Utilization of Regional Biomass Centered on Wastewater Treatment Plants

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Abstract: The purpose of this research is to utilize regional biomass at wastewater treatment plants. Organic waste produced by the operation of infrastructure was considered to have big potential as regional biomass, so its the mass production was investigated. To permit the utilization of organic materials such as trees and grass, the anaerobic co-digestion with bio-solid method and the slurry-compost of digestion sludge method were investigated. And finally, the maximum supply of biogas was estimated and technology needed to use it as fuel of natural gas vehicles was discussed.

Keywords: steam-exploded wood, anaerobic co-digestion, slurry-compost, natural gas vehicle

1. Introduction

In Japan in FY 2003, approximately 36% of bio-solid was disposed of as landfill and approximately 64% was used beneficially. In recent years, the rate of landfill has decreased and that of beneficial use has steadily increased as indicated in Figure 1. Bio-solid was utilized mainly on agriculture land. Recently incinerated ash and molten slag have been used as construction materials: for cement production and as aggregate.

Energy utilization of bio-solid is classified mainly as two methods. One is biogas, which is generated from anaerobic digestion and includes methane gas as its main constituent. The other is solid fuel, which is made of bio-solid. Biogas is usually consumed in wastewater treatment plant (WWTP), at digestion facilities, and in incinerators, but approximately 30% of that is left over and burned off.

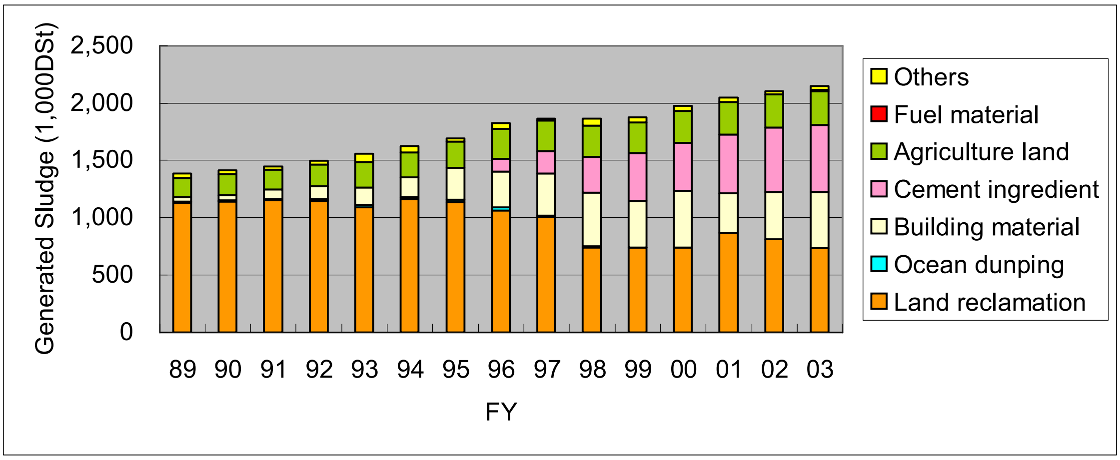


Figure-1 Transition of generated bio-solid

After the Kyoto Protocol came into effect in February 2005, the value of biogas has been transformed from in-house consumption to positive utilization. Biogas is expected to be an energy source that is characterized by carbon neutrality. And in this research, biogas is discussed mainly from the viewpoint of regional biomass utilization.

2. Estimation of regional biomass production

Various initiatives have been taken in the field of biomass utilization, contributing to reduced CO_2 emission and becoming very important elements in measures to fight global warming.

Several problems face biomass utilization. Its collection and transportation is very costly, because biomass is widely scattered in each region. And the facilities are small scale so they lack scale merit. Biomass is classified into waste biomass, unutilized biomass and resource vegetation. It is assumed that waste biomass such as food waste and wood generated by construction will be utilized quickly, because this waste biomass has been collected at specific places.

A large amount of vegetation waste is generated by river dike maintenance and trimming street-side trees. But it is difficult to say that vegetation waste is well utilized. For example, vegetation waste generated in suburban areas is incinerated with municipal solid waste. And its beneficial use for agriculture is restricted

Because the amount of vegetation waste from infrastructure operation is not included in organic resources, it is not expected that the use of vegetation waste will increase in the near future. If the amount of vegetation waste was precisely measured, utilization plans and methods would be investigated by an assessment based on a feasibility study. And if the resource information were open to the public, private companies would have opportunities to conduct case studies.

