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EVALUATION OF GREENHOUSE GAS EMISSIONS FROM LANDFILLS IN THE ST. PETERSBURG AREA – UTILIZATION OF METHANE IN ENERGY PRODUCTION, METGAS

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Evaluation of Greenhouse Gas Emissions from Landfills in the St. Petersburg Area – Utilization of Methane in Energy Production, METGAS

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Abstract

Solid wastes disposed to landfills generate methane, which is a potent greenhouse gas. All the greenhouse gases together can cause serious changes in the climate all over the world in the future. The present work studies the current situation of waste management in St. Petersburg, and evaluates methane formation in the landfills of the St. Petersburg region. On the basis of the methane formation calculated with mathematical models, the possibilities of landfill gas collection and utilization projects can be evaluated more realistically than earlier. The economy of landfill gas collection and utilization projects is evaluated in the perspective of Kyoto mechanisms in addition of conventional energy use.

The waste management system in St. Petersburg is based mainly on waste disposing to landfills. Annually over 1 million tons of solid municipal waste is generated in St. Petersburg, from which over 70 % is directly landfilled. A great majority of the wastes end up in a few very big landfills.

For the two biggest landfills of St. Petersburg the methane formation was calculated with the so called FOD-model. Even though the results show that the generated amount of methane is very significant, it is not economically viable to utilize landfill gas only for energy production in Russia. Especially natural gas is much more inexpensive and easier fuel to use than landfill gas. In case the emission reductions generated through the landfill gas projects can be utilized via the Kyoto mechanisms, the viability of landfill gas projects improves significantly. According to the results of this study, it seems that the biggest profit of the landfill gas projects at the main landfills of St. Petersburg can be achieved by acquiring and transferring emission allowances, and the produced energy is only a positive byproduct.

Tiivistelmä

Kaatopaikoilla syntyvä metaani on voimakas kasvihuonekaasu, joka osaltaan aiheuttaa ilmastonmuutosta ja jonka vaikutukset saattavat tulevaisuudessa olla hyvin vakavat. Tässä tutkimuksessa selvitettiin Pietarin alueen jätehuollon nykytilaa ja sen perusteella arvioitiin Pietarin alueen kaatopaikoilla syntyvän metaanin määrää. Tutkimuksessa on arvioitu laskennallisia malleja käyttäen alueella muodostuva metaanin määrä, jonka perusteella voidaan kaatopaikkakaasun keräily- ja hyödyntämishankkeiden toteuttamismahdollisuuksia arvioida aiempaa realistisemmin. Lisäksi hankkeiden taloudellisuutta on arvioitu perinteisen energianäkökulman lisäksi myös Kioton joustomekanismien tuomien mahdollisuuksien kautta.

Pietarin jätehuolto perustuu pääasiassa jätteen kaatopaikkasijoitukseen. Yhdyskuntajätettä alueella syntyy vuosittain yli miljoona tonnia, josta yli 70 % ohjautuu suoraan kaatopaikoille. Valtaosa jätteestä päätyy muutamalle hyvin suurelle kaatopaikalle.

Kahden suurimman pääkaatopaikan metaaninmuodostus arvioitiin käyttäen ns. FOD-menetelmää. Vaikka tulokset osoittavat, että syntyvä metaanimäärä on hyvin merkittävä, ei sen kannattavuus energiatuotantoa ajatellen ole järkevää Venäjän olosuhteissa. Varsinkin maakaasu peittoaa kaatopaikkakaasun niin hinnassa kuin käytettävyydessäkin. Mikäli kaatopaikkakaasun hyödyntämishankkeen tuloksena syntyviä päästövähenemiä voidaan hyödyntää Kioton joustomekanismien kautta, muuttuu tilanne olennaisesti. Näyttäisikin siltä, että Pietarin suurimmilta kaatopaikoilta saatavissa oleva taloudellinen hyöty tulisi pääasiassa tuotettujen päästövähennysten kauppaamisen kautta, ja metaanilla tuotettu energia olisi vain positiivinen sivutuote.

Foreword

The present study was carried out in the Northern Dimension Research Centre (NORDI), at Lappeenranta University of Technology (LUT) in 2004. The Northern Dimension Research Centre is a research institute run by LUT. NORDI was established in the spring 2003 in order to co-ordinate research dealing with Russia.

NORDI's mission is to conduct research dealing with Russia and issues related to Russia's relations with the EU, with the aim of providing up-to-date information on different fields of technology and economics. NORDI's core research areas are Russian business and economy, energy and environment, the forest cluster, the ICT sector, as well as logistics and transport infrastructure. The most outstanding characteristic of NORDI's research activities is the way in which it integrates technology and economics.

The increasing interest toward waste management in St. Petersburg, the lack of knowledge of landfill gas generation in the area and the effects of the Kyoto protocol in the field of methane utilization motivated this study.

The supervisor of this study has been Dr. Mika Horttanainen from Lappeenranta University of Technology, to whom I wish to give my special thanks. I would also like to express my gratitude to Dr. Alexander Voronov, who carried out a literature search on Russian studies concerning waste management of St. Petersburg and produced valuable information for this study.

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Lappeenranta, December 2004

Sami Lappalainen

Contents

List of acronyms

CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
$CO_{2\text{-ekv.}}$	Carbon Dioxide Equivalent
DOC	Degradable Organic Carbon
FOD	First Order Decay Model
ER	Emission Reduction
ERU	Emission Reduction Unit
ET	Emission Trading
JI	Joint Implementation
LFG	Landfill Gas
MSW	Municipal Solid Waste
SHW	Solid Household Waste
SIW	Solid Industrial Waste
SWL	Solid Waste Landfill
SWM	Solid Waste Management
VOC	Volatile Organic Compounds
WTO	World Trade Organization
WTP	Waste Treatment Plant

Annex 1	The industrialized countries and economies in transition listed in Annex 1 of the UNFCCC
Annex B	The emissions-capped industrialized countries and economies in transition listed in Annex B of the Kyoto Protocol

1 Introduction

1.1 Background

The latest predictions on climate change estimate that the temperature of the earth has increased by 0.6 °C in hundred years (IPCC 2001). According to the Intergovernmental Panel on Climate Change (IPCC 2000b), the temperature will elevate continuously, and in 50-100 years the increase will reach 5-6 degrees Celsius. This high elevation in earth temperature will mean serious changes in climate all over the world. Signs of changes are currently seen in the amounts of rainwater, thunder, and tropical storms.

It is strongly believed by researchers and scientists that the main reason for temperature increase are anthropogenic green house gas emissions. The principal green house gas is carbon dioxide, CO_2, which is formed in combustion of fossil fuels such as coal, oil, natural gas and peat. Another important source of green house gases is the dumping of waste. Aerobic decomposition of organic wastes produces CO_2 emission, whereas anaerobic decomposition produces methane, CH_4, and nitrous oxide, N_2O, emissions. Methane again is known to be an about 21 times stronger green house gas than CO_2.

In Russia the municipal solid waste (MSW) management is based mainly on land filling. The rough estimate is that around 97% of all wastes are dumped to landfills. The city of St. Petersburg alone produces almost 6 million cubic meters of household and industrial wastes in a year (Florinskaya et al. 2002). Nearly 75% of household wastes are land filled and only a minor amount goes to privately owned waste treatment plants near the city, where the different fractions of the wastes are separated (metals, plastics, organics etc) and recycled. Near St. Petersburg there are three large landfill areas, namely Novoselky, Samarka and Volkhonka. In addition of these three landfills, several smaller and unofficial landfill areas are used. The current status of Novoselky, Samarka and Volkhonka landfills is quite unknown since studies of these landfills are not available. It is predictable, though, that the negative impacts to the surrounding environment are remarkable, i.e. emissions to soil and ground water as well to air.

1.2 Objectives

The aim of this study was to estimate the methane emissions of the main landfills of St. Petersburg by mathematical modelling, on site measurements and literature. The purpose was to evaluate the methane production capacity of the landfills in case the methane would be collected and used for energy production in a local power plant. The landfill gas measurements were done by Finnish Bioenergy Ltd at one landfill.

The greenhouse gas emissions of the landfills can be reduced radically, and at the same time harmful CH_4 -emissions can be converted to heat and/or electricity by collecting the useable methane. Because the CO_2 gas ton is priced, it is possible to calculate the value for green house gas reduction and offer it for sale. The investments can be at least partly covered by selling the reduced CO_2 emissions to companies needing emission permits.

The overall condition of the landfills is reported. The object of the study is to provide updated facts to Finnish companies with potential business opportunities in the field of landfill gas utilisation (landfill gas collecting pipelines, pumping stations, flare burners, gas engines, heat recovery boilers, generators, systems engineering).

2 Waste management system in Russia, especially in St. Petersburg

2.1 General overview of the waste management system in Russia

Today the Russian Federation is recovering slowly from the 1998 economic crisis. This large country has a declining population, and a large proportion of the people live in poverty. The annual production of household waste per capita in Russia is approximately two times less than in western countries. However, in urban areas (especially in big cities), enormous amounts of residues are being produced as 78 percent of Russians live in cities (USAID).

Today in Russia the municipal solid waste (MSW) management is based mainly on land filling. The volume of MSW produced annually in the late 1990s accounted for 37.5 million tons or 120 million m^3 of which approximately 97 percent were disposed of by land filling, as shown in Table 1. The rest were re-used, composted or incinerated. It is difficult to give very precise figures, however, because the exact number of landfills and the volume of produced wastes in Russia are unknown due to the not very comprehensive statistics and the existence of thousands of unofficial landfill areas. Also reliable and updated information about the current status of MSW land filling in Russia is not sufficient. (Kalyuzhnyi 2003)

Table 1 presents the waste flows and the waste fractions of St. Petersburg, Moscow and Finland in addition to the whole Russia. However, these numbers are not directly comparable due to the different measuring methods and waste separation systems. In Finland, for instance, waste statistics are based on mass measurements, while in Russia they are based on volume measurements.

Today, waste management in Russia, like in other countries, is undergoing remarkable changes due to federal and provincial programs of MSW management accepted in the 1990s. There is a well-seen trend in Russia to close old poorly managed dumping places and open large modern landfills having an appropriate insulation and increased reutilization of MSW. As a result, the number of operating landfills is decreasing (e.g. by 50 % in the Moscow province during the last 5 years). (Kalyuzhnyi 2002)

Table 1. Production, composition, treatment and disposal methods for MSW in Russia and in Finland.

Parameters	Russia			Finland
	In general	**Moscow**	**St. Petersburg**	
Source of information	Cherp and Vinichenko (1996)		Florinskaya et al. (2002)	Statistics Finland (2001)
Total annual production, [M tons]	37.5	2.5-3	1.06	2.5
Annual production per capita, [kg]	252	300	232	488
MSW composition, [%]				
Paper and cardboard	20-36	37.7	15.6	40
Glass	5-7	3.7	13.7	5
Metal	2-3	3.8	4.6	5
Plastics	3-5	5.2	11.3	10
Textile	3-6	5.4	3.8	2
Rubber and leather	1.5-2.5	0.5	1.0	No data
Wood	1-4	1.9	0.8	No data
Food residues	20-38	30.6	34.9	33
Other	10-35.5	11.2	14.3	5
Treatment methods, [%]				
Reuse	1.3	No data	No data	33
Incineration	2.2	No data	No data	3
Landfilling	96.5	>95	>70	64

The quantities of landfill gas generation are quite unknown in Russia. However, Nozhevnikova and Lebedev (1995) have estimated that methane emissions from landfills in Russia are between 700 and 1300 Mm^3 or 500 and 900 kilo tons.

2.2 Waste generation in St. Petersburg

St. Petersburg is the largest city around the Baltic Sea and the second largest in Russia. The number of inhabitants in St Petersburg is over 4.6 million. It is also a major industrial center, where more than 55 plants produce 5 % of the industrial output in Russia. The St. Petersburg region has been identified as the most extensive source of pollution around the Baltic Sea. Environmental loading in the huge city conditions has become extremely high. One of the biggest problems in St. Petersburg is the vast generation of solid wastes.

