Collection and utilisation of landfill gas in the Nordic countries

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The Nordic Council of Ministers
was established in 1971. It submits proposals on co-operation between the governments of the five Nordic countries to the Nordic Council, implements the Council's recommendations and reports on results, while directing the work carried out in the targeted areas. The Prime Ministers of the five Nordic countries assume overall responsibility for the co-operation measures, which are co-ordinated by the ministers for co-operation and the Nordic Co-operation committee. The composition of the Council of Ministers varies, depending on the nature of the issue to be treated.

The Nordic Council
was formed in 1952 to promote co-operation between the parliaments and governments of Denmark, Iceland, Norway and Sweden. Finland joined in 1955. At the sessions held by the Council, representatives from the Faroe Islands and Greenland form part of the Danish delegation, while Åland is represented on the Finnish delegation. The Council consists of 87 elected members - all of whom are members of parliament. The Nordic Council takes initiatives, acts in a consultative capacity and monitors co-operation measures. The Council operates via its institutions: the Plenary Assembly, the Presidium and standing committees.

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1. Introduction

The EC's Council Directive 1999/31/EC on the landfill of waste directs member states to treat and utilise landfill gas. The Nordic countries implemented the Directive during the period between 1999 – 2002. Energisystemer AS was commissioned by the PA-group (the working group for products and waste) within the Nordic Council of Ministers, to collect and analyse available information about landfill gas systems in the Nordic countries.

The aim of this project is to give an overview of the collection and utilisation of landfill gas in the Nordic countries and to evaluate the practices. Also, the efficiency of the regulation in this field will be discussed focussing on the degree of consistency with the requirements in Council Directive 1999/31/EC.

Sandefjord, Norway 8.12.2001

Energisystemer as

Knut H. Birkeland

2. Summary and conclusions

The report summarises the information available on the collection and utilisation of landfill gas in the Nordic countries and discusses the impact of the EC Directive on the landfill of waste (1999/31/EC) on the development and utilisation of landfill gas systems. The information is collected by interviewing staff in the environmental agencies, consolidating data from landfill gas reports and analysis of landfill questionnaires. The main conclusions and findings are presented below.

Landfill gas treatment technology was introduced in the Nordic countries from 1982/83 after pressure from environmentalists, Today there are 633 operating landfills in the Nordic countries of which 158 have a landfill gas (LFG) collecting system. The EC Directive on landfill of waste requires LFG systems in all operating landfills that receive biodegradable waste.

The extraction technology differs between the Nordic countries. Denmark and Norway introduced automatically controlled efficiency energy systems, whereas Sweden worked on methods for handling waste and producing energy from it. The Norwegian and Danish systems have high investment costs, but they have a probable future focussing on the environment and long term economy.

The use of landfill pipelines, under pressure wells, construction etc. have differed from country to country. The Landfill Directive gives no instructions on how to handle the competition and environmental and economic situations.

Also technical legislation differs between the Nordic countries. In Norway, all PE-pipes must be covered, only steel is allowed over ground. In Sweden they allow PE-pipes over ground which creates a problem when Swedish companies install "Swedish requirements" in Norway and if local authorities have not got the necessary competence to refuse the installations.

The discussion about flares will continue. Denmark and many other EC countries accept that a flare is not necessary for plants that want to utilise the LFG energy. The other Nordic countries prefer a closed flare, however, most installations are facilitating open flares.

In total 730 GWh energy is produced from LFG and 600 GWh is utilised. About 18% of this energy is flared as Finland and Norway and some Swedish plants fail to utilise the energy. Sweden produces 63% of the energy from LFG in the Nordic countries.

Compared to the population, Sweden recovers 52 kWh energy annually per person from landfilled waste, whereas Denmark only recovers 4 kWh/person. This significant difference may be due to other methods of recovering energy from waste such as AD, incineration etc. It could also be indicative of the waste politics in each country.

The Nordic countries have different methods of calculating generated and collected LFG from landfills. The variation in methods is so different, that there are "national" variations of IPCC, which makes it difficult to compare them. Calculating different choices of parameters gives variation of total life for LFG-extraction from MSW (10% of original generated gas) from 27 to 36 years.

3. Sammendrag og konklusioner

Rapporten opsummerer den information, der er tilgængelig om opsamling og udnyttelse af gas fra deponeringsanlæg (deponigas) i de nordiske lande og rapporten diskuterer endvidere den indvirkning, som EU-direktivet om deponering af affald (1999/31/EC) har på udviklingen og brugen af deponigassystemer. Indsamlingen af informationen er sket via samtaler med personalet hos de centrale miljømyndigheder i de nordiske lande, sammenstilling af data fra deponigasrapporter samt analyse af udfyldte spørgeskemaer om deponeringsanlæg. De væsentligste konklusioner og resultater er præsenteret nedenfor.

Teknologien til behandling af deponigas blev indført i de nordiske lande omkring 1982/83 efter pres fra miljøfolk. I dag (2001) drives der 633 kontrollerede deponeringsanlæg i de nordiske lande, hvoraf 158 har et anlæg til opsamling af deponigas (på engelsk: LandFill Gas – forkortet LFG). EU-direktivet om deponering af affald stiller krav om, at der etableres LFG-systemer på alle aktive deponeringsanlæg, der modtager biologisk nedbrydeligt affald.

Teknologien til behandling af deponigas er forskellig mellem de nordiske lande. Danmark og Norge indførte automatiske LFG-energiudnyttelsessystemer, hvorimod Sverige arbejdede med metoder, hvor energifremstillingen indgik som en del af behandlingen af det biologisk nedbrydelige affald. De norske og de danske systemer har store investeringsomkostninger, men samtidigt vurderes systemerne at have en sandsynlig fremtid med fokus på miljøet og langtidsøkonomi.

Lovgivningen i forhold til de tekniske krav til LFG-systemer er forskellig mellem de nordiske lande. I Norge skal alle PE-rør tildækkes, kun stålrør er tilladt over jorden. I Sverige tillader man PE-rør over jorden, hvilket skaber problemer, hvis svenske virksomheder etablerer LFG-systemer ifølge "svenske krav" i Norge og/eller hvis de lokale (i nævnte eksempel norske) myndigheder ikke har den nødvendige kompetence til at afvise installationerne.

Diskussionen om affakling (åben/lukket gasbrænder) fortsætter. Danmark og mange andre EU-lande accepterer, at LFG-systemer etableres uden mulighed for affakling af deponigassen. De andre nordiske lande foretrækker affakling med lukket gasbrænder, uanset at de fleste affaklingsinstallationer er beregnet til åben gasbrænder.

I dag (2001) produceres der i alt 730 GWh energi af LFG i de nordiske lande, hvoraf 600 GWh udnyttes. Ca. 18% af den opsamlede LFG blev affaklet, idet de finske, norske og nogle svenske anlæg undlader at udnytte energien. Sverige producerer 63% af energien fra LFG i Norden.

I forhold til indbyggertallet udvinder Sverige årligt 52 kWh energi pr. person fra LFG, hvorimod Danmark kun udvinder 4 kWh/person. Denne markante forskel kan skyldes, at der anvendes andre metoder til udvinding af energi fra affald såsom affaldsforbrænding etc. Endvidere kan forskellen i energiproduktionen per indbygger fra LFG være afhængigt af den førte affaldspolitik i hvert enkelt land.

De nordiske lande anvender forskellige metoder ved beregning af fremstillet og opsamlet LFG fra deponeringsanlæg. Afvigelserne i metoder er så forskellige, at der er "nationale" afvigelser i IPCC (Intergovernmental Panel on Climate Change), hvilket gør det vanskeligt at sammenligne dem. Afhængigt af valg af parametre opnås således forskelle i den totale tid for LFG-produktion fra husholdningsaffald fra 27 til 36 år.

4. General introduction

The volume of waste has increased enormously since the 1940's and consequently the methods for treating and handling the waste have also had to change.

