XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

DEVELOPMENT OF A BIOGAS PURIFIER FOR RURAL AREAS IN JAPAN

Y. KIMURA[1], S. YASUI[2], T. HINATA[1], N. NOGUCHI[3], T. TSUKAMOTO[4], T. IMAI[5], M. KANAI[6], Z. MATSUDA[7]

[1]Y. KIMURA , Hokkaido Central Agricultural Experiment Station, Hokkaido, Japan kimurayo@agri.pref.hokkaido.jp.
[1]T. HINATA, hinata@agri.pref.hokkaido.jp.
[2] S. YASUI, Zukosha Co.Ltd, Hokkaido Obihiro, Japan, yasui@zukosha.co.jp.
[3] N. NOGUCHI, Hokkaido UNIV, Hokkaido Sappro, Japan, noguchi@bpe.agr.hokudai.ac.jp.
[4] T. TSUKAMOTO, IHI Shibaura. Co.Ltd, Hokkaido Obihiro, Japan, hateruma@polka.ocn.ne.jp.
[5]T. IMAI, Green plan.Co.ltd, Hokkaido Sapporo, Japan, imai-tos@awi.co.jp.
[6] M. KANAI, Air Water Co. Ltd, Osaka Sakai, Japan.
[7]Z. MATSUDA, Hokuren Agricultural Research Center, Hokkaido Sappro, Japan, juzo@bpe.agr.hokudai.ac.jp.

CSBE100492 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment Conference

ABSTRACT Currently, the biogas produced by biogas plants for dairy farms in Japan is a carbon-neutral energy. However, utilization of biogas is restricted solely to farming areas. In particular, because there is no effective method of transporting unused biogas and there is a need for establishing practical methods for biogas removal from operating systems. The purpose of this study was to expand the use of biogas produced from stand-alone biogas plants by employing a gas separation membrane in order to modify biogas to city gas 12A specifications, and to develop a biogas purifier (refining-compression-filling (RCF) facility) equipped with a device to fill high-pressure purified gas into cylinders to be taken outside the farming area. The amount of purified gas produced by the RCF facility we developed was approximately 97.0 Nm^3/day, for a raw material amount of approximately 216.0 Nm^3/day. The heat quantity of the purified gas was 38.9MJ/Nm^3 (9,290kcal/Nm^3), which was within city gas 12A specifications. Furthermore, the number of gas cylinders (filled pressure: 14.7 MPa, volume: 46.7 L) filled with the manufactured purified gas was 14.3 cylinders/day. We conducted a simulation that envisioned providing cylinders filled with purified gas from outside the farming area to common households in a town (Town A; 3661 common residential units) located in Northern Japan. Test calculations indicated that it would be possible to provide purified gas to approximately 6% of common residences in town A. From the above results, the RCF facility we developed allowed the modification of carbon-neutral biogas to conform to city gas 12A specifications, and allowed the transport of this gas out of the farming area.

Keywords: Biogas plant, Biogas Purifier, Biogas utilization system (BGUS), Gas separation membrane, Carbon-neutral.

INTRODUCTION Anaerobic fermentative treatment of livestock waste by biogas plants is more effective in lowering the environmental load compared with other methods of treating animal wastes. The biogas produced can be used as an energy source. Fifty biogas plants have been built in Hokkaido as a means of effectively utilizing livestock waste. However, many of the power generators installed in the plants to produce electricity, a representative method of utilizing biogas that has not been completely consumed within the facilities, are foreign-made. Thus because repairing the generators when problems occur is problematic, and because the price of surplus electricity being sold is too low to recover the running cost, there is a major problem of many generators being simply left in a state of disrepair when problems occur.

The use of biogas in Japan is premised on "consumption within the farm production system only by farm management." Because of this, a method to transport biogas outside the farm production system is desired to promote the use of biogas. It was assumed that effective utilization of biogas outside the farm production system could be accomplished by simply applying it to general gas equipment. However, because the amount of biogas produced and the concentration of methane fluctuates daily, its caloric value is not stable, and because there is also residual hydrogen sulfide, domestic gas equipment manufacturers have shown reluctance to directly using general gas equipment for biogas. Also, as part of the IGF21 Plan (Oda.,2009), the Ministry of Economy, Trade and Industry is advancing the integration of the gases 13A and 12A, which are highly caloric natural gases, for use as town gas by 2010. Thus there is the need for the standardization of high calorification of biogas and the stabilization of caloric value.

