2003 CDM/JI Project Study

Feasibility Study on Greenhouse Effect Reduction and Energy Exploitation Business Through Recovery of Methane (LFG) Discharged from Waste Disposal Site (Stung Mean Chey) in Phnom Penh

Report

Summary Edition

March 2004

Japan Waste Research Foundation

Introduction

In the Kyoto Protocol adopted in the Third Session of the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP3) held in December 1997, it was agreed that Japan would decrease the greenhouse gas emissions from 2008 through 2012 by 6% compared to 1990 levels. To attain this reduction goal, it is necessary not only to promote the global warming prevention measures in Japan but also to actively promote the international measures against global warming stipulated in the Protocol, such as the Clean Development Mechanism (CDM) that involves developed and developing countries and the Joint Implementation among developed countries.

The Global Environmental Centre Foundation entrusted Japan Waste Research Foundation with the Fiscal 2003 Global Warming Prevention Clean Development Mechanism Project Study (hereinafter referred to as the CDM/JI Project Study).

To carry out this study, Japan Waste Research Foundation established a study committee consisting of academic experts (with Masaru Tanaka, professor of the graduate school at Okayama University, as the chairperson) and received guidance and advice from the committee members at each of the phases from planning of the study to the preparation of the project design document (PDD). This study is for CDM through recovery of gas discharged at the waste disposal site in Phnom Penh, Cambodia

We are deeply grateful to the Cambodian Government, Ministry of Environment and Ministry of Public Works and Transport and the Phnom Penh Municipality's Department of Public Works and Transport and Department of Environment and all those who gave us assistance in the study.

March 2004

Daisaku Sugito
Chairman
Japan Waste Research Foundation

Organization for Study

1. Formation of Study Committee

To carry out this study for CDM through reduction of LFG at the waste disposal site in Cambodia, the Japan Waste Research Foundation formed a study committee (with Masaru Tanaka, professor of the graduate school at Okayama University, as the chairperson) to receive guidance and advice on the survey from the committee members.

List of Committee Members

Chairperson Dr. Masaru Tanaka, Professor, Graduate School of Natural Science and Technology, Okayama University

Members Dr. Yasushi Matsufuji, Professor, Fukuoka University

Mr. Ryo Hiraga, Director for Engineering Division, Institute for Environmental Management, Osaka

Mr. Junji Anai, Association of Solid Waste Consultants (observer)

Mr. Tatsuo Moroto, Deputy Director, Tokyo Research Center, JWRF, Japan Waste Research Foundation

2. Members of Study Team

List of Study Team Members

Leader: Mr. Toru Sanbongi, Executive Director, Japan Waste Research Foundation

Members: Mr. Tatsuo Moroto, Deputy Director, Tokyo Research Center, JWRF, Japan Waste Research Foundation

Mr. Teruaki Fujikawa, Deputy Director, Osaka Research Center, JWRF, Japan Waste Research Foundation

Mr. Shuji Kigawa, Senior Researcher, Osaka Research Center, JWRF, Japan Waste Research Foundation

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Contents

1 Outline of Study

1.1 Objective of Study

The clean development mechanism (CDM) is a scheme for reducing the greenhouse gas (hereinafter referred to as GHG) emissions between developed and developing countries. This report is about the feasibility study on a CDM project intended to reduce the methane gas discharged into the atmosphere at a waste disposal site in Cambodia, where no numerical target is set for GHG reduction.

1.2 Project under Study

The Stung Mean Chey disposal site (hereinafter referred to as the SMC disposal site) is the only disposal site in Phnom Penh, the capital of Cambodia (with a population of about 1.05 million and an area of about 290km^2 as of 2000). This disposal site has been in use since the 1960s and is currently receiving about 670 tons of municipal waste every day for disposal.

This disposal site, based on the open dumping system, is giving tremendous impacts on the surrounding environment such as fires, smokes, dusts, offensive odors, breeding of numerous flies and discharge of leachate, causing the citizens to make complaints about the poor environment of the disposal site to the authorities concerned.

The Cambodian government requested the Japanese government to provide cooperation in research as well as environmental improvement of the SMC disposal site and, in response to the request, the Japanese government carried out development study through the Japan International Cooperation Agency (JICA).

The JICA study team conducted an experiment on waste collection improvement, health education for residents and construction of a waste management database. The team also carried out a pilot project in which part of the current disposal site was reformed with landfill waste, covered with old landfill waste as cover soil and installed with gas vent pipes (5m deep) in the formed landfill layer (hereinafter referred to the pilot block). This pilot project was implemented to test switching the entire SMC disposal site from the open dumping system to the sanitary landfilling system.

This feasibility study (F/S) was made on the reduction and use and exploitation of landfill gas (hereinafter referred to as LFG) including methane gas discharged from the SMC disposal site.

1.3 Basic Viewpoints of Study

It would be common to examine the profitability of the project from the amount of discharged gases estimated based on the composition of waste, taking account of the decomposition rate (methanation rate) as well as LFG recovery rate assumed for the disposal site. In addition to these, the study examined the project profitability in an enhanced way by studying the LFG collection efficiency in the pilot block, examining measures for improvement, and building a monitoring system.

In terms of the use and exploitation of LFG, the study team verified the energy storage technologies using charcoal and other substances and examined the gas supply methods. In terms of system operation management, additionally, the study team provided, partly as technology transfer, the counterparts with guidance on measurement survey, monitoring methods and techniques for producing charcoal.

2 Outline of Host Country

2.1 Nature

Cambodia has a monsoon climate with rainy and dry seasons. In the rainy season from May to October, a southwestern monsoon blows from the Indian Ocean to land brings rain.

