management costs for wastewater treatment and disposal; (2) The cost savings contribute to providing a low-cost supply of functional compost for local organic agriculture as a replacement for both chemical fertilizer use and pesticide use.

The national government has nominated this project under its "Bistro Sewage" scheme and provides the municipality with financial assistance to develop associated facilities [MLIT (2), 2015].

(3) Material Recycling Link Model in Yilan Province (Taiwan)

Outline

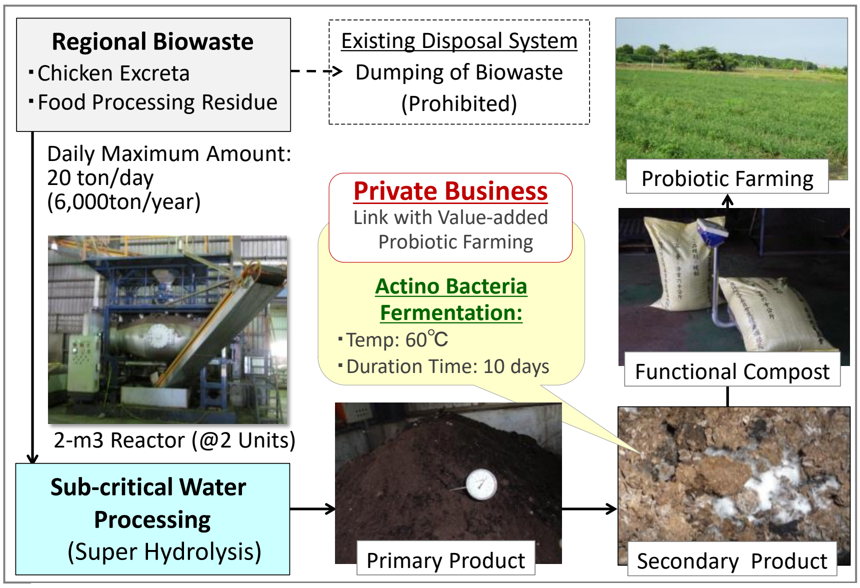
Yilan is a rural province located in north western Taiwan, an approximately 30-minute highway drive from the Taipei Metropolis. Recent urbanization in Taiwan has made people more eco-conscious than ever before and they tend to select value-added probiotic products generally with a higher price tag. Against this background, recent national policy changes aim to increase organic agro-production up to 1,500 km^2. [Taiwan Today, 2014]

The company Fehong Ltd. has formulated one link for a biowaste multiple recycling system in which chicken excreta and food residues are processed using an **innovative** subcritical water technology from Japan, as shown in **Figure 4**. Business operations commenced in 2009 and the technology was transferred to Jangsu Province, China, in 2014.

Technical Analysis

Technical data provided by the operating company indicates the following:

(1) This batch-type subcritical water processing equipment is capable of physicochemical hydrolytic batch processing of various types of biowaste with operation conditions including in-tank pressure of 1-2 MPa (10-20 atm) and temperature of 150-200°C at a rate of 10-60 min/batch [Tomonao Miyashiro, et al., 2012], [Sugiura Norio, et al., 2012]; (2) In processing chicken excreta and food residue, the



Technical/Operational Data

(1) Amount of biomass waste
20 ton/day, (6,000 ton/year)

(2) Amount of functional compost after Actino bacteria ferment.
15 ton/day, (4,500 ton/year)

(3) Farmland for spreading the functional compost:
225-450 ha

(3) Nutrient density of the compost:
(Case of Chicken Excreta)
3%-TN,
1.5%-P_2O_2,
2.5%-K_2O

Figure 4 Multiple Biowaste Recycling Link at Yilan Province, Taiwan

Note: (1) Data were obtained by the courtesy of Fehong Ltd

(2)Details of the Subcritical Water Technology is described in the ***Appendix****.*

equipment transforms the materials into low-molecular weight biomass such as amino acids from protein, taking about 30 minutes per batch, at an operating cost of approximately USD 30/ton; (3) The low-molecular weight biomass is easy to handle and can be fermented by actinobacteria naturally into nutritious compost in two weeks. It is verified that the compost contains spores of actinobacteria spore, dominant phylum of the compost's total bacteria phyla; (4) The compost is effective as a kind of bio-pesticide on farmland and aids production of probiotic pesticide-free crops by local farmers.