A method of solving this problem is the construction of a system that purifies biogas, fills storage cylinders at high pressure with the gas, and distributes the gas within the region. Thus it is necessary to develop a system of equipment that carries out in a single effort the basic technological sequence of biogas refining (Nagai, 2007), standardized high calorification of the gas, compression (high pressurization of the gas), and flow to storage cylinders. From results of field testing, there is also a need to develop a picture of problems that could occur in the actual use of this Biogas purifier (refining-compression-filling (RCF) facility), and clarify measures on how to address these problems.

This research study seeks to develop a RCF facility to utilize surplus, unused biogas produced by individual biogas plants. It also evaluates the system for use in an agricultural region by performing energy and environmental analysis of a biogas utilization system (BGUS), which is composed of the RCF facility and equipment that consume the refined biogas.

MATERIALS AND METHODS

Construction of biogas utilization system (BGUS)

Biogas utilization system (BGUS) Figure 1 shows a biogas utilization system (BGUS). As a measure to handle new energy supply and surplus biogas in an agricultural region, the system has as its core the RCF facility, which uses surplus biogas to produce refined gas. The BGUS also comprises equipment that consumes the refined gas. The system can be used to fill storage cylinders with surplus biogas from a biogas plant and supply general households and businesses in the region with fuel.

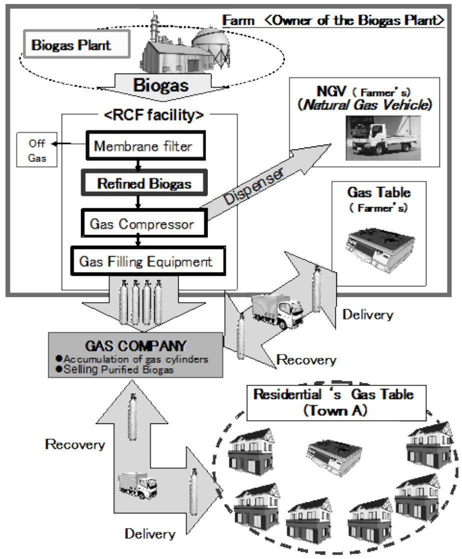

Figure 1. Biogas Utilization System (BGUS)

Refining-compression-filling (RCF) facility Figure 2 shows the refining process of the RCF facility. The facility produces less than $100Nm^3$ per day, which satisfies the condition for the amount of high-pressure gas producible by Class 2 producers as stipulated by the High Pressure Gas Safety Act(Ministry of Economy, Trade and Industry,1951). It is also satisfies the conditions for a "mobile production facility" established by the law.

Biogas purification is carried out by separation membranes inside the same facility. To give the gas after separation the same equivalent heat quantity as town gas 12A (Wobbe Index [WI: value obtained by dividing the caloric value of the gas by the square root of its specific gravity] of 49.2 – 53.8 and burning rate of 34 – 47 m/s), equipment to adjust the heat quantity by adding propane is also installed. (Test results of the development of the RCF facility is given in detail in document a.) The gas at the completion of the refining process is temporarily stored in storage units below the RCF facility. High-pressure filling of transportable cylinders using high pressure boosters makes it possible for the biogas to be utilized outside the farm production system as fuel for general households and compressed natural gas (CNG) vehicles.