The dynamics of waste generation rate has to be known in order to develop waste management strategies, as well as for modeling landfill gas emissions in the future, like in this study. However, as mentioned above, the statistics of generated waste amounts are not very comprehensive and updated information is not readily available. In the following, the estimation of the generated waste amounts in St. Petersburg between 1994 and 2000 is based on the data available from the Department of Natural Resources of the Northwest Region that has been published in the report "CONCEPTION: Waste management in St. Petersburg" (Florinskaya et al. 2002).

In recent years the population of St. Petersburg has been decreasing, which naturally influences the amount of formed waste. However, the amount of municipal solid waste (MSW) formed in the city has increased substantially from the beginning of the nineties. From 1994 to 2000 the amount of MSW increased by 20 %, even though the population of St. Petersburg decreased by 2.9 % within the same period, see chart A1 in Appendix 1. In 2000 the annually collected volume of municipal solid waste was about 5.3 million m^3, of which 25 % was generated by small business, including trade, and 75 % by households. (Florinskaya et al. 2002)

The specific amount of the formed waste (cubic meters per citizen) increased as well, being 1.25 in 2001 (Florinskaya et al. 2002). The dependencies of the specific amount of the formed waste for the same period are presented in graph A2 of Appendix 1, which shows considerable increase in the waste formation.

In the report "Protection of the environment, use of natural resources and maintenance of environmental safety in St. Petersburg", published in 1998 – 2001, the generated waste amount for the year 2005 is predicted to correspond to the amount of 5.7 million m^3 and for 2010 to 6 million m^3 per year (Florinskaya et al. 2002).

2.3 Waste management system in St. Petersburg

The solid waste management is a major problem for the city of St. Petersburg. Especially, storage and unsatisfactory treatment of all waste categories cause problems. At the moment, the waste management is based mainly on land filling in St. Petersburg, as in whole Russia. In St. Petersburg the generated wastes are divided to four classes of danger (excluding radioactive wastes), as well as to non-toxic ones. The most toxic wastes are categorised as the 1st and 2nd classes of danger and the wastes that are less toxic are categorised as the 3rd and 4th classes of danger.

More than 70 % of annually produced household and industrial wastes amounting to 5-6 million cubic meters are landfilled in three main landfills. However, in St Petersburg there exist two Waste Treatment Plants (WTP) in addition to the main official landfills. Both these WTPs are drum-composting units that process wastes of 3rd and 4th classes of danger. The operation of the WTPs is described in paragraph 2.3.2 below, but the current condition of the landfills of St. Petersburg is discussed in chapter 3.

2.3.1 Waste flows

The basic municipal solid waste flow system of St. Petersburg is shown in figure 1. The waste amounts presented in the figure are expressed first in volumetric units, because the measurement of waste amounts is based on determination of volume in Russia. In converting volumetric units to mass units 200 kg/m^3 density for wastes has been used.

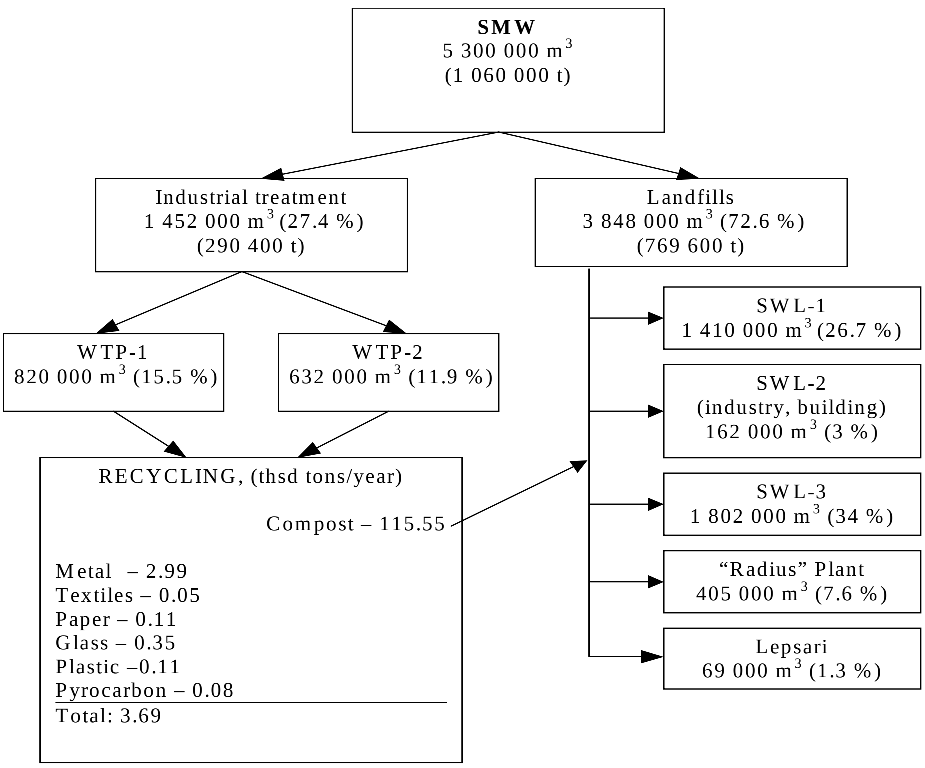

Figure 1. The scheme of MSW material balance in St. Petersburg (Florinskaya et al. 2002).

Of the total waste amount generated in St. Petersburg over 70 % is disposed to landfills. Together all the landfilled wastes amount to 3.8 million m^3 or 0.77 million tons. In addition, almost all the material composted in the waste treatment plants must be landfilled due to its inferior quality.

2.3.2 Waste treatment

Two so-called “mechanical waste processing plants” operate in the region of St. Petersburg. These plants compost solid wastes originating mainly in households and industry. Both these waste treatment lines contain at least a metal separation and rotating drum-composting unit.

The older waste treatment plant (WTP-1) begun its operation in the town of Gorelovo outside St. Petersburg in 1970. The factory located in a 50.1 ha area in the region of Volhov highway. The annual capacity of WTP-1 is about 0.9 million m^3 or 180,000 tons. This treatment plant contains manual separation for recyclable materials before the drum composting.

The second processing plant (WTP-2) was opened in 1994. WTP-2 is located in the town of Yanino and it’s area is 17 ha. The maximum processing capacity of the plant is about 0.5 million m^3 or 120,000 tons. This treatment plant contains only separation of magnetic metals before the drum composting.

The total annual capacity of these two plants is about 1.5 million m^3 (0.3 M tons), meaning that about 30 % of the wastes of St. Petersburg are processed at these composting plants. However, almost all the composted material must be landfilled, because the quality of the compost is too foul for reutilization.

The problems of insufficient waste treatment are recognized by city authorities and the Russian Federation's environmental control agencies. The St. Petersburg Environmental Administration has developed its priorities for the period 1996 - 2005, to solve the problems of waste treatment, including: solid domestic wastes, industrial wastes, sewage sludge and toxic wastes (Kamayeva 1998). According to The St. Petersburg Times (27.2.2004) WTP-2 in the town of Yanino will be refurbished by 2005. The plant will increase its capacity from 120,000 tons to 180,000 tons of waste processed annually.

2.4 Overview of Russian legislation for waste management

Russia inherited an environmental regulatory system from the former Soviet Union, where wastes were considered only as a possible secondary resource and hardly as a pollutant of the environment. Since Russia is now a federative state, the waste management system is jointly governed by federal and provincial authorities. The legal environmental framework includes laws and codes, presidential decrees and orders, Government decrees, and orders at federal and regional levels.

The development of environmental legislation was started in the beginning of the nineties and since then new laws have progressively replaced those of the former USSR. However, the necessary appropriate changes in the environmental legislation will require quite a long time.

The first remarkable reform took place in 1991 when "*The Federal Law on Environmental Protection*" was accepted. This basic document mandates the central government's overall responsibility for environmental protection. It provides the framework for environmental protection and management in Russia and regulates only the main directions of state policy in the field of waste handling. This law gives a basis for the development of specialised legislation in the area.

The Law on Environmental Protection was modified in 2002 and at the present form it determines:

- that polluting activities are strictly prohibited
- that assessment of the environmental impact caused by new projects and existing facilities is required
- that state environmental monitoring should be organised
- that the government can demand financial contributions from those causing damage to the environment
- inspection procedures to ensure compliance with the law
- procedures for dealing with environmental accidents. (Chekalin 2004)

The next basic act accepted in 1998 is "*The Federal Law on Waste in Production and Consumption*". This framework legislation stipulates the main principles of state policy in the field of solid waste management, like:

- delegation of authority for waste management at federal, regional and local levels
- environmental requirements for waste management activities and facilities
- accounting and reporting requirements
- economic regulation (including insurance requirements)
- authority for compensation and penalties. (COWI 2000)

A significant aspect of the Federal Law on Waste is that it establishes the concept of property rights for wastes for the first time in Russia. This was necessary in order to establish legal responsibilities for the treatment of present and past waste. The Law defines that the property rights for waste belong to the persons or entities whose activity resulted in the production of such waste. Under the Waste Law special licenses are necessary to deal with any type of waste and to transfer waste property rights. (COWI 2000)

Also the federal act *"On Sanitary and Epidemiological Well-being of the Population"* (1999) is associated with waste management. Its 22nd article stipulates sanitary and epidemiological requirements to collecting, using, transporting, storing, and landfilling of waste products of manufacture and consumption.

The sharing of power between federal, regional and local self-governing institutions is regulated by *Waste Law*. The Ministry of Natural Resources of the Russian Federation is a specially authorised federal executive body (Decree of Government N726 from 25.09.00) for state regulation of waste management, organisation and realisation of ecological control, development of normative basis and coordination with other federal institutions in this area (Nefediev et al. 2001).

Besides national legislation, the waste management in Russia is also adjusted by norms of international laws, in particular the Convention signed in Basel in 1989 and ratified in Russia in 1994.

The Basel Convention is a global agreement, ratified by several member countries and the European Union, for addressing the problems and challenges posed by hazardous waste. The Secretariat in Geneva, Switzerland, facilitates the implementation of the Convention and related agreements. It also provides assistance and guidelines on legal and technical issues, gathers statistical data, and conducts training on the proper management of hazardous waste. The Secretariat is administered by the UNEP. The key objectives of the Basel Convention are:

- to minimize the generation of hazardous wastes in terms of quantity and hazardousness
- to dispose of them as close to the source of generation as possible
- to reduce the movement of hazardous wastes. (Basel 2004)

The SWOT-analysis presented in table 2 illustrates the state of waste management legislation in Russia at the moment.

Table 2. SWOT-analysis of the legislation base of SWM in Russia (Chekalin 2004).

Strengths	**Weaknesses**
• Lately a lot of new laws in ecology and waste management have been created and approved at a federal, regional and local levels • A separate direction of laws on solid waste management has been allocated.	• The legislation base is not stable • The laws do not always meet the requirements of EU directives • The population and the organizations are poorly informed on the presence of laws and instructions and on their performance • In laws there are no concrete definitions of approaches to the manipulation of different kinds of waste products at different stages: collecting, transportation, processing, landfilling, etc. • The laws do not always correspond to a current situation and the principles of the complex approach to SWM • The laws are incomplete; they contain some overlapping responsibilities and inconsistencies.
Opportunities	**Threats**
• Russia is at the beginning of the process of establishing a legislation base for SWM and modern complicate base which will meet all the requirements • Russia can use the experience of the development of EU legislation on SMW.	• Difficult procedure of elaboration and approval of laws • Poor mechanism of implementation of approved laws.

3 Current condition of the main landfill areas of the City of St Petersburg

As mentioned above, of the total waste generated in St. Petersburg, over 3.8 million m^3 (~770,000 t) is annually disposed to landfills. These landfills are located both in St. Petersburg and in the Leningrad oblast regions. It is estimated that in the Leningrad region there exist 124 authorised landfills, 93 unauthorized landfills and 17 special dumpsites (Prioda). Relatively reliable information is available only from official landfills. In the following, the four main official landfills of St. Petersburg are described.