The amounts of driftwood at approximately 200 dams in Japan were investigated during 2003 and 2005[1]. As a result, the total volume of driftwood around dam reservoirs was estimated, obtaining a rough value. This shows that to promote the utilization of driftwood as biomass resources in the future, it will be necessary to continue the collection of these basic data, and to also establish a driftwood utilization system by referring to advanced initiatives.

Table 1 indicates the types of public works that produce biomass. To study biomass utilization, first, the amount and kinds of generated biomass will be precisely investigated. Next, the total volume produced in Japan will be estimated. Lastly, information management systems will be investigated.

Table-1 Kinds of biomass generated from national land manegement

administrative section	infrastructure, land and transport
road	freeway, national highway, local highway
river	river, dam, erosion control, seashore
city	street, park, sewarage
airport	runway
harbor	waterfront
railway	railroad

* biomass: grass, branches and leaves, drifwood, bio-solid

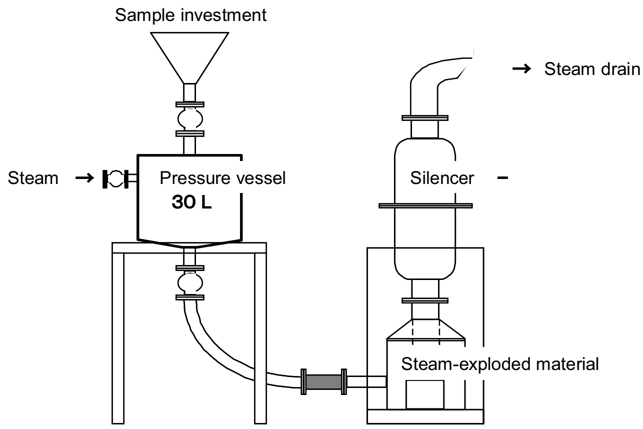
3. Recycling technology for organic waste

To promote the utilization of organic waste such as trees, and grass and bio-solid, recycling technology was developed considering the characteristics of both materials. From the results, it was concluded that anaerobic co-digestion of steam-exploded wood and bio-solid is feasible and can make a big contribution to biogas production. And the slurry-compost, method which contributes to agriculture use of bio-solid, was developed to treat fermentation residue.

It was observed that crushed wood is useful as bio-solid dewatering agent. And it was also observed that steam exploded wood with a small amount of bio-solid is an adequate compost that is usable as an, gardening material that can replace peat moss. Anaerobic co-digestion and slurry-compost were considered by this research.

3.1 Anaerobic co-digestion

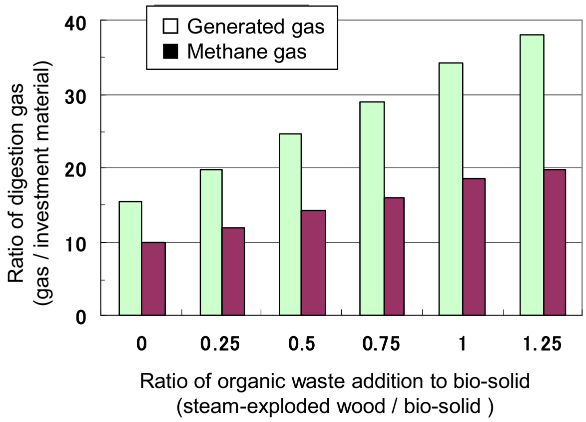
Wood material and dried grass alone are difficult to ferment and they need to be changed to a quality easily used by microorganisms. The steam-explosion method was investigated, as indicated in Figure 2. This method keeps samples at a high temperature and under high steam pressure for a certain time period then suddenly reduces the pressure. After that, the plant materials are shattered and softened.