Photo 1. RCF facility

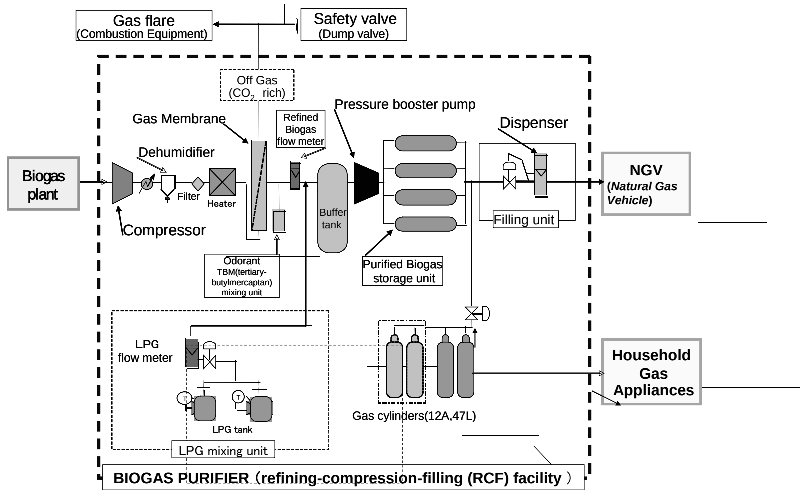

Figure 2. Purification process by refining-compression equipment

Onsite field testing Using the RCF facility, the following two tests were conducted from July 2007 to February 2008: 1) test of biogas refining using the RCF facility, and 2) test of utilization of refined gas by gas equipment. Items measured were the concentration of methane, Carbon Dioxide and Nitrogen in the raw biogas and refined gas, and the amount of refined gas produced after reforming. The raw biogas used in the present investigation was described in detail in a previous paper (Kimura *et al.*, 2009).

For utilization tests of refined gas, we tested gas tables (IC3300CB2) and CNG trucks (ABF-SYE6T ([revised]), and measured the amount of refined gas consumed.

Evaluation of regional utilization model revolving around biogas utilization system (BGUS) Based on the results obtained from onsite field testing, we selected Town A and established a regional utilization model that revolves around the BGUS. We evaluated the model's energy and environment aspects. We used LCA (Life Cycle Assessment) for the environmental assessment.

RESULTS AND DISCUSSION

Onsite testing – Test of surplus biogas purification using developed RCF facility

Operation of RCF facility Tables 1 and 2 show the results of testing of refining. The average electrical energy consumed by the RCF facility during the testing period was 5.5 KWh. Using the RCF facility, about 44 percent of the raw biogas (216.0 m^3) was reformed to refined methane (96.0 m^3). To increase the methane concentration of the biogas after purification to about 94.5% and to standardize the heat quantity, about 0.5% propane (1.0 m^3) was added. This resulted in refined gas (97.0 m^3) with heat quantity of 9,290 kcal/Nm^3 (38.9 MJ/m^3). The gas at the completion of the refining process had a WI of 49.3 and maximum combustion potential (MCP) of 34.3 m/s. These values fall within the specifications of town gas (WI: 49.2 – 53.8, MCP: 34 – 47 m/s). Also, the amount of raw gas produced per day was 216.0 Nm^3 and the amount of refined gas produced per day was 97.0 Nm^3, which satisfied the condition set by the High-Pressure Gas Safety Act of less than 100 Nm^3 per day as the amount producible by Class 2 producers.

Table 1. Daily average values for raw gas, off-gas, refined methane, and refined gas

		Feed gas (Biogas)	Off gas (Waste gas)	Purified Biogas	Propane of Heating value	Products Gas
Influent gas	(Nm^3)	216.0	120.0	96.0	-	97.0
Methane	(Nm^3)	114.9	43.8	91.1	-	89.5
Carbon Dioxide	(Nm^3)	84.7	73.7	4.9	-	1.7
Nitrogen	(Nm^3)	16.4	2.5	-	-	4.8
Propane	(Nm^3)	-	-	-	1.0	1.0
TBM	(Nm^3)	-	-	trace	-	trace

* TBM : tertiary-buty mercaptan

Table 2. Average composition of raw gas, off-gas, and refined gas, and percentage of refined gas from raw gas

		Influent	Off gas	Purified Biogas (Product Purity)
Methane	(%)	53.2	32.1	94.5
Propane	(%)	-	-	0.5
Dioxide	(%)	39.2	64.8	0.0
Nitrogen	(%)	7.6	3.1	5.0

* Product Purity: O_2 free

Application of refined biogas to general gas equipment Comparing the gross caloric value of liquefied petroleum gas (LPG) with refined biogas, we see that the value for LPG is 24,000 kcal/Nm^3 compared to 9,228 – 9,350 kcal/Nm^3 for refined biogas, or roughly 40% of LPG. Therefore, we enlarged the nozzle diameter of gas equipment to maintain the same degree of combustion capability as LPG during use. The results of combustion tests show that the area near the combustion had concentrations of less than 0 ppm CH_4 and 0 – 10 ppm CO, which were similar to that of LPG during combustion. The average amount of refined gas used by gas ranges was 0.41Nm^3 per day (150 Nm^3 per year). Also, we tested operation of CNG trucks under the conditions of 94 km as the usage distance of refined gas and an average speed of 56.4 km/h. The results show that the fuel consumption rate of the refined biogas was 10.6 km/Nm^3.

