International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:9, No:12, 2015

The Evaluation of Costs and Greenhouse Gas Reduction Using Technologies for Energy from Sewage Sludge

Futoshi Kakuta, Takashi Ishida

***Abstract*—**Sewage sludge is a biomass resource that can create a solid fuel and electricity. Utilizing sewage sludge as a renewable energy can contribute to the reduction of greenhouse gases. In Japan, the "National Plan for the Promotion of Biomass Utilization" and the "Priority Plan for Social Infrastructure Development" were approved at cabinet meetings in December 2010 and August 2012, respectively, to promote the energy utilization of sewage sludge. This study investigated costs and greenhouse gas emission in different sewage sludge treatments with technologies for energy from sewage sludge. Expenses were estimated based on capital costs and O&M costs including energy consumption of solid fuel plants and biogas power generation plants for sewage sludge. Results showed that the cost of sludge digestion treatment with solid fuel technologies was 8% lower than landfill disposal. The greenhouse gas emission of sludge digestion treatment with solid fuel technologies was also 6,390t as CO_2 smaller than landfill disposal. Biogas power generation reduced the electricity of a wastewater treatment plant by 30% and the cost by 5%.

***Keywords*—**Global warming counter measure, energy technology, solid fuel production, biogas.

I. Introduction

THE demand for fossil fuels including oil, coal, and natural gas is expected to increase further in the future. Since Japan has to rely on foreign supply of natural resources and energy, we are greatly influenced by the world energy situation. Therefore, measures need to be developed urgently in response to power shortages caused by the accident that occurred in the Fukushima Daiichi Nuclear Power Station during the Great East Japan Earthquake.

In 2009, the "Fundamental Law for Promotion of Biomass Utilization" was established to promote the use of biomass including sewage sludge. In accordance with this act, the local governments were required to develop "Biomass Utilization Promotion Plan". In 2010, the "Basic Plan on Promotion of Biomass Utilization" was approved in a Cabinet meeting. The plan urges that the sewerage sludge recycle rate should be 85% by 2020 through the utilization of the sewage sludge to produce biogas and solid fuel. Also in 2012, the third "Priority Plan for Social Infrastructure Development" was approved in a Cabinet meeting, and the goal was to increase the energy production rate from approximately 13% in 2010 to approximately 29% in 2016 by using organic matters in sewage sludge. Another goal was to improve the reduction in greenhouse gas emission in the field of sewerage works from approximately 1.29 million tons/CO_2/yr to 2.46 million tons/CO_2/yr [1], [2].

The sewerage sludge is a biomass resource that can produce solid fuels and generate electric power. So it is expected to contribute to a reduction in the greenhouse gas emission through the utilization of sewage sludge as renewable energy. This document reports the costs of producing energy from sewage sludge and the assessment of greenhouse gas emission reduction in Japan.

II. Current Situation of Utilization of Sewage Sludge in Japan

The sanitation coverage in Japan has reached 78% in 2012. The amount of sludge generated from sewage treatment plants is approximately 2.24 million tons per year (dry weight). As shown in Fig. 1, the recycle rate of sewage sludge was gradually increased over years and reached 80% in 2010. The reason for a sudden decrease in the recycle rate of sewage sludge in 2011 was an increase in the sludge stock volume due to the Great East Japan Earthquake. The sewage sludge is expected to be utilized as renewable energy (i.e. biomass). However, the current use of sewage sludge is mainly for construction materials such as cement ingredients.

Fig. 2 shows the percentage of organic matters in sewage sludge that is actually used to produce energy. Only 13.6% of the organic matter in sewage sludge is used for producing biogas and solid fuel. The application on forests and farm lands accounts for approximately 10.6%. Therefore, it is necessary to proactively engage in the utilization of sewage sludge for producing energy in order to respond to the recent social demands and backgrounds.