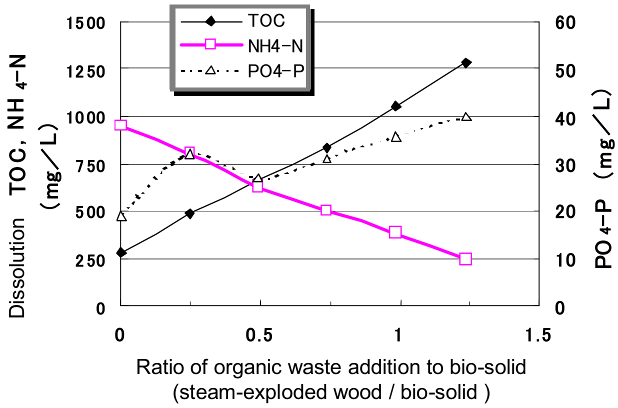
Figure－2 Steam-explosion Device

Methane fermentation was done using steam-exploded wood and bio-solid. Steam-exploded broadleaf tree chips prepared under pressure of 2MPa for 15minutes, that were confirmed to be easy degradable by a preliminary examination, were used for the experiment. The sequential experiment was done by inserting and removing samples once per day at 35 degrees for 50 days, while varying the ratio of the added plant waste to the bio-solid.

The methane gas productivity is important when the anaerobic co-digestion process is introduced at an actual facility. But it is feared that the whole process might change into acid fermentation, because of overloading of the function of the existing digestion tank. In a laboratory, the system does not change into acid fermentation but works well. Figure 3 shows the average methane gas recovered from steam-exploded wood and bio-solid under each condition after the experiment process has stabilized. And Figure 4 shows the dissolution characteristic of TOC, NH_4-N and PO_4-P in digestion sludge.



Figure－3　Recovery of methane gas
from steam-exploded wood



Figure－4　Dissolution characteristic of
TOC, NH_4-N, PO_4-P

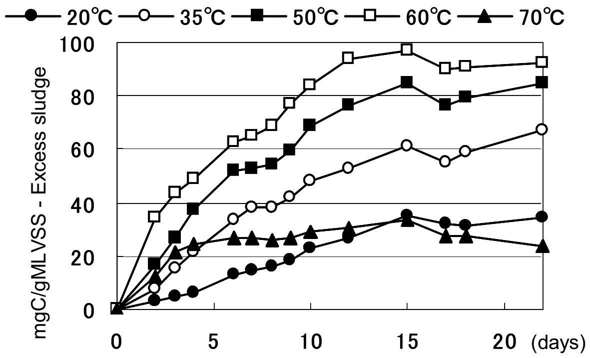
The methane gas production increased in proportion to the ratio of added steam-exploded wood to the bio-solid. On the other hand, a large quantity of soluble TOC and PO_4-P tend to remain in digestion sludge, but soluble NH_4-N decreased considerably when the steam-exploded material increased. It is observed that the system has high potential for practical use, if soluble TOC and PO_4-P in digestion sludge can be decreased effectively.

3.2 Slurry-compost[2)]

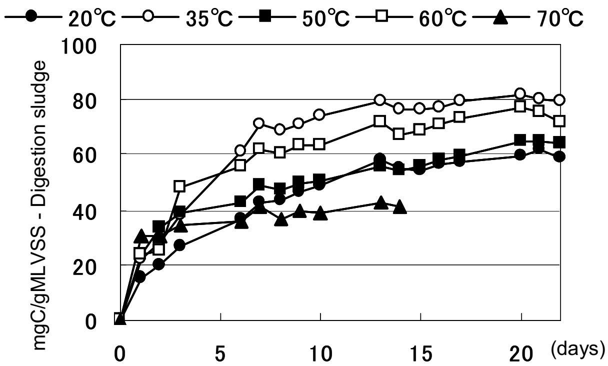
When slurry organic material such as bio-solid is utilized on agricultural land, the water content of the material is usually decreased by de-watering and compost is made from de-watered sludge. Slurry-compost is a technology developed to be applied to all kinds of slurry organic material. Excess sludge and digestion sludge are utilized in this research on the beneficial use of fermentation residue.

Slurry-sludge could be stabilized without de-watering if a large quantity of dissolved oxygen was provided. The purpose of aerobic digestion is not only the reduction of sludge but also its stabilization. “Slurry-compost” would be considered to be an improved aerobic digestion technology, if oxygen could be provided from a liquid surface by giving it high oxygen content.