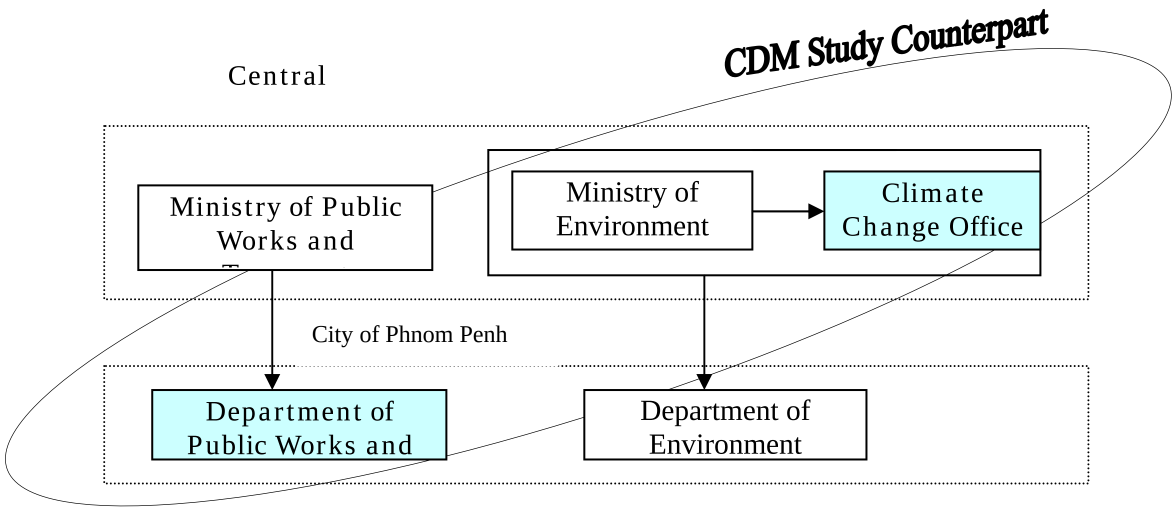
In the dry season from November to April, a dry northeastern monsoon blows. The central region has an annual rainfall of 1,200 to 1,900mm, 80% of which occurs in the rainy season.

2.2 Society and Economy

Cambodia, consisting of 24 provinces including four municipalities, has a population of 11,400,000 as of 1998 with an annual rate of population growth of 2.5% and with 85% of the total population living in the countryside. The country has a GDP growth rate of 4.5 to 6% for 2000-2002. While 12% of the GDP is foreign capital investment, more than half is provided as grant aid.

2.3 Organizations for Environmental Administration

In Cambodia, the central government and the city of Phnom Penh have administrative organizations in a hierarchical relationship. Under a ministry of the central government, there is a department with the same name, which belongs to Phnom Penh. The liaison for this study is the Climate Change Office under the Ministry of Environment and the actual counterpart is the Phnom Penh Municipality's Department of Public Works and Transport that manages the SMC disposal site.



3 CDM Project

3.1 Examination of Baseline Scenario

The SMC disposal site in the capital Phnom Penh, based on the open dumping system, has been in use since the 1960s and is currently receiving about 670 tons of municipal waste every day for disposal. Figure 3-1 shows the location of the disposal site.

(1) Baseline scenario

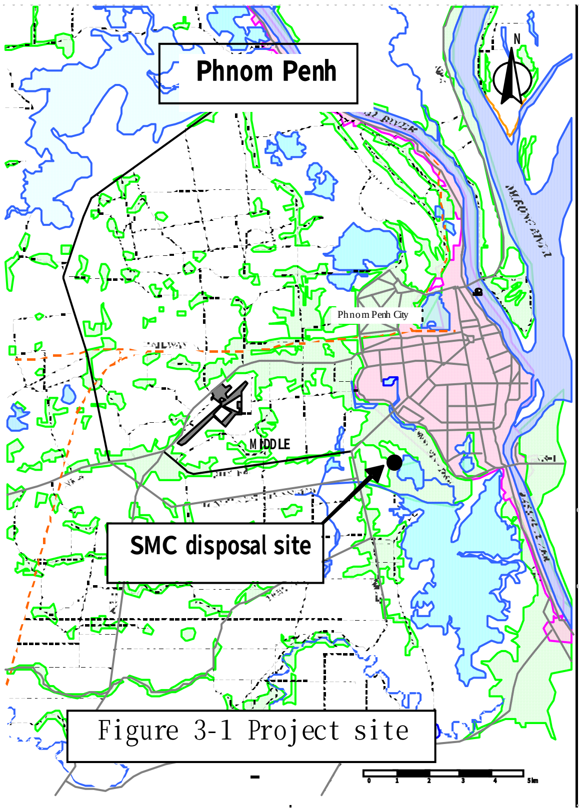


Figure 3-1 Project site

- The Master Plan Study on Solid Waste Management in the Municipality of Phnom Penh proposed by the JICA study team (proposed at the moment) recommends that the disposal site should be based on the sanitary landfilling system and should have gas vent pipes and cover soil but does not include the recovery of LFG.
- The Cambodian Ministry of Environment is not making any move to make the recovery of LFG obligatory in the waste management administration.
- The gas vent pipes installed in the pilot block of the JICA study emitted LFG with a methane gas concentration of 20 to 25% just after installation but around 25% at the end of February.
- It is difficult to use LFG with the current methane gas concentration as industrial energy. The commercialization of this gas is not probable except for carbon credit trading purposes. The LFG, if it will have a methane gas concentration of 45% or more in the future, might hopefully be used and exploited as, for example, energy for gas engines.
- According to the result of the demonstration test on site, LFG with a low methane gas concentration can be used as fuel for producing charcoal.
- Based on these circumstances, the following scenarios were created.

① Baseline scenario

- The assumption is that the amount of recovered methane is zero.

② Project scenario

- As a means of use and exploitation, methane gas recovered in the CDM project will be provided free of charge to the facilities producing charcoal through recycling of scrap wood such as coconut husks, if the local NGO desires so.
- If the gas will have a low methane concentration, it will be subject to flare gas combustion (destruction) to achieve global warming prevention effects.