Evaluation of regional utilization model revolving around BGUS

Estimate of energy consumption by CNG vehicles during crop production activities at model farm For our model, we selected a-Farm in Town A. It has a plot with an area of 75 ha. The crop activity was cultivation of pasture grass (cut twice yearly). In a-Farm's system of cultivating mid-moisture grass silage, trucks are used for laying fertilizer, harvesting grass, and spreading soil improvement materials. The trucks' distance of movement were measured and collected using a geographic information system (GIS). The total distance of 4-ton trucks involved in the production of pasture grass at a-Farm was 3,513 km per year. The amount of diesel fuel consumed was 462.2 L, and the amount of refined biogas consumed was 462.2 Nm^3. The amount of diesel fuel consumed per hectare of a-Farm's plot was 6.2 L/ha; for refined biogas it was 6.2 Nm^3/ha.

Players in regional utilization model revolving around BGUS The players that are studied in the utilization model (subjects playing roles) are: 1) the farmer with the biogas plant installation, 2) the biogas vendor, and 3) consumers of the refined biogas. The farmer with biogas plant installation manages the biogas plant and is responsible for the refining of surplus gas and compression, i.e. he or she is responsible up to the point of storing the refined gas in storage canisters. The biogas vendor is responsible for filling cylinders with refined biogas, delivering, installing, and recovering the cylinders, as well as modifying residential gas equipment. Consumers consume the gas.

The utilization model is centered on equipment that can be easily modified and introduced and which were tested by onsite field testing. The areas of use were established as "inside the farm production system" and "outside the farm production system." "Inside the farm production system" comprised equipment used in the farm and residence of the farmer that consume refined biogas produced by the RCF facility. The gas vendor delivered cylinders filled with refined gas. The routes utilized existing infrastructure.

Energy evaluation of regional utilization model revolving around BGUS Figure 3 shows the amount of refined biogas produced and consumed at a-Farm. Figure 4 shows the composition of gases produced at a-Farm and the percentage of consumption of refined biogas. The biogas plant produced an average of 185,000 Nm^3 biogas per year. Of the amount of biogas produced, about 35.3% of the gas was consumed by gas boilers within the plant. Raw biogas to be refined made up 42.5% of the gas produced, and unused biogas (biogas that was not used in any stage of the process) made up 22.2%. The amount of refined biogas completely treated by the RCF facility was about 35,000 Nm^3 per year (19.1% of the total biogas produced). The amount of refined biogas used within the farm production system as energy substitute for LPG by kitchen gas appliances and CNG trucks was about 600 Nm^3 per year (CNG trucks: 462Nm^3 per year; kitchen appliances: 150 Nm^3 per year). This amount made up 0.3% of the refined gas produced in a year. The amount of refined gas transported outside the farm production system was 35,000 Nm^3 per year. This made it possible to supply 219 out of 3661 residences (as of November 2008) in A-Town (roughly 6% of all households).

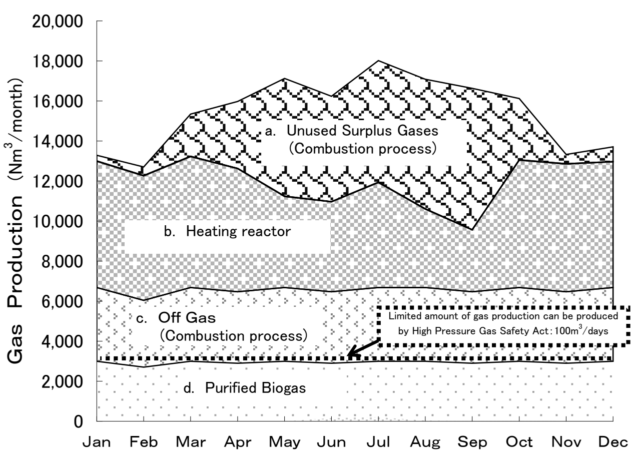

Figure 3. Composition of refined gas produced and consumed (a-Farm)