The sludge stabilization process can be assessed based on its CO_2 production accompanying the decomposition of its organic material. The transition of generated CO_2 is indicated in Figure 5 and Figure 6, where excess sludge (thickened sludge: MLVSS = 26 g/L) and digestion sludge respectively (MLVSS = 6.8 g/L) were raw materials. The liquid phase (slurry-sludge) was 0.8 L and the gaseous phase (oxygen) was 2.1 L in this experiment. And the oxygen was filled up at pressure of 2 atmospheres and maintained over 30% by filling up again.



Figure－5 Transition of generated CO_2 in excess sludge



Figure－6 Transition of generated CO_2 in digestion sludge

The amount of generated CO_2 differed according to temperature conditions or the kinds of sludge used as raw material, but it was restrained after two weeks in each case. In particular, it was observed that the digestion sludge was decomposed quickly under the normal temperature. Because the digestion sludge was decomposed biologically under an anaerobic atmosphere, it was assumed that another microorganism population (aerobic microorganism) treated the sludge biologically under an aerobic atmosphere.

A small-scale facility could be constructed for the slurry-compost method, and it would be easy to operate. So it is assumed that it would be beneficial in coping with small-scale demand and seasonal fluctuation of production.

4. Maximum supply of biogas[3)]

The sludge digestion process has been introduced at approximately 350 WWTPs in Japan, and about 280 million m^3 biogas has been generated per year. Power facilities, such as gas engines or fuel cells, have been installed at some WWTPs. Recently the number has been increased but it is still limited. About 180 million m^3 biogas has been utilized as fuel, including digestion tank heating and as additional fuel for incinerators. But the remaining biogas (about 100 million m^3) has been burned off as excess biogas.

Table 2 indicates the quantity of biogas usable as fuel that is supplied to all WWTPs in Japan, including cases where hypothetical conditions are set. The hypothetical conditions were calculated for a case where the quantity of solid material input was over 3.0%, the ratio of digestion tank utilization was 85% and the digestion period was 20 days, and the digestion tank was heated at 35 degrees by biogas, because there are many WWTPs with surplus capacity to satisfy these factors. In addition, the biogas of all bio-solid was also calculated.

The remaining biogas will be about 250 million m^3 at efficient treatment and about 300 million m^3 for digestion of all bio-solid respectively. The reduction of CO_2 will approach 200 thousands tons if the existent remaining biogas is totally utilized. This quantity is equivalent to that adsorbed by about 60 thousands hectare of natural forest.

Table-2 Quantity of biogas supply at total WWTPs

condition of bio-solid treatment at WWTP	qauntity of remaining biogas (1,000m3)	quantity of refined biogas (1,000m3)	reduction of CO2 (t)
present remaining biogas	107,200	53,600	199,400
efficient treatment	251,300	125,600	467,500
digestion of all bio-solid	310,800	155,400	578,200

* using the data in FY2002 for condition of biogas production

5. Biogas vehicles[3)]

New beneficial uses of biogas have been introduced and biogas is utilized outside WWTP after considerable refining. Refined biogas is provided to a plant manufacturing City Gas in Kanazawa city[4)]. And in Kobe City, a plant has been equipped to supply refined biogas to natural gas vehicles (city busses, trucks, etc,) [5)].

Biogas has usually been utilized at large-scale WWTPs, but it tends to be burned off at small-scale WWTPs because of limited users and utilization methods. Biogas is considered to be a resource equal to natural gas when it is refined. It would be possible to drive natural gas vehicles by fuelling them with refined biogas, so we call such a vehicle a “biogas vehicle”.

Attempts to power cars by biogas are not a new idea. The “pressurized gas supply project” was carried out in 1942 in Kyoto City during the Second World War. More than 100 Biogas vehicles were driven at the same time, but the project was given up at 1950 because the quantity of biogas available fell as its content in sewerage declined.

Table 3 indicates the quantity of biogas supplied at each WWTP under the same assumed conditions as in Table 2. About 10 standard cars can be operated as biogas vehicles at WWTP that retain about 100 thousands m^3 of biogas per year. And it is estimated that 60 and 310 normal cars could be operated at WWTP that retain biogas at rates of about 500 and 2,500 thousands m^3 per year respectively. At large-scale WWTP, more than 4,500 tons of CO_2 emissions could be reduced.