Historically waste was treated by burial in local landfills and by burning on open fires or in simple stoves. In the 1960's and 1970's more centralised landfills were established to handle waste from wider areas. Later the focus on environmental problems led to an increase in public awareness about the problems with pollution and contamination from waste.

During the last 20 years, knowledge about landfills has advanced and waste handling has become a major industry. Major efforts have been made in attempting to reduce both the levels of contaminants in the leachate and the volume of gas emissions to the atmosphere.

5. Landfill gas in Nordic countries

The first landfill gas (LFG) plants were built in the United States in the early 1970's, and the first LFG plants in the Nordic countries were introduced a decade later. In 1982/83 LFG extraction systems were built in Viborg, Denmark and Spillepeng, Sweden. Norway built its first LFG plant in Grinda in 1985/86, Finland its first around 1992, and Iceland in late 1996.

Figure 1 shows the growth in number of LFG plants in the Nordic countries from 2 plants in 1982, growing to 80 in 1994 [/10/], to 120 in 1997 [/1/] and up to 158 at the end of 2000 [/4,5,7,13,14,15/].

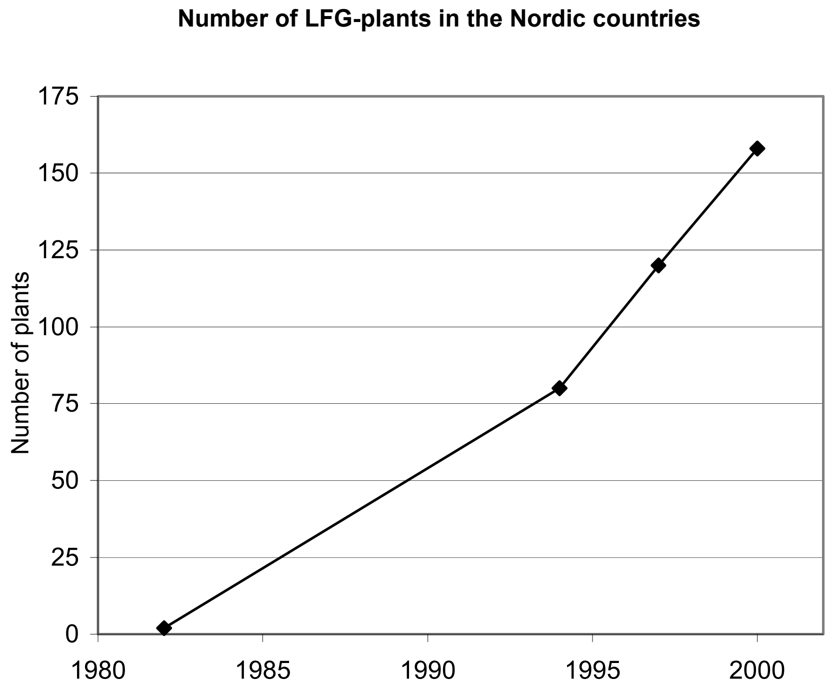

Figure 1. Historical development of the number of LFG-plants in the Nordic counties

5.1 Development of landfill gas plants in the Nordic countries

The early use of LFG collection systems was introduced at landfills after pressure from environmentalists. Some of the arguments used were [/1/]:

- Local environmental reasons – concern for the neighbours, employers and customers health
- Possibility of energy recovery
- Regional environmental reasons– reduce air, earth and water pollution
- Lengthen the life of the landfill

The US, Germany, the UK and Switzerland were the first countries to develop their own systems for extracting landfill gas. The Nordic countries which started collecting and utilising landfill gas later, based their systems on the American or European technology. Denmark and Norway use automatic or semi-automatic systems, Sweden uses high-speed technology and Finland uses low speed technology. Iceland is building traditional systems.

5.2 Landfills

There are 633 operating landfills in the Nordic countries. Out of these, only 139 have an LFG-collecting system (Fig. 2). On average 22% of the operating landfills have an extraction system. In addition, 19 plants are built on closed landfills. In total there are 158 LFG collecting systems in the Nordic countries.

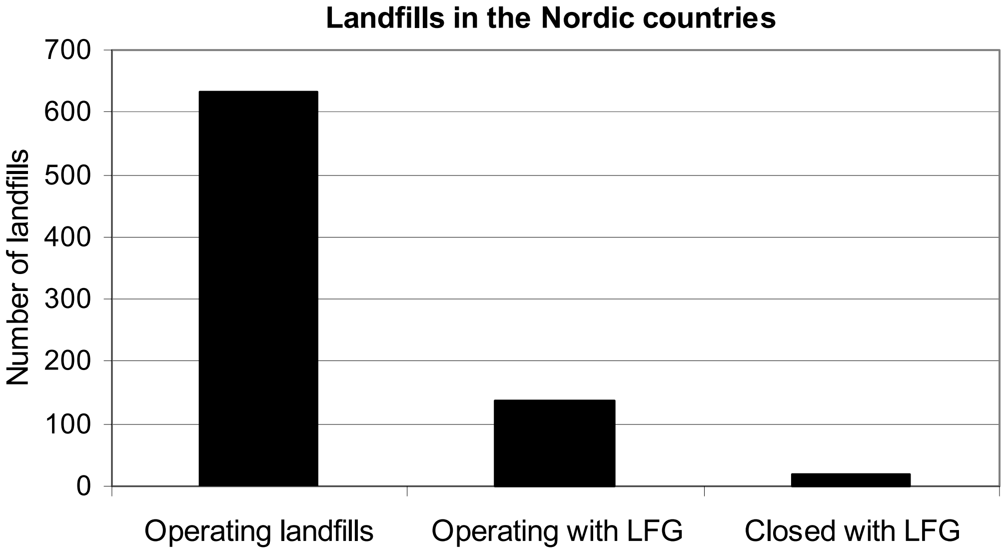

Figure 2. Number of operating landfills in the Nordic countries and LFG plants divided in operating and closed landfills.

Fig. 3 shows the number of LFG plants in each country. In Denmark about 38% of the landfills have a LFG treatment plant, which is above average for the Nordic countries.

This is due to the fact that many landfills without LFG treatment plants have been closed down during the last 20 years.

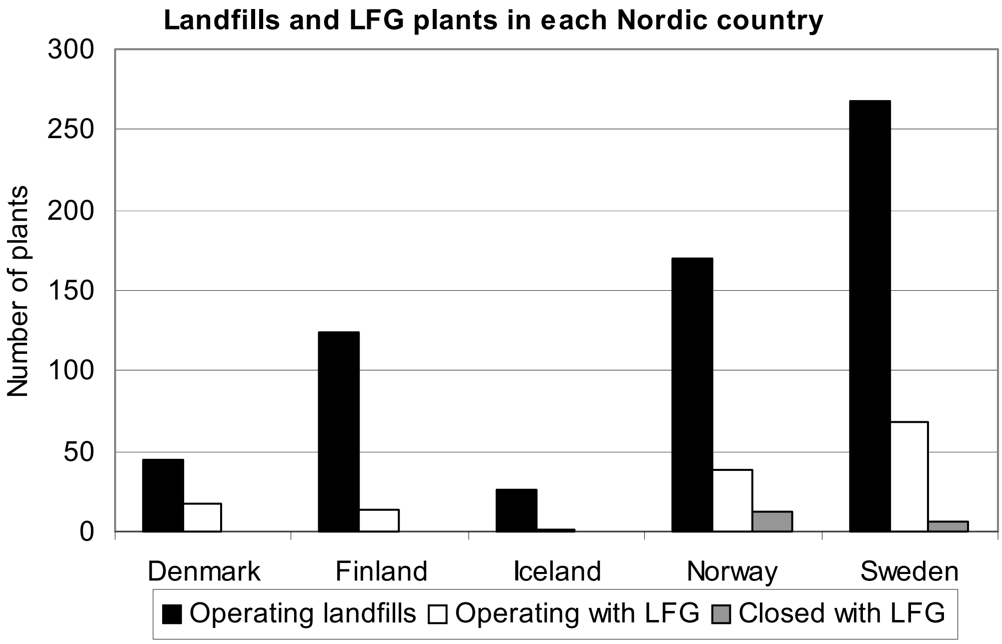

Figure 3. Number of operating landfills in the Nordic countries and LFG plants divided in operating and closed landfills.