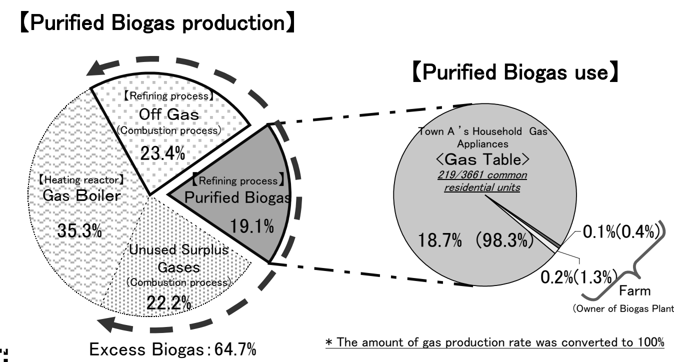

Figure 4. Percentage and breakdown of refined gas produced and consumed in Town A

Environmental evaluation of BGUS Specification of life cycle material flow and boundaries – figures 5 and 6 show the life cycle material flow of the BGUS. There are three greenhouse gases released during the course of BGUS, of which the biogas plant is the major component: carbon dioxide (CO_2), methane (CH_4) and nitrogen monoxide (N_2O). Carbon dioxide shown by the symbol CO2 in the diagram is emitted due to treatment of biomass (livestock waste in this case). It is not included in LCA because it is considered to be released to the atmosphere in the same amount as CO2 that was absorbed and removed from the atmosphere in the short term by plants, and thus is considered carbon neutral according to international agreements concerning emission of greenhouse gases made by the Intergovernmental Panel on Climate Change (IPCC). Chemicals indicated by the following symbols CO2 and CO2 (carbon dioxide), CH4 (methane), and N2O (nitrogen monoxide) are gases produced during crop production and biogas plant operation. Please note that when the symbol CO2 indicates the use of refined biogas as an alternative of fossil fuels by equipment, it is counted toward CO2 reduction. The scope of LCA evaluation is shown in Figures 7 and 8. The main sources of greenhouse gases produced in the processing of livestock waste by the biogas plant were divided roughly into three groups: 1) combustion of fossil fuels as power and heat sources for vehicles, 2) combustion of fossil fuels for the production of electricity when using commercial electricity, and 3) greenhouse gases produced by the livestock waste itself by fermentation or sublimation.

Further analysis shows that the process of generating carbon load can be divided into the following eight categories: 1) fuel combustion by equipment to transport livestock waste into the plant, 2) combustion of fossil fuels used by the biogas plant, 3) combustion of fossil fuels by equipment within the biogas plant, 4) deposit fermentation of solids after solid-liquid separation, 5) sublimation of digestive liquid during storage, 6) fuel combustion by equipment transporting digestive liquid and compost, 7) fuel combustion by equipment that spreads digestive liquid and compost, and 8) sublimation from digestive liquid and compost in fields after spreading. In addition, carbon load occurred during 1) use of commercial electricity in the process of refining surplus biogas, 2) combustion of fossil fuels by farm trucks inside the farm production system, and 3) combustion of LPG fuel by kitchen equipment inside and outside the farm production system. The LCA evaluation of the BGUS modeled in A-Town used the emission of carbon dioxide as its single indicator. It did not use other environmental indicators such as eutrophication of water in the region or acidification of the atmosphere in its evaluation.

Below were the qualifications used in the LCA.

- Because energy involved in the delivery of biogas cylinders by the gas vendor was almost the same as the previous delivery system, it was not counted as greenhouse gases that contribute to warming for analysis.
- Carbon dioxide produced when biogas was created by anaerobic fermentation of livestock waste and CO_2 produced by sediment fermentation were considered the same amount as CO_2 absorbed by plants during their growth, so they were considered carbon neutral and were not included in the count of greenhouse gases.
- Besides equipment in the farm production system, there were equipment in the barn, such as boilers and tractors, that use fossil fuels. Carbon dioxide emitted by these equipment were offset in the calculations comparing the previously existing biogas plant and the BGUS, so they were not

included in the LCA.