SWL-1:

The landfill "Southern" (SWL-1) located by the Volkhonka motor road in the territory of Leningrad at the border of St. Petersburg has been in operation since 1978. The depth of the landfill today is about 29 m. In the beginning of 2001 the area of the landfill was 34.5 hectares and it contained 29.3 million cubic meters waste, while the design capacity is 20.99 million cubic meters. The volume of waste deposited on the landfill has exceeded the design limits. Clearly the operation of the landfill will soon be finished. Today the design of rehabilitation of this landfill has been developed. Extension of the landfill area is problematic, as the adjacent territories belong to another constituent entity of the Russian Federation. In 2000 the landfill accepted 1,786,000 m^3 of municipal waste.

SWL-2:

The "Northern Samarka" (SWL-2) is the second largest landfill, occupying an area of 60 hectares. It is located in the Vsevolozhsky district of the Leningrad region, about 20 km from the border of St. Petersburg administrative area. The size of the landfill is about 60 hectares and it has been in use since 1974. This landfill is intended for construction and industrial wastes of the 3^{rd}-4^{th} classes of danger. The design capacity of the landfill is 31.04 million cubic meters. In 2001 the landfill contained 9.2 million cubic meters of waste and in 2000 it accepted 52,000 cubic meters of construction and industrial wastes.

SWL-3:

The largest landfill, called Novoselky (SWL-3), is located in the territory of the Vyborgsky district of St. Petersburg. It is about 2 kilometers away from the settlement of Novoselky. The size of the landfill that has been used since 1972 is about 84 hectares and it is intended for household wastes and wastes of industrial production. In 2001 the landfill contained 35.6

million cubic meters of waste and in 2000 it accepted 1802,000 cubic meters of waste. The maximal depth of the waste layer is 12 m. Also this landfill has exceeded the design limits of the maximal waste capacity.

Krasny Bor:

Krasny Bor is a special-purpose dumpsite for regional hazardous waste disposal located at the territory of Tosno in St. Petersburg. It was set up in 1969 as a test disposal facility with the design life of five years. However, it has been processing and depositing toxic industrial wastes for over 30 years, using mainly outdated technology. Since 1992 some improvements have been made, but there is an urgent need for a new plant. The area of the Krasniy Bor landfill is about 75 hectares. The territory of the landfill is fully used, which is regarded as a potential threat to the environment and to the water supply of St. Petersburg. The site of the ground was chosen due to the presence of unique Cambrian clay deposits having high water resistance in this region.

The most important numerical data of the main landfills described above is gathered in table 3 below.

Table 3. The main landfills of St. Petersburg.

	Volkhonka SWL-1	**Samarka** SWL-2	**Novoselky** SWL-3	**Krasniy Bor**
Waste type	MSW	SIW + Constr.	SHW + Constr.	Hazard. waste
Opened	1978	1974	1972	1969
Volume, [Mm^3]	29.3	9.2	35.6	-
Area, [ha]	34.5	60	84	75
Depth, [m]	29	-	12	-

MSW = Municipal Solid Waste, SIW = Solid Industrial Waste, SHW = Solid Household Waste

Besides the landfills described above, there are four other dumping areas in St. Petersburg that are already out of operation (Kupchinskaya, Primorskaya, Ugolnaya and Yablonevkaya). They occupy 270 ha and contain 17 million m^3 of waste. (Florinskaya et al. 2002)

4 Mathematical modeling of LFG generation in St. Petersburg

When planning and LFG utilization system, estimates of methane generation are necessary to quantify the design goals of the gas collection system, to assess the need of capital, and, in the case of LFG-to-energy projects, to determine potential revenues. This chapter presents firstly two different methods for estimating the methane generation rate and secondly estimations for methane generation at the biggest main landfills of St. Petersburg.

4.1 Two methods to estimate methane formation at landfills

There exist several models that describe methane formation in waste. Two commonly used methods for estimating the methane generation rate in landfills are the mass-balance method and the first order decay model (FOD). The mass-balance method is applicable for a rough approximation of landfill gas production, while the FOD model is more precise by taking the time component into account, which increases the accuracy of the results.

The mass-balance method is a very simple model that will provide only rough methane flow estimates that may be 50 percent higher or lower than the actual methane flows. Therefore, it should be used primarily as a screening tool to determine if a more detailed assessment is warranted. The general equation for the mass-balance method is described in Appendix 2. In order to model with this method, only the following variables have to be known:

- the average annual waste acceptance rate
- the rate of methane generation from the waste.

The First Order Decay (FOD) model is more complicated than the mass balance method described above. According to the IPCC (Intergovernmental Panel on Climate Change) it is good practice to use the FOD model, if possible, because it more accurately reflects the emissions trend (IPCC 2000a). The FOD model allows for the degradation processes that occur over time. The general equation for the FOD model is also described in Appendix 2. The use of this model requires that the following variables are known or can be estimated:

- the average annual waste acceptance rate
- the number of years the landfill has been open
- the number of years the landfill has been closed, if applicable
- the potential of the waste to generate methane
- the rate of methane generation from the waste.

For more information about the models see the source reference: IPCC 2000a.

4.2 Modelling of methane formation generally in St. Petersburg and in the biggest main landfills

In this paragraph firstly the methane production potential of all wastes landfilled in St. Petersburg and secondly the methane formation in the biggest main landfills of the same area are estimated.

In St. Petersburg about 770,000 tons of municipal solid waste is annually landfilled, as presented in paragraph 2.3.1. By knowing the waste flow to landfills and assuming some variables, the methane formation can be roughly modelled in order to get a general picture of gas generation. For this purpose the mass-balance method is more convenient than the FOD model. The calculations of modelling are described in the Appendix 3.

According to the massbalance-based model the annual methane formation in the landfills of St. Petersburg seems to be roughly about 40,000 tons, but here it must be noted that the actual methane formation may be 50 % more or less than the calculated formation rate, as mentioned above.

Next, the methane formation in the two biggest landfills of St. Petersburg is estimated. These landfills are SWL-1 (Volkhonka) and SWL-3 (Novoselky). SWL-2 (Northern Samarka) is also very a large landfill, but being intended mainly for construction and industrial waste the methane generation is not so remarkable there. For this reason the methane formation in SWL-2 is not modelled. For SWL-1 and SWL-3 there is required information available to use FOD model. The calculations and initial data used in modelling are described in the Appendix 3.

The methane formation is modelled in two cases for both of the landfills mentioned above. These landfills have exceeded the design limits of their maximal waste capacity. In the first case (Case I) it is assumed that the waste dumping to landfills will end in 2005 and in the other case (Case II) it is assumed that the waste dumping will continue until 2010. In the modelling factor $t_{½}$ is used, which describes the time needed for the degradable organic carbon in the waste to decay to half of its initial mass. Because this factor is not accurately known, the methane formation has been modeled for three different $t_{½}$ values (5, 10 and 15 years). The most likely value for $t_{½}$ is from 10 to 15 years. The most important results of the modelling are gathered to table 4 in which the estimated methane formation during years 2005 and 2010 is presented. In each case presented in the table one of the value pairs represents the result for $t_{½}$ = 5 years and the other $t_{½}$ = 10 years. More precise results can be found in the charts of the Appendix 4.

Table 4. Estimated methane formation in SWL-1 and -3 using the FOD model.

CH_4 formation in		2005	2010 (Case I)	2010 (Case II)
SWL-1	CH_4	11,200-13,700 t	8,900-9,700 t	12,700-15,100 t
	($CO_{2\text{-ekv.}}$)	(0.24-0.35 Mt_{CO2})	(0.18 Mt)	(0.27-0.37 Mt)
SWL-3	CH_4	12,400-15,000 t	9,800-10,600 t	14,200-16,700 t
	($CO_{2\text{-ekv.}}$)	(0.21-0.34 Mt)	(0.19-0.20 Mt)	(0.30-0.41 Mt)

Case I = waste dumping to landfill will end in 2005, Case II = waste dumping to landfill will end in 2010

The results reveal that methane formation in both landfills is very significant. Energy point of view the methane flows described above are equal to 16 – 27 MWs of fuel power.

However, it must be noted here that there may exist some uncertainty in the prediction of the initial data used in the modeling, for instance in: waste amounts at the landfills, composition of wastes and some other factors related to waste decomposition in the landfills. For individual landfills the statistics of accepted waste amounts are not very comprehensive. One reason for this is that the accepted waste amounts are based on measurement of volume, which is not as accurate as measurement of mass. The general composition of the wastes generated in St. Petersburg can also differ from the composition of wastes actually disposed to an individual landfill. The prediction of the decomposition rate of the wastes may cause uncertainty especially at dumpsites filled with the area method that are commonly used in Russia.

The economical significance of the generated methane flow is evaluated in chapter 8.

5 Utilisation of landfill gases in energy production

The waste material stored in landfill generates various harmful gas emissions that can be reduced by gas collecting systems. By using active gas collection most of the landfill gas can be extracted and either flared to control the emissions of methane and VOCs or used in energy production, which can also reduce pollutant emissions into air by replacing fossil fuels. There are several technical opportunities for landfill gas utilization in energy production, as seen in figure 2. Other advantages of the gas collection in addition to energy production or emission reductions are for example decreased fire danger and odor nuisance in landfills. In the following chapters active gas collection, the energy content of landfill gas and methods of energy utilization are discussed further.

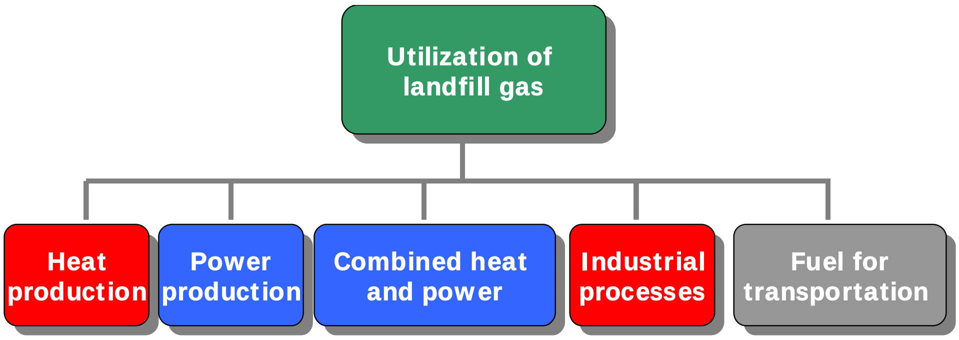

Figure 2. Technical opportunities for using methane in energy production.

5.1 Active collection of landfill gases

Typical landfill gas collection systems have three central components: collection wells, a condensate collection with a treatment system and a blower. In addition, most landfills with energy recovery systems will have a flare for the combustion of excess gas and for use during equipment down times. Gas collection typically begins after a portion of a landfill (called a cell) is closed. There are two collection system configurations: vertical wells and horizontal trenches. Vertical wells are by far the most common type of well used for gas collection. Trenches may be appropriate for deeper landfills, and are commonly used in areas of active filling. However, both types of wells can be used in active landfills. Active landfill gas collection requires creating a partial vacuum, which induces a pressure gradient toward the extraction well. Each wellhead is connected to lateral piping, which transports the gas to a main collection header. From the blower the gas is led either to flaring or to energy production. Often the gas has to be also treated before energy use.

Minimal processing of LFG involves condensate removal chambers as part of the LFG collection system and reduction of the amount of moisture in the gas stream. Additional gas treatment devices are used to extract more moisture and contaminants. The process typically involves compression and refrigeration of LFG and/or chemical treatment or scrubbing to remove additional moisture and trace gas compounds such as mercaptans, sulfur compounds, siloxanes, and volatile organic compounds. Utilization of LFG as a high-grade fuel involves extensive gas pretreatment to separate the carbon dioxide and other major constituent gases from the methane in addition to removal of impurities. (Conestoga-Rovers & Associates 2004)

The efficiency of methane recovery naturally depends on starting time of gas extraction. Often the active gas recovery begins only after landfill closure, when great deal of methane has already released into air. However, gas recovery is becoming more common during the active period of landfill. The total amount of recovered methane for a covered landfill sites with active gas recovery can be up to 90 % of the total methane production (Conestoga-Rovers & Associates 2004).