Figure 3 shows that almost 4 or 5 of the existing Nordic landfills do not have an extraction system.

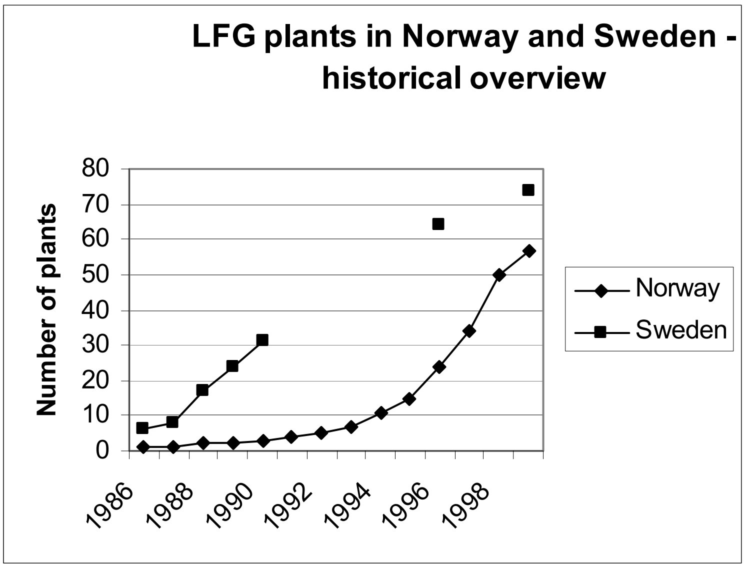

Figure 4. The growth of LFG plants in Norway and Sweden

5.3 Technology of landfill gas plant

A LFG plant consists of six parts:

1. Gas drainage
2. Pipelines
3. Under pressure system
4. Safety systems
5. Measuring system
6. Over pressure system/utilisation

5.3.1 Gas drainage

According to early theories waste should be landfilled for at least 10 years before there was enough biological activity to produce viable amounts of biogas. Therefore the first LFG plants were built on old landfills.

Early LFG technology was simple. Perforated steel pipes with a diameter of 50 mm was pressed down in the waste and connected to a PE pipeline (Fig. 5). Only a modest number of landfills used steel pipes. In Sweden they used steel pipes on 6 or 7 landfills, in Denmark on a few, and in Norway only on one plant and on 3 wells. In Finland no landfills used steel pipes. The situation in Iceland is different as the waste is pressed into 1m^3 blocs before it is landfilled.

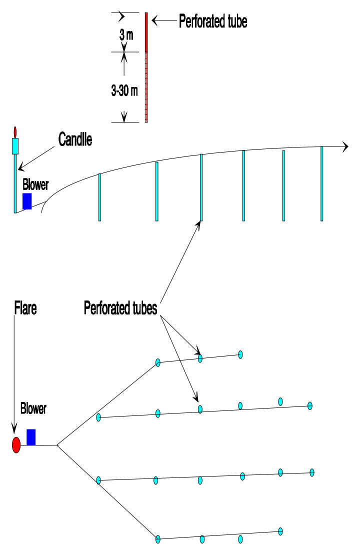

Figure 5. An early stage of LFG extraction: Steel pipes pressed down into the waste, with a system of connected pipes.

This was an inexpensive extraction system, but in many cases there were problems with the perforation and low quality gas. Today steel pipes is only used in testing.

Drilled wells were introduced parallel to the steel pipes. The steel pipe was exchanged for perforated PE or PVC pipes (diameters between 80 and 300 mm). Gravel was placed around the pipes to prevent the waste from to clogging the perforations. In Norway and

Sweden the perforations should cover at least 8% of the area. The pipes were perforated with slices or drilled holes with diameters between 8 and 14 mm. In Denmark the perforations consisted of small slices to facilitate water drainage.

Figure 6. Sliced, drilled and water drainage pipes for gas wells

Figure 7. Large size well – diameter 1500 mm (Kastet – Norway)

The diameter of the drilled wells varies a lot. Until a few years ago Denmark and Sweden normally used drilled wells with diameters from 80 to 150 mm (medium size) and Norway used wells with a diameters between 600 and 1500 mm (large size). Finland used smaller sized drilled wells.

Figure 8. Large size well – diameter 600 mm (Gatedalen, Norway)

In the early 1990's the mean production from large sized well plants in Norway was 4,6 Nm^3 biogas with 50% CH_4 per ton waste a year and the total production in Sweden was 3,6 Nm^3 tons per year. Today a production of 3,5 Nm3 seems to be accepted [/2/.]

Since research showed that methane production starts shortly after the waste volume is large enough, horizontal wells are now built on operating landfills. Even on old landfills that are up to 25 m deep, horizontal wells have been constructed with good results in Norway and Sweden. The construction of horizontal wells is more or less identical for all the Nordic countries. Horizontal wells consist of a ditch with a gradient to allow leachate to run in the desired direction. Perforated PE pipes may be laid down and gravel or another porous material is covering the pipes.

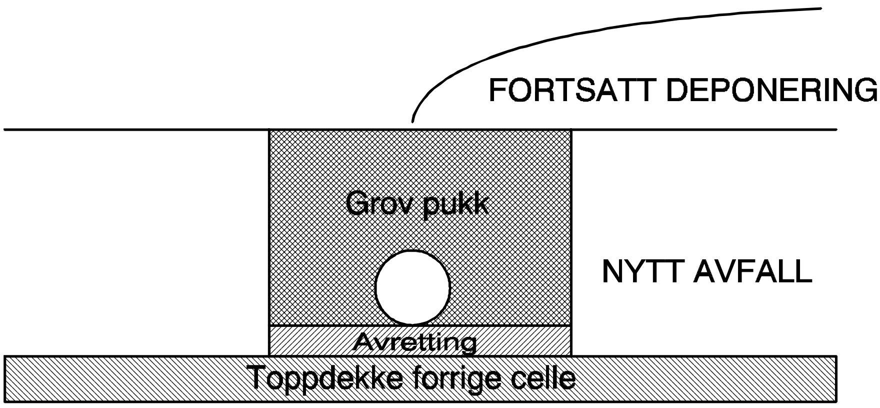

Figure 9. Horizontal well – Principe. A perforated pipe (Ø=80 – 200 mm) is covered with gravel (1 x 1 m).

Normally gas is sucked out when the well is covered with 2-4 m of waste. Experts in Norway and Sweden are discussing which end of the well the gas should be drawn to the low or the high point, with no conclusions as yet. In Norway some wells are constructed with water drainage in the low point.

The distances between horizontal wells are 10 to 40 meters horizontally and 2 to 7 meters vertically, depending on the construction and/or the composition of the waste .

Some special horizontal wells have been constructed in Finland, Norway and Sweden where suitable hazardous waste fractions such as empty glass bottles or used tyres were used in the gas drainage layer.

To connect the well and the pipeline can be complicated and expensive. A vertical well from the surface to the bottom was supposed to increase the stability of the landfill. As the surrounding material sink, the well would keep its permanent length. Today a simple construction is used. The pipeline is simply lowered a few meters into the well.

Some landfills where LFG extraction was part of the construction of the landfill; the gas is removed from the bottom of the well.

5.3.2 Pipelines

In the USA where the LFG technology was developed they have experienced no problems with frost during cold winters. They also had few problems with water getting trapped in the pipes (so-called water loops) because their pipeline system was on the ground (figure 10). In the Nordic countries it is found necessary to dig the wells and the pipes at frost-free depth.