Futoshi Kakuta and Takashi Ishida are with the Japan Institute of Wastewater Engineering Technology, Tokyo, Japan (e-mail: f-kakuta@jiwet.or.jp, t-ishida@jiwet.or.jp).

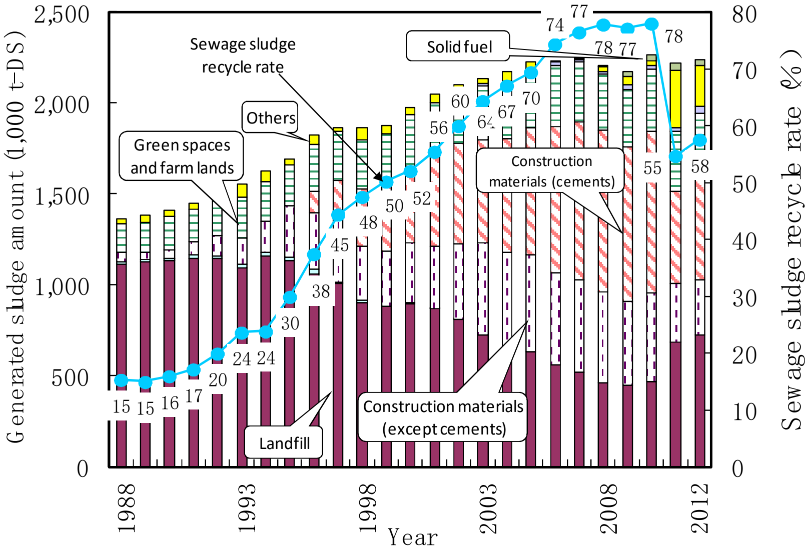


Fig. 1 Changes in the Amount of Sludge Generated and the Use Purpose

III. Examples of Actual Technology Implementation for Producing Energy from Sewage Sludge

As shown in Fig. 3, the energy resources produced from the sewage sludge include biogas generated by anaerobic digestion, solid fuels produced by sludge dewatering, thermally decomposed gases, and waste heat from incineration for electric power generation. The biogas is used as fuel for electric power generation. The refined biogas is also used as vehicle fuel and resource for utility gas. There are two solid fuel production technologies. One is the sludge carbonization technology that heats up sludge in an anaerobic condition to produce fuel, and the other is the drying technology that produces solid fuel by evaporating water from the sludge. In the thermal decomposition and gasification technology, the combustible gases are generated by thermally decomposing the sludge, and the generated gases are used for drying, gasification, and electricity generation. The incinerator waste heat electricity generation technology uses waste heat generated in the incinerator to produce electric power. [3]

