DAS – IB GmbH

DeponieAnlagenbauStachowitz

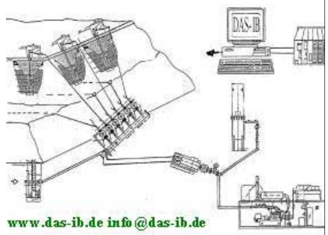
LFG - & Biogas - Technology

Biogas-, sludge gas and landfill gas technology:

- Consulting, planning, project management
- Training of system operators
- Expert i.a. in accordance with § 29a of the Federal Immission Control Act; and Qualified Person reg. the Ordinance on Industrial Safety and Health and the Technical Regulations (TRBS 1203)

Techn. domicile:
Preetzer Str. 207
24147 Kiel, Germany

Comm. domicile:
Flintbeker Str. 55
24113 Kiel, Germany



www.das-ib.de info@das-ib.de

Phone.: # 49 / 431 / 68 38 14 / 53 44 33 - 6 or 8
Fax.: # 49 / 431 / 200 41 37 / 53 44 33 -7

Energy supply of a landfill site in the after care period by LFG, sun, oil, natural gas etc

 # 310

Wolfgang H. Stachowitz

DAS – IB GmbH, LFG - & Biogas - Technology, Kiel, Germany

Contents

1 Task

DAS - IB GmbH was placed in charge of the development of concepts regarding the future landfill-gas utilisation / self-sustaining energy supply on two landfills.

The existing types of gas utilisation and the energy supply on the landfills mainly consist of the gas collection system with a gas well, a gas compressor station, and a gas-Otto engine each (Deutz TBG 234 V 8 with 250 kW_{el}), a high-temperature flare system and, in one case, a propane gas heating boiler. With each of the existing CHPs, the electric and thermal energy demand of the existing plant technology (e.g. heating system of the buildings and leachate treatment plant) was covered in the past. As a result of the current and future landfill gas resources and of the landfill age with the regressive amounts of gas to be expected, the respective existing CHP would presumably have to be shut down in summer 2011 or operated discontinuously.

Therefore, the concepts of DAS – IB GmbH will investigate the future gas utilisation taking into account the possibility of self-sufficient operation (internal energy supply) of the existing plant technology and compare the different possibilities with regard to economic criteria.

1.1 Interfaces

In these concepts, the following methods were examined regarding the covering of electrical and thermal base loadsl:

- Microgas turbine
- Dual fuel engines
- Gas-Otto engines
- Heating boilers (two-media burners with landfill gas) in connection with a
- Photovoltaic solar power plant (PV).

The installation of the new aggregates shall take place in the respective installation room of the landfills, on available roofs of the buildings or in containers. Besides utilisation of the existing gas compressor stations (smaller rebuildings / adaptations will be necessary) with the raw gas analysis, the smokestack, the emergency coolers and the heat extraction will remain in use as far as this is possible.

The photovoltaic solar power plant (PV) is installed on the roof surface area of the main and adjoining building. In the event that the electricity is exclusively provided via the PV plant, it is necessary to thermally use the collected landfill gas in the aforementioned heating boiler to maintain the heat supply.

1.2 Initial situation and data basis of the concept

The concepts are based on the following documents of each landfill:

- Measured values landfill gas quality and quantity for the individual gas wells, lines and the entire gas system
- Operational evaluations: introduction quantities over time, gas measurements (utilisation and surfaces) over time
- Ground plan gas collection system
- The technical data of the existing machine technology
- A landfill gas prognosis on the basis of the current operational evaluation and the assumptions / adaptations of DAS – IB GmbH.

In the following illustration, the chronological course of the collected landfill gas quantities and the respective methane concentration of a landfill from November 2000 to June 2010 is presented.

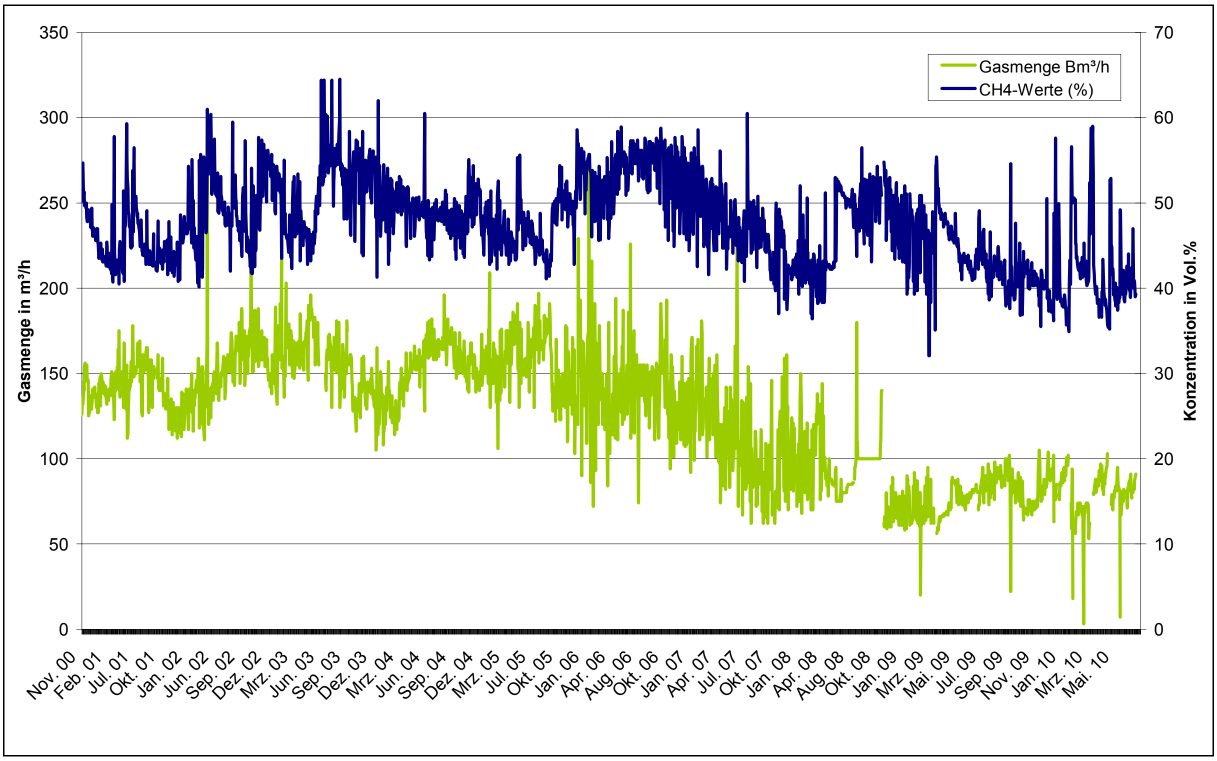


Illustration 1: Development of the collected gas quantity and quality on the basis of monthly mean values. Source: own figure on the basis of "Measured values landfill gas quality and quantity". graph: Gas quantity / CH_4 values (%) /Gas quantity in... / Concentration in vol.-% / -> months -> Oct.-Dec.-March ......