5.2 Energy content of landfill gases

The volume of the gases released during anaerobic decomposition of one ton of municipal solid waste is between 200 – 400 Nm^3 totally or 5 – 10 Nm^3 in a year (Helynen et al. 1999). The typical percentage distribution of gases found in a MSW landfill is seen in table 5.

Table 5. Typical properties of landfill gases.

	Unit	Landfill gas	Natural gas
CH_4	vol %	40 – 65	> 98
CO_2	vol %	30 – 50	-
C_2H_6	vol %	-	< 1
N_2	vol %	0 – 10	< 1
O_2	vol %	0 – 2	< 0,5
Heating value	MJ/Nm^3	15 – 23	35,6

The energy content of landfill gas depends on the concentration of methane, the heating value of which is about 36 MJ/Nm^3. It means that two cubic meters of landfill gas have about the same energy content as one liter of oil. Figure 3 illustrates the net heating value of landfill gas in proportion to methane concentration.

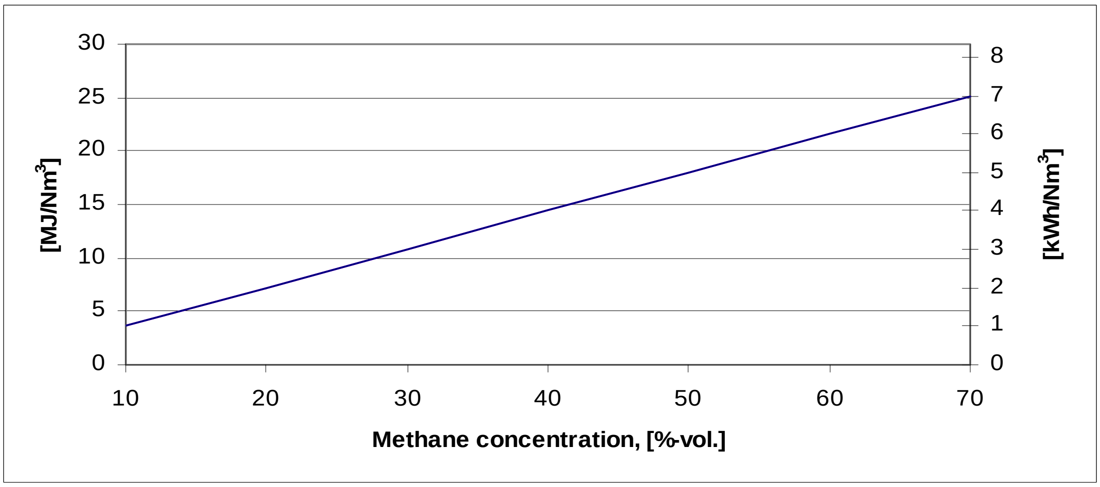

Figure 3. Net heating value of landfill gas depending on methane concentration.

5.3 LFG utilisation in a local power plant

One of the most common uses of landfill gas takes place in gas furnaces, in which the gas is used for heating water in a boiler system. The size of an LFG fed boiler is generally relatively small due to the low gas generation rate. A boiler/steam turbine configuration fuelled only with LFG is applicable mainly in very large landfill gas projects, where the gas flows support systems of nearly 10 MW. However, the small boiler plants that already exist near landfill sites are an interesting option for retrofitting the boiler to use LFG. The average boiler conversion can cost as a few as several thousand dollars for minor adjustments on small boilers to tens of thousands for more elaborate retrofits on larger units (EPA 2001).

The most typical boiler technology suitable for retrofitting is the natural gas or oil fuelled package boiler used in a variety of commercial and industrial applications. The two most common types of package boilers are water wall boilers and fire tube boilers. These boilers have been demonstrated to operate successfully on LFG (EPA 2001). Minor equipment modifications are needed to adapt a boiler to use LFG. Changes that have to be taken into consideration are caused by the greater gas flow, higher corrosivity, and lower flame temperature associated with LFG. Table 6 presents some solutions for these problems. In addition boiler conversion, LFG transportation from the landfill to the burner often requires construction of a long pipeline. The feasible piping distance depends on the flow rate of LFG, being typically less than 2-3 km. This is often a problem because landfills are often situated rather far from settlements or industry. The advantages and disadvantages of retrofitted boilers are listed in table 7.

Table 6. Challenges and solutions when retrofitting a boiler to use LFG (EPA 2001).

Challenges in LFG conversions	Solutions
Greater volume of gas flow	Use larger orifices on fuel control valves.
Flame stability	Equip ultraviolet sensors with redundant scanners.
	Employ dual fuel burners.
Lower flame temperature	Increase superheater size (heat exchanger surface area).
Corrosion	Insulate preheater and flue stack.
	Preheat combustion air with steam coils. Ensure that the water circulation meets the manufacturer's specifications
Deposits	Remove deposit during routine maintenance

Table 7. Advantages and disadvantages of a boiler converted to use LFG.

Advantages	Disadvantages
▪ Low costs of retrofitting ▪ Substitutes fossil fuels directly ▪ Dual fuel capability. The boiler can operate also using one of the fuels ▪ Can handle gas composition and flow variation changes ▪ Capable of combusting low-methane-content LFG (< 30 %) using dual fuel ▪ Corrosion resistant	▪ Long pipeline for LFG transporting often needed ▪ Inefficient electricity production at smaller sizes

5.4 LFG utilisation in a micro turbine

Microturbines are an emerging landfill gas energy recovery technology option and they may play an important role in future landfill gas project development, if the technical and economical questions facing them can be overcome. Mircoturbines are recently commercialized distributed generation technology that produces usually less than 1 MW electrical power. Microturbines are generally best suited to relatively small applications and are designed to produce electricity for onsite energy needs and for end users in close proximity to the generation site.

An individual microturbine unit size is typically between 25 – 250 kW, but microturbines have the ability to group these units into larger sets. They can also be used at landfills where the gas output is too low for larger engines and conventional turbines.

Microturbine technology is based on the design of much larger combustion turbines employed in the electric power and aviation industries. They differ from traditional combustion turbines in that they spin at much faster speeds. The electrical efficiency of a microturbine plant is relatively low (~15-25%) because of its small size. In order to achieve better electrical efficiency despite low peak temperatures, a heat exchanger (recuperator) is usually used for preheating the combustion air with the help of hot turbine exhaust gas, as seen in figure 4. Another heat exchanger is used for obtaining process heat in combined heat and power (CHP) applications. If the first heat exchanger can be switched off the released process heat can be increased at the expense of electrical efficiency if required. This enables a very good adjustment to variable heat requirements.

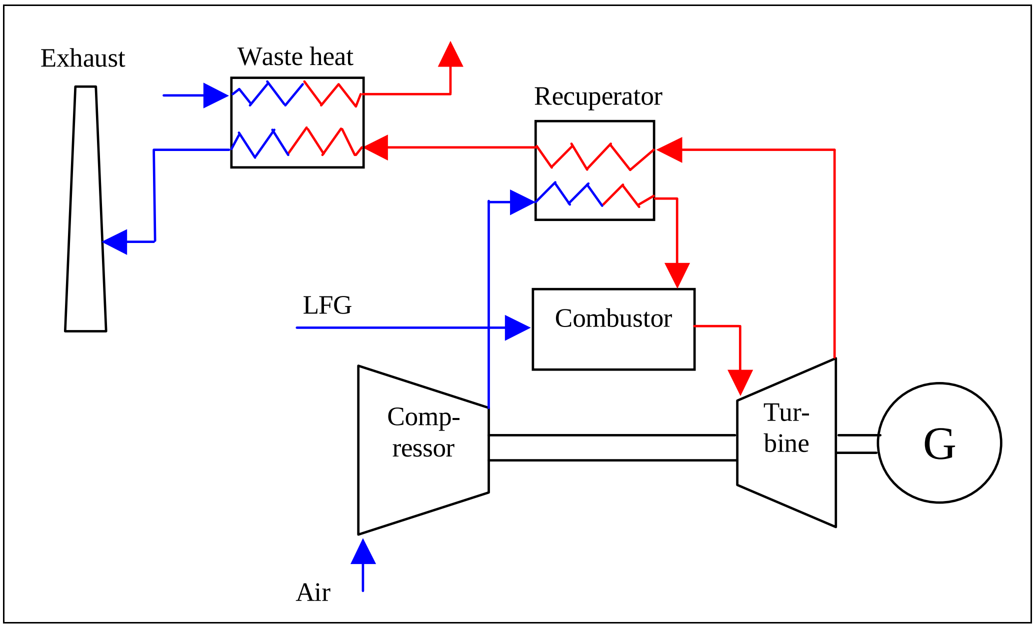

Figure 4. General schematic of the CHP microturbine process.

The microturbine plants need to be equipped with a fuel pretreatment system that removes moisture and in some cases also siloxanes before LFG enters the turbines. Combusting LFG containing siloxanes produces a fine silica powder that can form harmful deposits on interior machine surfaces and may erode the microturbine components.

The investment costs for a complete CHP microturbine plant ranges from 1000 to 1700 €/kW$_{el}$ for plants from 25 to 250 kW$_{el}$ in size (Vartiainen et al. 2002).

Landfill gas mircroturbines offer the advantages and include the disadvantages shown in table 8 when compared to other types of LFG utilization technologies.

Table 8. Advantages and disadvantages of a microturbine.

Advantages	Disadvantages
▪ Compact design ▪ Low maintenance costs at maintenance intervals of at least 8000 hours of operation. Few moving parts. Corrosion resistant. ▪ Easy installation; Because of compact design and low plant weight it is possible to have a small plant area ▪ Capable of combusting low-methane-content LFG (30 – 35 %) ▪ Low pollutant emissions ▪ Quiet because there are no low frequency noise emissions	▪ Full market maturity of the technology is not yet achieved ▪ Low efficiency ▪ Microturbines are sensitive to siloxane contamination ▪ No long-period operating information available

5.5 LFG utilisation in a reciprocating internal combustion engine

Reciprocating internal combustion engines are a widespread and well-known technology. Combustion engines are available for power generation applications in sizes ranging from a few kilowatts to over 5 MW. There are two basic types of combustion engines: spark ignition (Otto-cycle engine) and compression ignition (Diesel engine). The essential mechanical components of the Otto-cycle and Diesel-cycle are the same. In landfill gas utilization systems both types of engines can be used.

Gas engines have higher electrical efficiencies than gas turbines of comparable size. The electric efficiencies of gas engines range from 30 % for small stoichiometric engines (<100 kW) to over 40 % for large lean burn engines (> 3 MW). The waste heat recovered from the hot engine exhaust and from the engine cooling systems produces either hot water or low pressure steam for CHP applications in which the overall efficiencies range from 70 to 80 %.

The capital costs of gas engine installations are generally lower than gas turbine installations up to 3-5 MW in size, but gas engine maintenance costs are higher than comparable gas turbines.

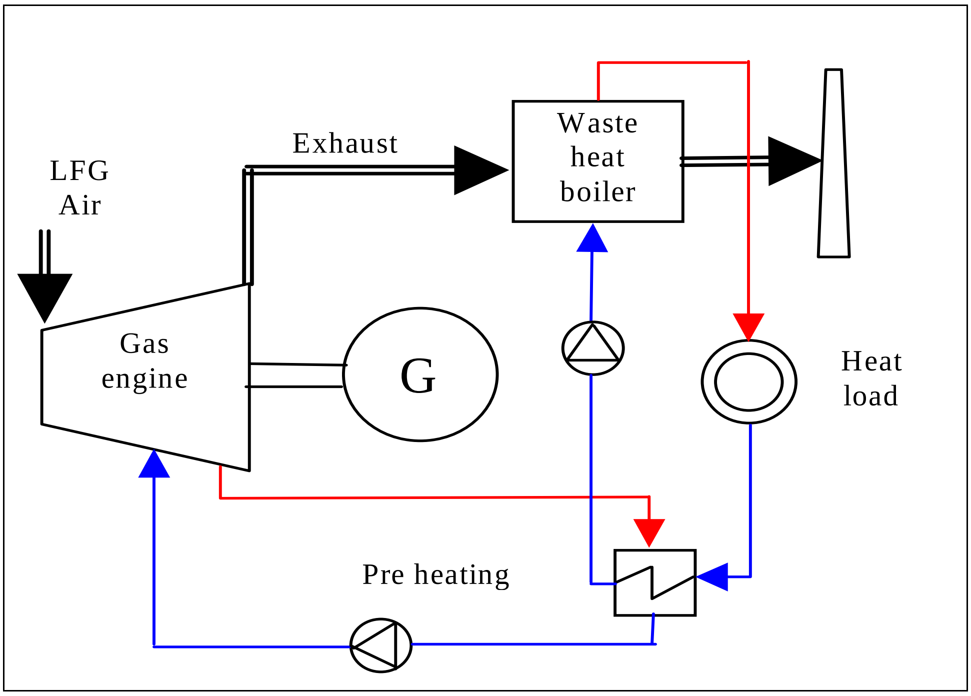

Figure 5. General schematic of the CHP gas engine process.