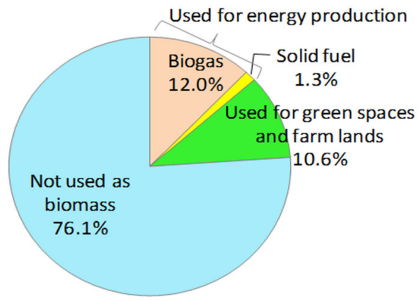


Fig. 2 Breakdown of Utilization of Sewage Sludge Biomass

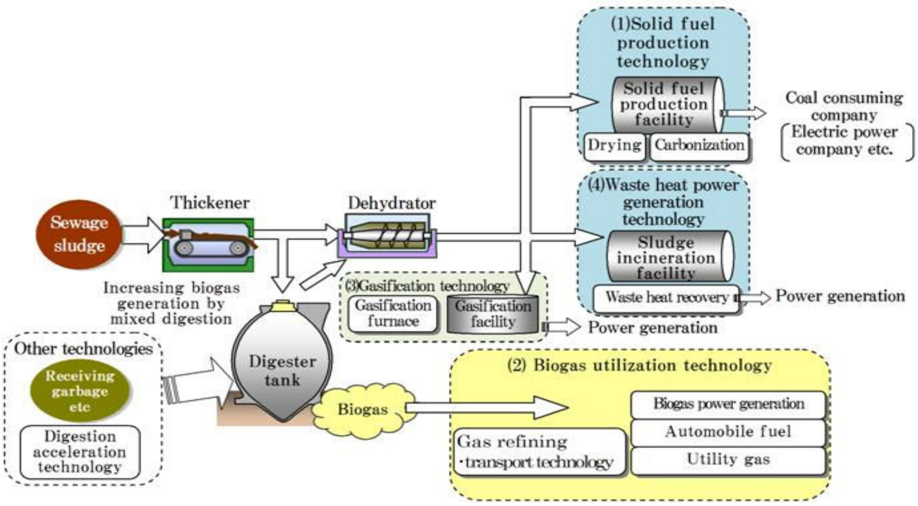


Fig. 3 Energy Resources Generated from Sewage Sludge

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:9, No:12, 2015

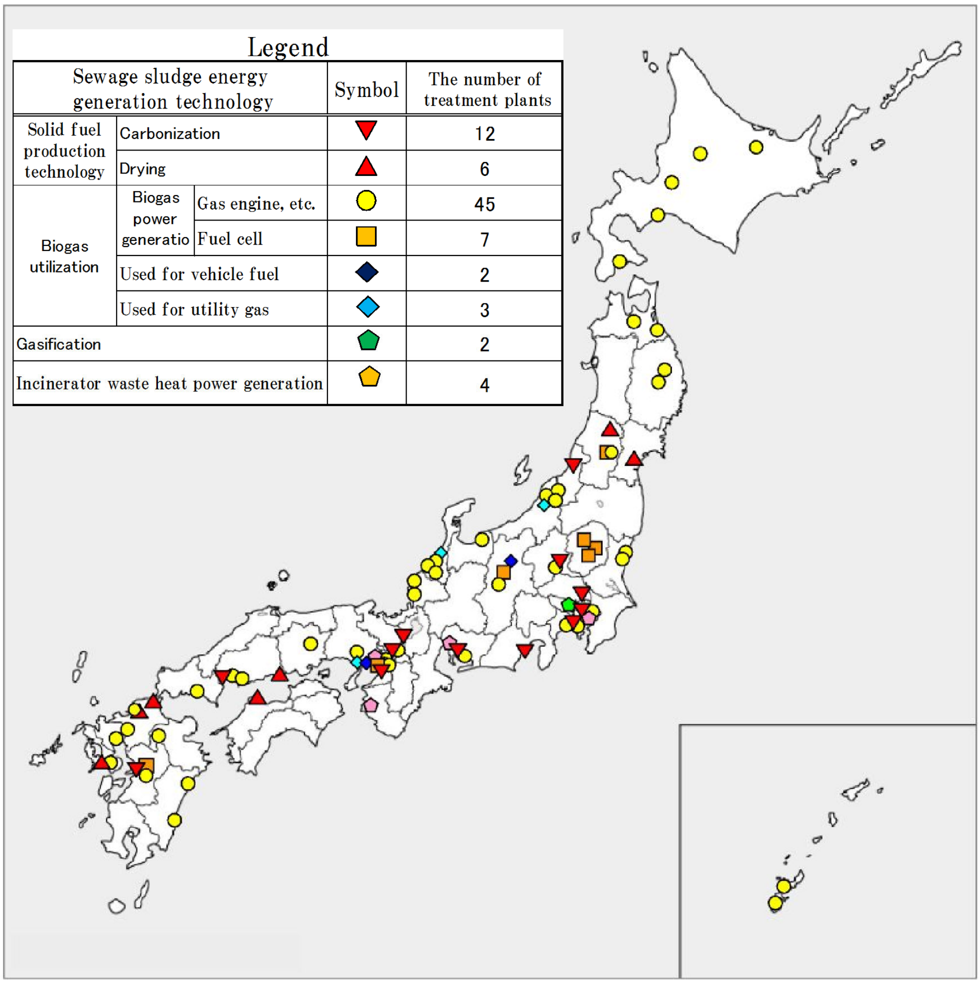


Fig. 4 Plant Locations in Japan that have Implemented Energy Production Technology and that Plan to Implement

Fig. 4 shows the cities that have implemented or are planning to implement the sewage sludge energy production technology. Currently, the biogas power generation technology is implemented in 45 plants, and the number is increasing nationwide. The solid fuel production facility is implemented to replace the existing incineration facility for a better use of resources. This technology has been implemented especially in cities with a relatively high population.