Socioeconomic Analysis

Introduction of this innovative subcritical water technology has driven this link in a multiple biowaste recycling system forward as follows:

(1) It produces reliable compost with a probiotic effect that has been granted a governmental certificate; (2) The functional compost, which is highly evaluated in the local market and has been authenticated by a public institution, is usually sold at USD 220/ton, meeting the subcritical water processing cost; (3) The selling price of this functional compost double that in Japan, presumably because of people's recent heightened quest for food-safety and probiotic products as clearly highlighted at the International Taipei Food Show 2014. [TETDC, 2014]

This link in a multiple biowaste recycling system is thus verified as feasible for a private business operation, with subcritical water technology playing a key role.

(4) Summary

These studies clarify that there are two main approaches to formulating multiple biowaste recycling systems, as shown in **Figure 3.** This diagram indicates a path toward future development from technical and socioeconomic viewpoints.

Approach (1)

Biowaste recycling, coupled with fermentation technology, directly leads to waste incineration/disposal cost reduction. The financial gain thus realized is able to support the provision of free-of-charge liquid manure or functional compost utilization. Financial assistance from the government provides stakeholders with a stable and strong launching pad.

Approach (2)

The introduction of innovative subcritical water technology provides a workable link integrated with value-added probiotic agro-production. Financial assistance from the public sectors would raise the business viability of such systems.

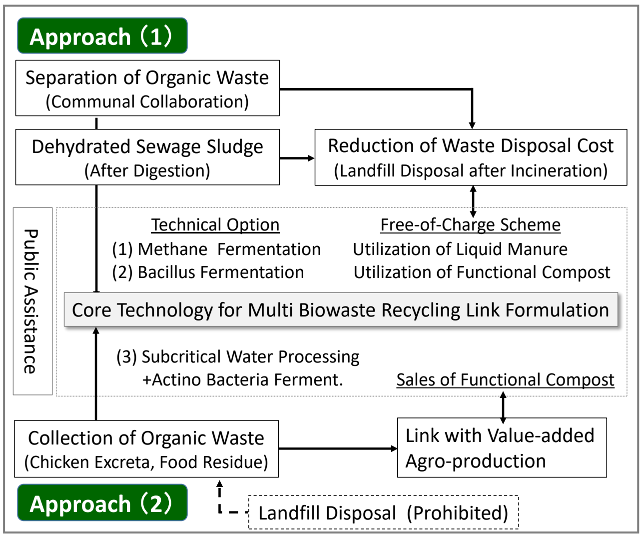


Figure 4 Approaches to Formulate the Multiple Recycling Link on the basis of the Best Practices

4. BANDUNG CASE STUDY

The Bandung Municipality has been growing more rapidly than expected in recent decades. Its population stood at approximately 2.49 million in 2013. The huge amount of domestic waste generated in the municipality has become a major concern, while a catastrophic waste avalanche occurred at Leuwigajah dumpsite killing more than 100 people in 2005. The amount of domestic waste exceeds 7,400 m^3/day or 1,496 ton/day (about 0.61 kg/capita), of which 63% is organic. [Sudojono Priana (1), 2014] However, it is widely recognized that reforming the current landfill disposal system would be a laborious challenge for the municipality.

In response, we have been organizing the Japan Indonesia Conference on Water and Environmental Sanitation (JICWES) since 2011 to establish a 'knowledge hub' among researchers, experts, and administrative officers in both countries. Our target is to propose an appropriate waste management system based on the biowaste recycling links shown in **Figure 5**.