In Illustration 1, it can be seen that a clear reduction in the collected gas quantities and their methane content has taken place since January 2009. In addition, it is obvious that with the increase of the volume flow since 2009, the methane content of the landfill gas decreases with a certain retardation. In contrast, a reduction of the volume flows normally leads again to increasing methane contents (see Illustration 2).

On a landfill, 32 gas wells were operated to collect the landfill gas. However, as a result of the regressive gas yields caused by increasing biological inactivity, only nine gas wells still achieved a measurable gas yield, for example during the measurement in July 2010. Within the scope of these measurements, the DAS – IB GmbH employees ascertained that the measuring sections of the individual gas wells are suitable for regular measurement only to a limited extent, as the compositions (measurement port and ball valves) were not standard and to some extent difficult to access.

Possible improvements regarding the existing gas collection system of both landfills are not subject to examination in this report.

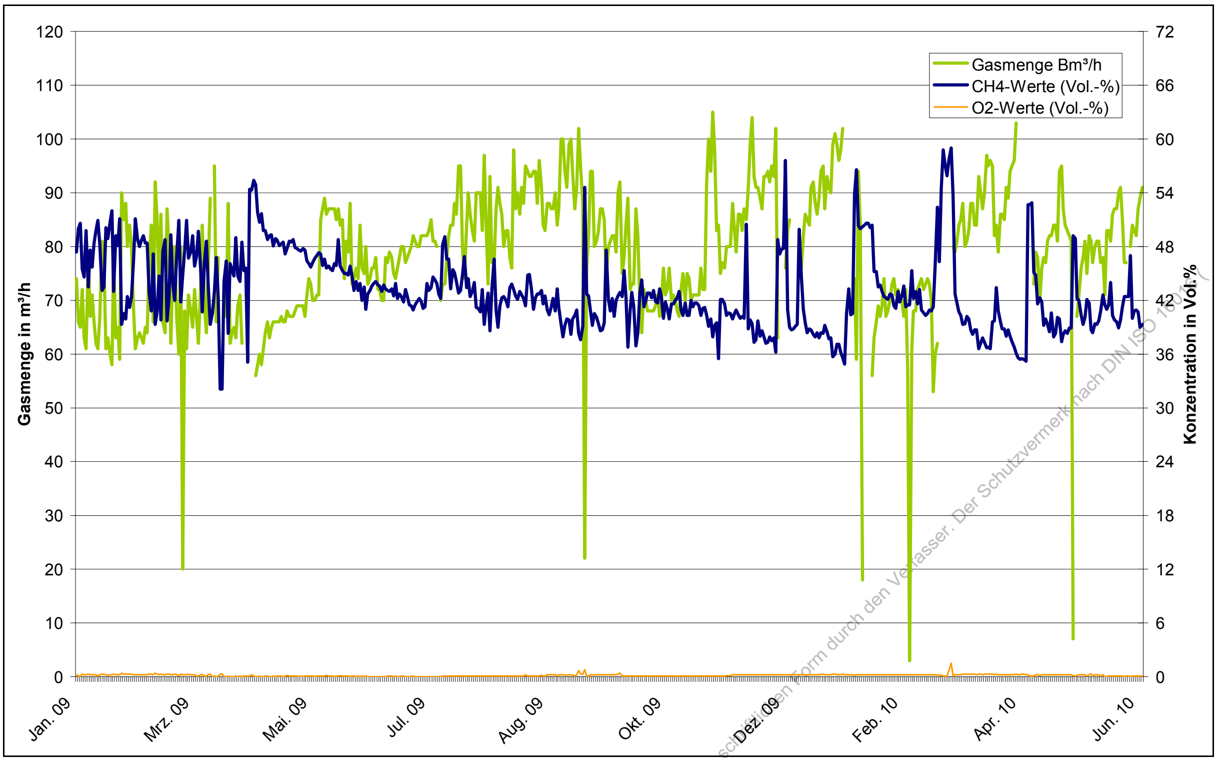


Illustration 2: Course of the landfill gas composition of a landfill on the basis of the monthly mean value of individual measurements from January 2009 onwards. Source: own figure on the basis of "Measured values landfill gas quality and quantity". graph: Gas quantity / CH_4 values (%) / O_2 values / Gas quantity in... / Concentration in vol.-% / -> Monate -> Mar.- May -Oct.-Dec.-.....

The landfill gas composition shows that the landfill is probably in the final phase of gas production (see Illustration 2). From the individual values of the gas wells it is concluded that, during the presented period, all gas wells seemed to be in the air infiltration phase.

For the prognosis of the development of the gas quantities, different models are usually used, for example the model of Rettenberger and Tabasaran (RETTENBERGER 1992) or the model of Weber (WEBER 1990). As the Weber model forecasts better results for open landfills and the Rettenberger model better results for sealed landfills (see SCHNAPKE 2006), DAS – IB GmbH used the Rettenberger model for the landfill with its own adaptations for the gas prognosis.