IV. Cost of Sewage Sludge Energy Production Technology and Estimated Greenhouse Gas Emission Reduction

The following sewage sludge energy production technologies have been implemented in the recent years, and their costs and greenhouse gas emission reduction effects are evaluated for a treatment plant with a capacity of 50,000 m^3/day.

(i) Solid fuel production technology: Solid fuel is produced by carbonization of dewatered sludge.

(ii) Biogas power generation: Biogas is generated by anaerobic digestion and is used to generate electricity to be used within the plant.

A. Study Case

(1) Solid Fuel Production Technology

Many mid-scale treatment plants send dewatered sludge to landfills. However, the capacity of the landfill is limited. Hence, we considered an effective utilization of the sludge instead of sending it to landfills as waste, and evaluated two cases: one with a newly built solid fuel production facility and the other with a newly built digester tank and solid fuel production facility. In addition, the conventional incineration facility is also studied for the comparison purpose. The operation costs and emission amounts of greenhouse gases are calculated for the solid fuel production facility and incineration facility, and the digestion process and dewatering process are also taken into account.

TABLE I
STUDY CASE OF SOLID FUEL PRODUCTION TECHNOLOGY

	Digestion process	Dewatered sludge treatment	Process flow
Current situation	No	Disposed by contractors (direct landfill disposal of dewatered sludge)	Thickened sludge → Dehydrator → Dewatered sludge (Sent to landfill)
CASE1	No	Incineration	Thickened Sludge → Dehydrator → Sludge incineration → Incinerated ash
CASE2	No	Solid fuel production	Thickened Sludge → Dehydrator → Solid fuel production → Solid fuel
CASE3	Digester tank newly built	Solid fuel production	Thickened Sludge → Digester tank → Dehydrator → Solid fuel production → Solid fuel

2. Biogas Power Generation Technology

Mid-scale treatment plants with an anaerobic digestion facility use biogas to heat their digester tanks, however; many of them are incinerating the excess gases. We evaluated a case in which the generated biogas is used to produce electricity to be used within the plant. Since the amount of biogas generated and the amount of heat used to heat the digester tank varies depending on seasons, this variation is taken into account when setting the capacity and numbers of the power generation facility. We also considered the recovery of waste heat from electricity generation and the use of biogas, which is currently used for heating, to generate electricity.