Figure 10. In the US pipelines are located on the ground and the wells are connected directly to the pipeline in open air (Orlando landfill, LA)

The pipeline technology has advanced during the recent years in the Nordic countries. From using a system of connecting a number of wells (Fig. 5) with pipelines to a local collection station and further to a main collecting station (Fig. 11) it is now more common to connect each well directly to the main/sub station by separate pipelines (Fig. 12). Experience in Denmark and Norway (and later other countries) has shown that each well has to be treated as an individual object.

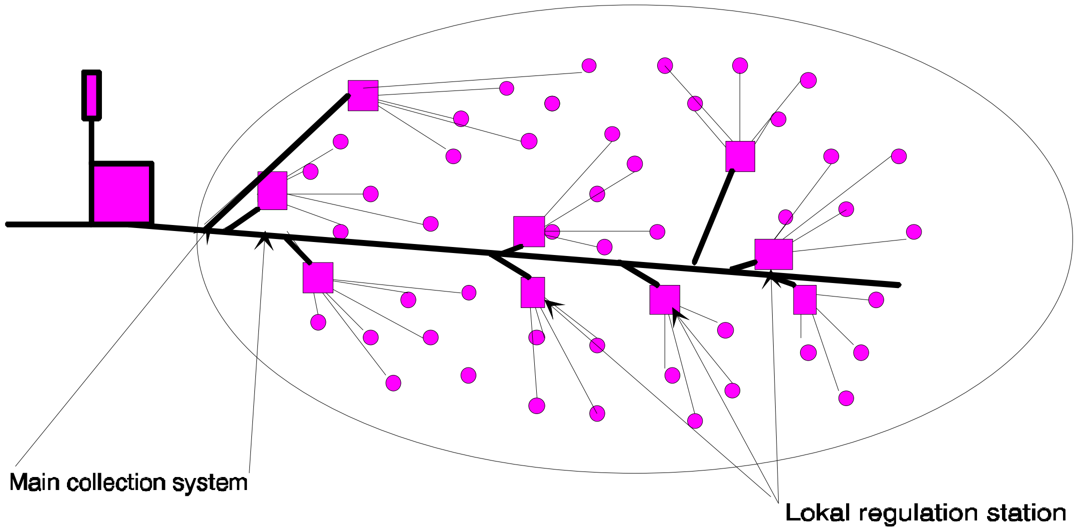

Figure 11. LFG plant with sub stations. Each well has a pipeline to a sub collecting station. From the station there is one pipeline to the main collection station (Sweden).

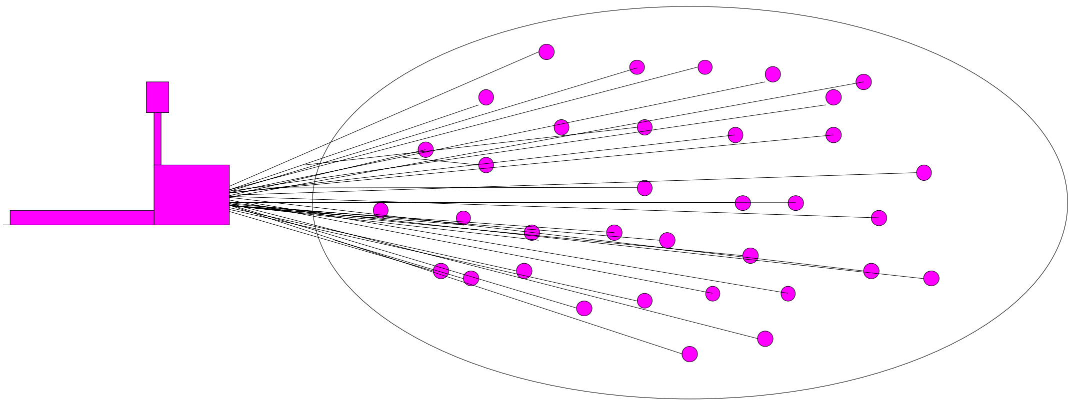

Figure 12. All the wells have separate pipelines leading to a control and regulation station.

A major drawback with the pipelines is that the water in the gas condenses and if the pipelines have some water loops, it is impossible for the gas to pass through. The under pressure is normally less than 70 mbar, so even a small loop makes maximum trouble.

In the Nordic countries there are three different preferences for speed of the gas in the pipes:

- High speed
- Normal
- Low speed

A research into practices in the different countries showed that in Sweden one company thinks that there are no problems with water loops if the speed of the gas is high enough. Therefore they use pipelines with a diameter of only 32 mm (high speed).

In Finland one company argues that water loops are less of a problem with wells with diameters of 80 mm (low speed).

Other companies in the Nordic countries use PE pipelines with diameter 40 - 63 mm (normal speed) (figure 13) and use high technology to prevent water loops.

Figure 13. Pipelines (PE63) with underpressure transport LFG from the wells to the collecting station.

5.3.3 Under pressure systems

The technology used is very similar in the Nordic countries. The under pressure is established by a fan or a blower whereas earlier it was common to use centrifugal fans (Fig. 14).

Figure 14. Centrifugal fans were used in early LFG technology (Grinda, Norway).

Today a side channel blower or a compressor is more common (Fig. 15). Normally the under pressure is between 15 and 150 mbar below atmospheric pressure.

Figure 15. Side channel blowers are common to create an underpressure in Nordic LFG plants (Fitjar, Norway)

Earlier LFG extraction plants used equal pressure on many wells. Today, landfill owners prefer pressure control of each well to secure maximum gas output. It can be difficult to make fine adjustments on the gas stream with normal cheap valves (butterfly, ball valve etc.) and so special gas valves are used.

All pipelines are connected to a manifold. The manifold has 3 functions:

1. Mix the gas from all pipelines to a gas with as constant quality as possible
2. Expand the gas to drain out water
3. Give equal underpressure to each pipeline before pressure regulation.

To fulfill these 3 aims, the manifold should have a large volume. Only one of these large volume manifolds have been built (SVA, Norway; Fig. 16), probably because of installation costs. However, at least 10 plants in Norway have been built with a horizontal cyclone manifold (Ø=600 mm). These manifolds achieve all three aims, are cheaper and more space effective than large volume manifolds (Fig. 17).

Figure 16. Large volume manifold installed at SVA, Norway

Figure 17. Manifold with diameter 600 mm, gas valves and taps for manual samples. Svartasmoget, Fitjar, Norway

The typical manifold in Nordic countries is constructed as small as possible, normally between 80 and 200 mm (Fig. 18).

Figure 18. The typical manifold in Nordic countries. Automated volume control and rotameters for manual volume registration on each well. Denmark.

The blower system is connected to the manifold via a standard filter to stop particles, and in some cases even a cyclone to remove excess water and particles (Fig. 19).

Figure 19. Filter and cyclone to remove excess water and dust/particles (Svatrasmoget, Fitjar, Norway).

5.3.4 Safety systems

The methane content in landfill gas makes it an explosive gas. Methane content between 5 and 15 vol% in air creates an explosive mixture. LFG, with a methane concentration higher than 30 % burns in air.