The investment costs for a complete CHP gas engine plant range from 450 to 1400 €/kW$_{el}$ for up to 10 MW$_{el}$ plants (Vartiainen et al. 2002).

Table 9 shows the advantages and disadvantages of landfill gas-fed reciprocating internal combustion engines when compared to other types of LFG utilization technologies.

Table 9. Advantages and disadvantages of a gas engine.

Advantages	Disadvantages
▪ Proven reliability when properly maintained ▪ Low first costs ▪ Excellent load-following characteristics ▪ Good electric efficiencies ▪ Easy installation	▪ Gas engines are sensitive to siloxane contamination ▪ The methane content of the LFG has to be more than 38 % ▪ Corrosion of engine parts and catalyst ▪ Pollutant emissions

6 Landfill gas measurements and results of measurements and gas analysis

On one of the landfills near the city of St. Petersburg the generated landfill gas composition was measured in order to evaluate the methane formation. In this chapter a short description of the landfill, the gas measurement methods and the results of the measurements are given. At first it must be noted that this landfill was not an optimal target for LFG measurement due to its small size and short municipal waste acceptance history, but in the present study it was not possible to choose other landfills.

6.1 Description of Morosova landfill

The landfill gas measurements presented in this report were done in the privately owned landfill in Morosova, which is a small settlement about 35 km east from the centre of St. Petersburg and 1.5 km from the Neva river and Ladoga lake. The landfill is owned by a local waste management company called ”OOO Rostehnokomplekc”, which collects industrial and household wastes from the district of Morosova. It must be noted that this landfill does not receive wastes from the urban centre of St. Petersburg due to its remote location. Hence, it cannot be assumed that this landfill represents an average landfill in the St. Petersburg region. However, Morosova landfill is a typical small-scale landfill, dozens of which exist in the city area.

The Morosova landfill was based on an old gravel pit in 1954. Until 1998 it received only industrial waste but after that year both industrial and household wastes have been accepted. Today about half of the wastes originate from industrial sources and another half comes from local households. The area of the landfill is about 4.5 hectares and the average depth of the waste layer is about 5 meters, while the maximal permitted depth is 6 meters at the moment. According to the owner of the landfill the altitude of the old quarry floor is 11.5 meters above sea level and today the top of the waste layer reach to 17 meters above sea level. On the basis of these dimensions it can be roughly estimated that Morosova landfill contains about 225000 cubic meters of wastes.

In the Morosova landfill the solid wastes are spread layer by layer to the whole area of the landfill. This so called “area method” is used widely in Russia. The methane formation is slower with this method compared to the “cell method” commonly used in modern landfills, because there is a longer delay between waste disposal and the beginning of anaerobic decomposition of the waste.

6.2 Measurement methods

The landfill gas measurements at Morosova landfill were done by a company called Finnish Bioenergy Ltd. The measurements were done in two periods (23.-30.6.2004 and 11.-12.10.2004). The gas was extracted from the landfill by drilling 1.6 m deep wells into waste lift and placing gas outlet pipes (diameter 40 mm) to the wells. The sample gas flow was extracted using a vacuum pump, as seen in figure 6. The sample gas was analyzed with a "Gas Data - Landfill Monitoring System"-gauge shown in figure 7, which can measure the following gas components: methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and hydrogen sulphide (H_2S).

Figure 6. Landfill gas measurement system.

Figure 7. Landfill gas monitoring gauge.

The landfill gas samples were taken from 7 different measurement points. The sample gas was extracted with the vacuum pump from each well until the pointer reading of the methane concentration was steady (about 15 minutes).

6.3 Results of measurements and gas analysis

The results of the measurements on Morosova landfill are shown in table 10. The results 1 to 4 shown in the table were measured on June 23-30, 2004 and the results 5 to 7 are measured on October 11-12, 2004.

Table 10. Results of gas measurements in Morosova landfill.

Sample	Gas flow [l/min]	CH_4 [%]	CO_2 [%]	O_2 [%]	H_2S [ppm]
1	0	0.0	11.0	7.1	1.1
	150	0.0	14.0	3.1	1.2
2	0	0.0	0.0	18.7	1.2
	150	0.0	0.0	18.7	1.1
3	0	0.0	0.1	18.6	1.3
	120	18.6	26.0	2.6	1.4
4	0	0.0	4.2	14.0	1.4
	150	22.0	34.0	0.0	1.1
	500	20.5	33.0	0.0	-
5	0	0.0	0.0	18.6	2.0
	45	0.0	0.0	18.1	2.0
6	0	0.0	3.7	15.5	1.8
	400	0.0	2.3	16.7	1.7
7	0	2.4	17.0	47	38
	300	1.3	7.4	11.2	3.4

The results shown in table 10 reveal that methane formation in Morosova landfill is very low and in most of the measurement points methane was not generated at all. There can be several reasons for the low methane formation in this landfill e.g.: low share of organic fraction, short period of municipal waste dumping, aerobic decomposition of wastes and unconstant moisture content. Due to the open top of the landfill the surface layers of waste are in aerobic conditions, which leads to aerobic decomposition (composting). Also the high temperature (~50 °C) of the extracted sample gas indicates composting.

According to the results presented above, the Morosova landfill is not a potential object for landfill gas collection projects. For this reason the total methane formation is not modeled for this landfill.

7 Kyoto flexible mechanisms in financing the investments a landfill gas energy process

Most industrialized countries (Annex 1 countries, including Russia) have committed themselves to reducing emissions of carbon dioxide, methane and four other greenhouse gases in order to achieve the targets set under the Kyoto Protocol. These countries have the ability to apply 3 different mechanisms in which they can collaborate together with other parties and thereby achieve an overall reduction in GHG emission at a lower overall cost. The three mechanisms are: Joint Implementation (JI), Clean Development Mechanism (CDM) and Emissions Trading (ET). These mechanisms provide the framework for a trading system where $CO_{2\text{-ekv.}}$ emission reductions have a value. Hence, it is possible to calculate the price for GHG reduction and offer it for sale as “an emission allowance”. By selling the $CO_{2\text{-ekv.}}$ allowances for parties that need emission permits, the investments in emission reduction projects (for instance landfill gas utilisation projects) can be at least partly covered.

Landfill gas destruction or utilisation projects are an effective way to mitigate GHG emissions and generate emission allowances, because methane is known to be an about 21 times stronger green house gas than CO_2. By reducing one ton of CO_2 one emission allowance having a certain value can be produced, but converting one ton of methane to carbon dioxide by burning it, the achieved number of emission allowances is around twenty-fold.

In the following chapters the market value of $CO_{2\text{-ekv.}}$ emission allowance and Kyoto flexible mechanisms are discussed.

7.1 Market value of $CO_{2\text{-ekv.}}$ emission reductions generated by exploiting collected landfill gases

In January 2005 the European Union Greenhouse Gas Emission Trading Scheme (EU ETS) will commence operation as the largest multi-country, multi-sector Greenhouse Gas emission trading scheme worldwide. At the moment the European carbon market is still developing. The prices of so-called EU ETS allowances will be determined by market forces that are driven by expectations and fundamentals. While the major fundamentals are still to be decided, expectations dominate at this stage. This makes the prices quite hard to predict in the longterm. However, there are many estimates available for the allowance prices at least at the end of the first commitment period (2008-2012).

One of the most recent reports about the EU ETS allowance price projections has been made by Enviros Consulting (Enviros 2004). According to this report the allowance price has varied between 6.5 – 13.5 €/t_{CO2} since 2003 and between 7.10 – 10.2 €/t_{CO2} since April 2004. In the same report it is also estimated that the expected allowance price for the years 2005 to 2007 will be around 5 €/t_{CO2} with 50 % level of confidence, and after this period the price seems to rise again to over 10 €/t_{CO2} by the year 2010, as seen in figure 8.

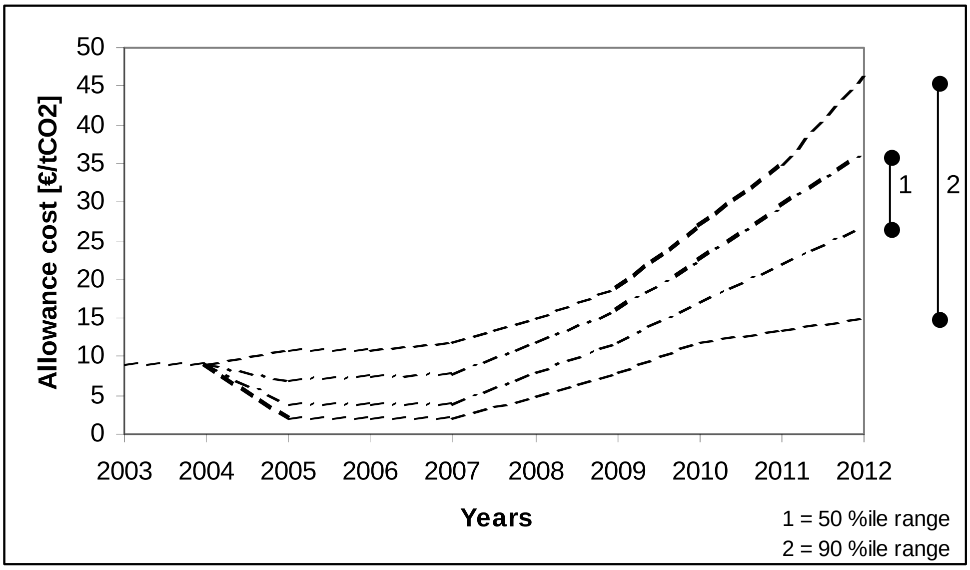

Figure 8. EU ETS allowance price projections (Enviros 2004).

7.2 Kyoto flexible mechanisms and ERs

The three different Kyoto flexible mechanisms that can be used as financing instruments for GHG emission reduction projects at the beginning of 2008 are described in this paragraph.

Joint Implementation (JI) is a mechanism that will allow any Annex 1 country to transfer to, or acquire from, any other such party emission reduction units (ERUs) resulting from projects aimed at reducing green house gas emissions with Kyoto targets. Carbon sink projects are also eligible for crediting under the Joint Implementation scheme. The designated emission reduction unit (ERU) has been defined as the reduction of GHG emissions by 1 ton of CO_2 or CO_2-equivalent. ERUs can be used for complying with the Kyoto targets. Emission reductions can be generated through JI during the first commitment period (2008-2012), which provide 5 years of potential revenue for a project. The JI is the Kyoto flexible mechanism of highest relevance between Russia and other industrialized (Annex 1) counties.

The Clean Development Mechanism (CDM) will allow climate change mitigation projects only between Annex 1 countries and non-Annex 1 countries. Emission reductions can be generated through CDM during the first commitment period (2008-2012). Annex 1 countries may use certified emission reduction (CERs) generated from the project activities to contribute to the compliance with part of their emission reduction commitments. One CER unit is equal to 1 ton of $CO_{2\text{-ekv.}}$ reduction. This mechanism is not available between Russia and other industrialized (Annex 1) counties, because one of the parties has to be a developing country (non-Annex 1 country).