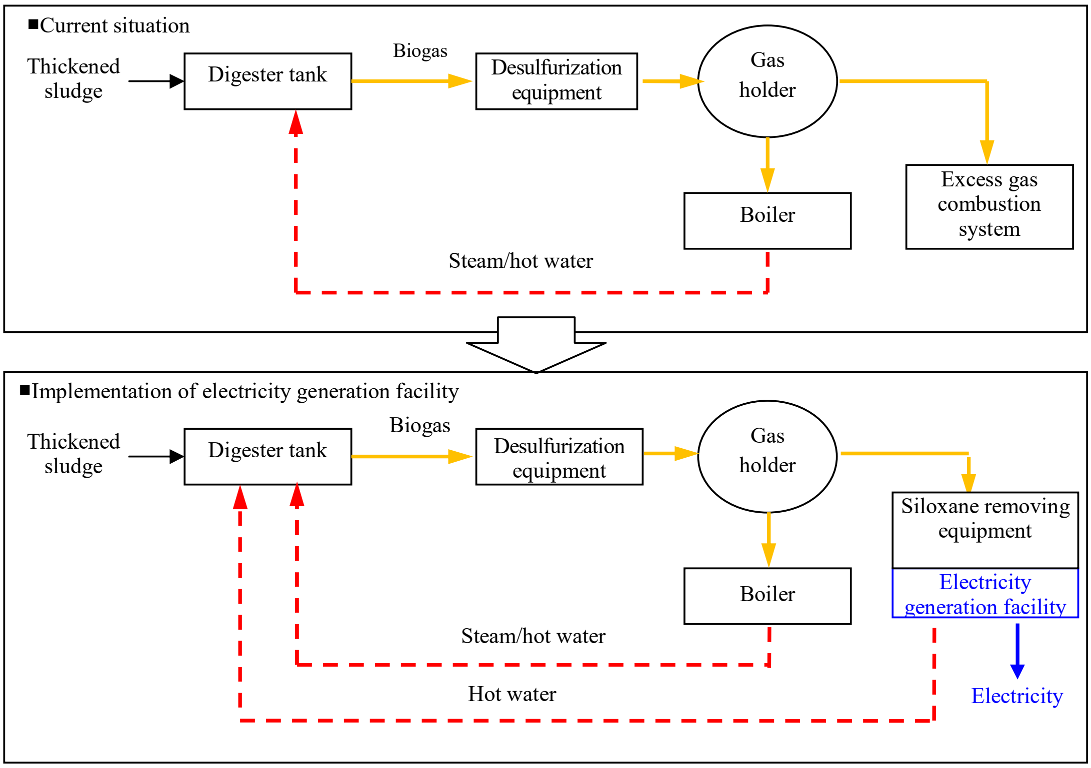


Fig. 5 Facility Configuration Flow for Biogas Power Generation

B. Setting Conditions

(1) Cost Information

The construction costs of energy production facilities include the infrastructure and building construction costs and machinery and electrical work costs. The operation and maintenance costs include the management costs (incl. labor costs) necessary for operation and maintenance, utility costs, repair costs, etc. The cost function for the solid fuel production facility was developed based on the results obtained by interviewing local governments and main manufacturers of the solid fuel facility. The cost function for biogas power generation facility is developed based on the costs obtained by interviewing the treatment plants (See Table II). The operation costs, except those in the energy production facility, are calculated by using the cost function defined in the "Master Plan Manual for Usage of Biosolids" by the Ministry of Land, Infrastructure, Transport and Tourism and Sewage Works Association (March, 2004). [4], [5]

TABLE II
COST FUNCTION

Technology	Phenomena		Cost function
Fuel production facility (carbonization)	Construction cost	Machine and electricity	Y_1=206.94X_1 ^ 0.612
		Infrastructure construction	Y_1=64.741X_1 ^ 0.391
	Operation and maintenance cost		Y_2=1.8778X_1+105.9
Biogas power generation facility	Construction cost	Machine and electricity	Y_1=1.3132X_2
		Infrastructure construction	Y_1=0.0263X_2+5.8284
	Operation and maintenance cost		Y_1=0.0263X_2+5.8284

X_1: facility scale (t-wet/day)
X_2: Power generation facility scale (kW)
Y_1: Construction cost (million yen)
Y_2: Operation and maintenance cost (million yen/year)

(2) Greenhouse Gas Emission Amount

(i) Solid Fuel Production Facility

The energy consumption in each process is calculated by setting a specific consumption per sludge volume based on the results obtained by interviewing local governments, and from the existing technical documents, etc. The greenhouse gas emission factor is calculated by using the factors shown in Table III.

(ii) Biogas Power Generation Facility

Since biogas is carbon-neutral energy, we assumed that the greenhouse gas emissions associated with electricity purchase are reduced by the biomass power generation and calculated the greenhouse gas emission reduction effect.