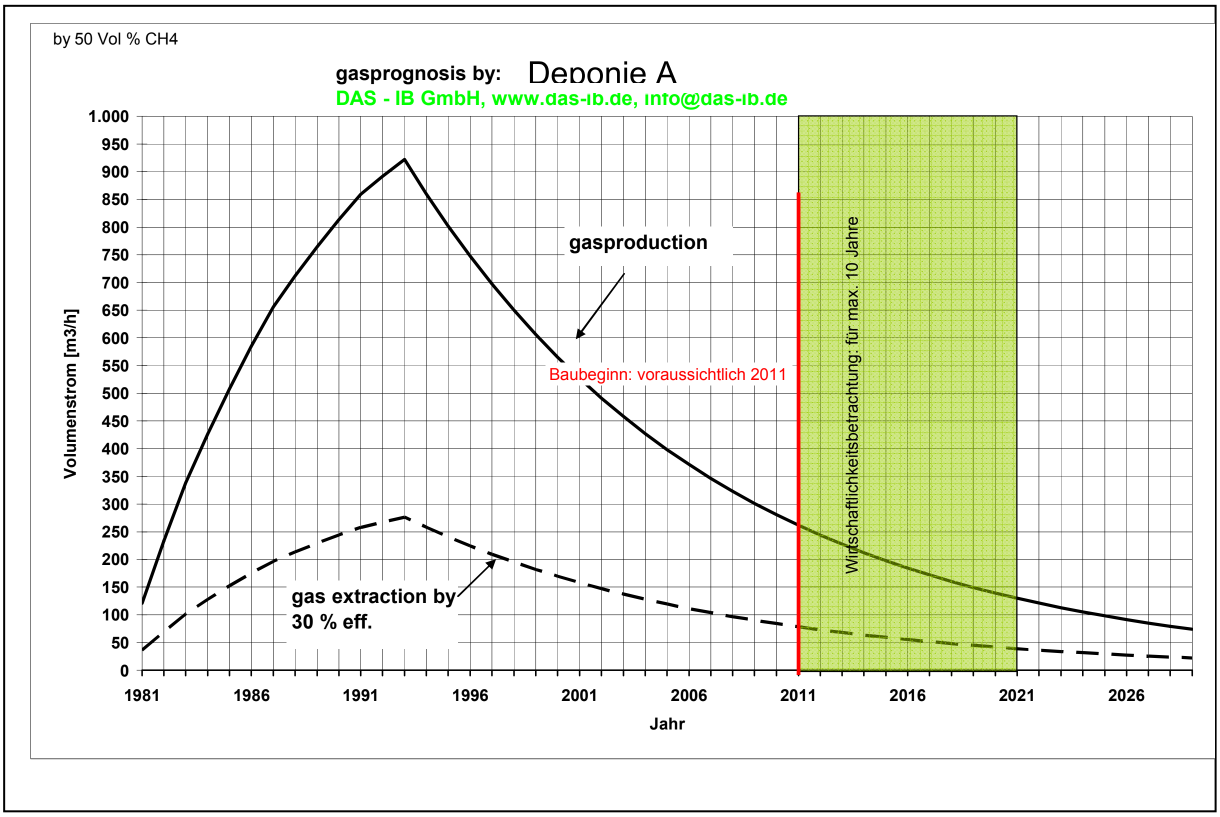


Illustration 3: draft of the landfill gas prognoses (at an assumed efficiency of the collection system of 30% and a CH_4 content of 50 vol.-%) of the landfill. Graph: Gas prognosis by:....Landfill A/ Volume flow / Gas production / Start of construction: probably in 2011 / Profitability analysis for max. 10 years / Year

The landfill gas prognoses production over time - in Illustration 3 was calculated according to the following empirical formula.

$$G = 1{,}868 \bullet C_{org.} \bullet (0{,}014 \bullet \vartheta + 0{,}28) \bullet (1 - 10^{-k \bullet t})$$ **Formula 1**

with:

C_{org} This value normally lies between 170 and 220 kg / Mg_{waste} for domestic waste but should be chosen for each landfill on the basis of the available analysis data. We have calculated with 104 kg / t to make an adjustment to the actual measured values regarding the landfill gas quantities.

ϑ : The temperatures in landfills lie in the range between 20°C and 50°C. It is important to state that the use of the model is only permissible for the mesophilic range.

k-value: On the basis of our experience and the actual measured values on location, we have chosen a k of 0.07.

It must be noted that, in view of the information presented to us regarding placed amounts and qualities of waste which were available for the prognosis, exact prognosis is impossible and that the obtained values, as shown in Illustration 3, can only serve as an orientation.

On the basis of the comparison of the landfill gas prognoses yields and the actually collected landfill gas quantities (see Illustration 4), it can be assumed that the landfill gas yield in the example will decrease within the next 10 years to 20 m³ / h at 50 vol.-% CH_4.

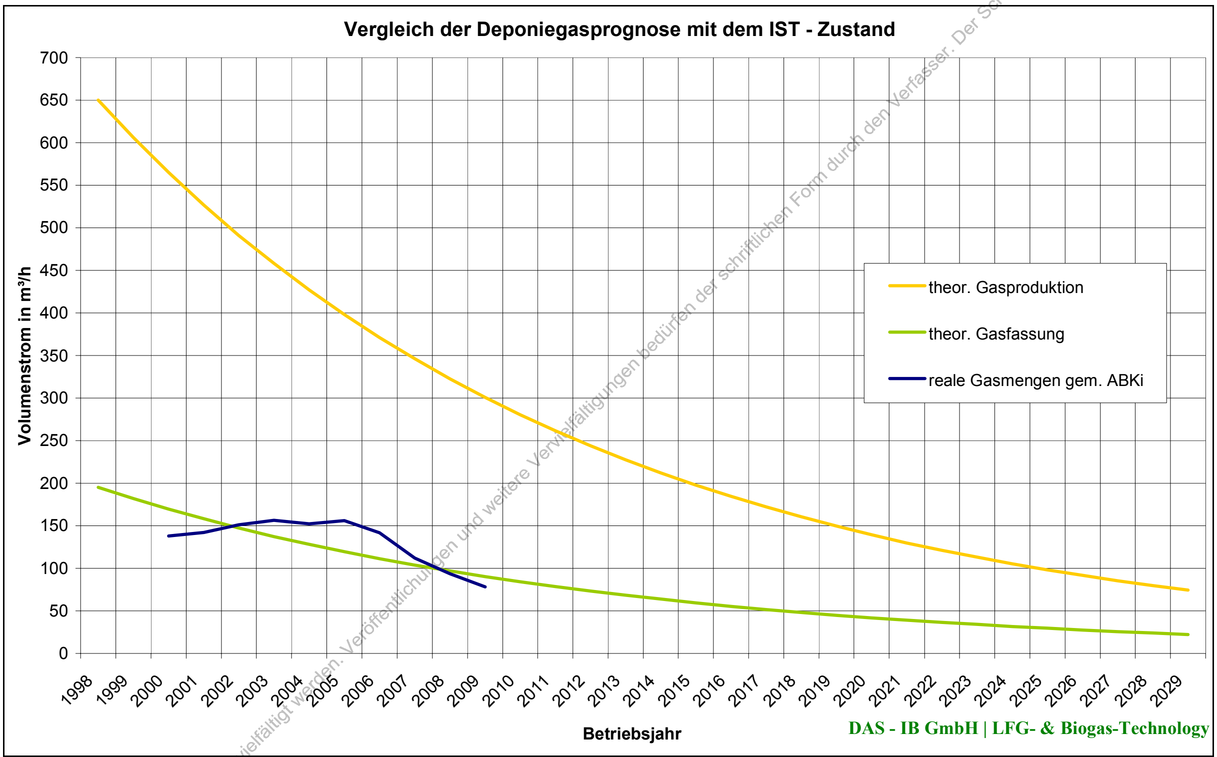


Illustration 4: Comparison of the current landfill gas yields with the values we forecasted (assumed efficiency of the collection system 30 %, and a CH_4 content of 50 vol.-%). Graph::Comparison of the landfill gas prognosis with the current situation / Volume flow in...../ Theor. gas production / Theor. gas collection / Actual gas quantities acc. to operation by owner / Year of operation

The development of the methane proportion in the landfill gas cannot be deduced from the prognoses regarding the development of the quantity, as further influencing factors such as the ambient fraction in the landfill gas which is due to oversuction and the behaviour of the biology cannot be figured out.

2 Possible landfill gas utilisations

For safe landfill gas utilisation, those aggregates which can reliably be operated under economic basic conditions (investment costs, operating and maintenance costs) even at lower methane contents are particularly suitable.