There are several technologies, such as the membrane system, that refine biogas, reducing CO_2 after sulfide separation. It was assumed that adsorption reduction, which uses treated wastewater at WWTP, would be a useful method. Biogas includes a very small quantity of silicate compound that originates from shampoo, and this material must be reduced.

On the other hand, the law requires that natural gas vehicle fuel must have an odor. A fixed quantity of propane gas will be added to fuel for Biogas vehicles to add an odor and perform calorie coordination. And Biogas vehicle fuel must also be compressed to 20MPa for house use and small-scale filling up facilities, and to 25MPa for business use. Business use pressure permits high speed filling and could be applied at gas stations, but an employee responsible for its use must always be on duty at such facilities.

Table-3 Quantity of biogas supply at each WWTP

WWTP	qauntity of remaining biogas (1,000m3)	quantity of refined biogas (1,000m3)	number of driving biogas vehicles		
			normal car	2t packer	large bus
large-scale	2,500	1,250	310	250	50
middle-scale	500	250	60	50	10
small-scale	100	50	10	10	2

* driving length per year and per fuel unit, normal car: 60,000km/year and 15km/m3
2t packer: 20,000km/year and 4km/m3, large bus: 50,000km/year and 2km/m3

"Natural gas" supplied by gas companies have been designed as standard fuel for natural gas vehicles. Each refined biogas must be inspected to confirm that it has the same quality as "natural gas". If biogas refining systems are standardized, Biogas vehicles will be introduced easily.

6. Conclusion

Measures to increase biogas production were investigated by this research. These were the utilization of steam-exploded wood with bio-solid, efficiently using digestion tanks, and by digesting all bio-solid. For example, a high temperature - high concentration digestion system works satisfactory in Osaka city[6]. In the future, Economical anaerobic digestion systems that provide a steady high sludge decomposition rate must be done.

It will become increasingly important to develop technologies for utilizing biogas: biogas vehicle systems for example. In order to utilize regional biomass centered on WWTP, the following issues must be tackled. Utilizing biomass must not only benefit WWTP, but also regional areas. And it must also be possible to use the fermentation residue.

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- Recycling technologies for organic waste
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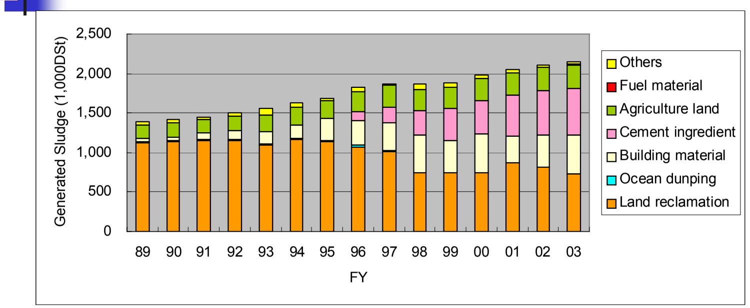
- Biogas vehicles

Introduction

- Beneficial use of bio-solids
  - Agriculture land
  - Construction material
    - Incinerated ash
    - Molten slag
  - Energy utilization
    - Biogas
    - Solid fuel

Transition of generated bio-solid



Approximately 64% of bio-solids was used beneficially.

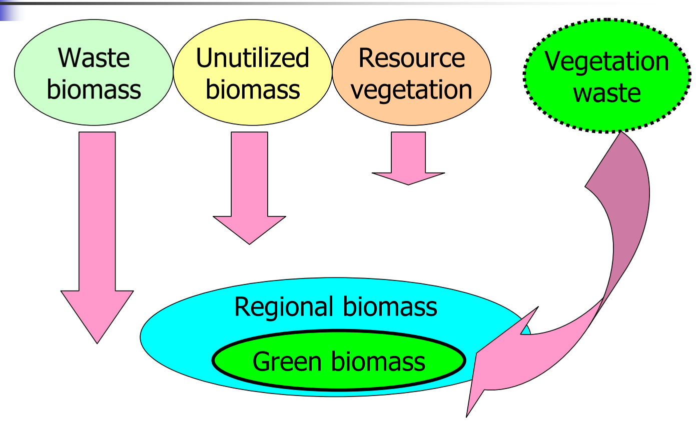
Utilization of regional biomass centered on WWTP