In this study, the Indonesian expert team conducted a survey on people's consciousness on separation of organic waste at source and the possibility of liquid manure use by the local agro-sector.

sorted into organic and inorganic types at home, but currently they do not usually sort their waste; (2) They feel sorting would cost time without providing any benefits, although they perceive that organic waste should have monetary value; (3) Little support is expected from the community because local residents already have an urbanized mindset; (4) Hotel personnel agree with the idea of sorting waste at source and will act if the government asks them to; (5) Market people in 'Balubur Towns Square' will collaborate in sorting waste, although they think intensive efforts are needed in areas such as education, on-the-job training and public regulation to force action through. [Sudojono Priana (1), 2014]

Amount of Domestic Waste In Bandung Municipality

Source	Solid Waste Generation (ton/day)
Housing	909
Market	143
Road	70
Commercial	105
Industrial	84
Others	185
TOTAL	1,496 ton/day (0.61kg/c/d)

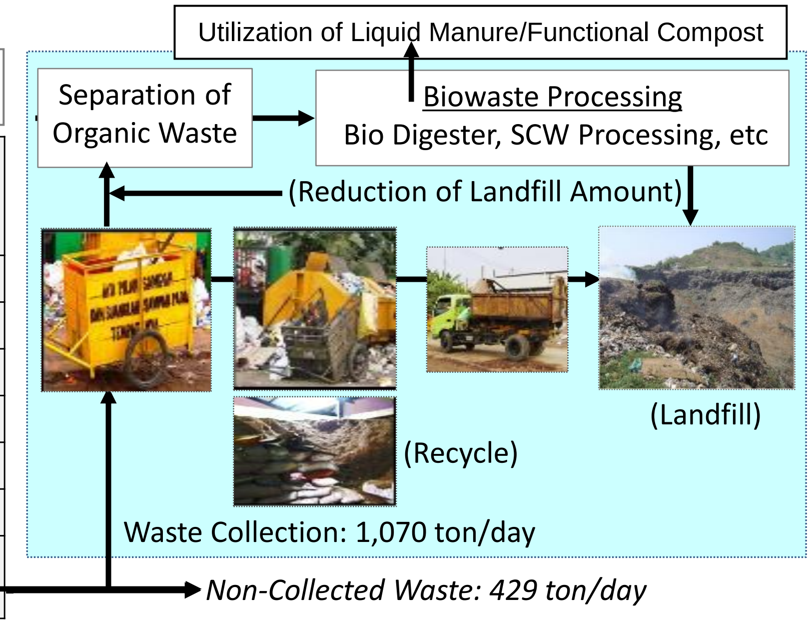


Figure 5 Multiple Biowaste Recycling Link Model Proposed for Bandung Municipality

Note: *Data was obtained by the courtesy of JECWES*

(1) Survey Results

<u>Separation of Organic Waste at Source</u>

A questionnaire survey was carried out with 195 persons, consisting of 100 persons in private households and 76 in shops, hotels and restaurants. All questionnaires were completed in a mixed residential area known as 'Eco Village' in the downtown area of Bandung.

The survey reveals the following:

(1) Most respondents agree that waste should be

<u>Liquid Manure Use by the Local Agro-sector</u>.

This study was conducted with the assistance of experts on agriculture in Indonesia. Of the 157 km^2 of Bandung municipal area, approximately 24.4 km^2 is consists of farmland. However, use of liquid manure from a bio-digester would not be easy for the following reasons:

(1) The number of farmers applying organic liquid fertilizer (OLF) in their paddy fields is small. This is because OLF is more laborious and incurs additional

costs for land treatment and transportation; (2) Farmers believe that conventional chemical fertilizers give maximal paddy yields, and would require OLF to have adequate specifications and be properly certified to raise their production; (3) In the case of rice cultivation, the use of OLF would require new spreading methods to avoid surface runoff, since some areas have an abundance of water flowing naturally through the rice fields. [Sudojono Priana (2), 2014]

(3) Summary

This case study reveals that suitable measures are needed in Bandung to change current mindset and encourage waste separation. Similarly, measures are needed to overcome farmers' reluctance to use liquid manure from a biogas plant. It is recommended that the first priority should be to focus on markets and hotels, because better collaboration is expected as compared to other categories such as private households. Efforts must be continued in tandem with well-prepared capacity building efforts, as suggested by JICA's guidelines [JICA, 2004].

