Final report

1.1 Project details

Project title	Methane emission from Danish biogas plants
Project identification (program abbrev. and file)	2013-1-12093
Name of the programme which has funded the project	ForskEL
Project managing company/institution (name and address)	AgroTech A/S Agro Food Park 15, 8200 Aarhus N
Project partners	Dansk Gasteknisk Center
CVR (central business register)	30589335
Date for submission	24.06 2015

1.2 Short description of project objective and results

The objectives of the project were to develop an operational method for identification and quantification of methane leaks at biogas plants, to determine methane emission factors of identified leakages, to develop a maintenance handbook describing the general leakage problems and their maintenance and repair, and to assess the environmental and economic impacts of methane leakage to improve the environmental and economic profitability of biogas production.

The project has developed an operational method usable for periodical maintenance routine at biogas plant, and has determined the emission factors of identified leakages at 10 Danish biogas plants before and after leakages identification and repair. The project has developed a maintenance hand book targeted improved maintenance and management of leakage problems at biogas plants, and has assessed the environmental and economic impact of the leakages to improve the economic and environmental impact of biogas production.

Kort beskrivelse af projektets formål og resultater (In Danish)

Projektet havde til formål at:

- udvikle en operationel metode til at identificere og kvantificere metanlækage på biogasanlæg
- bestemme lækagernes emissionsfaktor
- udarbejde en vedligeholdelses håndbog målrettet driftledere, som beskriver de mest generelle lækagetyper og deres reparation
- bestemme lækagernes miljø og økonomiske effekter med henblik på at forbedre biogasproduktionens miljøpåvirkning og økonomiske udbytte.

Projektet har udviklet en operationel metode, som kan benyttes i forbindelse med periodisk vedligeholdelse på biogasanlæg med henblik på at identificere lækager og reducere metantabet fra biogasanlæg. Projektet har desuden bestemt lækagernes emissionsfaktorer ved undersøgelse af lækagetabet på 10 danske biogasanlæg før og efter identifikation og udbedring af identificerede lækager. Projektet har udarbejdet en håndbog målrettet forbedret vedligeholdelse og reparation af lækageproblemer på biogasanlæg. Med henblik på at forbedre biogasproduktionens økonomiske og miljømæssige fordele har projektet bestemt de miljømæssige og økonomiske effekter af metantabet fra identificerede lækager på danske biogasanlæg.

1.3 Executive summary

1.3.1 Background

During production and storage of biogas at biogas plants methane may emit to the environment through leaks in cover material, assemblies, safety valves, etc. This loss of methane cause loss of income for the biogas plants, but do also generate environmental problems, as methane is an important greenhouse gas.

The use of an optical gas imaging camera for identification of methane concentration in atmospheric air is a novel method for identification of methane leaks at biogas plants . The project has developed an operational method for identification of methane leaks at biogas plants by use of the optical imaging camera, and has developed an operational method for quantification of methane leaking from the identified leaks. The developed methods were evaluated by identification and quantification of methane leakages at 10 Danish biogas plants.

1.3.2 Main activities

The first activity performed was to investigate and evaluate the possibilities for identification of gas leaks on biogas plants by use of an optical gas imaging camera (Figure 1). Two different types of cameras (GF 320, Flir and GasFundIR HSX, Flir) were evaluated at biogas plants by AgroTech in order to be able to choose the best suitable for the specific conditions related to leak identification at biogas plants. The gas imaging camera (GF 320, Flir) was found to be the best suited for detection of methane leaks, as it is able to identify low concentration of methane in atmospheric air and thereby to localize the exact position of methane leaks.

After development of the leak identification system, the next step was to develop a measuring system useable for quantification of the amount of methane leaked from each leakage. Several types of quantification systems were developed and evaluated before a final flexible dynamic chamber sampling system suited to the various types and designs of leakages identified at biogas plants were designed and evaluated (1.5.4).

The optical imaging camera and the developed measuring system were used for identification and quantification of methane leakages at 10 selected Danish biogas plants. The 10 plants represented older/newer, smaller/larger plants, and plants from different suppliers.

In total more than 50 leakages were identified at the studied biogas plants. The owner of the biogas plants were informed about the leakages and the amount of methane emitted from the individual leakages. Following that, the biogas plants were given the opportunity to repair the identified leakages, before a second measuring event was carried out at the biogas plants which had performed repair of identified leakages.

