ENERGY RECOVERY FROM LANDFILL GAS
IN DENMARK AND WORLDWIDE

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ABSTRACT
When waste is deposited in landfills, an anaerobic decomposition takes place, and landfill gas will be produced. The gas contains approximately 50% methane, which can be used for energy purposes. During the last 25 years plants for extraction and utilization of landfill gas has been developed, and today there are approximately 950 plants worldwide. Extraction of gas reduces the emission of methane into the atmosphere minimizing in that way the greenhouse effect. Furthermore, landfill gas substitute fossil fuels such as oil, coal and gas that are all contributing to the greenhouse effect. The risk of explosion is also more or less eliminated.

1. LANDFILL GAS PLANT

A landfill gas plant consists of an extraction system and a utilization system. The whole recovery system can be made for different types of extraction and utilization systems. In figure 1 a wide range of different applications is shown.

The extraction system can for example consist of vertical perforated pipes, horizontal perforated pipes or ditches, and in some cases a membrane covering, under which the produced gas is collected. The gas is sucked out of the landfill by means of a pump or a compressor leading the gas into the production system. The most common use of gas is as fuel in a gas engine running an electric generator. The gas can also be used in a gas boiler for production of hot water for heating or process heating. Under normal circumstances it will not be necessary to purify the gas, except from removal of impurities (particles), if the gas is to be used in a gas boiler or gas engine. In some cases the gas is upgraded to almost pure methane, after which it can be used in the natural gas network. In figure 2 the principle of a typical Danish landfill gas plant is shown.

Figure 1. Landfill Gaz Utilization Options
(Source: Conestoga-Rovers & Associate)
1.1. Extraction System

Mostly, the gas extraction takes place through vertical perforated pipes. This might be due to the fact that this is the simplest way of carrying out the system, when the landfill has already been established.

However, in a number of sites horizontal suction pipes will be built in when the waste is deposited on the landfill. In this way the gas can easier be extracted from the very beginning of the gas production, as the gas can then be sucked out before closure/covering of the landfill.

Sometimes an impermeable membrane will cover the landfill, and almost all the gas can then be collected and recovered. This, however, is a very expensive solution, but it is used in countries, in which there are strict demands as regards covering of landfills. But, as such a solution obstructs penetration of water the gas production will soon stop. Therefore, injection of water under the membrane will be necessary in order to maintain a gas production.

The gas is sucked out of the landfill by means of a gas pump or a compressor leading the gas to the utilization plant by means of pressure in the transmission pipe.

The connection of the single wells to the pump and utilization system can be done in different ways. The oldest and maybe most common way, is to connect the wells to a main collection pipe which go around on the landfill.

The main problem with this system is the difficulty involved with the regulation of both the quality and quantity of the gas. Another problem is to find the location of leakiness when all the wells are connected in one big system.

To save operation costs and to have good conditions for the workers, the best solution is to have single pipes from each well to a pump and regulation house.

1.2. Utilization System

The gas can be used in a gas boiler for the production of hot water for heating or process heat. Very often the landfill gas is used as fuel in a gas engine, which drives a power generator. Under normal conditions it will not be necessary to clean the gas, except for the removal of particles if the gas is used in a gas boiler or a gas engine.

There are also other possibilities for using the gas, such as direct use, upgrading to natural gas quality, fuel for Vehicles, use in fuel cells, leachate evaporation, etc. The different use will be looked upon in the following paragraphs.
1.2.1 Power production and Combined Heat and Power Plant (CHP Plant)

The most known use of the gas is in a gas engine running an electric generator producing power. The normal plant sizes with gas engines produce between 350 and 1200 kW power per engine. In a number of European countries it is also normal to use the waste heat from the cooling water, exhaust and oil cooling system of the engine. This, however, is unusual in the USA, although more than 50% of the available energy is hereby lost.

In larger plants, in which the power production lies around or above 4 MW, gas turbines are sometimes used, and in very large plants steam turbines can also be used. Thus, the largest plant in the world delivers 45 MW power from a steam turbine.

CHP plants compared with only power production are the most efficient system for utilizing the energy from landfills. The stream of energy is shown in figure 3.