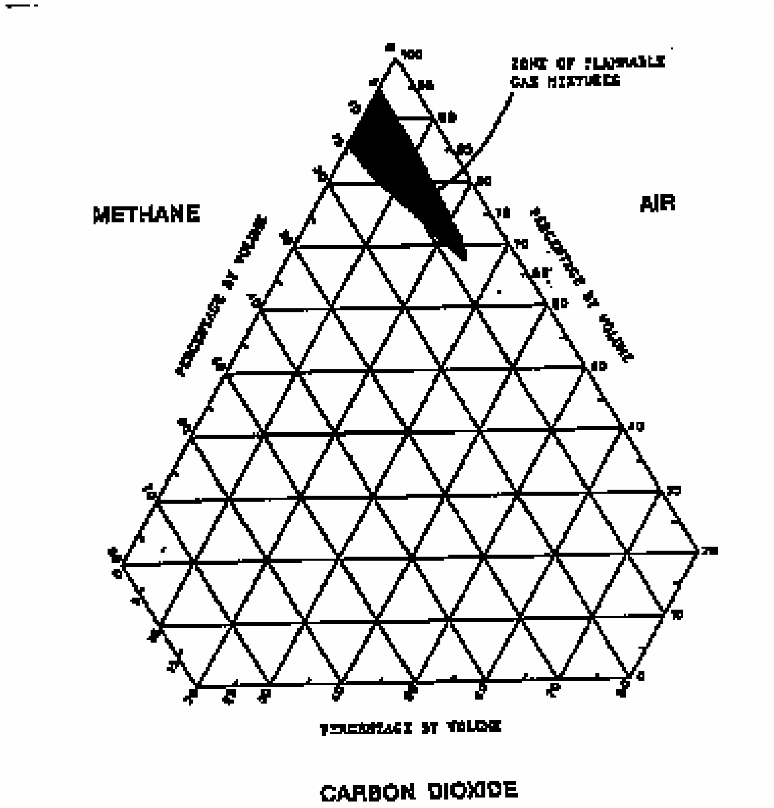

Figure 20. The diagram for CH_4

In all the Nordic countries laws regarding explosive and combustible products restrict treatment of LFG. The plant must have permission from the appropriate authorities. In Denmark, Finland, Iceland, and Norway this is the local fire service and in Sweden it is the local building authorities (in Sweden a plant that use the gas on the spot, pressure less than 1 bar, do not need permission).

Countries in warmer climates than the Nordic countries, may use simpler solutions with minimum safety equipment as they can use open-air solutions (Fig. 21).

Figure 21. Open solution needs minimum of safety requirements (USA).

In Norway and Sweden some LFG plants have been built using a philosophy of simpler solutions. The Nordic adjustments includes some covering for vital instruments/engines to protect against rain and snow, although the rest of the construction is not under cover.

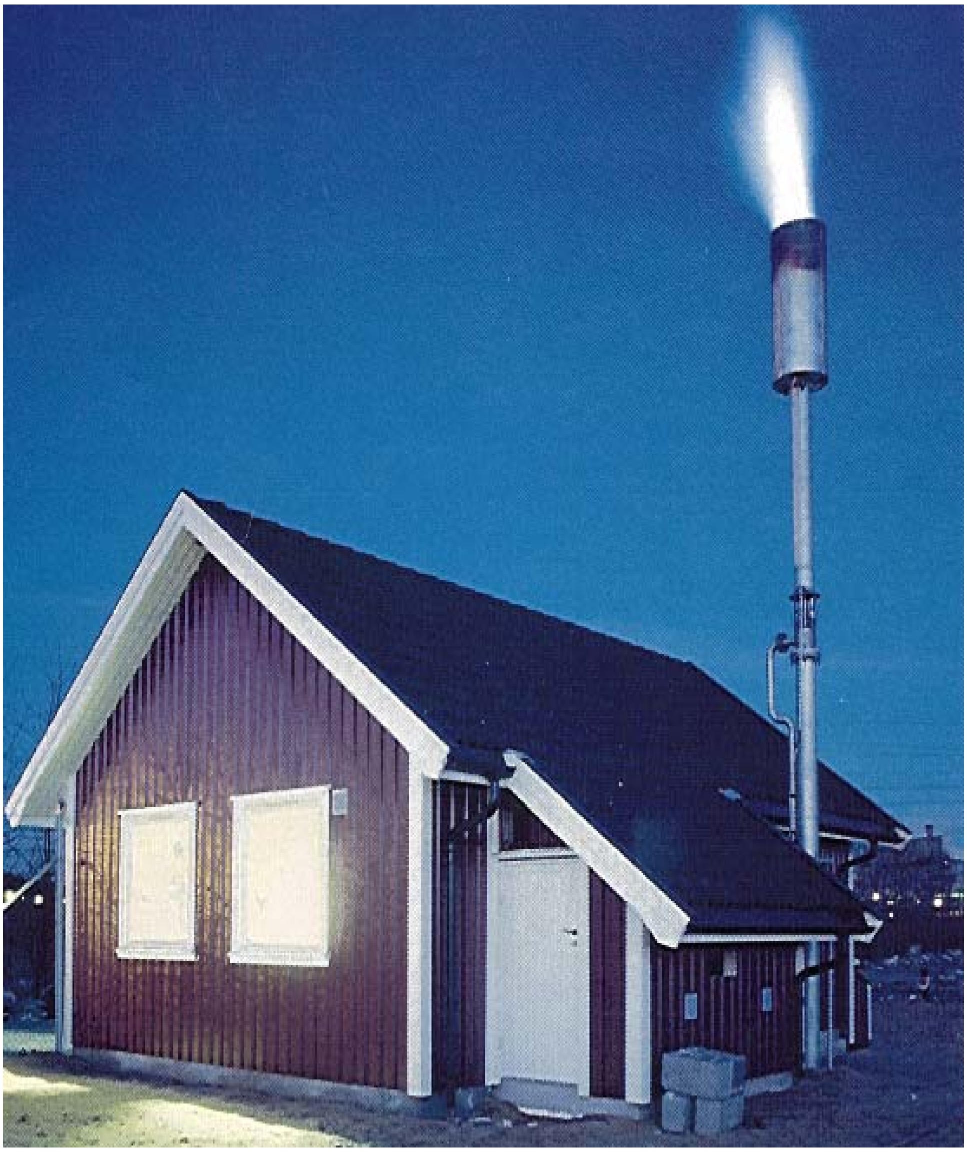

Figure 22. Built-in pumping stations in Nordic countries. In some cases, the stations resemble a home such as in Gatedalen, Norway, and in other places more like industrial buildings

In all Nordic countries except Sweden, gas pipes overground ought to be in steel, although there are built LFG plants in Norway with overground PE pipes. In connection to analysis, it is permitted to use natural gas quality equipment.

The practice regarding equipment differs a little between the Nordic countries, especially for the blowers. Sweden accepts gas-tight engines, but Norway requires flameproof machines (EX-labeled) .

The plant must go to an immediate shut down (minimum requirements) if one of the following situations occurs:

- Fire or smoke
- Gas in the processing room (40 to 60% LEL). Not required for open solutions.
- Too much oxygen in the gas (from 3 to 8 vol%)

Normally it is a two-step regulation, one alarm warning that something is abnormal and a second step closing the plant.

To shut down the plant a safety valve is used. It should be opened manually or by power (electricity or hydraulic). If a critical situation should occur, the valve should close automatically with no use of power. Such valves are more expensive than valves closing by power. The last type however, has been installed on many landfills in Nordic countries.

Some plants give warnings by flashing lights, other use a telephone or a direct connection to a 24 hour monitoring station such as the fire service, a wastewater treatment plant or a security company. Safety warnings will be activated by one or more of the factors listed below:

- Low methane content
- Too high under pressure
- Too high/low overpressure
- Too high temperature in outlet gas
- Too high/low temperature inside the collecting station
- Too low temperature in the flare
- Engines overheating
- Analysis system not working

The older plants normally have better security systems. This is probably due to two main reasons, the technology at the time of construction was new and “unsafe”, and the gas collected was to be used as an energy source and be of good quality and of expected quantity.

Newer plants, where the owners have been obliged to build a gas extraction system, seem to opt for the cheapest solution.

According to the landfill directive (Annex 1, 4.2), landfills that receive biodegradable waste must collect and treat landfill gas and utilise the energy, or if this is not possible, the gas must be flared.

Efficient utilisation of gas requires the upgrading of many landfills, especially in Norway. The degree of upgrading depends on the efficiency requirements, however, this is not specified in the landfill directive.

5.3.5 Measuring systems

Until now there has only been safety requirements on measuring systems. However, appendix III in the Directive, requires a gas measurement programme to be introduced. The programme must cover the whole landfill to ensure that the biological processes work satisfactorily and that emissions to the atmosphere are minimised.

This part of the directive will require a lot of work for Nordic landfills. Only a few of the landfills are constructed or prepared for this type of control. The method for achieving this control varies from country to country. Both manual measurements at intervals and automated continuous measurements saved and treated in a data system are acceptable. The directive does not indicate a preference.