(2) Project boundary

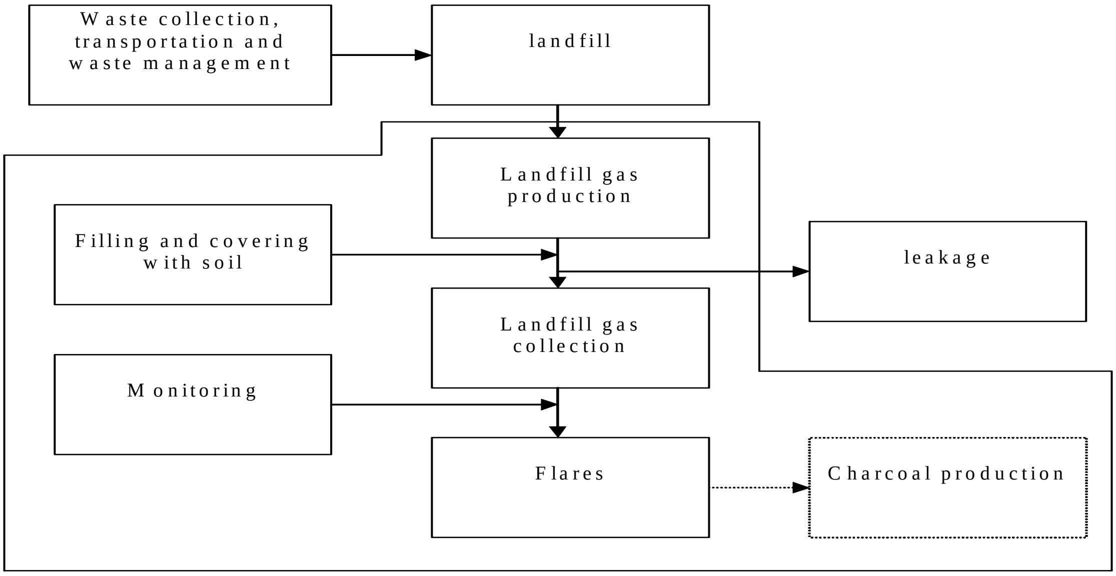


Figure 3-2 Summary of project boundary

Landfilling with waste is carried out regardless of the CDM project. The amount of GHG discharged due to the project, which corresponds mainly to the power consumption of ① vehicles and heavy equipment required for transport of cover soil and construction and ② monitoring equipment, is not considered because it is only a small quantity of carbon dioxide load that occurs temporarily. Part of the recovered gas is sometimes used for producing charcoal and other purposes, which are classified under the use and exploitation of LFG.

Although the difference between LFG generated in the landfill site and LFG actually recovered can be assumed as leakage in the definition of a project boundary, only the recovered LFG is subject to the study.

Figure 3-2 shows the summary of the project boundary.

3.2 Project Period

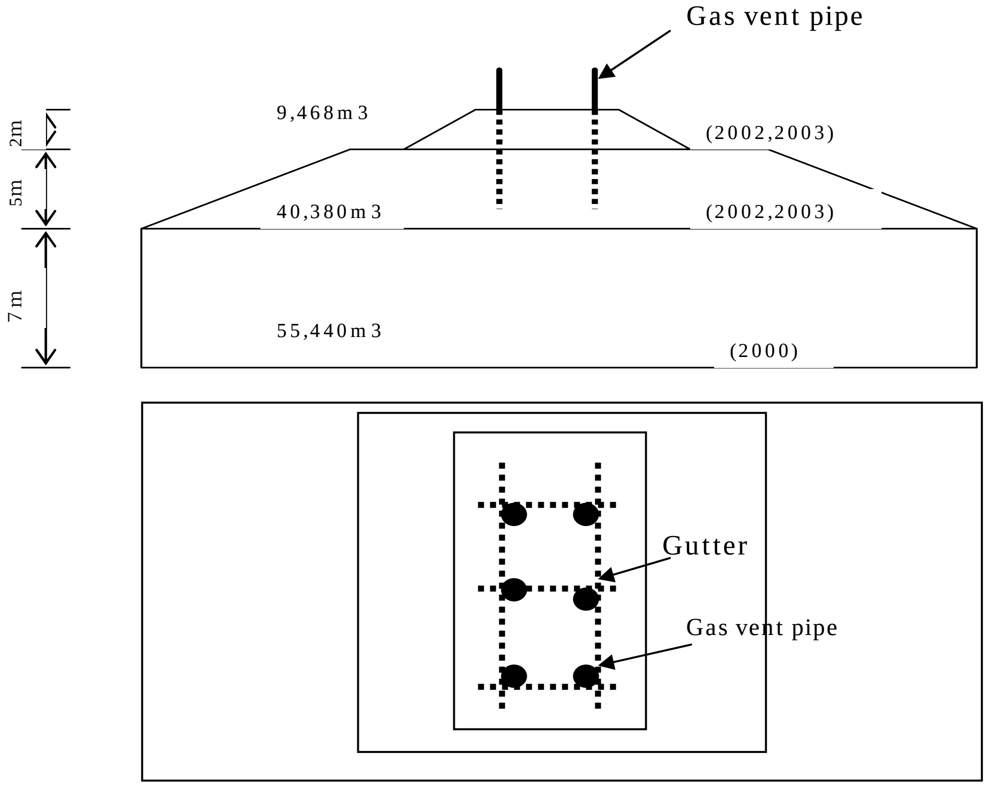
- The project period and the credit acquisition period shall be seven years, from 2005 to 2011.

3.3 Assumed GHG Reduction Amount

(1) Present conditions of project site

- Fires are breaking out because of spontaneous combustion of LFG discharged from the disposal site and because of people burning rubber tires to recover metals in them.

Since the carry-in of landfill is not managed at the SMC disposal site, the custodians of the disposal site were interviewed about the history, age and layer thickness of waste at the disposal site. An outline is shown in



- Figure 3-3.

Figure 3-3 Outline of amount and history of waste stacked in the pilot block

(2) Amount of methane generated in pilot block

In this study, the amount of methane generated in the pilot block was measured. The result was then applied to the estimation of the amount of gas to be generated in the CDM project.

1) Equation for deriving the amount of methane to be generated

There are various equations proposed for deriving the methane generated at the disposal site.

① Equation proposed by EPA of the U.S.A.

$Q = \Sigma\ 2 kL_0 M_i (e^{-kti})$

Where

L_0: Amount of methane gas generated from one ton of waste, which is assumed to be in the range from 6.2 to 270 m^3/Mg

k: Assumed to be in the range of 0.003 to 0.21 per year k is a value that depends on the moisture, pH, temperature and carbon content of the waste and can be determined only after long-term observation.