Microgas turbines are power units where the generator, compressor and turbine are fixed on a fast-running crane shaft. A peculiarity is the air suspension of this shaft and that the microgas turbine requires no cooling water.

The combustion air enters the microgas turbine by flowing via the generator, cooling the latter during this process to be subsequently compressed in the compressor. In the recuperator, the air is preheated through the hot waste gas (this enhances the efficiency), and is then mixed with the combustible matter and ignited in the combustion chamber. The hot combustion gases are expanded in the turbine and thus drive the compressor and the generator. When the waste gases have released part of their thermal energy in the recuperator, they leave the microgas turbine towards the waste gas heat exchanger or the stack.

The advantages: low maintenance costs, lower waste gas emissions as in gas engines, higher thermal use than in gas engines, operation with lower methane contents than in dual fuel and gas engines possible, longer service life than gas engines, REL remuneration (the German EEG-Vergütung) plus technology bonus (*please check this with your power plant operator).*

Disadvantages: high investment costs, lower electrical efficiency than gas engines.

Dual fuel engines are converted diesel engines which are operated, for example, through the injection of fuel oil or veg - Oil, the so-called auxiliary burning. Auxiliary burning allows utilisation also of landfill gas with a low calorific value.

According to the specifications of the manufacturers, a dual fuel engine can utilise landfill gas from a content of approximately 38 vol.-% methane onwards, at a pilot fuel consumption of approximately 0.8 l / h. Decisive for the operation of the engines is the methane / carbon dioxide ratio, with the CO_2 proportion being the "obstacle" in the system. With a low CO_2 proportion of 10 to 13 vol.-%, the dual fuel engine could also be operated up to 28 vol.-% with modifications to the gas train and the mixer to increase the volume flows, without superelevated pilot fuel consumption.

It is technically possible to operate dual fuel engines to 100% with pilot fuel and to eliminate low-caloric landfill gas through co-firing. The statutory approval situation and the profitability of the operating mode would need to be examined separately in this case.

Advantages: operation with lower methane contents than required for gas engines, low cost.

Disadvantages: operation only possible with pilot fuel, reduced service life compared to gas engines

Gas - Otto - engines function according to the Otto engine principle and were specifically further developed for the operation with biogas and landfill gas. To minimise the nitrogen oxide emissions, these engines are operated as so-called lean mix engines under high air excess. Gas-Otto – engines are used, for example, for the energetic use of poor gases (bio- and landfill gases), which develop during the fermentation of organic waste.

Advantages: more robust than dual fuel engines, tried and tested

Disadvantages: economic operation optimal at methane values of approximately 50 vol.-%.

Grid-connected ***photovoltaic solar power plants*** mainly consist of the photovoltaic modules, one or more inverters, and a safety device for the automatic disconnection in the event of failures in the public utility power plant network. The inverter converts the direct current supplied by the PV modules into alternating current, the performance and voltage values of which are adjusted to the electric supply mains. For grid-connected plants, line-commutated inverters are employed. The total performance of the plant depends on the surface area of the PV modules. Currently merchantable modules require between 7 and 10 square metres per installed kWp (kilowatt peak, defined as effective power at a radiant exposure of 1,000 W / m²). In Central Europe, with an optimum south orientation and an inclination of the modules of approximately 30°, an annual yield between 800 and 1,000 kWh can be expected per kW_p nominal plant performance, depending on the position and on the local conditions.

Heating boilers with a two-media burner are standard heating boilers with specifically-developed burner systems in which, for example, landfill gas, biogas, propane, natural gas or fuel oil as combustible gases are converted into thermal energy.

2.1 Basics of the profitability analysis

All indications regarding investment and operating costs are based on suggested pricing offers for the projects of more than 10 plant manufacturers.

All prices indicated hereafter are net prices, meaning without VAT. Costs such as engineering services according to the HOAI (Fee Structure for Architects and Engineers) and approvals are not taken into consideration. The basics for the suggested pricing offers are the following specifications of the respective customers we received:

- Landfill gas prognosis
- Raw gas analyses
- The internal power demand as an annual mean value of the existing plant technology on the landfill, with 65 kW_el in the following example
- The heat demand as an annual mean value of the existing plant technology on the landfill, with approximately 125 kW_{th} in the following example
- The installation in the existing CHP room of the landfill or as new containers.

The actual costs of the necessary adaptation of the gas compressor station and the installation on location were basically taken into consideration for our profitability analysis with an amount of € 10,000 for all bidders / examinations.

The internal energy demand of the respective aggregate is based upon approximately 2% of the electric power at full load, unless otherwise stated (see turbine).

For the preparation of the concept, the profitability analysis was made as follows in a simplified form:

- The service life of all aggregates is 10 years.
- The operating hours amount to 7,500 h per annum. This corresponds to a capacity utilisation of approximately 85% within a period of 10 years.
- The runtimes of the respective aggregates depend on the respective landfill gas prognosis and on the max. firing thermal capacity calculated on this basis at a mean calorific value of 5 kWh / m³ and less, in particular for the turbine.

- The investment costs are split into even annual burdens. Distribution is effected in such a manner that the residual value of the aggregate amounts to € 0 before the end of the service life.
- The maintenance costs were considered on the basis of the operating hours and offers / price indications. The respective maintenance measures include full maintenance of the aggregates through the manufacturer.
- The indicated fixed costs consider the supply of the plant technology according to the aforementioned power and heat quantities through external third parties where no gas utilisation is realised. These fixed costs also refer to the aforementioned operating hours per annum as a mean value and amount to € 0.15 per kWh for the electric energy plus the provisioning costs of € 2,000 / a, and the thermal energy costs of € 0.09 per kWh.
- In the event that the amounts of thermal and electric energy provided by the aggregates do not suffice to supply the aforementioned base loads, additional procurement costs are incurred. These additional financial burdens form the aforementioned fixed costs.
- Basically in Germany, the electricity produced by the engines was fully remunerated at approx. € 0.09 per kWh and the above operating hours according to EEG 2009 at 0.09 € pro kWh, as regards the turbine and possibly plus the technology bonus.
- The excess heat was not additionally remunerated in our concept.
- To detect the electric and the thermal power in the partial-load range, the averaged electric or thermal efficiency was used.
- Inflation was not taken into account.
- The existing plant technology such as the emergency cooler, waste gas stack, gas compressor and raw gas analysis was utilised as far as this is possible.

The averaged annual operating costs are therefore composed as follows:

Mean annual costs = $K_{Annu.} + K_{Operat.} + K_{Procur.} - K_{Remuneration}$

with: K_{Annu} = Annuity p.a. on the basis of the total investment and a financing term of seven years

$K_{Operat..}$ = Annual burden caused by maintenance costs incl. operating costs or by the internal power demand of the respective aggregates or the pilot fuel demand

$K_{Procur.}$ = Additional costs incurred when the above thermal or electric base loads are not covered by the aggregate.