Emissions Trading (ET) allows for the transfer of Assigned Amounts of greenhouse gas emissions among Annex B countries. Countries that emit less than their caps are allowed, under the Protocol, to sell surplus allowances (AAU, Assigned Amount Units) to those countries that have exceeded their cap. While the implementation of the three flexible mechanisms at international level will become possible only once the Kyoto Protocol comes into force, the EU is moving ahead with its own internal emissions trading system that begins in 2005.

8 Utilization of landfill gas in economical point of view

8.1 Capital costs of landfill gas utilization system

The capital costs of a landfill gas utilization system come from the components of the gas collection system like collection wells, a common header pipe and a blower station and also from gas utilization devices. In Russia landfills are not usually covered after the active period of operation, which can also cause great expenses. Landfill gas cannot be recovered successfully from poorly managed open dumps.

The construction cost of landfill gas a collecting system that uses vertical gas extraction wells depends greatly on the amount of wells. Depending on the depth of the landfill, landfill cover and other local conditions, the spacing for vertical gas extraction wells will vary from 30 to 60 meters (Tchobanoglous et al. 1993). When the dimensions of the landfill and the distance between the wells are known, the construction costs can be roughly calculated. In this report the total costs of LFG collection are not estimated, but table 11 below presents indicative prices for different components that are used in landfill gas utilization systems. These prices hold true quite well also in Russia because the costs mainly come from investments in the gas collecting equipment.

Table 11. Capital costs of components used in landfill gas collection systems (Conestoga-Rovers & Associates 2004).

Component	Capital costs	
Gas collection system:		
• 100-150 mm diameter vertical well	150-350	$/vertical metre
• common header pipe	~ 200	$/metre
• blower station	25 000-50 000	$/1000 m^3 per hour of LFG
Pilot burner	50 000-100 000	$/1000 m^3 per hour of LFG

According to Tuhkanen (2001), the production costs of landfill gas for the purpose of energy use in Finland are about 3.4 – 4.5 €/MWh, when the gas collecting facility operates at full capacity. Because this kind of data is not available for Russian landfills, it is now assumed that the above costs are also valid in Russia. Anyway, the major costs come from repayment of collecting and utilization equipment, which are the same in Russia as in Finland. Also the covering of landfills can cause significant costs when it is not otherwise done.

8.2 Production costs of LFG compared to natural gas prices in Russia

To assess the landfill gas as a fuel from economical point of view, it has to be compared to other similar fuels that are available. In Russia natural gas is the best point of comparison for landfill gas because of its similar properties, use and good availability.

Table 12 shows that the natural gas prices for domestic industrial users and the household sector in Russia are very low, even lower than the production costs of the gas. At the same time the export price of natural gas is substantially higher than the production costs, meaning that the majority of the expenses are covered by profit from natural gas export.

Table 12. Production costs and prices of natural gas in Russia.

	Prices	
	$/1000 m^3	€/MWh
Prices for households	16	1.3
Prices for domestic industry	28	2.3
Production costs	34	2.8
Export prices	80-100	6.7-8.3

Due to the current prices of natural gas in Russia, it is not economically viable to collect landfill gas only for the purpose of energy production when the production cost will be about 3.4 – 4.5 €/MWh$_{LFG}$. This situation will possibly change in near future if Russia joins the WTO (World Trade Organization). Also Russia's ratification of the Kyoto protocol will change the position of landfill gas in the field of energy production.

As a price for joining the WTO, the EU has pressed Russia to agree to raise the low prices of natural gas, which are being supplied to Russian industry for less than it costs to extract the fuel from the ground. The EU wants Russian energy prices for domestic industrial users to cover the cost of production and a profit margin. Otherwise Russian energy-intensive exporting industries such as steel and fertilizers would face unfair trade complaints by EU industry and punitive European tariffs. Russia has already offered to increase the price to $37-$42 per 1,000 cubic meters by 2006 and $49-$57 by 2010, from the current $28. (The St. Petersburg Times 2004)

8.3 Estimated potential value of emission reductions in the biggest landfills of St. Petersburg

As mentioned above, converting one ton of methane to carbon dioxide by burning it, the achieved number of emission allowances is about 20 t_{CO2}. Assuming that the price of one emission allowance is about 9 €/t_{CO2} like today and probably in 2008 as well (see chapter 7.1), and also knowing the methane flow, the value of total emission reductions can be estimated.

In this study, the potential value of emission reductions for SWL-1 (Volkhonka) and SWL-3 (Novoselky) have been calculated. The methane generation rates used in these calculations are based on the mathematical modeling presented in chapter 4.2, in which was assumed that the waste dumping to landfills will end in 2005 or will continue until 2010.

The most important results of the calculations shown in table 13 indicate that the potential of emission allowances is very significant in both landfills. At the best years the value of achieved allowances could be up to 3 million euros while the lowest methane generation in the considered cases produce still over 1 million euros per year. This profit is multiple compared to the profit gained from the hypothetical energy utilization of methane. All the results of the calculations can be found in the charts presented in Appendix 4.

Table 13. Potential value of emission reductions on SWL-1 and SWL-3 (see Appendix 4).

Landfill	2005 [million €/a]	2010 [million €/a]	2015 [million €/a]
SWL-1 (waste acceptance to 2005)	2.0-2.5	1.6-1.7	1.2-1.3
SWL-1 (waste acceptance to 2010)	2.0-2.5	2.3-2.7	1.8-1.9
SWL-3 (waste acceptance to 2005)	2.2-2.7	1.8-1.9	1.3-1.4
SWL-3 (waste acceptance to 2010)	2.2-2.7	2.5-3.0	2.0-2.1

(Assuming that the price of one emission allowance is about 9 €/t_{CO2} and $t_{½}$ is 10 to 15 years)

8.4 In Southeast Finland locating companies with potential business opportunities in LFG utilization in Russia

The Finnish companies that will have potential business opportunities on the field of landfill gas utilisation in Russia can be categorized in the following way:

- suppliers of equipment that can be used in landfill gas collection and utilization,
- construction contractors,
- designers of landfill structures,
- consultants dealing with emission reduction,
- companies needing to buy emission allowances,
- companies which can supply knowledge on landfill gas utilization and emission reduction business, and
- companies which can help in finding the customers and networking between Finnish and Russian parties.

A few companies that supply equipment for the collection and utilization of landfill gas operate partly in Southeast Finland. There are also companies which carry out design and construction of landfill structures. Southeast Finland is a remarkable center of forest industry with several pulp and paper factories. There is also steel industry, which will probably have the hardest problems with GHG emissions in the future. These industrial sectors in addition to energy production demand a great amount of emission allowances. One way to acquire more allowances is to take part in Joint Implementation projects aimed at reducing green house gas emissions generated in the landfills of St. Petersburg. The waste management and knowledge centers in the region could work as suppliers of knowledge and co-operation partners between Finnish and Russian parties in the field of landfill gas utilization and emission reduction business.

9 Conclusions

The amount of municipal solid waste formed in St. Petersburg has increased significantly from the beginning of the nineties, being today over 5.3 million m^3 (over 1 million tons) per year. About 72 % of all the waste formed in St. Petersburg is landfilled, and over 60 % is disposed to the two biggest main landfills in the area. Both these landfills have exceeded the design limits of their maximal waste capacity. It is possible that these landfills will have to end their operation soon.

The estimated landfill gas formation shows that there is great potential for GHG reduction in St. Petersburg. Roughly about 40,000 tons of methane per year is formed there, but it is obvious that only part of this can be recovered. The best opportunities for methane utilization exist in the biggest landfills where the gas generation rate and methane content are high. The modelled methane formations in the two biggest landfills, SWL-1 and SWL-3, reveal that the methane formation at both landfills is very significant. However, it is not economically viable to collect landfill gases only for the perspective of energy production, even from the largest landfills, due to the low prices of energy in Russia. Economically viable landfill gas utilization projects require that the $CO_{2\text{-ekv.}}$ emission reductions are maximized and the achieved emission allowances are traded through to the carbon market. Joint Implementation is the most relevant Kyoto flexible mechanism that will allow any Annex 1 country to transfer to, or acquire from Russia emission reduction units (ERUs) resulting from landfill gas utilization projects aimed at reducing green house gas emissions with Kyoto targets. According to the calculations it seems that at the best years the value of achieved allowances could be up to 3 million euros, while the lowest methane generation in the considered cases will produce over 1 million euros per year at SWL-1 and SWL-3.

In this report the landfill gas formation of a small privately owned landfill in Morosova was measured. The results of the measurements indicate that the Morosova landfill is not a potential target for landfill gas collection projects due to its very low methane formation rate.

As regards the significance of the landfill gases formed in St. Petersburg from the perspective of benefits for Southeast Finland, the main opportunities are associated with equipment supply of LFG systems as well as the acquiring emission allowances.

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Appendixes

1. Appendix – Development of waste formation in St. Petersburg from 1994 to 2000

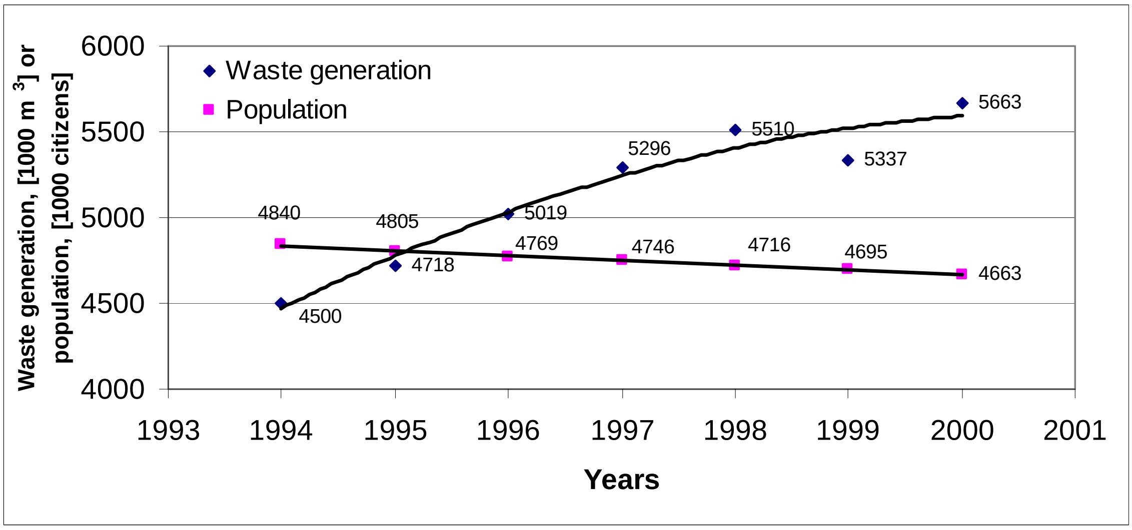

Figure A1. **Change in population and amount of waste during the period 1994 – 2000 (Florinskaya 2002).**

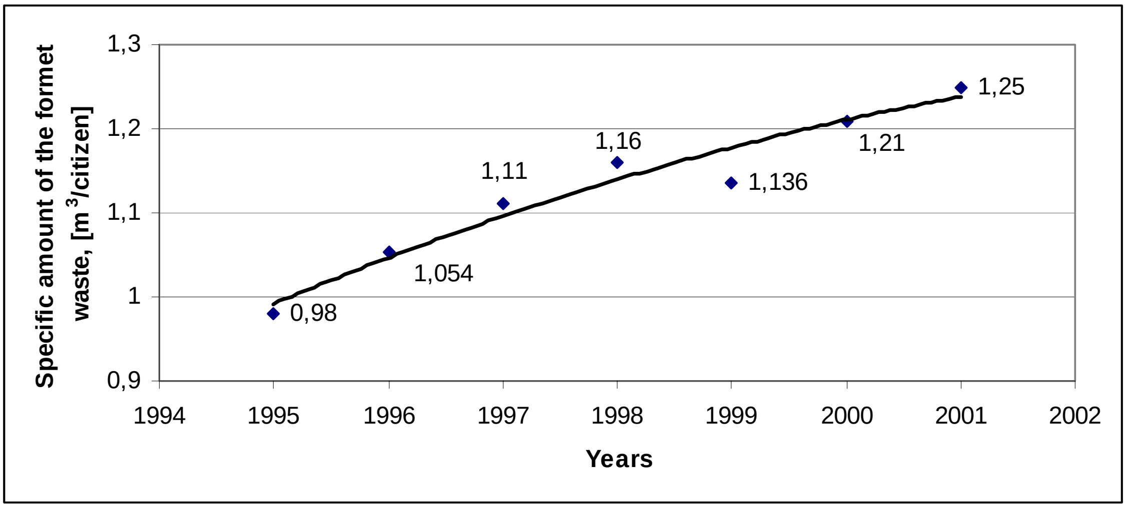

Figure A2. **Change in specific amount of waste during the period 1995 – 2001(Florinskaya 2002).**

2. Appendix - Landfill gas modeling equations

Equations of the mass-balance model (IPCC 2000a):

$$CH_4 \ generated \ in \ a \ year \left[Gg/a \right] = M(x) \cdot L_0(x) \, , \qquad \text{(Eq. 1)}$$

where *M(x)* = waste acceptance to landfill in year x, [Gg/a]

$L_0(x)$ = methane generation potential, [Gg_{CH4}/Gg_{waste}].

$$L_0(x) = MCF(x) \cdot DOC(x) \cdot DOC_F \cdot F \cdot 16/12 \qquad \text{(Eq. 2)}$$

where *MCF(x)* = methane correction factor in year x (fraction)

DOC(x) = degradable organic carbon in year x (fraction), [Gg_C/Gg_{waste}]

DOC_F = fraction of DOC dissimilated[1)]

F = fraction by volume of CH_4 in landfill gas

16/12 = conversion from C to CH_4.