② Equation proposed by IPCC (used in this study)

CH_4=Land x MCF x DOCFrac x GasFrac x CH_4Frac x Conv-Recov

Where

CH_4	:Amount of methane discharged (Gg/y)
Land	:Annual amount of landfill (Gg/y)
MCF	:Methane correction factor
DOCFrac	:Organic carbon content
GasFrac	:Organic carbon gasification rate
CH_4Frac	:Methane content of LFG
Conv	:16/12(CH_4/C)
Recov	:Amount of methane recovered (＝0.0)

In this study, the equation proposed by IPCC was used to estimate the amount of gas to be generated because the JICA team surveyed the characteristics of wastes and the concentrations of methane in LFG were measured in this study.

The following shows the method of establishing each of the specifications required for the calculation.

2) Methane correction factor

The methane correction factor (MCF) is the amount of methane generated from a non-managed type disposal site with a landfill layer more than five meters deep, which is assumed as 80% of the amount of methane gas generated from the managed-type disposal site (while that from a managed-type disposal site is assumed as 100%). Although the CDM project will be based on the managed type, the factor for the non-managed type with a landfill layer more than five meters deep is used because, in consideration of the past records, waste will be disposed of in a non-managed type for the time being.

The methane correction factor is assumed to be 0.8 in consideration of the depth.

3) Organic carbon content

The organic carbon content (DOCFrac) is derived by breaking down the organic carbon content of waste carried in by waste types shown in Table 3-1, and then calculating it using the following equation:

$$\text{DOC Frac} = 0.40 \times A + 0.17 \times B + 0.15 \times C + 0.30 \times D \quad = \quad 0.15$$

Where A, B, C, and D represent the wet weight ratios of waste types.

Table 3-1 Organic carbon content (JICA Study Team)

Category	Composition (%)	DOC	Organic carbon content
A. Paper & Textile	0.09	0.40	0.04
C. Kitchen Waste	0.63	0.15	0.09
(B.＋D.)Grass & Wood	0.07	0.235	0.02
Total	0.79		0.15

Note: In the study report, the organic carbon content is: B+D＝(0.17+0.30)/2= 0.235

4) Organic carbon gasification rate

The organic carbon gasification rate (Gas Frac) is the amount of methane discharged each year, which was calculated by applying the following equations on the past landfill amount and the estimated landfill amount for the future and integrating the result by the elapsed time.

Equation proposed by Department of Engineering, Fukuoka University

$y = 0.76X - 0.02$ (0 to 3 years)

$y = 30.61 \log X - 6.91$ (4 years or more)

Where

y: Gasification rate (%)

X: Elapsed time , months (X>1)

Since this equation derives a cumulative amount, the factor for each year is as shown in the following table:

Table 3-2 Gas Frac (%)

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GasFrac	3.10	8.11	8.08	18.22	3.06	2.42	2.01	1.71	1.50	1.33	1.19	1.09	0.99	0.91	0.85

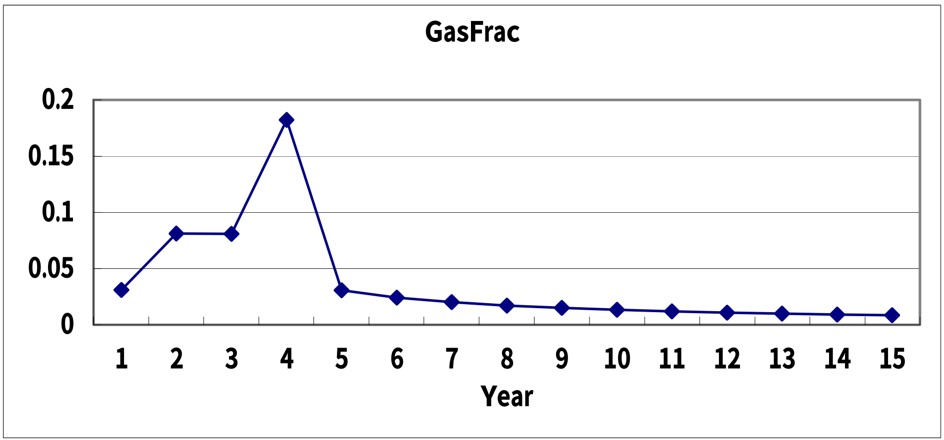


Figure 3-4 Organic carbon gasification rate

5) Methane content of LFG

The methane content of LFG (CH_4 Frac) is assumed to be 20% since the methane content of LFG measured in the pilot block was 20 to 25%.

6) Amount of methane discharged from the CDM project area

Based on the measurement values obtained in the pilot block, the amount of methane discharged from the CDM project area was calculated as follows:

CH_4 = {(9,468+40,380) / 2 x 0.031+(9,468+40,380) / 2 x 0.0811+55,440 x 0.1822} x 0.8 x 0.15 x 0.20 x (16 / 12)

= 394.76 tons per year

The daily amount (394.76 / 365) = 1,081.5 kg per day

As a result of study on the influence of fires due to spontaneous combustion and other causes, the fires were found to destroy only what can be regarded as the surface layer at the time of fires, leaving the deep layers of waste intact.

Thus, the amount of gas lost due to fires is assumed to be 10%. Although the destruction by fires including spontaneous combustion lowered the global warming factor by 1/21, they are assumed to cut the project scale by 10%.

Amount of methane gas that can be recovered (CH_4)

= 1,081 x (1-0.1) = 972 kg per day

(3) Methane recovery test in model block and recovery efficiency

Figure 3-5 shows the gas recovery facility location in the model experiment block. In the CDM project, a gas recovery system will be installed based on the result of this study.