$K_{Remuneration}$ = Proceeds from the above EEG (REL) power feeder

Taking into account the aforementioned boundary conditions, the following fixed costs, summed up in Table 1, are incurred per year for the self-supply of the "Example" landfill through external third parties.

Table 1: Fixed costs for the external energy supply

Thermal energy	125	kW
Calorific value $H_{U\ propane}$:	6,57	kWh / l
Costs per l propane:	0,56	€ / l
Efficiency:	90 %	
Costs per kW and year:	710,30 €	
Costs per year:	**88.787,42 €**	
Electric energy	65	kW
Availability fees per years:	2.000,00 €	
Price per kW:	0,15 €	
Costs per kW and year:	1.155,77€	
Costs per year:	**75.125,00 €**	

On the basis of the fixed costs indicated in Table 1, the total costs for the examination period of 10 years amount to approximately 1.64 million euros.

2.2 Microgas turbine

Using the microgas turbine, max. 65 kW_{el} can be produced out of landfill gas with min. 35 vol.-% methane (see Table 2).

The internal power demand for the additional compressor required to compress the landfill gas to an operating pressure of approximately 5 bar_g is approximately 15 kW_{el} and is additionally bought or deducted from the Renewable Energy Law remuneration for feeding. For the employment on landfills, an activated-carbon filter, which was taken into account, is additionally required to reduce the siloxane loads.

Table 2: Efficiency and output ranges of the microgas turbine according to the manufacturer's data

Capacity utilisation	$\eta_{therm.}$	kW **therm.**	$\eta_{electr.}$	kW **electr.**
100 %	52,67 %	115	29,0 %	**65,0**
75 %			*27,5 %*	48,8
50 %			*24,0 %*	30,0
Mean value	*52,7 %*	*115*	*26,8 %*	*48*

Taking the aforementioned gas prognosis as the basis, the microgas turbine can be operated under full load during nine out of ten years.

According to the manufacturer's indications, two microgas turbines at each plant are operated in Germany as reference plants on the Eichelbuck, Sinsheim and Lemberg landfills. Many more in the States und UK.

2.3 Dual fuel engines

The required dual fuel engine with 110 kW_{el} has an electrical efficiency of approximately 40.5%, according to internal indications and a gas consumption of at least 51.6 m³ / h at 50 vol.-% CH_4 and 1.4 kg / h pilot oil.

Unfortunately, despite several telephone consultations, we were only offered an aggregate of 250 kW_{el}, which was too large. As a result of the required high firing thermal capacity which does not match the amounts of gas and our request, this suggested pricing offer is not taken into consideration.

2.4 Gas-Otto engines

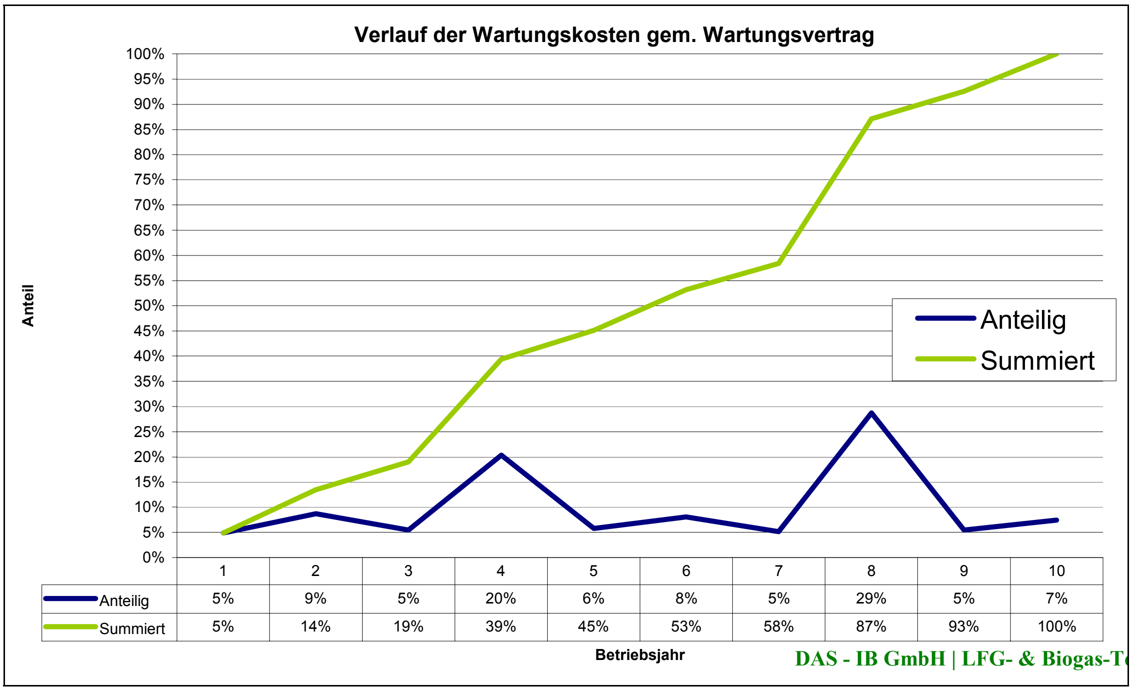
<u>Provider 1:</u>

On the basis of the aforementioned landfill gas prognosis, the motor can only be operated under full load during the first two years (according to the manufacturer's indications, see Table 3). The average utilisation capacity is approximately 83% for the utilisation period of 10 years.

Table 3: Efficiency and output ranges according to the manufacturer's data

Capacity utilisation	$\eta_{therm.}$	kW **therm.**	$\eta_{electr.}$	kW **electr.**
100 %	49,9 %	171	*36,2 %*	**124**
75 %	49,8 %	132	*35,1 %*	93
50 %	50,3 %	96	*32,5 %*	62
Mean value	*50,0 %*	*133*	*34,6 %*	*93*

According to the manufacturer's indications, this aggregate is presently supervised on three landfills. Until now, a mean annual runtime of 8,000 operating hours was achieved. As a result of the technical design, the module can probably only be operated until 2022, taking into account the aforementioned landfill gas prognosis. All other examined systems can be further operated, as these consider lower firing thermal capacities in the technical design. The course of the maintenance costs is presented in the illustration below to be able to estimate the actual annual maintenance costs.



	1	2	3	4	5	6	7	8	9	10
Anteilig	5%	9%	5%	20%	6%	8%	5%	29%	5%	7%
Summiert	5%	14%	19%	39%	45%	53%	58%	87%	93%	100%

Illustration 5 *Course of the maintenance costs on the basis of the manufacturer's data*

Grapg: Course of the maintenance costs in accordance with the maintenance agreement / Percentage / Pro rata / Totalised / Year of operation

This illustration clearly shows that comprehensive maintenance measures on the motors are necessary every four years of operation.

Provider 2:

If the efficiency and output ranges from Table 4 and the aforementioned landfill gas prognosis are taken as the basis, the compact module can be operated under full load over a period of six years. The average utilisation capacity of the module is approximately 94% for the entire utilisation period of 10 years.