TABLE III
GREENHOUSE GAS EMISSION FACTORS

			Emission factor
Electricity		CO_2	0.551kg-CO_2/kWh
Fuel (Type-A heavy oil)		CO_2	2.71kg-CO_2/L
Treatment process	Incineration (high temperature incineration)	CH_4	0.0097kg-CH_4/t-wet
		N_2O	0.645kg-N_2O/t-wet
	Carbonization	N_2O	0.0312kg-N_2O/t-wet
Amount reduced by using an alternatives to coal		CO_2	2.41 t -CO_2/ t
Dewatered sludge landfill		CH_4	0.0667t-CH_4/t-DS

C. Results of Feasibility Evaluation

(1) Solid Fuel Production Facility

(i) Cost Effects

Fig. 6 shows the results of preliminary calculation. The result shows that the cost of a case with incineration facility (CASE1) is 4.25 million yen/yr, and the cost of a case with solid fuel production facility (CASE2) is 4.18 million yen/yr. When compared to the operation cost of the current situation (3.79 million yen/yr) in which dewatered sludge is sent to a landfill, the costs of these two cases are higher than the current situation. The cost of a case with digestion and solid fuel production (CASE3) is 3.50 million yen/yr, which is cheaper than the current situation and its feasibility can be confirmed. However, even if a new digestion facility is built in CASE3, the existing dewatering facility needs to be continuously used for a while, and the cost may not be reduced in the dewatering facility. Hence, the operation cost is estimated to be 3.77 million yen/yr when no reduction in the cost of dewatering facility is taken into account. The local governments that do not have much capacity for landfill disposal are in need of some solutions. For this reason, the implementation of solid fuel production facility is the preferred choice when compared to the incineration facility.

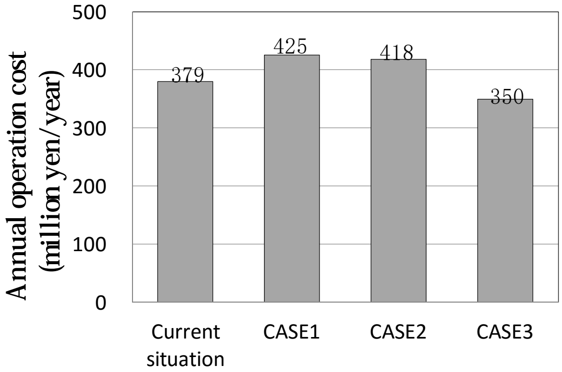
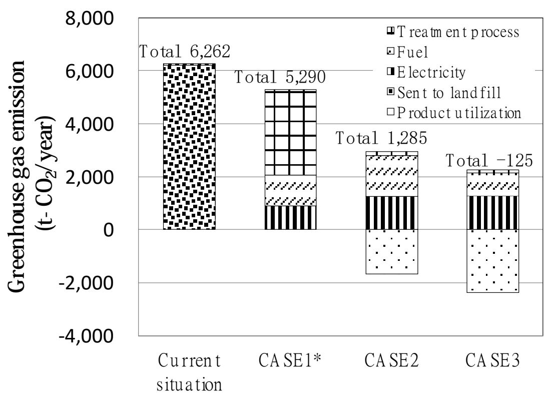


Fig. 6 Operation Cost of each Case [Solid Fuel Production Technology]

(ii) Greenhouse Gas Reduction Effect

Fig. 7 shows the results of the calculation. The estimated greenhouse gas emission under the current conditions is 6,262 t-CO_2/yr, and 99% of this emission is from dewatered sludge sent to a landfill. It is possible to use solid fuel products as an alternative to coals in CASE2 and CASE3 in which solid fuel production is implemented. Therefore, when the greenhouse gas emission reduction effect obtained by using solid fuel products as an alternative to coals is taken into account, the greenhouse gas emissions are calculated to be 1,285 t-CO_2/yr and -125 t-CO_2/yr respectively. The result shows that it is possible to significantly reduce the greenhouse gas emissions in terms of protecting the environment.