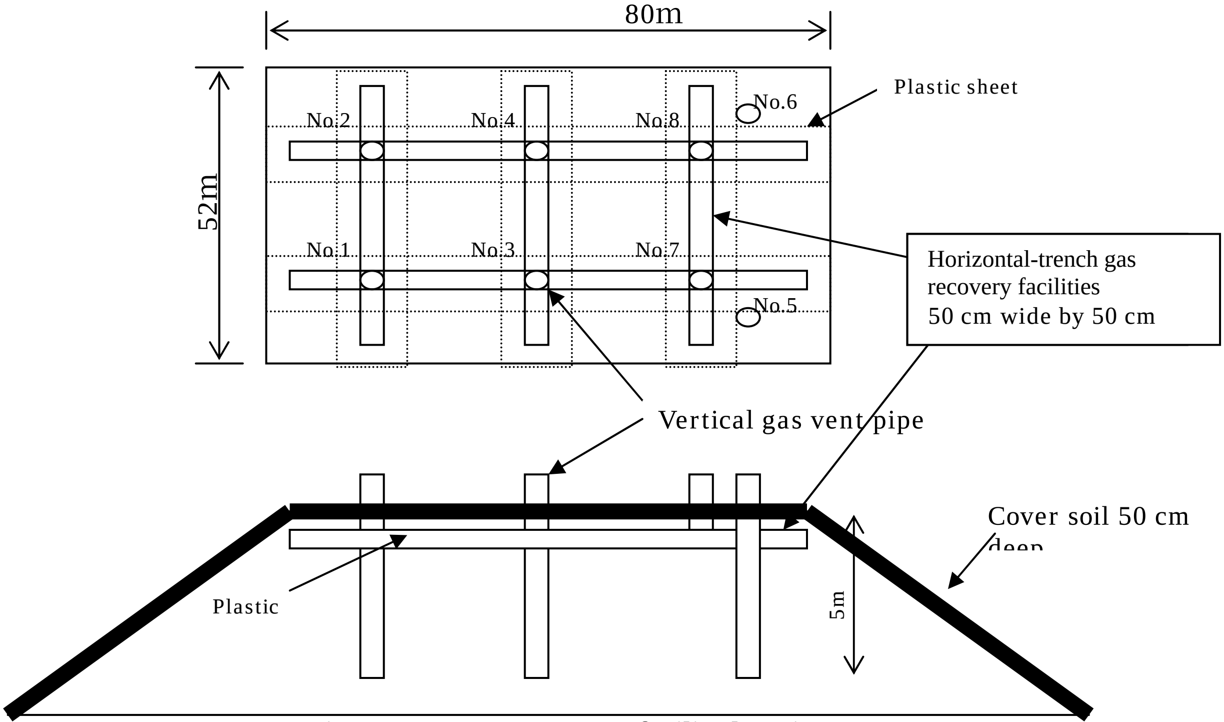


Figure 3-5 Gas recovery facility location

① LFG recovery device

- The vertical gas vent pipes Nos. 1 through 6 installed in the model block are 5 m deep (JICA study).
- The upper part of the horizontal trench were covered with plastic sheets and, above them, cover soil 50cm deep (installed in the CDM study). The pipes Nos. 7 and 8 were short pipes inserted only shallowly into the landfill layers in order to measure the amount of gas that can be collected only from the horizontal trenches (installed in the CDM study).

② Observation method

Temperature (℃) and humidity (%): Anemohygrometer

Velocity (m/s) ⇒ Flow rate: Anemohygrometer

Methane concentration (%), hydrogen sulfide concentration (ppm), carbon oxide concentration (ppm): Mobile detector

③ Measurement result

- The total average of methane gas concentration from the vertical gas vent pipes (installed by JICA down to the depth of 5m) was 20.6%. There was little change in the average values from late December to early February when observed in chronological order.
- The methane gas concentration of LFG from the horizontal-trench gas recovery system (installed in the CDM study) started to be measured in late January. The methane gas concentration was 21.5% in late January and 24.1% in early February.

④ Methane recovery efficiency

- Due to the delay in waste forming and cover soil operation by the JICA study team, pipes Nos. 5 through 8 could not be measured, resulting in a delay in the start of observation.

- Through the comparison of methane recovery efficiency values for pipes Nos. 5 and 6 and Nos. 7 and 8 in the second week of February, which somewhat lacks accuracy, those for the vertical gas vent pipes accounted for 60% to 70% of the total and those for the horizontal trenches dug in the surface accounted for around 30% to 40%.

Table 3-3 Contribution of vertical gas vent pipes and horizontal trenches to recovery

(unit: kg per day)

Pipe	Vertical gas vent pipe	Horizontal trench	Total
NO.5&7	295(71%)	119(29%)	414(100%)
NO.6&8	269(62%)	164(38%)	433(100%)

According to the result of observation started in late December, the amount of methane recovered at the experiment site was about 900 kg per day. Based on this result, the methane recovery efficiency can be calculated as follows:

Recovery efficiency: 900 / 972 x 100 = 92.6 %

(4) Amount of methane reduced

① Amount of methane gas discharged from the disposal site

There are many obscurities about the SMC disposal site, which has been in use for more than 30 years, because there remains little data from the past.

Based on the measurements taken and values predicted for the future by the JICA study team concerning waste amount and other items, this study applied the amount of methane gas and other items in LFG up to 1996 to calculate through extrapolation the amount of methane gas that can be generated, which is shown in Table 3-4.

Table 3-4 Predicted amount of methane gas to be generated in the CDM project period

(unit: tons per year)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1996	134	350	349	787	132	105	87	74	65	57	51	47	43	39	37	0
1997	0	146	381	380	857	144	114	95	80	71	63	56	51	47	43	40
1998	0	0	160	418	416	939	158	125	104	88	77	69	61	56	51	47
1999	0	0	0	174	454	452	1,020	171	136	113	96	84	74	67	61	55
2000	0	0	0	0	188	493	491	1,108	186	147	122	104	91	81	72	66
2001	0	0	0	0	0	205	537	535	1,207	203	160	133	113	99	88	79
2002	0	0	0	0	0	0	223	584	582	1,312	220	174	145	123	108	96
2003	0	0	0	0	0	0	0	242	633	631	1,423	239	189	157	134	117
2004	0	0	0	0	0	0	0	0	259	677	675	1,522	256	202	168	143
2005	0	0	0	0	0	0	0	0	0	279	729	727	1,638	275	218	181
2006	0	0	0	0	0	0	0	0	0	0	300	784	781	1,761	296	234
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total	134	496	890	1,759	2,048	2,338	2,630	2,933	3,251	3,577	3,617	3,154	2,662	1,146	979	824
*										3,577	7,194	10,348	13,010	14,156	15,135	15,959