To comply with the directive, a landfill must be divided into different segments according to origin, age and contents, and each segment must have their own separate measurement parameters.

A major problem for the Nordic countries may be how to separate the different parts of an operating landfill and how to measure the desired parameters. It is not clear that a substation will separate satisfactory. Sweden in particular has a lot of landfills with substations.

For a large number of landfills in Denmark, Finland, Iceland and Norway, each well is directly connected to the analysis system – these plants will have to upgrade their analysis system to the new requirement.

5.3.6 Over pressure system/utilisation

After the blowers, the gas has an overpressure. If the gas is to be flared, the overpressure can be low (10-50 mbar), but if the gas is to be utilised as heat or electricity or to be upgraded to vehicle fuel or to natural gas quality then the pressure must be higher.

5.4 Flares

There are two main types of flares, open flares and closed flares.

5.4.1 Open flares

Open flare is the original type of flare. There are many different versions and different names of such flares, for example, candle flares or utility flares.

The majority of older flares are "candles". They are cheap and work well, but it is very difficult to measure desired parameters like dioxins, NO_X etc in such flares. It is easier to measure these parameters in closed flares. However, closed flares are very expensive compared to "candles".

5.4.2 Closed flares

Closed flares seem to be chosen for two main reasons:

- As it is not acceptable with a visible flare in for example a residential area or in the vicinity of a main road . In such cases the open flare is covered by a cylinder.
- More accurate data is required about the flue gas. A special construction is required with an isolated chimney and controlled mixing of air. These are complicated and expensive to run, normally increasing operating costs by 70%.

In connection with the US Clean Air Act, the Department of Environment EPA carried out a comparative study on closed and open flares in 1994. They concluded that both types of flare destructed LFG at a 98% level if they were constructed and operated correctly. The study suggested that open flares are "a demonstrated technology for control of landfill emissions and will be considered, along with collection systems, as a basic component in the selection of BDT (best demonstrated technology)". Despite this, closed flares are preferred.

The new EC-Directive requires that the use of landfill gas shall be carried out in a manner which minimises damage or deterioration of the environment and risk to human health. In practice, if a flare is to burn cleanly the temperature must be higher than 750^{o}C to avoid production of dioxins and below 1450^{0}C to avoid NO_x. This means that a temperature between 870 ^{0}C and 1100 ^{0}C is required. In addition, to achieve a clean burning of the gas, 3 seconds are required as a minimum retention time.

Over the last couple of years, most tender competitions have specified high temperature closed flares, but in the majority of accepted bids open flares were chosen.

None of the Nordic countries have legislation concerning biogas burnt in flares, but there are some recommended standards for exhaust emissions from utilising units (incineration /CHP).

There is little control of the efficiency of the combustion except for internal control or in Norway if the regional authority (Fylkesmannen, SFT) requires it. Most Nordic landfills have landfill gas systems with open flares and the maintenance is part of the internal control system.

All LFG plants must have a flare except in Denmark were plants that utilize the energy in the gas are exempt from this requirement.

5.4.3 Pipelines

In many cases the gas is transported to the user in pipelines. The length of these may vary from a few meters to around 10 km.

Normally the gas is transported without any treatment, but in cases where it is difficult to make low-point water drains (as in sub sea transportation), the gas has to be dried.

There are four main methods for drying the gas, adsorption (in a drying medium that has to be changed or dried and reused), absorption (a filter that must be emptied), cooling, or compression combined with cooling.

Figure 23. Drying LFG for transportation 40 m below sea level. Seawater is the cooling medium. (Brennevinsmyra, Mandal, Norway)

Wet gas is transported in PE pipelines (80-200 mm) with low pressure (80-300 mbar) and dry gas normally in PE pipelines (50-100 mm) with high pressure (1-4 bar).

Law restricts the construction of these pipelines. Denmark and Sweden have their own regulations whereas Norway has a short description followed by a note that the Danish or Swedish rules and legislation should be followed for items not covered by the description.

6. Utilisation

The market for energy from LFG is very different in the Nordic countries. Denmark and Sweden have local district heating systems that can normally use all of the gas produced. Finland has no such systems near their landfills, but do have other energy demand facilities. Iceland has an (low-) energy overproduction (hot water) and Norway has almost no district heating systems.

Most European countries including Denmark have a "green current subsidising programme". Such financial support is established to make it economically profitable to produce electricity from LFG.

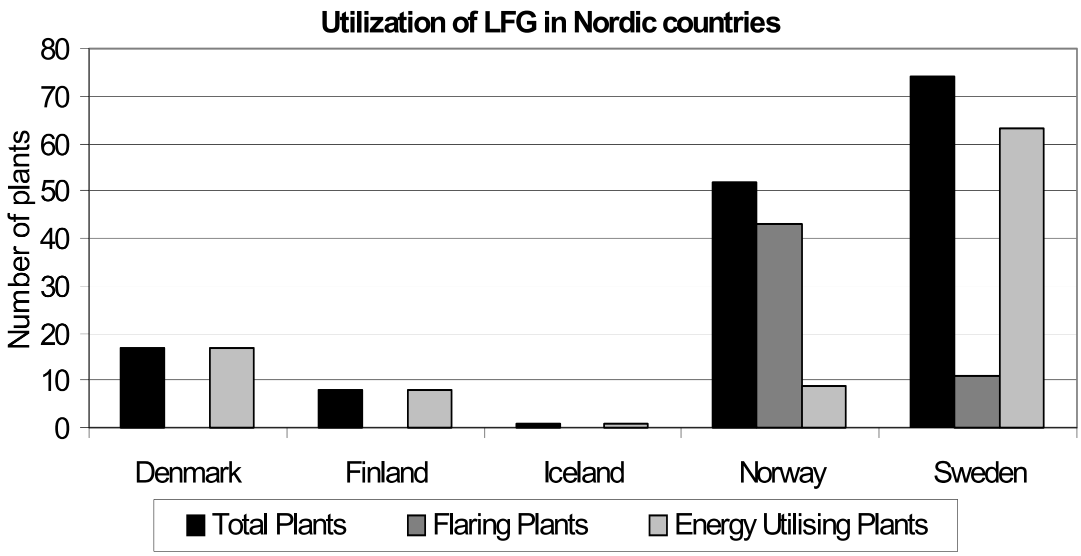

Figure 24. Utilization of energy from LFG in Nordic countries

Figure 24 shows that in Denmark, Finland and Iceland all LFG plants utilise the energy. In Sweden 85% of the plants utilise the energy, while in Norway this is true for only 17%.

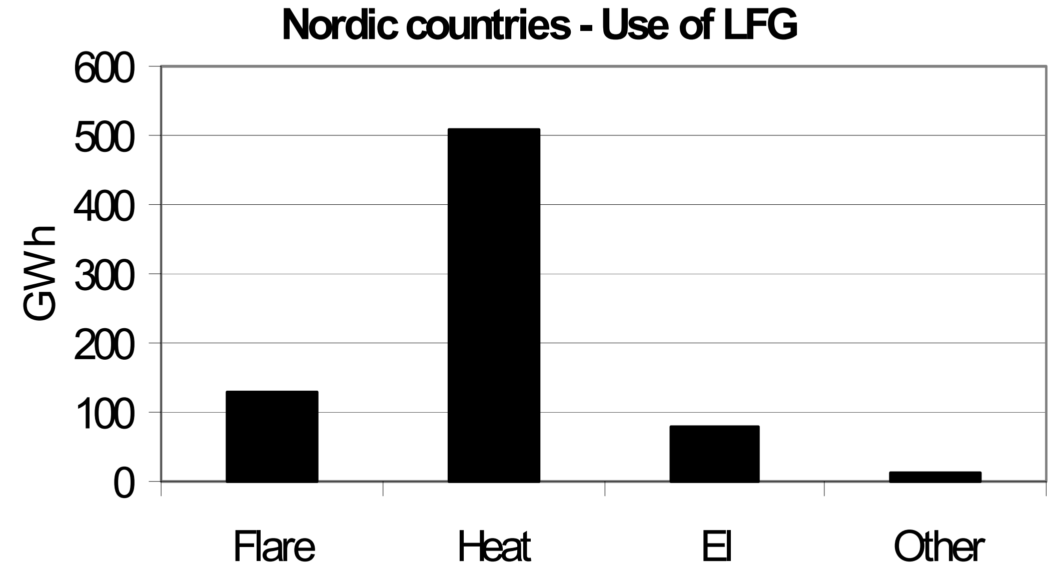

Figure 25. Utilization of energy divided into different way of treating LFG in Nordic countries

In total 730 GWh is produced from LFG in the Nordic countries, 600 GWh is utilised and 130 GWh is flared. Figure 25 shows the different ways in which the energy is used. The reason why around 18% of the LFG in the Nordic countries is flared is because Finland and Norway flare almost half of their production (Fig. 26) and that Sweden, although only 5% is flared, gives a large contribution because of their high total production (table 1).