Table 4 Efficiency and output ranges according to the manufacturer's data

Capacity utilisation	$\eta_{therm.}$	kW **therm.**	$\eta_{electr.}$	kW **electr.**
100 %	45,4 %	170	38,4 %	**104**
75 %	45,2 %	129	37,1 %	78
50 %	45,3 %	80	35,1 %	52
Mean value	*45,3 %*	*126*	*36,9 %*	*78*

Provider 3:

If the efficiency and output ranges from Table 5 and the aforementioned landfill gas prognosis are taken as the basis, the compact module can be operated under full load over a period of five years. The average utilisation capacity of the module is approximately 91% for the entire utilisation period of 10 years.

Table 5 Efficiency and output ranges according to the manufacturer's data

Capacity utilisation	$\eta_{therm.}$	kW **therm.**	$\eta_{electr.}$	kW **electr.**
100 %	46,1 %	125	*35,2 %*	**104**
75 %	46 %	77	*34,4 %*	78
50 %	46 %	71	*32,3 %*	52
Mean value	*46,1 %*	*91*	*34, %*	*78*

The providers use the same short block and therefore normally also obtain almost identical efficiency degrees. Differences result from manufacturer-specific adjustments and the equipment.

Provider 4:

If the efficiency and output ranges from Table 6 and the aforementioned landfill gas prognosis are taken as the basis, the compact module can be operated under full load over a period of seven years. The average utilisation capacity of the module is approximately 97% for the entire utilisation period of 10 years.

Table 6 Efficiency and output ranges according to the manufacturer's data

Capacity utilisation	$\eta_{therm.}$	kW therm.	$\eta_{electr.}$	kW electr.
100 %	50,8 %	125	32,5 %	**80**
75 %		105	30, %	60
50 %		77	27,5 %	40
Mean value	*50,8 %*	*102*	*30, %*	*60*

2.5 Comparison of the plant utilisation

Illustration 6 shows the capacity utilisation of the different aggregates depending on the available firing thermal capacity. A soon as this firing thermal capacity no longer covers the maximum energy demand of the aggregate, the respective aggregate can only be operated under partial load (min. 50 % load).

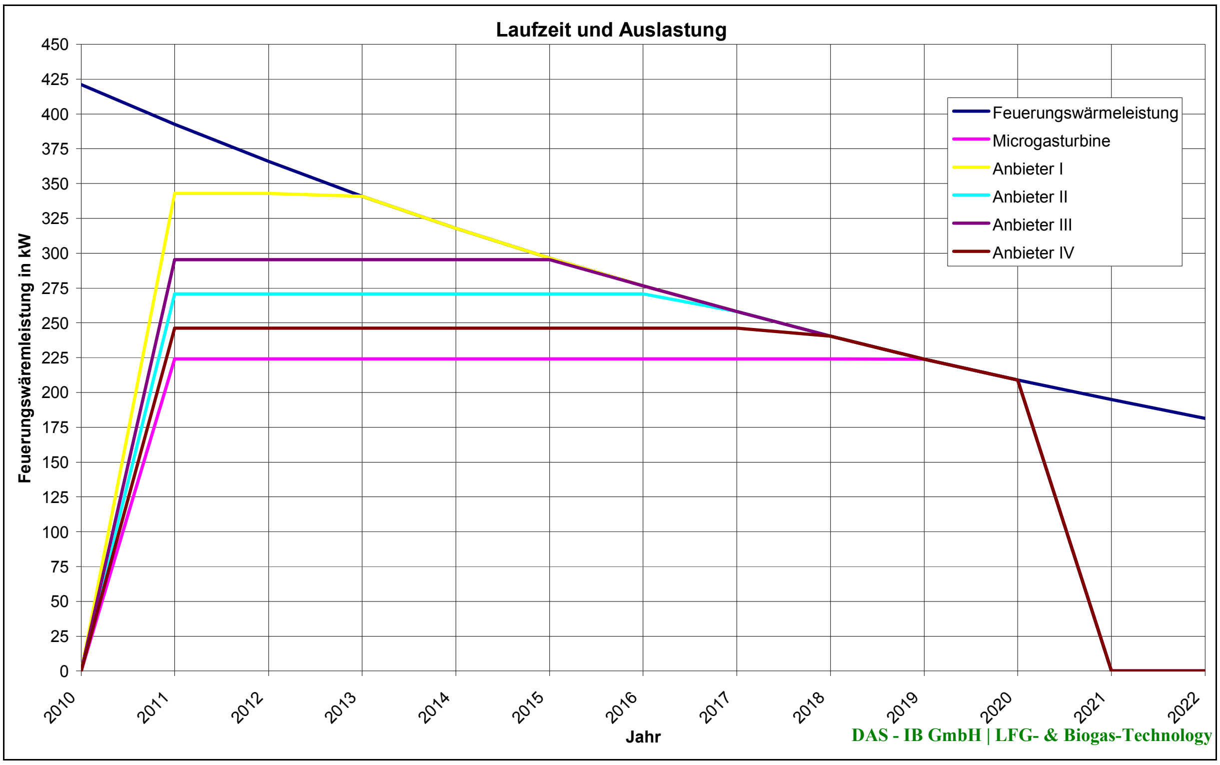


Illustration 6 Capacity utilisation of the different aggregates on the basis of the available firing thermal capacity

Graph:: Runtime and utilisation / Firing thermal energy – Microgas turbine – Provider I – Provider II – Provider III – Provider IV / Firing thermal energy in kW / Year

Table 7 sums up and compares the average utilisation and the number of full-load years.

Table 7 Degree of utilisation and number of years of full load

	Microgas turbine	Provider I	Provider II	Provider III	Provider IV
Electric power in kW (100%)	65	124	104	104	80
Thermal output in kW (100%)	115	171	170	125	125
Years under full load:	10	2	6	5	7
Ø Degree of utilisation:	99 %	83 %	94 %	91 %	97 %

The averaged annual proceeds from the sale of electricity are presented and compared in Table 8.

Table 8 Averaged proceeds from the sale of the amount of electricity produced p.a.

	Microgas turbine	Provider I	Provider II	Provider III	Provider IV
Ø Proceeds from the sale of electricity p.a.:	37.722 €	62.625 €	59.678 €	57.833 €	45.455 €

3 Further methods to cover the energy demand

Besides the already presented methods, the combination of a photovoltaic solar power plant to cover the electric base load and a LFG heating boiler can also be used in landfill gas operation for heat supply. If the landfill gas burner with boiler is not used, the landfill gas needs to be disposed of thermally by means of the high-temperature flare.

3.1 Photovoltaic solar power plant

The Renewable Energy Law stipulates that a buyback price for the produced solar power is paid to the operator of a photovoltaic solar power plant over a period of 20 years. The moment at which the plant is started up is decisive for the level of remuneration because remuneration decreases with every new year (degression).