- Gather regional biomass at WWTP
- Step up the production of recycle
  - Compost, construction material
  - Biogas, solid fuel
- Utilize the products efficiently
  - In-house consumption
  - Positive utilization

Estimation of regional biomass production

- Waste biomass
  - Food waste
  - Wood generated by construction
- Unutilized biomass
- Resource vegetation
- Vegetation waste
  - River dike maintenance
  - Trimming street-side trees

Regional biomass



Green biomass utilization

- The amount and kinds of generated biomass will be precisely investigated.
- Total volume produced in Japan will be estimated.
- Information management systems will be investigated.

➡ Inventory system of green biomass

Kinds of biomass generated from national land management

administrative section	infrastructure, land and transport
road	freeway, national highway, local highway
river	river, dam, erosion control, seashore
city	street, park, sewarage
airport	runway
harbor	waterfront
railway	railroad

* biomass: grass, branches and leaves, drifwood, bio-solid

Infrastructure operation at river and road offices

River dike maintenance (e.g. Edogawa river office)

Mowing

Burning up at the field

Trimming street-trees (e.g. Tottori river and road office)

Chipping branches

Spreading over the grass

Recycling and utilizing biomass from public works

Data base for biomass

Driftwood into dam reservoirs

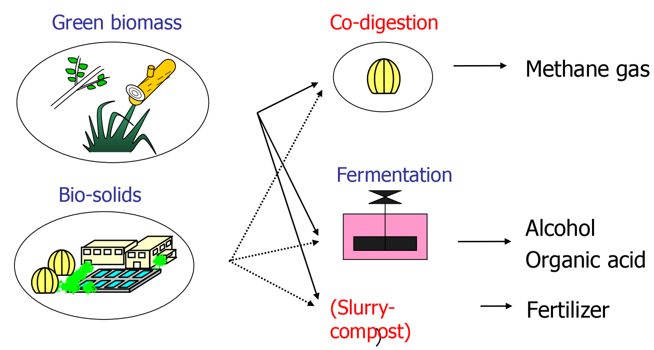
Technologies for recycling

Alternative material of peat moss (Thick layer basic materials spaying)

Develop the system which provides and manages the data base of biomass from each public work.

Pilot works for practical use about the developing and existing useful technologies

Recycling technology for organic waste

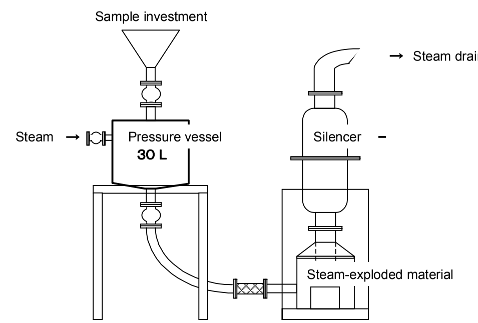


Recycling technology for organic waste
(1) Anaerobic co-digestion

- Material
  - Green biomass (Wood, dries grass)
  - Bio-solid
- Steam explosion method
  - Keep at a high temperature and under high steam pressure for a certain period
  - Then suddenly reduces the pressure

⇒ Green biomass is shattered and softened

Steam-explosion device



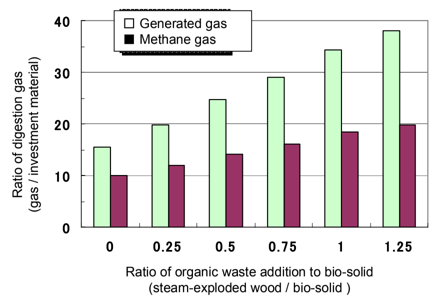
Wood chips before and after the steam explosion treatment

Steam-exploded broadleaf tree chips prepared under pressure of 2MPa for 15 minuets.