* The effective utilization of heat generated by incineration is not taken into account.

Fig. 7 Greenhouse Gas Reduction Effect [Solid Fuel Production Technology]

(2) Biogas Power Generation Facility

(i) Cost Effects

Fig. 8 shows the results of the calculation. The amount of electricity purchased from an electricity company is reduced by approximately 30% compared to the current situation. The reduction in electricity cost results in cost reduction by approximately 5%, and therefore the calculation shows that the implementation of biogas power generation is effective. By installing multiple small generators, the amount of electricity agreed upon for a power generation facility that is constantly operating can be reduced even in the case of trouble, for example, one of the generators can be stopped and the basic electricity price can be significantly reduced. In addition, a study on implementation of generators shows that the effect of implementation becomes greater when other types of biomass are accepted.

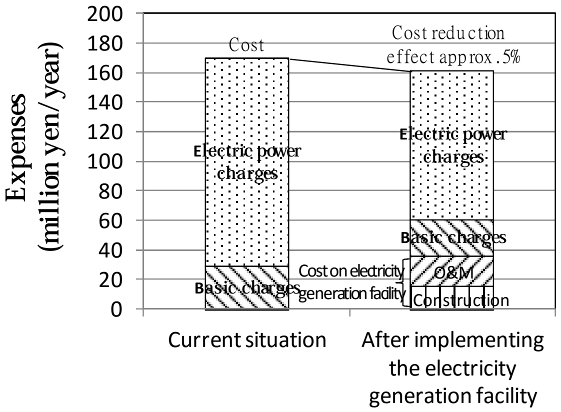


Fig. 8 Cost Effects of Biogas Power Generation

(ii) Greenhouse Gas Reduction Effect

Fig. 9 shows the results of calculation. Before implementing the biogas power generation, approximately 5,500 t-CO_2/yr of greenhouse gas is emitted due to the electricity consumption in the treatment plant, however; the result shows that it can be reduced by 30% when a digestion gas power generation is implemented.

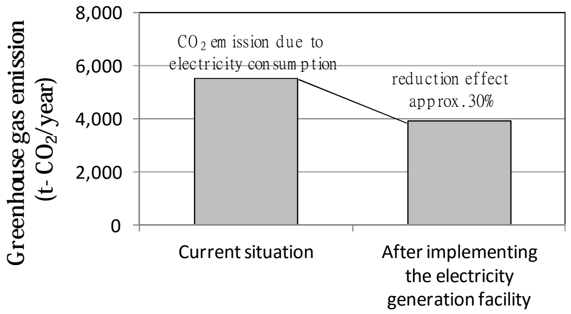


Fig. 9 Greenhouse gas reduction effect obtained by biogas power generation

V. Conclusion

In this study, we confirmed that the implementation of the sewage sludge energy production technology is effective for mid-scale treatment plants in which alternative means for sludge disposal are required, or excess biogas is generated. We hope that the spread of the sewage sludge energy production technology contributes to a reduction in energy consumption and global warming in the area centered around the sewage treatment plants.

Reference

[1] Basic Plan on Promotion of Biomass Utilization (2010): Ministry of Agriculture, Forestry, and Fisheries, pp11.
[2] Third Priority Plan for Social Infrastructure Development (2012): Ministry of Land, Infrastructure, Transport, and Tourism, p79.
[3] Sewerage Works in Japan (2014): Japan Sewage Works Association, pp84.
[4] Guidelines for Sewage Sludge Energy Generation Technology Revised (2015): Ministry of Land, Infrastructure, Transport and Tourism, Water and Disaster Management Bureau, Sewerage and Wastewater Department, pp29-29.
[5] Master Plan Manual for Usage of Biosolids (Comprehensive Plans for Sewage Sludge Treatment) (2004): Ministry of Land, Infrastructure, Transport and Tourism, City and Regional Development Bureau and Sewage Works Association, pp77-87.