![Figure 3. Sankey-diagram describing the energy flows of the CHP plant](image)

In principle, there are two types of gas engine plants: spark-ignition engines and dual-fuel engines. Spark-ignition engines can be used for CHP plants with generating capacities all the way from 20 kW to 6-8 MW. Dual-fuel engines are not made for very small capacities.

Spark-ignition engines are made in large numbers and the design is relatively simple. They are, consequently, not as expensive as dual-fuel engines, for which reason most gas engines used are of the spark-ignition type.

Both spark-ignition engines and dual-fuel engines are piston engines. In a spark-ignition engine, sparking plugs are used to ignite the gas, while in dual-fuel engines, 5-8% diesel fuel is injected to ignite it. The injection system naturally implies a more complex plant, but offers supply reliability, because dual-fuel engines can be switched at short notice to 100% diesel fuel operation.

1.2.2 Boiler System

The second most common use of landfill gas takes place in gas furnaces, in which the gas is used for heating of water in a boiler system. This is a simple system, and reason for this solution not being the most used must be the fact that the price per kW power produced is almost higher than the price per kW heat. Another reason could also be that the power is relatively easily sold in unlimited quantities via the power distribution network.

The heat from some boiler systems is used in greenhouses, either by normal circulation of hot water, or by heating of air that is blown into the greenhouses. This is also a relatively simple and efficient way to use the gas.
1.2.3 Direct Gas Use

Some of the landfills in UK are made in old open clay mines, from which the clay has been used in brickyards for making bricks. Many of these factories use natural gas in the kiln. When the waste in the landfills just outside the brickyard produce landfill gas it is obvious to try using the gas directly in the kiln instead of using natural gas. In some cases the landfill gas is used in a mix with natural gas.

Another possibility could also be using the gas in kilns for cement production.

1.2.4 Upgrading to Natural Gas Quality

Some plants upgrade the landfill gas to natural gas quality. Consequently, the gas can be distributed through the natural gas distribution network. In this way the utilization plant is spared. In return, big investments in gas purification plants will be necessary. In the USA there has been approximately 10 plants of this kind, however, only 5 of these are left. In Holland there are 4 plants, but it should be noticed that in Holland the demands as regards gas quality are not quite as strict as in the US.

Prior to delivery of upgraded landfill gas to the natural gas network it is required that the gas must be free from particles and liquid. Furthermore the gas must be odourized.

The main step in the upgrading process is the separation of methane and carbon dioxide. For this process three techniques are applied:
- Chemical Absorption
- Pressure Swing Adsorption (PSA)
- Membrane Separation

1.2.5 Use of Gas in Vehicles

Various places in the world, for example the USA, Brazil, France, etc., there are plants, in which the landfill gas is compressed and used in either compactors, refuse collection vehicles, busses or ordinary cars. The tax system differs in the single country and is important when finding out whether the system is profitable or not. Furthermore, the profitability depends on the system that is chosen, thus, it will be relatively expensive when investing in a system that is only used for a few numbers of vehicles.

1.2.6 Fuel Cell

The landfill gas can also be used in fuel cells. This system has been tested in the USA during some years with a production from 25 kW and up till 200 kW plant. The investment is high, for which reason it is not yet a profitable solution.

Fuel Cells may be compared to large electric batteries, which provide a means to convert the chemical bonding energy of a chemical substance directly into electricity. The difference between a battery and a fuel cell is, that in a battery, all reactants are present within the battery and are slowly being depleted during battery utilization. In a fuel cell the reactants (fuel) are continuously supplied to the cell.

Compared to traditional power generation technology, fuel cell has some characteristics, which could be mentioned:
- High electricity conversion efficiency levels about 40 to 50 %;
- Air emission are extremely low;
- Low labor and maintenance requirement;
- Low noise level;
1.2.7 Leachate Evaporation

Treatment of leachate is one of a number of environmental concerns when looking at the operation of a landfill. The design, construction and operation cost can be heavily influenced by the need for leachate treatment. Leachate can be treated in a normal waste water treatment plant. In some cases the leachate is recirculated through the landfill, in which process some “self cleaning” of the leachate takes place. Another possibility is to use the landfill gas as fuel for evaporation of the leachate.