The Renewable Energy Law amendment, adopted on 9 December 2010, stipulates a reversion of the solar power promotion by up to 50 percentage points in four steps by 1 January 2012: retroactively to 1 July, the funding rates are reduced by up to 13 per cent and to 1 October by a further three per cent. As of 1 January 2011 reversion of the grants by up to 13 per cent is effected and as of 1 January 2012 by a further up to 21 per cent. The concrete level of the promotion reduction will be based on the market growth.

As was the case for the gas engine aggregates, a plant in grid-connected operation without stand-alone operation is examined here. In addition, the following basic conditions form the basis of our profitability analysis:

- The roof surface area usable for the installation of the PV plant is approximately 700 m².
- There is an optimum roof orientation which is adjusted with support frames.
- The carrying capacity of the roof construction must be guaranteed (unchecked assumption).
- Estimation because of EEG 2011: From 2011 onwards: 27.31cents / kW
- The annual output of a similar plant at the location

According to the suggested pricing offers, a PV plant with an output of approximately 128 kW_p can be installed taking into account the aforementioned basic conditions, with an expected annual yield of approximately 104,000 kWh. The average remuneration over the entire operating period of 20 years amounts to approximately € 20,500 per annum.

With a total investment of approximately € 365,000, the annuities are at approx. € 18,000 per year with a financing term of 20 years.

Besides the utilisation variant presented here, there is also the possibility to let the roof surface area to a leasing company and, in this manner to only provide the roof surface area to third parties. This variant was not examined here.

3.2 Landfill gas burners with boiler and secondary equipment

In a heating boiler with a specifically developed two-media burner (landfill gas burner / fuel oil or propane burner), the collected landfill gas or the second fuel gas is burnt.

In the following landfill locations in Germany, for example, a boiler or a combustion chamber is employed in landfill gas operation with a specifically developed burner:

- Landfill sites Höxter and Speyer-Nonnenwühl with normal boilers (< 100 kW_{th}) for heating purposes, and Lübeck-Niemark, Bad Segeberg-Damsdorf, Mainz-Budenheim, Alsdorf-Warden (Aachen). Mechernich (Euskirchen), Lampertheim with combustion chambers of > 1 MW_{th}

The investment costs for an appropriate landfill gas burner with boiler and secondary equipment amount to approximately € 34,000, with average maintenance costs of € 1,500 per annum.

Due to the following factors, the combination of a PV plant and a landfill gas boiler was not further considered for the comprehensive profitability analysis of the methods.

- The aforementioned examination is based on a PV utilisation period of 20 years.
- Price development of the acquisition costs of the PV plant difficult to evaluate as a result of the dynamic market situation
- High dependence of the profitability analysis of PV plants on the currently rather dynamic, politically-induced power remuneration (in accordance with the REL) which is difficult to evaluate
- Operating costs for the auxiliary firing of the landfill gas boiler tied to the oil price.

4 Comparison of the utilisation methods

4.1 Profitability analysis of the utilisation possibilities

The economic evaluation of the aforementioned technical solutions is based upon our assumptions which, in consultation with the customers, were defined as follows:

- Operating period of 10 years
- Financing term of seven years
- Residual value of the plants of € 0 at the end of the financing term
- Financing with capital resources of 100%

The maintenance costs were calculated per operating hour on the basis of 7,500 operating hours per annum on average for 10 years.

The operating profit after a utilisation period of 10 years is the sum of the annual burdens caused by annuity and operating costs less the proceeds from the power feeder.

Summed up, the investment costs, the annual maintenance costs, the annuities p.a. and the operating profit after a utilisation period of 10 years are presented in Table 9.

Table 9 Comparison of the costs on the basis of the suggested pricing offers and price settings before

	Microgas turbine	Provider I	Provider II	Provider III	Provider IV	Fixed expenses for external energy supply
Invest aggregate:	208.000 €	116.200 €	100.950 €	140.000 €	111.600 €	- €
Delivery, installation and start-up on location:	5.000 €	7.800 €	15.000 €	13.000 €	Incl. invest	- €
Adaptation on location:	10.000 €	10.000 €	10.000 €	10.000 €	10.000 €	- €
Total investment costs:	223.000 €	134.000 €	125.950 €	163.000 €	121.600 €	- €
Annuity p.a.:	31.858 €	19.144 €	17.994 €	23.287 €	17.372 €	- €
Maintenance costs per operating hour:	1,50 €	2,57 €	3,23 €	2,05 €	2,40 €	€ / Bh
Ø Maintenance costs p.a.:	11.250 €	19.253 €	24.225 €	15.375 €	18.000 €	- €
Ø Additional electricity costs p.a.:	13.596 €	- €	- €	- €	- €	75.125 €
Ø Additional heat costs p.a.:	5.506 €	9.099 €	6.528 €	12.588 €	7.781 €	88.787 €
Ø Operating costs p.a.:	**62.210 €**	**47.495 €**	**48.747 €**	**51.250 €**	**43.153 €**	**163.912 €**
Ø Proceeds from the sale of electricity p.a.:	**37.722 €**	**62.625 €**	**59.678 €**	**57.833 €**	**45.455 €**	
Ø Operating profit p.a.:	**-24.488 €**	**15.129 €**	**10.932 €**	**6.583 €**	**2.303 €**	**-163.912 €**
Operating profit after the operating period of 10 years:	**-244.878 €**	**151.294 €**	**109.318 €**	**65.828 €**	**23.027 €**	**-1.639.124 €**

As can be seen in this table, the advantages of the microgas turbine lie in the low maintenance costs, the comparatively high provision of heat (thermal efficiency) and in a plant capacity utilisation of 99% on average. For our profitability analysis however, the high investment costs and the high self-energy demand of 15 kW_{el}, which is reflected in the additional electric-power purchasing costs, turned out to be disadvantageous. In this manner, additional costs of approximately € 13,600 p.a. are already incurred in the first year of operation to cover the power requirements. Thanks to good thermal efficiency, the additional heating costs of approximately € 5,500 p.a. are lowest, compared with other aggregates. The advantages of the landfill gas utilisation with a microgas turbine lie in the low exhaust emissions and long operating periods even at low methane concentrations. This results in an overall economic advantage of the microgas turbine of 1.39 million euros compared to the energy supply through third parties.

The module of the first provider can only be operated with full load during the first two years and is only utilised to approximately 83% over 10 years. However, it nevertheless provides electric energy for sale due to comparatively good efficiency and the high electric and thermal power output. The additional gain from the sale of electricity amounts to approximately € 62,000 p.a. The additional costs to cover the heat requirement amount to approximately € 9,000 per annum. This comes to an overall economic advantage of the aggregate of 1.79 million euros compared to the energy supply through third parties.