Result of LCA – Table 5 shows the results of LCA and the amount of greenhouse gases reduced by the BGUS. The following IPCC emission coefficients were used: CO_2:1; CH_4:23; N_2O:296 (Hishinuma et al., 2008&2009, Hinata 2004). The total carbon load of the shared portion of the previous biogas plant was 271 t-CO_2eq. Against this value, CO_2 reduction in the total carbon load of common portions from the biogas plant that introduced the BGUS was counted as produced by about 6.3% of A-Town's households to which biogas was sent (which did not include the farm in A-Town with the biogas plant installation) and by farm trucks and kitchen equipment that used refined biogas as substitute energy source in the biogas plant, besides the livestock waste treatment system that existed in the previous biogas plant.

The results of analysis show that the total carbon load of the common portions of the BGUS was 102 t-CO_2eq. Compared with the carbon load of the common portion of the biogas plant before introduction of the BGUS and of the gas utilizing equipment inside and outside the farm production system (334 t-CO_2eq), a reduction of 232 t-CO_2eq was achieved.

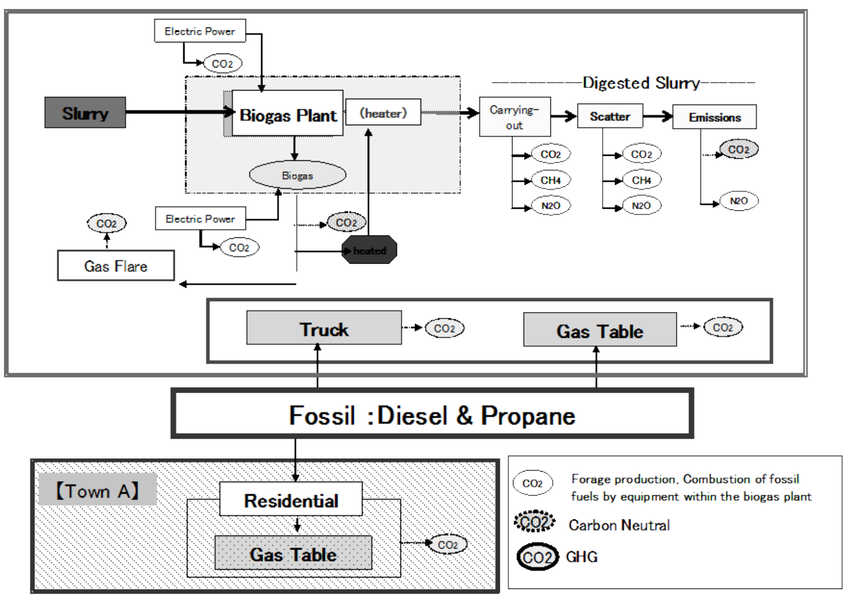

Figure 5. Life cycle flow of previously existing biogas plant

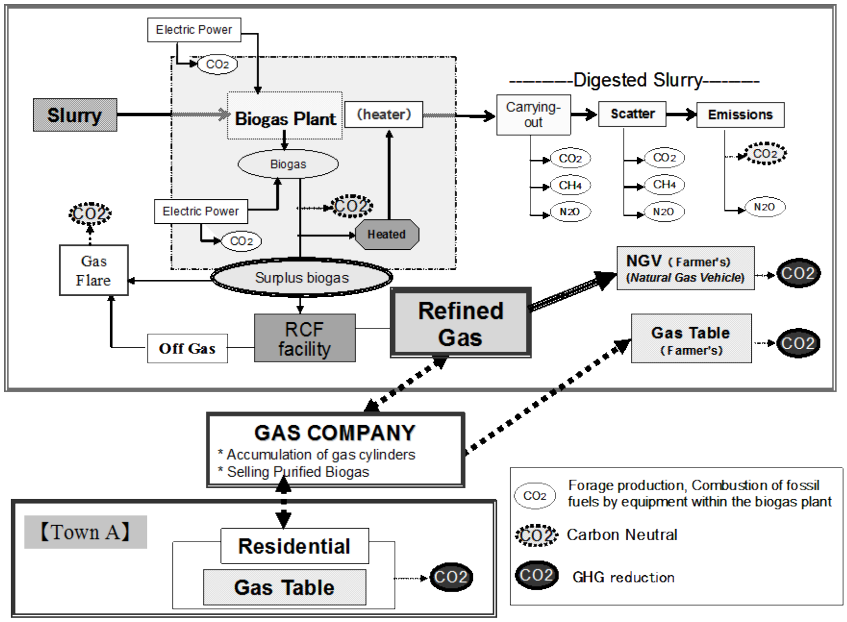

Figure 6. Life cycle flow of BGUS (filling refined biogas cylinders, supplying by gas vendor)