2. RECOVERY OF LANDFILL GAS IN DENMARK

2.1. Research and Development

Since 1981 the Danish Ministry of Energy/the Danish Energy Agency has subsidized various projects. The aim has been to determine the possibilities of exploiting landfill gas from the relatively small landfills in Denmark. In addition, the aim of some of the projects was to optimize gas recovery.

2.2. Pilot Plant

In 1983/84 a pilot project was established in Viborg on approximately 1 ha of the landfill of Viborg Municipality. The plant consisted of eight wells with perforated pipes, from where the gas was sucked up by a gas pump via a recovery system. The gas was applied as fuel in a gas engine/generator unit.

The engine was a diesel engine rebuilt for spark ignition. The production of electricity was approximately 30 kW and the production of heat approximately 55 kW. The pilot project was supplied with a comprehensive measuring equipment which continuously measured gas-flow, gas composition, energy production, temperature, pressure, weather parameters, etc.

The results from the pilot plant showed that 15-20 m³ landfill gas per hour could be recovered from the experimental site, corresponding to approximately 3 m³ landfill gas per year from each ton of waste.

2.3. Demonstration Project

In 1985 the first full-scale plant in Denmark was established, i.a. as a demonstration project for the EU. The plant is erected on a landfill at Viborg with approximately 350,000 tons of waste.

The plant consists of a recovery system with 32 vertical wells. From the landfill, gas is piped to a district heating station where it is used in a boiler and in two engine/generator units. One of them was a Stirling machine, which can run on different types of fuel and with a fluctuating calorific value. The machine caused many problems and is not running any more.

2.3.1 Automatic measuring and regulation system

An automatic measuring and regulation system was developed in Denmark in 1983 in connection with a Danish Energy Research Program and later in connection with the EU demonstration project in Viborg, in order to avoid some of the problems occurring by manual regulation of the gas flow especially in shallow landfills.

This system has been improved throughout the years and is nowadays built up in a container and called a MPR module (Measuring, Pumping and Regulation module), see figure 2.
From each well a horizontal pipe leads to a measuring and adjustment container. Where the gas pipes from the individual wells enter the measuring and adjustment system in the container, samples are taken and analyzed automatically in an infrared analyzer.

![Figure 4](image)

**Figure 4.** Adjustment of the gas quantity (Source: Willumsen)

At the beginning, a set-point for the gas quality was chosen for each well and put into a computer system. Dependent on the results of the automatic measuring, a valve on the gas pipe in question is adjusted inside the container. In this way a constant methane percentage is reached and necessarily also a varying gas flow. Figure 4 shows the changing of the gas quality as the regulation system opens and closes the gas flow.

Today the system is developed to optimize the gas extraction and to have the maximum available energy output from each well.

### 2.4 Existing Landfill Gas Plant in Denmark

To give an overview of the Danish plants, data appears from table 1. The total gas production from the plants is approximately 140,000 m$^3$ per day, corresponding to the energy consumption of approximately 13,000 Danish households.

**Table 1.** Danish Landfill Gas Plant 2001 (Source: Willumsen).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Start of plant</th>
<th>Waste amount 1,000 t</th>
<th>Gas production m$^3$ LFG/hour</th>
<th>Energy content kW/time</th>
<th>Utilization System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viborg</td>
<td>Oct. 1985 + Oct. 2001</td>
<td>1,000</td>
<td>200</td>
<td>1,000</td>
<td>CHP Plant and Boiler</td>
</tr>
<tr>
<td>Grindsted</td>
<td>Nov. 1985</td>
<td>290</td>
<td>120</td>
<td>540</td>
<td>District Heating</td>
</tr>
<tr>
<td>Hedeland</td>
<td>Nov. 1986</td>
<td>1,000</td>
<td>0</td>
<td>0</td>
<td>District Heating</td>
</tr>
<tr>
<td>Esbjerg</td>
<td>May 1988</td>
<td>1,400</td>
<td>360</td>
<td>1,660</td>
<td>CHP Plant</td>
</tr>
<tr>
<td>Østdeponi</td>
<td>July 1989</td>
<td>800</td>
<td>360</td>
<td>2,000</td>
<td>CHP Plant</td>
</tr>
<tr>
<td>Sandholt - Lyndelse</td>
<td>June 1992</td>
<td>800</td>
<td>340</td>
<td>1,660</td>
<td>Power production</td>
</tr>
<tr>
<td>Højer</td>
<td>Dec. 1992</td>
<td>260</td>
<td>100</td>
<td>580</td>
<td>Power production</td>
</tr>
</tbody>
</table>
3. LANDFILL GAS PLANTS WORLD-WIDE