In this regard, it is suggested that experience and expertise gained in the Oki-cho model, where overall coordination in formulating the recycling link was well implemented, could be applicable also to Bandung.

From a technical standpoint, careful scrutiny of possible technical options is desirable, particularly over the balance between initial and operational costs and the benefit obtained by utilization of liquid manure and/or functional compost. The options currently available are threefold: methane fermentation, bacillus fermentation and subcritical water processing (see above-shown **Figure 4**).

5. CONCLUSIONS AND FUTURE TASKS

The following conclusions can be drawn from this work:

(1) The formulation of biowaste recycling links is a major challenge for every country in the world. Active participation means the availability of suitable approaches as identified in the best practices analyzed in this study.

(2) From a technical viewpoint, the core technology described above should be scrutinized on a case-by-case basis. In principle, the quality of the final product and its acceptability by the agro-sector are the basic points of evaluation.

(3) From a socioeconomic viewpoint, securing financial resources is vital to promoting a modal shift away from current one-way waste management systems and agro-production based dependent on chemical fertilizers.

A financial dividend may be achieved by reducing the cost of biowaste disposal through a multiple biowaste recycling system in which waste is separated at source.

(4) The lessons from this study suggest that multiple biowaste recycling systems integrated with organic/probiotic agro-production could be feasible in every situation in every country.

(5) In this regard, it is noted that application of the Oki-cho model and the Yilan model is under way in Vietnam and Malaysia, respectively.

ACKNOWLEDGEMENTS

This project-based research owes a great deal to many experts and engineers who have been making great efforts to formulate the links in multiple biowaste recycling systems all the way.

The Bandung case study could not be carried out without sincere collaboration among the members of the Japan Indonesia Conference on Water and Environmental Sanitation (JICWES). The activities of JICWES are supported by the Japan Environmental Sanitation Center (JESC) and financed by the Environmental Restoration and Conservation Agency (ERCA).

ISSN: 2432-552X

APPENDIX: OUTLINE OF SUBCRITICAL WATER (SCW) TECHNOLOGY

(1) Technological Principle of SCW Technology [Hiroyuki Yoshida, 2007]

Critical Water Reaction

When water is subjected to ultra-high heat and pressure (374℃ or more and 22 MPa or more), great thermal energy is produced and the water molecules are violently agitated. Herein, hazardous substances such as dioxins and chlorofluorocarbons can be broken down in a short period of time.

Subcritical Water Reaction

In a subcritical water state, which is a high-temperature, high-pressure state below that of critical water (practically about 200℃ and 2 MPa), the water molecules (H_2O) are split into H (a proton component) and OH (a hydroxide component) that are incorporated into the product, bringing about a "hydrolysis reaction" in a short period of time.

As a result, high-molecular organic matter is converted into low-molecular compounds that can be used easily by microorganisms, thereby becoming products suitable for high-efficiency methane fermentation and functional composting. Examples: Proteins and starches are converted into amino acids and glucose, respectively.

In addition, subcritical water has low permittivity, therefore enabling it to extract the oils in organic matter also in a short period of time.

In such cases, two practical systems, a batch system and a continuous system, have been commercialized.

(2) Merits of Batch-type System

The system comprises a rugby-ball-shaped pressure vessel equipped with an agitator to enable stable, high-speed hydrolysis and oil extraction for a wide range of liquid and solid biomass with small energy consumption. This makes it possible to promote resource recycling for even difficult-to-process materials such as wood scraps. (see **Figure A-1**)

In case of methane fermentation, the product being treated is well-hydrolyzed at around 180℃ to increase biogas generation by approximately 50%.