*Cumulative amount

② Amount of gas destroyed due to spontaneous combustion and other causes

Since the amount of gas destroyed is assumed to be 10% of the amount of generated gas according to the study on the history of fires, the amount of methane that can be recovered in the project and the amount of greenhouse gas to be reduced through combustion including the use and exploitation of it, were calculated as a carbon dioxide equivalent:

- Cumulative amount of methane gas to be recovered:
  15,959 x (1-0.1) x 0.926 ＝ 13,300 tons (in the seven years from 2005 through 2011)
- Carbon dioxide gas equivalent: 13,300 x 21 ＝ 279,300 tons (CO2 eq)

③ Approximate cost of gas recovery

- Total investment amount: 958,000 dollars (see Table 3-5)
- Unit of greenhouse gas reduction cost: 958,000 / 279,300 = 3.43 dollars per ton (of CO2)

(5) Methane combustion experiment

① Combustion experiment of discharged gas

- Since the gas was directly ignited at the discharge opening of a vertical gas vent pipe, the flare was sometimes blown out by winds. Then, bricks were put at the discharge opening to successfully maintain 24-hour combustion.
- The automatic combustion system placed at pipe No.1 will function well as a flare system due to spontaneous eruption.

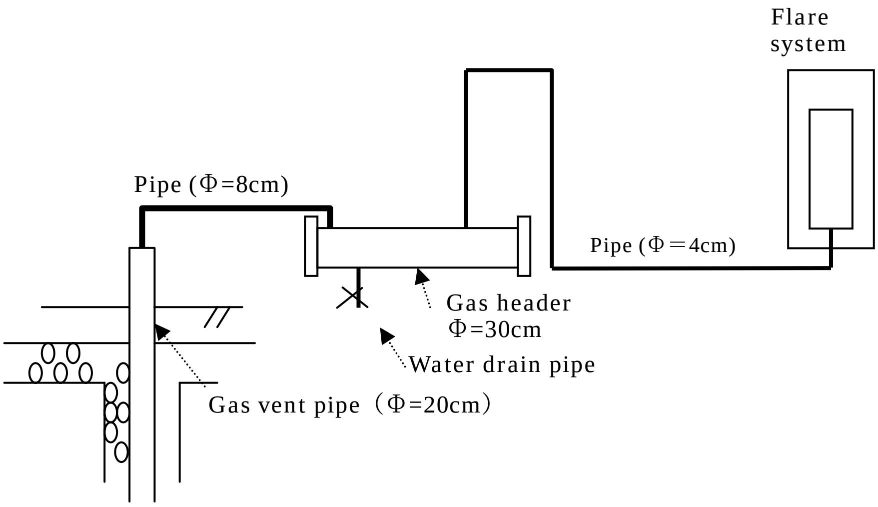


Figure 3-6 LFG combustion system

② Experiment of directly using discharged gas

- A charcoal production system was installed near Gas Well No.2 to produce charcoal with discharged gas.
- The system was a simple one consisting of a kerosene drum surrounded by bricks, and combustion equipment consisting of a simple pipe with its end bent, having no special combustion opening.

- The system reached 300℃ in an hour after the start of combustion and continued combustion at about 800℃ for 8 hours, successfully producing good charcoal.
- Although the process was conducted using only LFG as fuel, continued combustion was successfully maintained due to spontaneous eruption.
- The methane concentration of LFG was around 20% to 25%, which was good enough for use as fuel for producing charcoal.

Photo 1 Wood and bamboo charcoal produced

3.4 Estimated Project Cost

(1) Outline of specifications for project cost estimation

- Operation period of the disposal site: Will last until 2006, after which a new disposal site will be constructed.
- Waste forming and soil covering after landfilling is completed: Will be implemented for two years, 2005 and 2006.
- Monitoring units to be installed for observation: All will be purchased in 2005.
- Equipment maintenance cost: 5,000 dollars will be earmarked every year.
- Personnel cost: 10,000 dollars for five persons will be earmarked every year.

(2) Estimated project cost

Table 3-5 Estimated cost of CDM project (unit: dollars)

	2005	2006	2007	2008	2009	2010	2011	Total
Waste forming and soil covering	455,000	353,000	0	0	0	0	0	808,000
Installation of measuring equipment, etc.	45,000	0	0	0	0	0	0	45,000
Monitoring cost	5,000	5,000	5,000	5,000	5,000	5,000	5,000	35,000
Personnel cost	10,000	10,000	10,000	10,000	10,000	10,000	10,000	70,000
Total	515,000	368,000	15,000	15,000	15,000	15,000	15,000	958,000

3.5 Use and Exploitation of Energy by Nearby Residents

(1) Outline of result of study on energy usage status

1) Electric power

Twenty families were randomly chosen out of those living in houses near the SMC disposal site.

- How much is the unit cost of electricity charge that you are paying (riels per KWh)?

<Answer> 550: Three, 900: Two, 1000: Six, 1200: Six, 1700: Three

- Is the electricity charge appropriate?

<Answer> Inappropriate: 90%, Appropriate: 10%

2) Fuel demand from residents near the SMC disposal site

The following study was conducted to identify the fuel usage status at home.

① Study area and number of samples

- The area near the SMC disposal site was divided into four subareas, from each of which 10 to 15 families were chosen and interviewed.