Sequential methane fermentation experiment

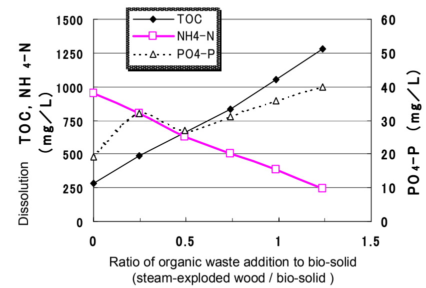
Inserting and removing samples once per day at 35 degrees for 50 days, while varying the ratio of the added plant waste to the bio-solid.

Recovery of methane gas from steam-exploded wood



Methane gas production increased in proportion to the ratio of added steam-exploded wood to the bio-solid.

Dissolution characteristics of TOC, NH_4-N, PO_4-P



A large quantity of soluble TOC and PO_4-P tend to remain in digestion sludge, but soluble NH_4-N decreased considerably when the steam-exploded material increased.

Recycling technology for organic waste

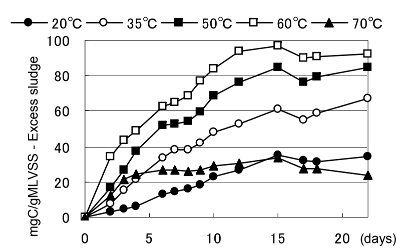
(2) Slurry-compost

- Material
  - All kinds of slurry organic material
- "Slurry-compost"
  - The reduction of sludge and its stabilization
  - Oxygen could be provided from a liquid surface by giving it high oxygen content

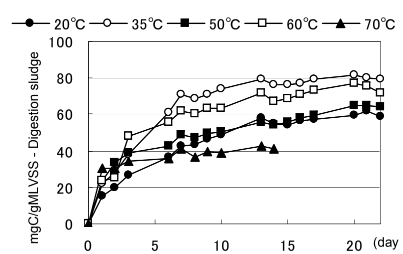
Considered to be
"an improved aerobic digestion"

Transition of generated CO_2

Excess Sludge



Digestion Sludge



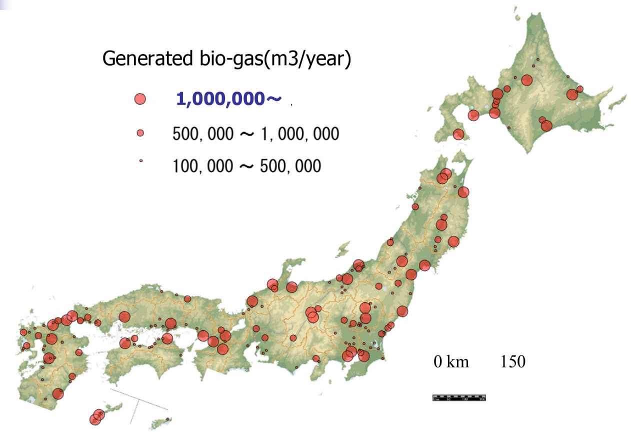
Digestion sludge was decomposed quickly under the normal temperature.

Because the digestion sludge was decomposed biologically under an anaerobic atmosphere, it was assumed that aerobic microorganism treated the sludge.

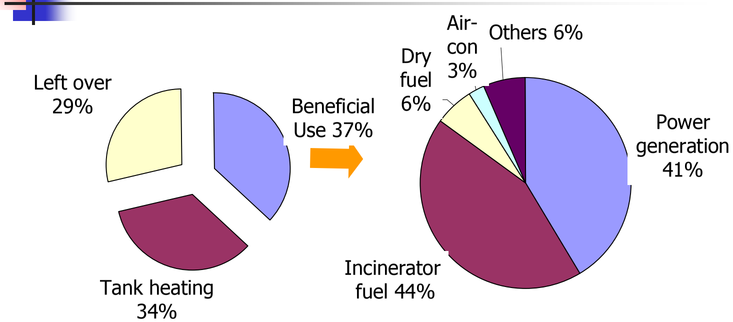
Maximum supply of biogas

- Digestion process has been introduced at approximately 350 WWTP.
- Power facilities, such as gas engines or fuel cells, have been installed at some WWTP.
  - Recently the number has been increased but it is still limited.