Table 5. Total carbon load before and after introduction of BGUS

	CO_2(kg)	CH_4(kg)	N_2O(kg)
A. Previously existing Biogas plant (before the introduction of biogas utilization system (BGUS))			
(1) Farm （Owner of the Biogas Plant）			
#1 Biogas plant and digested slurry			
・Gas flare (Combusted: Surplus biogas: *Carbon Neutral*)	*(219,260)**	-	-
・Electric Power (Biogas Plant)	6,042	-	-
・Volatilization (from digested slurry in grass field, Scatter digested cattle slurry)	45,215	0.27	21.62
<Subtotal>	51,257	0.27	21.62
GWP	51,257	6	6,400
GWP (CO_2 eq) (a)		**58 t- CO_2 eq**	
#2 Gas and diesel Equipment			
・Truck(Diesel) and Gas table(Propane)	70,973	-	-
GWP	70,973	0	0
GWP (CO_2 eq) (b)		**71 t- CO_2 eq**	
(2) Town A (216 common residential units)			
#1 Purified Biogas Equipment			
・Gas table	80,024	-	-
GWP	80,024	0	**0**
GWP (CO_2 eq) (c)		**205 t- CO_2 eq**	
Total GWP (A=a+b+c)		**334 t- CO_2 eq**	
B. Biogas Plant with biogas utilization system (BGUS)			
(1) Farm （Owner of the Biogas Plant）			
#1 Biogas plant and digested slurry			
・Gas flare(Combusted: Off Gas and Surplus biogas: *Carbon Neutral*)	*(115,177)**	-	-
・Electric Power (Biogas Plant)	6,042	-	-
・Volatilization (from digested slurry in grass field, Scatter digested cattle slurry)	45,215	0.27	21.62
<Subtotal>	51,257	0.27	21.62
GWP	51,257	6	6,400
GWP (CO_2 eq) (a)		**51 t- CO_2 eq**	
#2 Biogas Purifiers (refining-compression-filling (RCF) facility)			
・Electric Power (RCF facility)	43,642	-	-
GWP(Global Warming Potential)	43,642	0	0
GWP (CO2 eq) (b)		**44 t- CO_2 eq**	
#3 Purified Biogas Equipment (*Carbon Neutral*)			
・NGV(Truck) and Gas table (Instead of Purified Biogas)	*(1,407)**	-	-
GWP	0	0	0
GWP (CO_2 eq) (c)		**0 t- CO_2 eq**	
(2) Town A (216 common residential units)			
#1 Purified Biogas Equipment (Instead of Purified Biogas)			
・Gas table (*Carbon Neutral*)	*(80,024)**	-	-
GWP	0	0	0
GWP (CO_2 eq) (d)		**0 t-CO_2 eq**	
Total GWP (B=a+b+c+d)		**102 t- CO_2 eq**	
C. Greenhouse gas reduction (c=A - B) (Effect on the introduction of BGUS)		**232 t- CO_2 eq**	

GWP: Global Warming Potential , CO_2: Carbon dioxide, CH_4: Methane, N_2O: Nitrous oxide
CO_2 eq: CO_2 equivalents, (*00,000*)*:Carbon Neutral

CONCLUSION The above results show that standardization of surplus biogas to town gas standard 12A by the developed RCF facility, use of the refined biogas by general gas equipment, and transport of the gas outside the farm system are possible. The experiment also shows that for a town with dairy farming, it is possible to reduce the emission of carbon dioxide in the region by supplying the town with refined gas that is local-produced, locally-consumed, and carbon-neutral.

Acknowledgements This research project conducted by the MLIT (Ministry of Land, Infrastructure, Transport and Tourism) Japan.

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