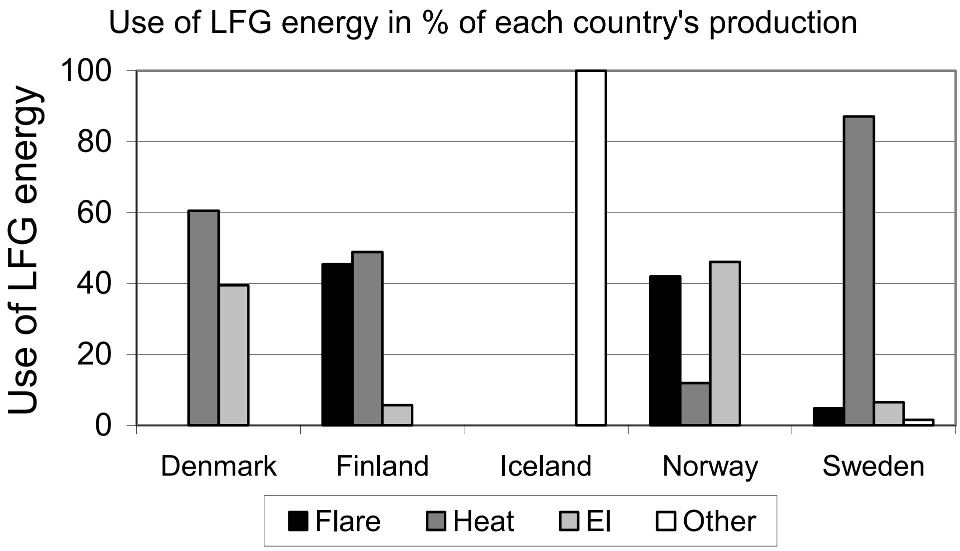

Figure 26. Use of LFG energy in % of each country's production.

Producing heat is the dominant way to use the energy (70%), electricity accounts for 11% and other (the gas is mostly upgraded to vehicle fuel) 2%.

Table 1. Energy production from LFG in GWh

Country	Flare	Energy utlization Heat	El	Other
Denmark	0	13	8,5	
Finland	80	86	10	
Iceland	0	0	0	5,9
Norway	27,9	7,9	30,6	
Sweden	22	400	30	7

Sweden is the dominant producer of LFG in the Nordic Countries. They produce 63% of the energy (table 1 and figure 27) with Finland producing 24%. Denmark, Iceland and Norway only produce 13% between them.

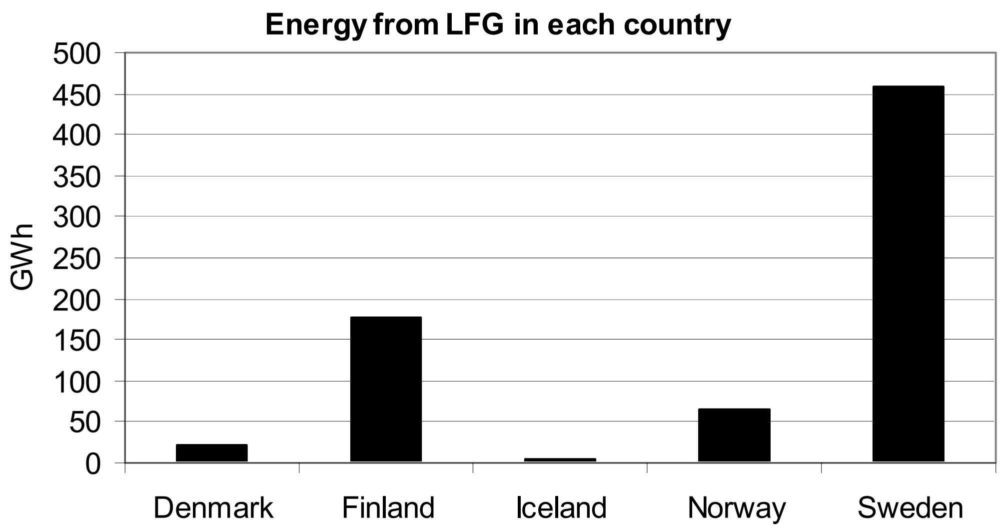

Figure 27. Energy in GWh from LFG produced in each country.

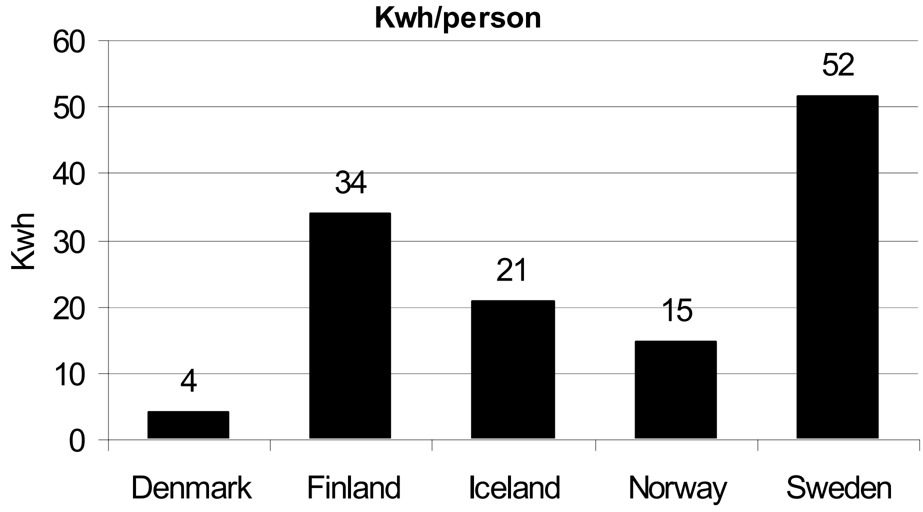

Figure 28. Energy in KWh from LFG produced pr person in each country.

If the energy produced from landfills per person in each country is calculated (Fig. 28) it shows that Denmark produces less LFG energy from waste per person than the other countries. Norway and Iceland produce modest amounts too, however, Sweden has a high level of LFG energy production per person. This may be because of their use of methods of waste handling - incineration, AD etc. or due to the fact that Denmark has reduced the number of landfills dramatically over the last 20 years. All waste deposited in closed landfills is not included in Danish statistics, as it is in the other countries.