Distribution of digestion facilities



Utilization of biogas



Bio-gas was generated 280 million m^3 per year in Japan.
And approximately 30% is left over and burned off

Quantity of biogas supply at total WWTP

condition of bio-solid treatment at WWTP	qauntity of remaining biogas (1,000m3)	quantity of refined biogas (1,000m3)	reduction of CO2 (t)
present remaining biogas	107,200	53,600	199,400
efficient treatment	251,300	125,600	467,500
digestion of all bio-solid	310,800	155,400	578,200

* using the data in FY2002 for condition of biogas production

Hypothetical conditions:
1. The quantity of solid material input was over 3.0%.
2. The ratio of digestion tank was 85% and the digestion period was 20 days, and the digestion tank was heated at 35 degrees by biogas.

3. In addition, the biogas of all bio-solid was calculated.

Biogas vehicles

- New beneficial use of biogas
  - Biogas is utilized outside, such as City gas, WWTP after considerable refining.
- Natural gas vehicles
  - Refined biogas = natural gas

⇒ "Biogas vehicles"

Number of driving biogas vehicles at each WWTP

WWTP	qauntity of remaining biogas (1,000m3)	quantity of refined biogas (1,000m3)	number of driving biogas vehicles		
			normal car	2t packer	large bus
large-scale	2,500	1,250	310	250	50
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* driving length per year and per fuel unit, normal car: 60,000km/year and 15km/m3
2t packer: 20,000km/year and 4km/m3, large bus: 50,000km/year and 2km/m3

Large-scale:
The "pressurized gas supply project" was carried out during 1942-1950.
More than 100 biogas vehicles were driven at the same time.

Small-scale:
About 10 standard cars could be operated as "Biogas vehicles" at WWTP that retain about 100 thousands m^3 of biogas per year.

Kobe biogas

- Kobe biogas
  - Refined biogas = 98% methane gas
  - Kobe city bus opened the business from 2nd October, 2006
- Full-scale plant
  - Spring 2008 open
  - 2,000m^3/day
  - 40 buses (50km/day)

(PWRI, Kobe City, KOBELCO ECO-SOLUTIONS CO.)

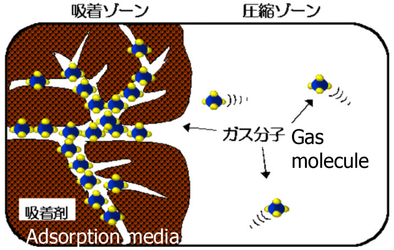
Standardization of biogas

- City gas has been designed as standard fuel for natural gas vehicles.
- Each refined biogas must be inspected to conform that it has the same quality as "natural gas".
- If biogas refining systems are standardized, biogas vehicles will be introduced easily.

Biogas adsorption system

Adsorption zone
吸着ゾーン

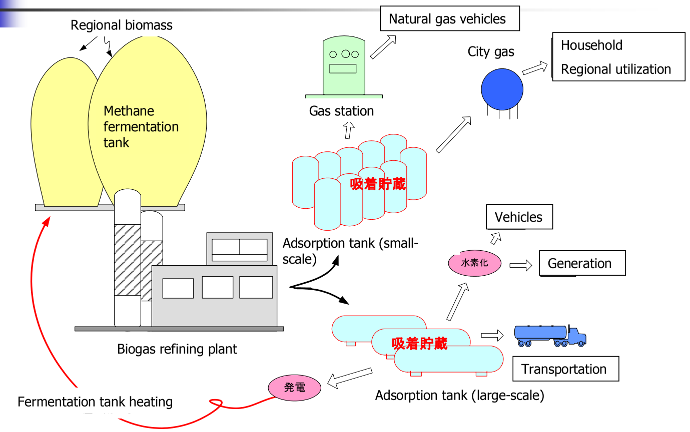
Compression zone
圧縮ゾーン



Gas storage tank by adsorption
(e.g. Tsuruoka city)

Left small tank: adsorption type
Right big tank: usual type

Biogas utilization project



Summary

- Data base of regional biomass
  - Change vegetation waste into green biomass
- Recycling technology for green biomass
  - Economical co-digestion system
  - Utilization of fermentation residue
- Technologies for utilizing biogas
  - Biogas vehicles system

Transition of generated bio-solid