In case of composting, the primary product is fermented by good actino-bacteria and the end

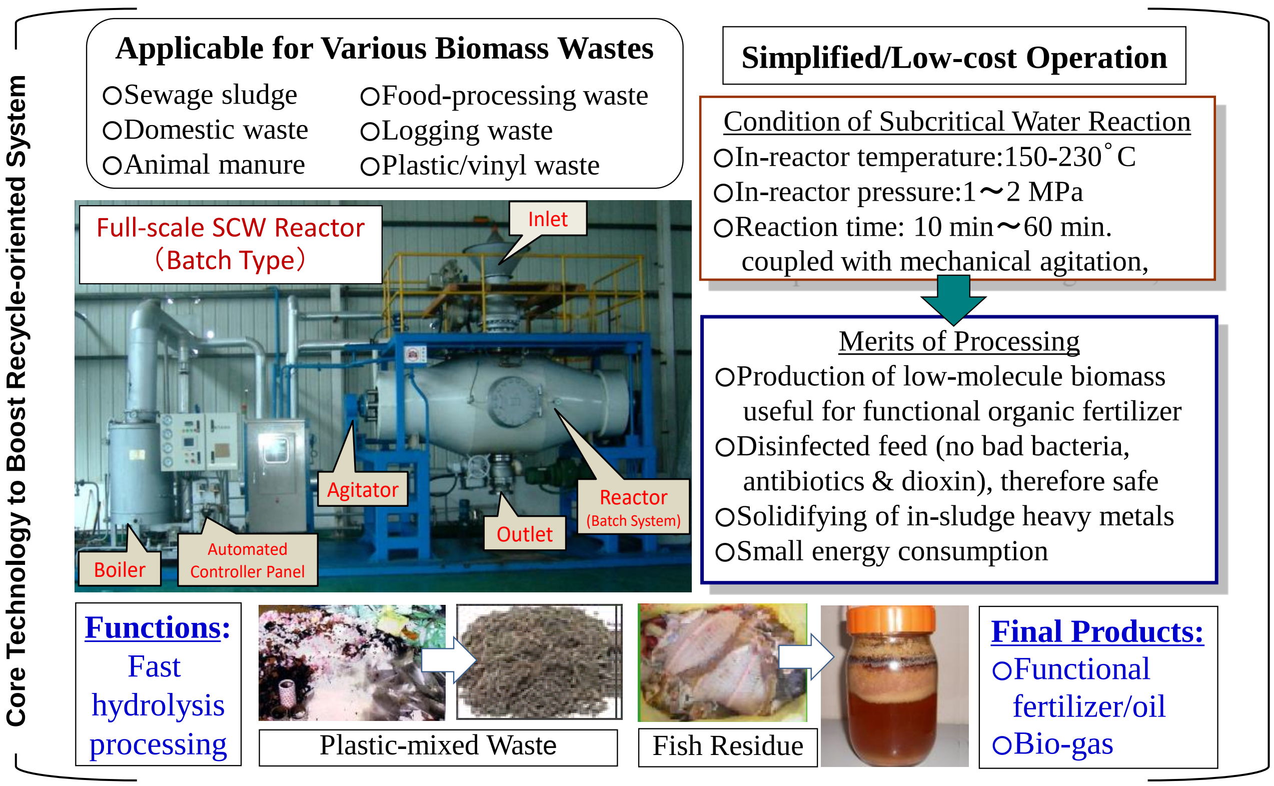


Figure A-1 Technological and Operational Characteristics of Subcritical Water Reactor (Batch-type) product is verified to be functional compost that inhibits continuous cropping failure. Therefore, the batch system is expected to be quite workable to replace current landfill system by recycle-oriented system in Asia. [Jun Matsushita, Tomonao Miyashiro, Saburo Matsui, et. al., 2014]

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