1) = DOC_F is an estimate of the fraction of carbon that is ultimately degraded and released from solid waste landfill, and reflects the fact that some organic carbon does not degrade, or degrades very slowly, when deposited in landfill.

Equation of the first order decay (FOD) model (IPCC 2000a):

$$CH_4 \ generated \ in \ a \ year \left[Gg/a \right] = \sum_{x=t_0}^{t} \left[\left(A \cdot k \cdot M(x) \cdot L_0(x) \right) \cdot e^{-k(t-x)} \right], \qquad \text{(Eq. 3)}$$

where *t* = year of inventory

t_0 = starting year of calculation

A = $(1 - e^{-k})/k$; normalization factor which corrects the summation

k = ($k = \ln 2/t_{½}$) methane generation rate constant, [1/a]

$t_{½}$ = the time taken for the DOC in waste to decay to half its initial mass, [a]

3. Appendix - Mathematical modeling of methane formation in landfills of St. Petersburg

Massbalance-based modeling of total methane generation in landfills of St. Petersburg:

The methane generation potential L_0 can be estimated using the equation (Eq. 2) as follows:

assumed variables:

MCF(x) = 0.8 (factor for unmanaged landfills ≥ 5 m deep landfills)

DOC(x) = 0.195 Gg_C/Gg_{waste} (calculated based on composition of wastes)

DOC_F = 0.5 (recommended value)

F = 0.5 (recommended value is between 0.4 – 0.6)

(more information about the selection of variables see Tuhkanen 2001 or IPCC 2000a)

$$\Rightarrow L_0 = 0.8 \cdot 0.195\ Gg_C/Gg_{waste} \cdot 0.5 \cdot 0.5 \cdot (16/12)\ Gg_{CH4}/Gg_C = 0.052\ Gg_{CH4}/Gg_{waste}$$

Total methane generation in landfills of St. Petersburg can be estimated using the equation (Eq. 1), when waste flow to landfills is 770,000 t/a:

$$\Rightarrow CH_4 \text{ generated in a year} = 0.052\ Gg_{CH4}/Gg_{waste} \cdot 770\ Gg_{waste}/a = 40.04\ Gg_{CH4}/a$$

$$\approx \underline{40{,}000\ t_{CH4}/a}.$$

FOD method based modeling of methane generation in SWL-1 and SWL-3:

Because the First Order Decay (FOD) model is more complicated than the mass-balance method, all the calculations cannot be presented as for the mass-balance method above. In this paragraph only the initial data required for modeling is presented (see table A1). This data is put into equation 3 described in Appendix 2. The modeling has been made using the MS Excel program and the results of modeling are presented in Appendix 4.

The annual amounts of landfilled waste are not known exactly. The waste quantities presented in table A1 are partly assumed on the basis of the proportional part of generated waste amounts in whole St. Petersburg and the total waste volumes of the landfills which were known in 2001. The exactly known waste amounts are written in a bold font in table A1.

Table A1. Initial data used in the modeling of methane formation in SWL-1 and -3.

Initial data for SWL-1		Initial data for SWL-3	
t	= from 1990 to 2020	t	= from 1990 to 2020
t_0	= 1978	t_0	= 1972
A	= $(1 - e^{-k})/k$	A	= $(1 - e^{-k})/k$
k	= ($k = \ln 2/t_{½}$)	k	= ($k = \ln 2/t_{½}$)
$t_{½}$	= 5, 10 and 15 a	$t_{½}$	= 5, 10 and 15 a
L_0	= 0.052 Gg_{CH4}/Gg_{waste}	L_0	= 0.052 Gg_{CH4}/Gg_{waste}
ρ	= 200 kg/m^3 (bulk density)	ρ	= 200 kg/m^3

Year	**M(X), [m^3]**	**M(X), [t]**	**Year**	**M(X), [m^3]**	**M(X), [t]**
1978	1,000,000	200,000	1972	500,000	100,000
1979	1,000,000	200,000	1973	548,000	109,600
1980	1,000,000	200,000	1974	596,000	119,200
1981	1,000,000	200,000	1975	644,000	128,800
1982	1,000,000	200,000	1976	692,000	138,400
1983	1,000,000	200,000	1977	740,000	148,000
1984	1,000,000	200,000	1978	788,000	157,600
1985	1,000,000	200,000	1979	836,000	167,200
1986	1,050,000	210,000	1980	884,000	176,800
1987	1,100,000	220,000	1981	932,000	186,400
1988	1,150,000	230,000	1982	980,000	196,000
1989	1,200,000	240,000	1983	1,028,000	205,600
1990	1,250,000	250,000	1984	1,076,000	215,200
1991	1,300,000	260,000	1985	1,124,000	224,800
1992	1,350,000	270,000	1986	1,172,000	234,400
1993	1,400,000	280,000	1987	1,220,000	244,000
1994	**1,446,660**	**289,332**	1988	1,268,000	253,600
1995	1,500,000	300,000	1989	1,316,000	263,200
1996	1,600,000	320,000	1990	1,364,000	272,800
1997	1,700,000	340,000	1991	1,412,000	282,400
1998	1,750,000	350,000	1992	1,460,000	292,000
1999	1,786,000	357,200	1993	1,508,000	301,600
2000	**1,786,000**	**357,200**	**1994**	**1,564,000**	**312,800**
2001	1,786,000	357,200	1995	1,600,000	320,000
2002	1,786,000	357,200	1996	1,700,000	340,000
2003	1,786,000	357,200	1997	1,770,000	354,000
2004	1,786,000	357,200	1998	1,873,000	374,600
	Continue			**Continue**	

2005	1,786,000	357200	1999	1,802,000	360,400
2006*	1,786,000	357200	**2000**	**1,802,000**	**360,400**
2007*	1,786,000	357200	2001	1,900,000	380,000
2008*	1,786,000	357200	2002	1,950,000	390,000
2009*	1,786,000	357200	2003	2,015,000	403,000
2010*	1,786,000	357200	2004	2,015,000	403,000
			2005	2,015,000	403,000
			2006*	2,015,000	403,000
			2007*	2,015,000	403,000
			2008*	2,015,000	403,000
			2009*	2,015,000	403,000
			2010*	2,015,000	403,000

* = These values describe assumed future projections of waste acceptance to landfill.

4. Appendix – Results of mathematical modeling of methane formation in the landfills of St. Petersburg

Volkhonka (SWL-1):

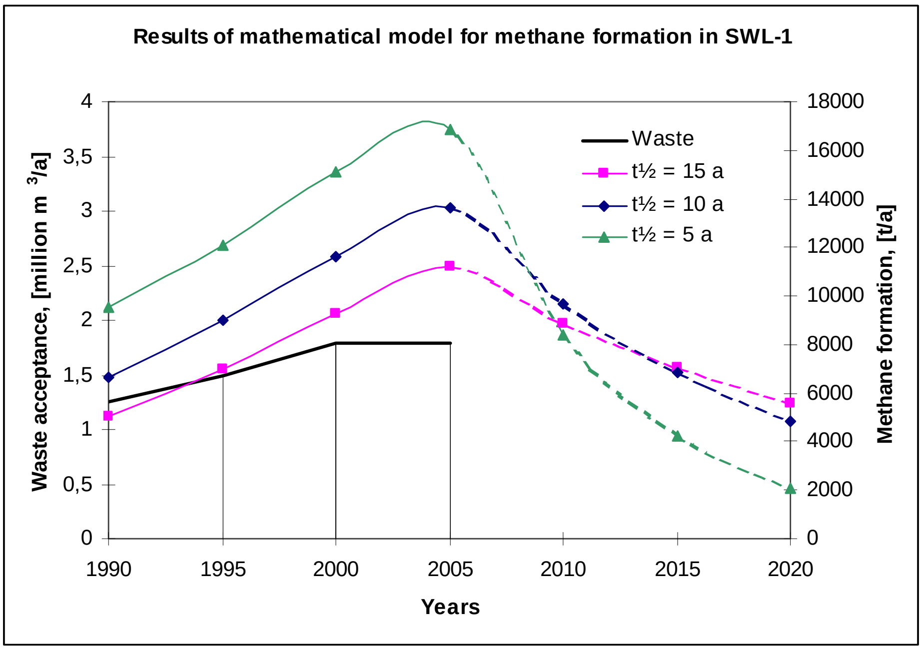

Figure A3. Methane formation if the landfill will end its operation by the end of 2005.

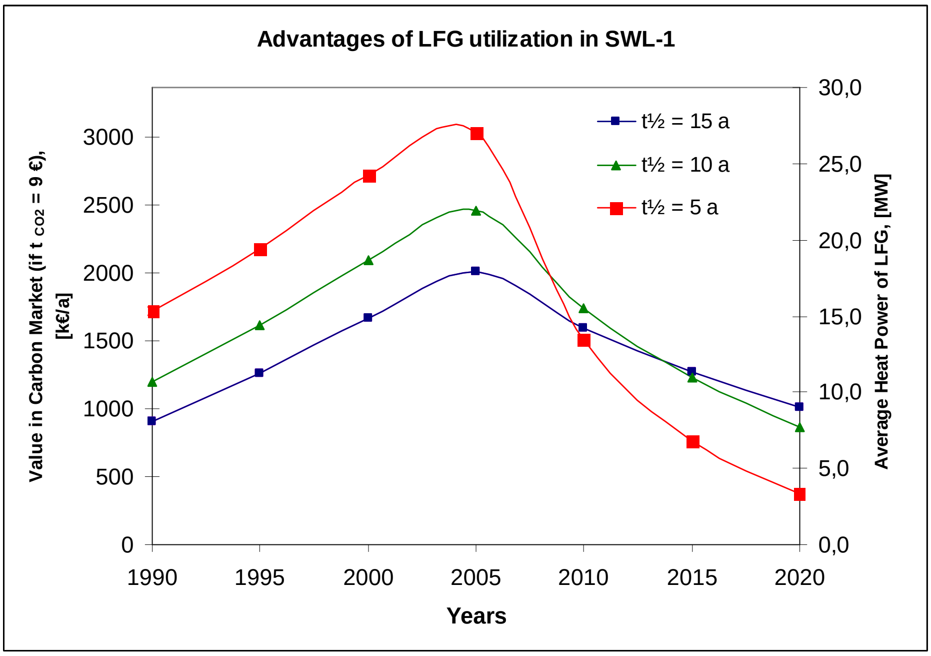

Figure A4. Advantages of LFG utilization if the landfill will end its operation by the end of 2005.