Today approximately 950 landfill gas plants exist worldwide, from which the gas is used for energy purposes. In table 2 is an overview for the location of the plants. However, the numbers for some of the countries may be taken with reservation, when it has not been possible to get exact data from all the countries.

Table 3. Number of landfill gas plants world-wide 2001 (Source: Willumsen)

<table>
<thead>
<tr>
<th>Country</th>
<th>Approx. number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>325</td>
</tr>
<tr>
<td>Canada</td>
<td>25</td>
</tr>
<tr>
<td>Germany</td>
<td>150</td>
</tr>
<tr>
<td>France</td>
<td>10</td>
</tr>
<tr>
<td>Holland</td>
<td>60</td>
</tr>
<tr>
<td>England</td>
<td>135</td>
</tr>
<tr>
<td>Spain</td>
<td>10</td>
</tr>
<tr>
<td>Italy</td>
<td>40</td>
</tr>
<tr>
<td>Austria</td>
<td>15</td>
</tr>
<tr>
<td>Switzerland</td>
<td>10</td>
</tr>
<tr>
<td>Norway</td>
<td>20</td>
</tr>
<tr>
<td>Denmark</td>
<td>21</td>
</tr>
<tr>
<td>Sweden</td>
<td>70</td>
</tr>
<tr>
<td>Finland</td>
<td>10</td>
</tr>
<tr>
<td>Poland</td>
<td>10</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>5</td>
</tr>
<tr>
<td>Hungary</td>
<td>5</td>
</tr>
<tr>
<td>China</td>
<td>3</td>
</tr>
<tr>
<td>Australia</td>
<td>25</td>
</tr>
<tr>
<td>Brazil</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>955</strong></td>
</tr>
</tbody>
</table>
4. ECONOMY

4.1 Investment costs in LFG recovery system

The extraction system consists of collection system (in the waste) and a suction system, consisting of pumps, monitoring and control systems. For an average 10 meter deep landfill the investments in collection system will range from 20,000 - 40,000 US$/ha, and the suction system range from 10,000 US$/ha - 45,000 US$/ha.

The average range of investment costs per kWₑ power installed for an entire landfill gas recovery system is summarised in the following table 3.

<table>
<thead>
<tr>
<th>Component</th>
<th>Costs in US$/kWₑ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection system</td>
<td>200-400</td>
</tr>
<tr>
<td>Suction system</td>
<td>200-300</td>
</tr>
<tr>
<td>Utilization system</td>
<td>850-1,200</td>
</tr>
<tr>
<td>Planning and design</td>
<td>250-350</td>
</tr>
<tr>
<td>Total</td>
<td>1,550-2,250</td>
</tr>
</tbody>
</table>

4.2 Revenue from landfill gas recovery

Revenue from landfill gas recovery is significantly dependent on the type of energy produced. Price for selling of electric power to grid range from one country to another but will normally be in the range of 0.01 US$/kWhₑ (off peak hour) to 0.08 US$/kWhₑ (peak hour) with an average of 0.04 US$/kWhₑ.

To make landfill gas recovery feasible without subsidies the produced electricity in the USA and United Kingdom should be sold at a price of some 0.030 US$/kWhₑ or higher. For small landfills (less than 500,000 ton) e.g., Denmark the produced electricity should be sold at 0.055 US$/kWhₑ or higher to make landfill gas recovery feasible.

Price and regulations in the country for subsidizing renewable energy sources (to promote CO₂ reduction). Subsidies for selling of electric power may range from 0.004 US$/kWhₑ in the USA to 0.04 US$/kWhₑ in Denmark.

5. REFERENCES


ENERGIJOS GAVYBA IŠ SĄVARTYNŲ DUJŲ DANIOJE IR PASAULYJE

Reziumė