This is better illustrated in Fig. 29. If the population pr. square km^2 is compared with numbers of landfills operating,

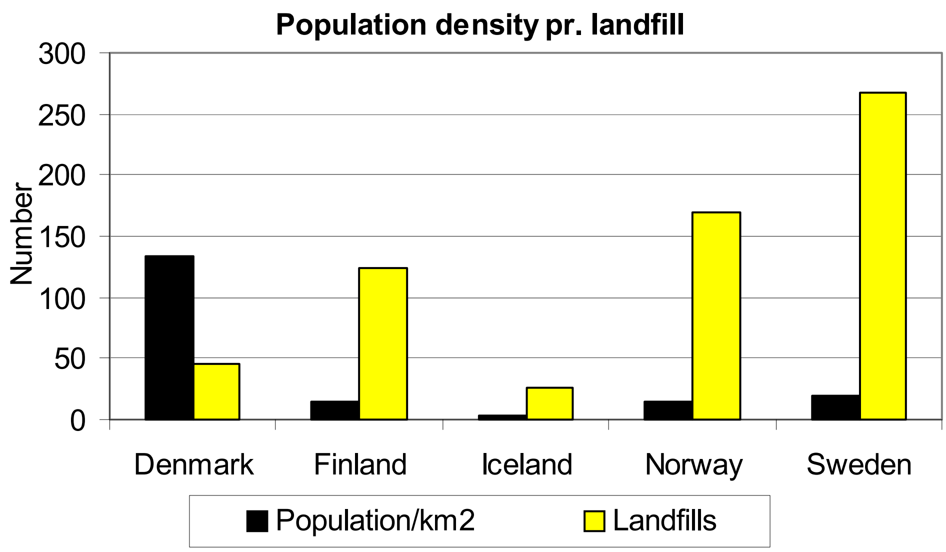

Figure 29. Energy in KWh from LFG produced pr person in each country.

Denmark has a very high population per landfill whilst the other countries have a number of small landfills to cover low-density population areas. If most of these small landfills had a LFG collecting system the energy production from LFG in kwh per person would be like that of Sweden (Fig. 28).

Finland, Iceland and Norway have to put in effort in order to fulfil the EC-directive. In spite of the figures, Denmark has an extraction system on all operating landfills and operate in accordance with the EC-Directive, but the energy output per person is extremely low compared to other Nordic countries.

6.1 Control and upgrading

All countries have some form of internal technical inspection and Denmark, Norway and Sweden occasionally used external inspection.

There is no obligatory control of emissions to the atmosphere.

None of the countries have a national programme for technical upgrading of the process, pipelines or the well system.

There is no legislation or stimulation methods concerning optimising the efficiency of the gas extraction, however in Denmark there is economical compensation if the gas is used to produce electricity. This is probably why Denmark utilise almost all gas in CPH-plants where 40% of produced energy is electrical.

6.2 Gas production and lifetime

Biogas production starts almost immediately after the air in the waste is aerobically digested. After a period of maybe 150 years most of the carbon is used and production will cease. If the gas is extracted, the production will end much more rapidly, also depending on the efficiency of the microorganisms producing the gas .

There are different ways to estimate the gas production lifetime. The Norwegian model for household waste is used to calculate how long it will take before the production is only 10, 20, 30 and 40% of the gas generated the first year (Tab. 4).

Table 4. Norwegian model used to estimate how long time it will take before the production has decreased in % from gas generated first year related to half-life time

% of gas generated the 1.st year	*Half-life time in years*		
	7,5	**9,5/10**	**11**
10	27	31	36
20	17	22	26
30	13	17	19
40	10	13	15

If we presume that it will become difficult to collect LFG once gas production falls 10-20% of gas generated in the first year, it will take between 17 to 36 years (depending on the half-life) before a gas plant on a normal MSW landfill will cease to operate.

According to the landfill directive, the composition and amount of gas must be measured at least every 6th month.

The LFG curve in figure 30 shows that some landfills should start to suck down nitrogen and oxygen very soon.

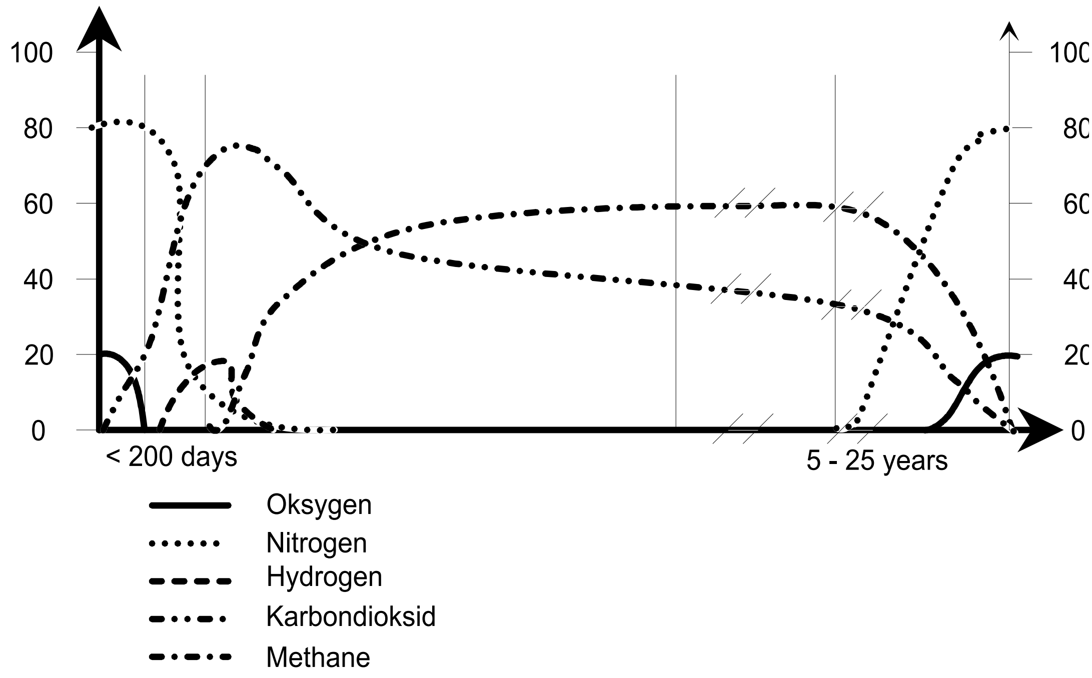

Figure 30. LFG generating curve. Remark the gas composition in end of the graph

So far none of the LFG-plants have been closed down, but the volume of collected gas has been reduced on some old closed landfills. (Hedeland in Denmark was a special case and will not be discussed in this report). Brånås in Norway has produced electricity and hot water for 10 years. The CHP-unit will be changed with a gas burner for further delivery of hot water because of reduced amounts of methane.

7. References

/1/	Birkeland, Knut	LFG in Nordic countries, Kalmar 1997
/2/	Birkeland, Knut	LFG in Norway, NOLET, Luleå 1998
/3/	Ettala, Matti	Pers med. 1997
/4/	Ettala, Matti	Vanhoyen ja sulejettujen kaatopaikkojen merkitys kasvihuonekaaspäästöjen vähent¨miseksi. 140 Ympãristöministeriö 2001
/5/	Gíslason, Stéfan	Answer on a ”Landfill gas questionnaire”. Miljøministeriet, Iceland 2001
/6/	Gustafsson, Ludvik E	“LFG – landfill gas in Iceland. A question list answer”. Environmental and Food Agency of Iceland, 1997.
/7/	Hansen, Jørgen G.	Answer on a ”Landfill gas questionnaire”. Miljøstyrelsen Denmark 2001
/8/	Hope, T	Pers med/Own experiences. Ryfylke Miljøverk, Norway 1998
/9/	Kleffelgård, Tore, SFT	Answer on a ”Landfill gas questionnaire”. SFT, Norway 2001
/10/	Lagerkvist, Anders	Nordic LFG-Database, NOLET Symposium 1996
/11/	Tingstorp, Sofia	Answer on a ”Landfill gas questionnaire”. Natrvårdsverket, Sweden 2001
/12/	Roger, T	Pers med. ROAF, Norway. 2000

/13/ RVF — Afallsanlägningar med deponering. Statistik 1999. RVF Rapport 00:14. ISSN 1103-4092 – Sweden

/14/ SFT — Gassuttak deponier pr. 31.12.1999 – Norway

/15/ Willumsen, Hans — Oversigt over danske lossepladser (1999). LFG Consult – Denmark

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