A: Many store-cum-house buildings along the highways,

B: Many rag collectors along the access roads to the disposal site,

C: Old residential area,

D: New residential area (many stand-alone houses)

② Study contents

- Family attributes: House type, length of residence, family size, revenue
- Fuels: Uses of fuels, amount of fuel used, fuel cost

③ Study result

- Family size: About 5 to 8 members
- Revenue: Mostly U.S.$100 to 200. Less than U.S.$300 at the maximum in Group B. There are some families with U.S.$500 to 1,000 in Group D.
- Fuels: Propane gas was used by half of the families. Charcoal ranked second, accounting for 36%. Among others, firewood accounted for 14%.
- Families that use charcoal the most among all the fuels: Account for 36% of the total. Families that use charcoal the second most among all the fuels accounted for 52%. Charcoal was found to be used by 88% of the families.
- Amount of fuel used: Firewood ranked first, marking 130.9 kg/month/family. The runner-up was charcoal, marking 39.4 kg. As to gas, about one cylinder of propane (about 15 kg) was consumed per month.
- Fuel cost: Gas was the most expensive, standing at U.S.$5.6. Firewood was the cheapest, standing at U.S.$4.

(2) Examination of direct use of LFG at SMC disposal site

1) Power generation

LFG, having a low methane concentration of 20 to 25%, cannot be readily used as fuel for power generation.

2) Cylinder gas used by nearby families

According to the research made on the families near the SMC disposal site, gas users must purchase cylinder gas because the city has no gas supply system. One family uses about 15 kg of cylinder gas per month. From this data, LFG generated at the SMC disposal site can be exploited as family fuel as shown in the following table.

One cylinder containing 15 kg of gas costs 9 dollars at the market. Assuming that the construction of a facility for refilling cylinders costs 200,000 dollars and one cylinder is sold at 30% off the market price, a profit of 254,230 can be made according to the calculation:

72,100 cylinders x 9 dollars x (1 - 0.3) - 200,000 dollars = 254,230 dollars

However, LFG actually has a methane concentration of 20 to 25% and is equivalent to one-fifth of commercial cylinder gas when filled in the same cylinder. Thus, one household will consume five cylinders per month. Consequently, five times as many replacement cylinders will be required and they will need to be delivered and transported five times as often, increasing the cost of operation, maintenance, and management. Additionally, LFG constantly discharged from the SMC disposal site will need to be stored in a storage tank with five times as much capacity as for regular gas, which is not realistic.

In order to consider the feasibility of gas supply business, it is necessary to examine the trade-off relationship with the equipment cost for removing nitrogen and carbon dioxide from LFG (isolating methane gas). However, this CDM project is limited to a period of 7 years, after which there will be the problem of handover of facilities. Therefore, gas supply business will not be carried out.

Table 3-6 Estimated number of households if methane is used as cylinder gas

Year	Amount of generated methane gas (tons per year)	Amount of available methane (tons per month)	Number of households that can use methane (households)
2006	3,617	301	20,000
2007	3,154	262	17,400
2008	2,662	221	14,700
2009	1,146	95	6,300
2010	979	81	5,400
2011	824	68	4,500
2012	696	58	3,800
Total	13,077		72,100

3) Fuel for producing charcoal

It has been confirmed that burning 40 kg of wood in one metal drum at one time will produce about 10 kg of charcoal. One process will take about 10 hours, during which the following amount of methane gas will be consumed:

- Amount of LFG consumed: 0.87 x 0.04 x 0.04 x 3.14 x 60 x 60 x 10 = 157.35 m3
- Amount of methane gas (CH_4) consumed: 157.35 x 0.25 x 16 / 22.4 = 28 kg
- Premises of calculation: Flow rate of 0.87m per sec, hose radius of 0.04m, required time of 10 hours,
- Methane concentration of LFG: 25%
- Methane molecular weight: 16g
- Volume of methane per mol: 22.4L

Since one round of charcoal production takes 10 hours, the amount of methane available per day was derived and the amount of charcoal that can be produced was calculated.

Assuming this operation can be conducted for 240 days per year, 306.2 tons of charcoal can be produced in seven years. The charcoal, which usually sells at about $0.1015 per kilogram, will bring in $31,080 in sales.

① Producing charcoal from wood

Charcoal made from wood will not turn a profit because firewood, the charcoal material in this case, costs about $0.0321 per kilogram and will be reduced to about one-fourth of the original weight when burned into charcoal.

(Unit price of charcoal) - (Unit price of firewood x 4) = 0.1015 - 0.0321 x 4 = -0.0269

② Producing charcoal from waste

Charcoal was produced from coconut husks and sugar cane sheath and bagasse carried into the disposal site. It was found that the resulting charcoal, not easy to use as it is, can be used as new fuel when powdered, mixed with cassava starch, clay powder, pine resin, and water, compressed, and dried. The business of producing charcoal from waste is currently under examination by the Phnom Penh Municipality's Department of Public Works and Transport.

Table 3-7 Estimation of charcoal production business using organic unused waste (coconut husks, bagasse, etc.) as raw materials

Year	Amount of generated methane gas (tons per year)	Amount of available methane (kilograms per day)	Amount of charcoal that can be produced (kilograms per day)	Charcoal production (kilograms per year)	Sales total (dollars)
2006	3,617	9,909	353	84,720	8,599
2007	3,154	8,641	308	73,920	7,502
2008	2,662	7,293	260	62,400	6,333
2009	1,146	3,139	112	26,880	2,728
2010	979	2,682	95	22,800	2,314
2011	824	2,257	80	19,200	1,948
2012	696	1,906	68	16,320	1,656
Total	13,077			306,240	31,080

3.6 Financial Analysis

Without the CDM project, there will be only the project cost and no revenue. Therefore, no project will be feasible unless carbon credits are considered.

The FIRR for the cases where one ton of CO_2 is worth 3, 4, and 5 dollars is obtained in the following table. The inflation rates and interest rates are not considered. If CERs are traded at $4 per ton of CO_2, the FIRR will be 3.4%. If they are traded at $5, the FIRR will be 26.4%.