Volkhonka (SWL-1):

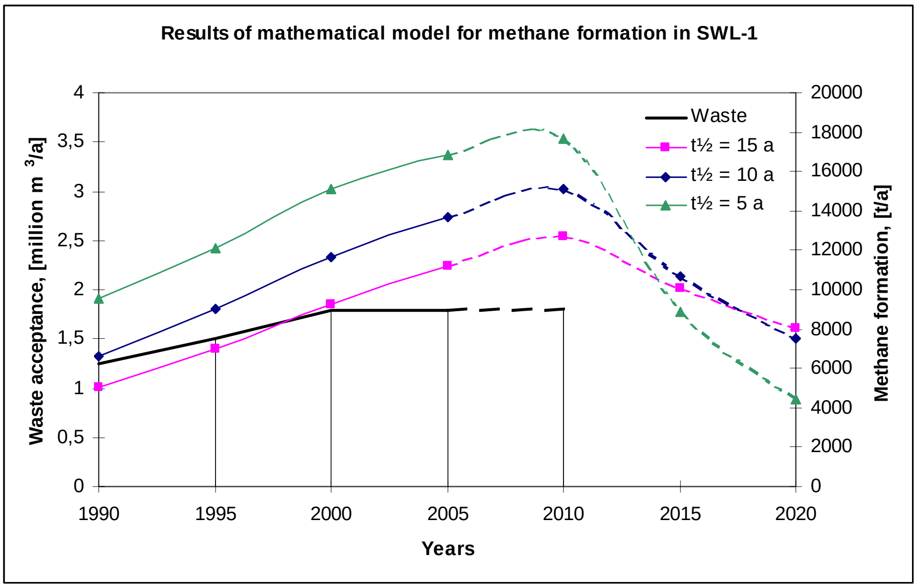

Figure A5. Methane formation if the landfill will end its operation by end the of 2010.

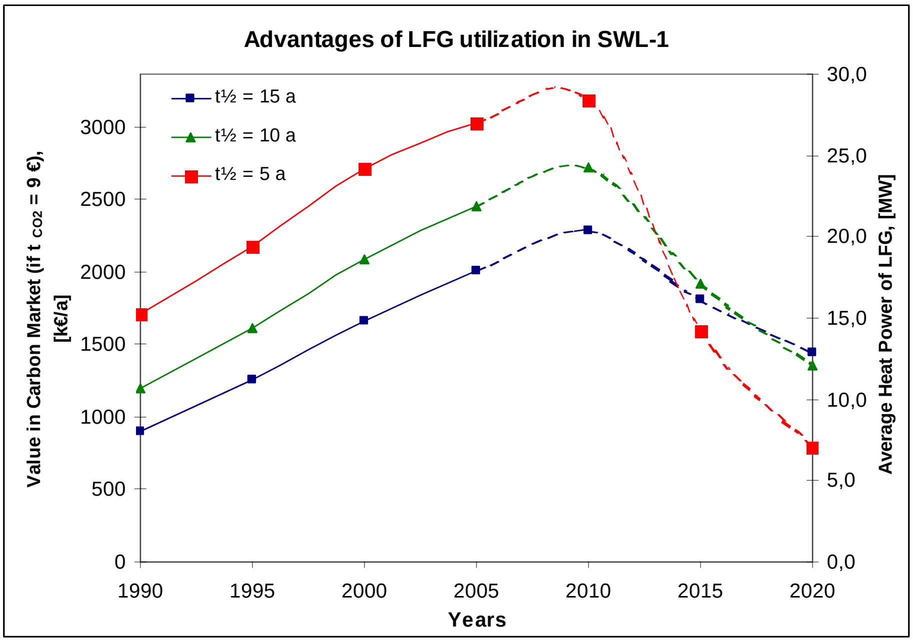

Figure A6. Advantages of LFG utilization if the landfill will end its operation by the end of 2010.

Novoselky (SWL-3):

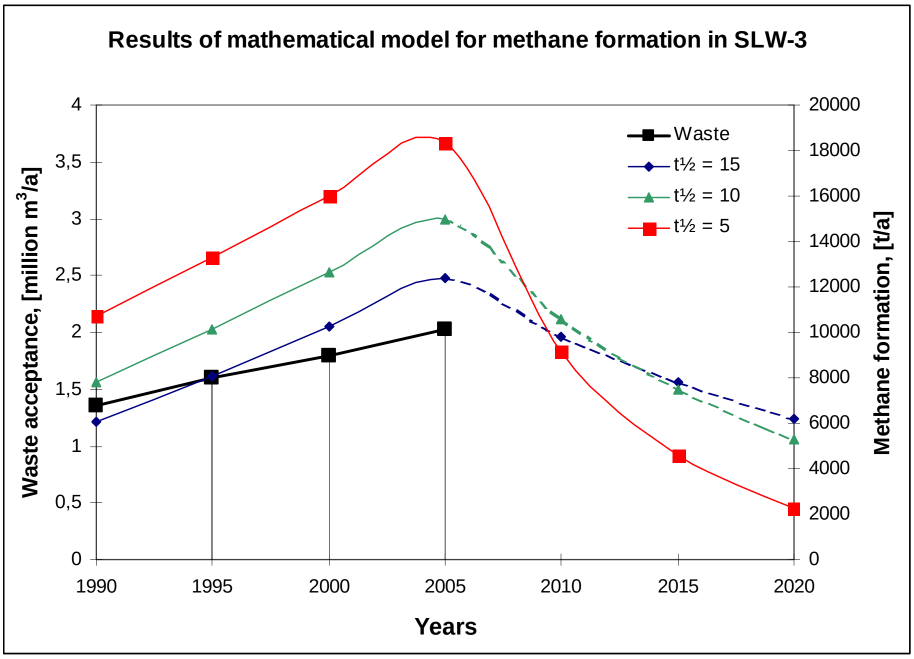

Figure A7. Methane formation if the landfill will end its operation by the end of 2005.

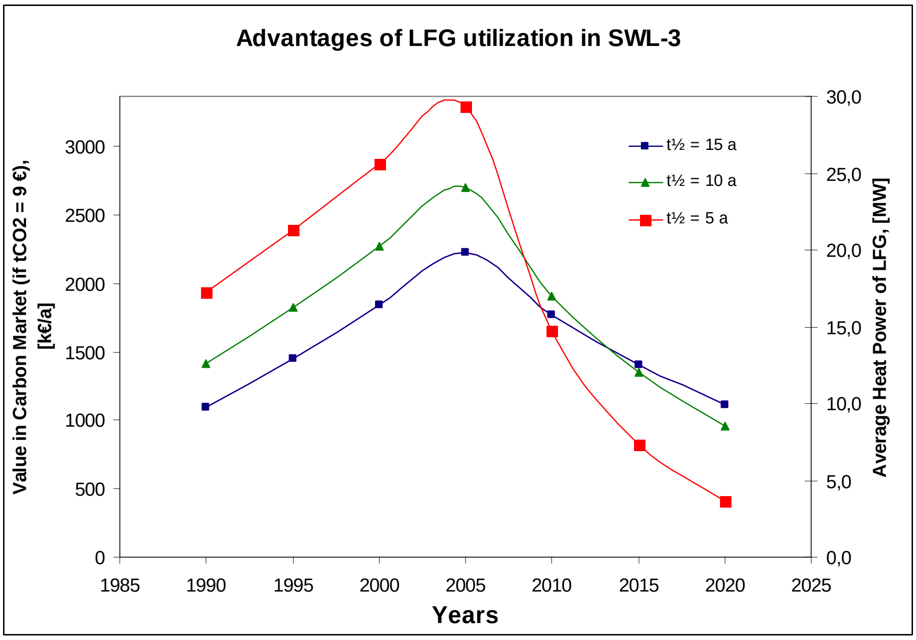

Figure A8. Advantages of LFG utilization if the landfill will end its operation by the end of 2005.

Novoselky (SWL-3):

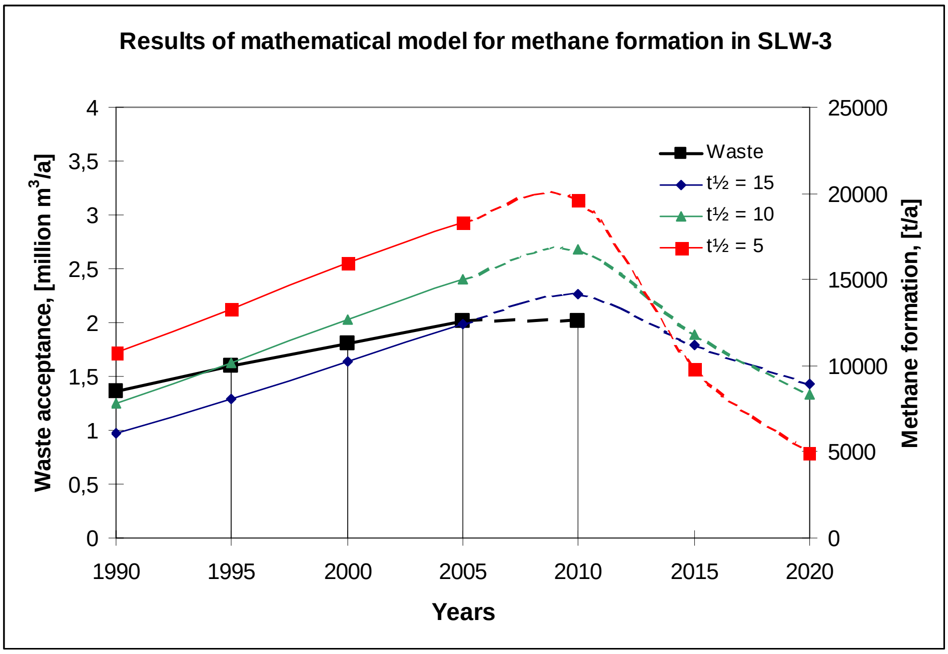

Figure A9. **Methane formation if the landfill will end its operation by the end of 2010.**

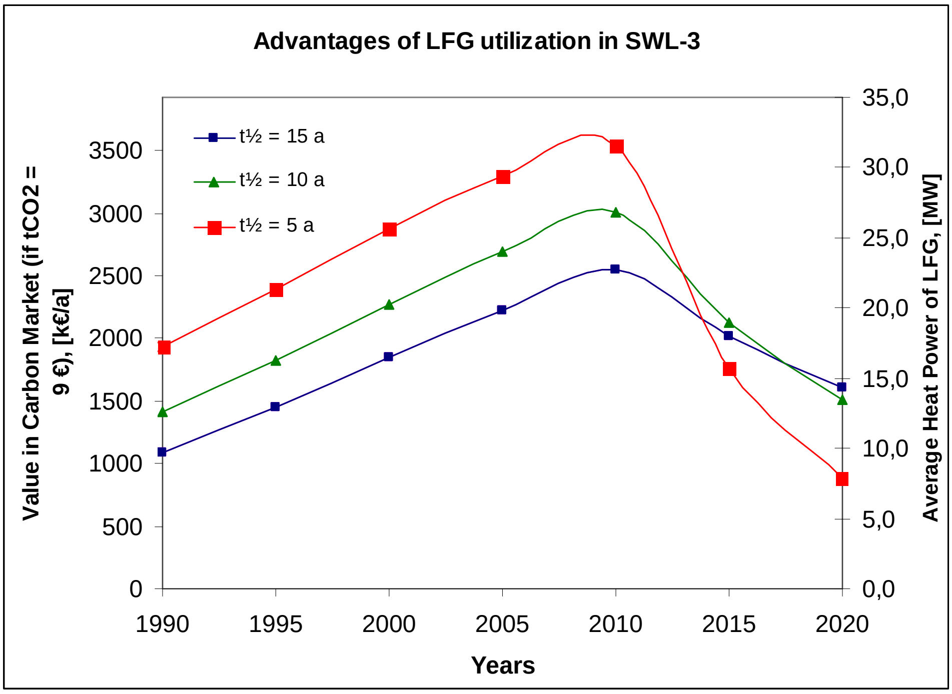

Figure A10. **Advantages of LFG utilization if the landfill will end its operation by the end of 2010.**