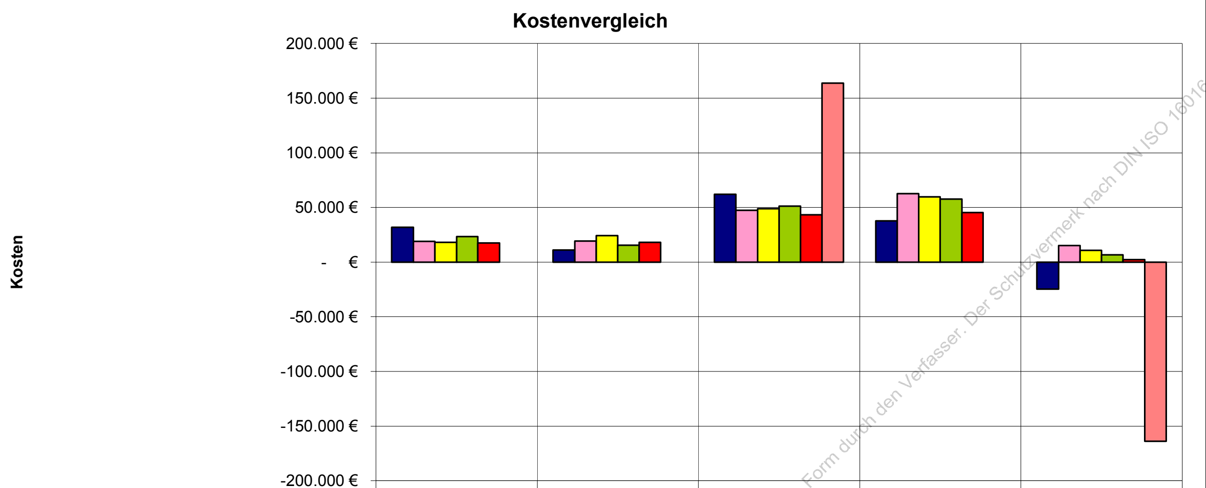
The advantages of the second provider's aggregate are the comparatively low investment costs and the relatively high electrical power of approximately 104 kW. The disadvantages are high maintenance costs of € 3.23 per operating hour. The proceeds from the sale of the surplus electrical energy amount to approximately € 59,000 per annum. However, this aggregate also produces additional costs of approximately € 6,500 p.a. to cover the heat demand. This results in an overall economic advantage of the module of 1.75 million euros compared to the energy supply through third parties.

The lowest investment costs for the aggregate are those of the fourth provider. However, this aggregate has the second-highest plant capacity utilisation, namely of 97% on average. As a result of the low thermal performance, the costs to cover the heat requirement amount to approximately € 7,700 per annum. The revenues from the sale of the electricity are approximately € 45,000 per annum. This results in an overall economic advantage of the compact module of 1.66 million euros compared to the energy supply through third parties.

As far as all possibilities of utilisation are concerned, it is striking that, at the latest during the last three years of operation, the heat requirements cannot completely be covered which involves additional costs.

5 Summary and discussion of the results

As can be seen from the comparison of the annual operating profits of all variants in Illustration 7, gas-Otto engines can be recommended as the most profitable variant for employment on the "concept" landfills, taking into account the indicated boundary conditions.



	Annuität p.a.:	Ø Wartungskosten p.a.:	Ø Betriebskosten p.a.:	Ø Erlöse aus Stromverkauf p.a.:	Ø Betriebsergebnis p.a.:
Microgasturbine	31.858,42 €	11.250,00 €	62.209,72 €	37.721,94 €	-24.487,77 €
o.	19.143,62 €	19.252,92 €	47.495,38 €	62.624,81 €	15.129,43 €
	17.993,58 €	24.225,00 €	48.746,62 €	59.678,38 €	10.931,76 €
	23.286,65 €	15.375,00 €	51.249,75 €	57.832,56 €	6.582,81 €
	17.372,12 €	18.000,00 €	43.152,74 €	45.455,45 €	2.302,71 €
			163.912,42 €		-163.912,42 €

Illustration 7 *Comparison of the operating profits to be expected*

Graph Comparison of costs / Costs / Annuity p.a. / Maintenance costs p.a. / Operating costs p.a. / Revenues from the sale of electricity p.a. / Operating profits p.a.

Microgas turbine / Provider I / Provider II / Provider III // Company

6 Sources

DAS – IB GmbH 2010 Bio- und Deponiegashandbuch. DAS – IB GmbH, Lehrgangsbuch: ISBN-Nr.: 3-88312296-3, 9th edition, April 2010.

E-QUAD POWER SYSTEMS 2007 Product data sheet Capstone C30 www.microturbine.de/uploads/File/C30%20_dt_V3_Web.pdf

HIEMSTRA, R. 2010 Optimierungen von Gasfassungssystemen: Deponien, Altlasten und Altablagerungen . In: DAS – IB GmbH. [Publ.]: Deponie- & Biogasanlagen, Synergien nutzen - voneinander lernen IV. April 2010.

PARRAGI, D., ESCHEY, H. AND HAUBRICHS, R. 2007 Durchgängiges Deponiegas-Behandlungskonzept mit herkömmlichen und innovativen Verfahren über den gesamten Methanbereich. In: DAS – IB GmbH. [Publ.]: Deponie- & Biogasanlagen, Synergien nutzen - voneinander lernen.

April 2007.

RADU, A. 2009 Erfahrungsbericht Mikrogasturbinen im Biogas - / Deponiegasmarkt Deutschland In: DAS – IB GmbH. [Publ.]: Deponie- & Biogasanlagen, Synergien nutzen - voneinander lernen III. April 2009

RAMTHUN, A. 2009 Wirtschaftliche Deponiegasentsorgung auf Deponien mit geringem Gasdargebot In: DAS – IB GmbH. [Publ.]: Deponie- & Biogasanlagen, Synergien nutzen - voneinander lernen III. April 2009

SELDER, K., ENTFELLNER, G. AND STACHOWITZ, W.H. 2008 Konzeption für die Gasbehandlung oder -verwertung auf der Deponie Buckenhof . In: DAS – IB GmbH. [Publ.]: Deponie- & Biogasanlagen, Synergien nutzen - voneinander lernen II. April 2008.

SCHNAPKE, A. 2006 Entwicklung eines Konzeptes zur Schwachgasbehandlung für den Deponiestandort Penig des Abfallwirtschaftsverbandes Chemnitz (AWVC) – Technische, ökonomische und ökologische Variantendiskussion. Thesis, TU Dresden & DAS – IB GmbH, December 2006.

SCHNAPKE, A. AND STACHOWITZ, W.H. 2007 Entwicklung eines Konzeptes zur Schwachgasbehandlung auf einer Deponie. In: DAS – IB GmbH. [Publ.]: Deponie- & Biogasanlagen, Synergien nutzen - voneinander lernen. April 2007.

STACHOWITZ, W.H. 2009 Perspektive der Deponieschwachgasnutzung - Technik und Wirtschaftlichkeit in der Deponienachsorge; 21st Kasseler Abfallforum und Bioenergieforum 2009.