Table 3-8 FIRR

Case	FIRR
1: 3 dollars / CO_2 eq ton	-15.2%
2: 4 dollars / CO_2 eq ton	3.4%
3: 5 dollars / CO_2 eq ton	26.4%

Table 3-9 Estimated project cost and estimated revenue due to CER

Year		2005	2006	2007	2008	2009	2010	2011	Total
Waste forming and soil covering		455,000	353,000	0	0	0	0	0	808,000
Measuring equipment and monitoring facility		95,000	72,000	5,000	5,000	5,000	5,000	5,000	192,000
Personnel cost		10,000	10,000	10,000	10,000	10,000	10,000	10,000	70,000
Total		560,000	435,000	15,000	15,000	15,000	15,000	15,000	1,077,000
Revenue	CH_4（t）	3,577	3,617	3,154	2,662	1,146	979	824	15,959
	CO_2eq（t）	75,117	75,957	66,234	55,902	24,066	20,559	17,304	335,139
	Capture(t)	62,603	63,303	55,199	46,589	20,057	17,134	14,421	279,305
	3 dollars/t	187,808	189,908	165,598	139,766	60,170	51,402	43,263	837,915
	4 dollars/t	250,410	253,210	220,798	186,355	80,226	68,535	57,685	1,117,219
	5 dollars/t	313,013	316,513	275,997	232,944	100,283	85,669	72,106	1,396,524

Capture (t) = (Amount of generated methane) x (Amount of methane reduced due to fires) x (Recovery efficiency)
＝CO_2eq x（1-0.1）x 0.926

4 Environmental Impacts and Contribution to Environmental Improvement

The implementation of the CDM project is expected to produce the following effects:

- The SMC disposal site will be subject to soil covering and methane recovery starting in 2005.
- This operation will improve the landscape by preventing fires, smokes, scattered dusts and waste, stopping offensive odors and breeding of flies and mosquitoes.
- This operation will alleviate the health damages of nearby residents and decrease fatal accidents to waste pickers, etc.
- While the penetration of a small amount of rainwater will be necessary for methane fermentation, the cover soil will decrease the amount of rainwater penetrating into the landfill layers, reducing the outflow of leachate.
- The implementation of the CDM project will contribute to significant environmental improvement and there is no possibility that it will give rise to new environmental problems.

5 Comments from Interested Parties

5.1 Climate Change Office, Department of Planning and Legal Affairs, Ministry of Environment

- According to Declaration No.195 signed by the Minister of Environment on June 23, 2003, the Climate Change Office was established under the Department of Planning and Legal Affairs, Ministry of Environment to serve also as the local agency of UNFCCC.
- Outline of functions: The Office establishes plans and policies, works for UNFCCC, assesses new technologies to discover whether they give adverse influences on climate change or reduce greenhouse gases, builds the national capacity, and carries out educational campaigns.
- The Cambodian government signed the UNFCCC on December 18, 1995. A committee was formed in 1996 and the Prime Minister signed the Kyoto Protocol on July 4, 2002, which took effect on August 22, 2002.
- In 1999, the Climate Change Enabling Activities Project (CCEAP) supported by UNDP and Global Environment Facility (GEF) was initiated to take an inventory of greenhouse gases from 1994 and make predictions and reduction plans for 1994 through 2020.

5.2 Expectations on CDM Project

- The government of Cambodia, an agricultural developing country, is keenly aware that global warming has significant impact on the environment, society, and economy of the country. The Climate Change Office, having a positive attitude toward the promotion of CDM, has an acute interest in projects and investing activities from other countries and, in particular, strongly desires that this project be implemented after this Feasibility Study is completed.
- The Phnom Penh Municipality's Department of Public Works and Transport (DPWT) and Phnom Penh Waste Management Authority (PPWM) has high expectations on the realization of the CDM project through recovery of methane generated at the disposal site.

- One of the reasons why the Cambodian side takes such a positive attitude is that, if this CDM project is implemented, soil covering and gas vent pipe installation can be carried out with the fund earned through credit trading and thus Phnom Penh City need not take budgetary steps for them when the disposal site is closed in 2006.
- The nearby residents, having witnessed that the soil covering and gas vent pipe installation in the model block greatly improved the environment of the disposal site, have high expectations on the implementation of the CDM project.
- Soil covering may cause the waste pickers to lose their means of living. However, soil covering shall be conducted in a way that does not prevent the waste pickers from collecting valuables but ensures their waste collecting activities according to the sanitary landfilling plan made by the JICA study team, to which the waste pickers have given their consent.

6 Capacity Building

- In Cambodia, the host country, the city of Phnom Penh has the "Department of Environment (DOE)" as the subordinate organization of the Ministry of Environment (MOE) as well as DPWT as the subordinate organization of the Ministry of Public Works and Transport (MPWT).
- In this CDM study, the counterpart is DPWT that manages the site, not the "Phnom Penh Municipality's Department of Environment (DOE)."
- The director is Mr. Nhem Saran while Mr. Moeung Sophan, deputy manager of the project management section, actually serves at the liaison. Both of these persons are well aware of the advantages that the CDM project will bring to Phnom Penh and thus continues to take positive attitudes.
- The maintenance and monitoring of the gas vent pipes installed in the JICA pilot project is under the charge of the following DPWT personnel:

  Mr. KHEM Sandap Mr. TED Sambath
- The on-site observation was made by the above-mentioned persons until the end of February 2004 to carry out continued study.

7 Possible Contributions to Sustainable Development of Host Country and Region

- If the CDM project is implemented, the host country will enjoy a number of benefits. The improvement of the environment of the disposal site will greatly contribute to the sustainable development of the metropolitan area.

8 Possibility of Dissemination to Similar Facilities

- The technologies for providing cover soil and installing gas vent pipes at the disposal site to recover methane are not so sophisticated. Cambodia has a sufficiently high level of technology to conduct this project.
- Generally, this project is highly likely to disseminate to other developing countries. However, it is necessary to consider how to solve such problems as the cost burden of soil cover materials, procurement, maintenance and theft prevention of analyzers

and measuring instruments and education of personnel.

- Cambodia has 23 provinces. According to the result of survey conducted in this feasibility study, only less than 300 tons of waste is disposed of every day in all the waste disposal sites throughout the country except the one in the capital, Phnom Penh. Even in the Siem Reap region with the maximum disposal amount, only 57 tons of waste is disposed of every day. Therefore, it can only be concluded that there is only a low possibility of dissemination to similar facilities in Cambodia.
- For other Southeast Asian countries, there is a good possibility of dissemination as long as they have similar geographical, natural and socio-economical conditions.