The identified leakages were classified in different groups. The emission from the different types before and after repair was measured to quantify the repair effect of the different types of leakages. The different types of repairs and the effects of repair were described in a handbook targeted at managers and biogas plant owners.

The environmental and economic effects of the methane leakages were evaluated and reported.

Finely the developed methods for identification and quantification of methane leakages were evaluated in a joint international evaluation project taking place at a Swedish biogas plant in Linköping in Sweden.

1.3.3 Main results

The project has developed an operational method usable for periodical maintenance routine at biogas plant. The developed method consists of a method suited for identification of leakages at biogas plants and a method for quantification of the leaking methane from the identified leakages. The developed method was evaluated by identification and quantification of leakages at 10 Danish biogas plants.

More than 50 leakages in total were identified at the studied plants. The emission from the identified leakages varied considerably, both between individual biogas plants and individual leakages. The highest emissions were in general observed from leaking pressure safety relief valves. The total measured methane emission through leakages was found to sum up to 4.2 per cent of the total methane production at the studied biogas plants.

Many of the identified leakages were maintained and repaired by the biogas plants managers after they were informed about the leakages identified at their biogas plants. Following that, a new identification and quantification study was performed, which found that the methane emission through leakages was reduced to sum up to only 0.8 % of the total methane production at the studied biogas plants.

The loss of methane through leakages was found to have considerable economic and environmental consequences. Both the environment and the economic output of the biogas production will therefore benefit if the leakage loss can be reduced by periodical leakage studies performed at biogas plants.

1.4 Project objectives

The objective of the project was to develop an operational method for identification and quantification of methane leakage at biogas plants. The knowledge generated by this method should enable plant owners and managers to reduce the leakages, and, thereby, optimize the environmental and economic benefits of biogas production.

Another objective was determination of the emission factors of the leakage. This objective was met by quantification of methane emission by the developed method at 10 Danish biogas plants. Based on these studies an average emission factor of methane leakage at biogas plants should be estimated.

Development of a maintenance handbook aiming to help plant owners to manage and repair identified methane leaks was another important objective of the project. The maintenance book was based on the experiences obtained during the development of the measuring system, and the identification and quantification of leaks performed at the biogas plants.

The last objective was to assess the environmental and economic impact of methane leakage at biogas plants. This was assessed by measurement of the methane emission taking place at Danish biogas plants.

The project followed the plan scheduled at the project initiation. The milestones of the project were met as planned except that the termination of the project was postponed by 6 month to allow the integration of results obtained during an international evaluation of the developed method.

1.5 Project results and dissemination of results

1.5.1 Selection of biogas plants

The Danish Energy Agency has registered 66 active agricultural biogas plants in Denmark in 2012. Of these 45 plants are classified as farm scale biogas plants and 21 as centralized biogas plants. All the registered Danish biogas plants were invited to participate in the project for free.

The offer was sent in May 2013 and 19 biogas plants responded positively. A questionnaire about previous procedures for leak detection, expectation of leaks and emission etc. was sent to the positive respondents and 14 answered. Of the 14 plants 10 plants were selected to the project according to their geographic location. The 10 plants represented older/newer, smaller/larger plants and plants from different suppliers (*Table 1*).

Table 1. Biogas plants selected to participate in the project and information about type of plant, methane production, year of construction and supplier.

Biogas plant	Type of Biogas Plant	Methane Production [m^3 methane/year]	Year of construction	Biogas Plant supplier
1	Farm Scale	300,000	2002	Lundsby
2	Farm Scale	500,000	2002/2005	Lundsby
3	Farm Scale	100,000	2009	Gosmer Biogas
4	Farm Scale	450,000	2001/2007	Dansk Biogas/Lundsby
5	Farm Scale	900,000	1998/2005	Dansk Biogas/Lundsby
6	Centralized	1,300,000	1988/2012	Bruun & Sørensen
7	Centralized	4,875,000	1995/2011	Prikom/Hedeselskabet
8	Centralized	1,200,000	1986	W. W. Engineering
9	Centralized	3,900,000	2001	Green Farm Energy
10[b]	Centralized	-[b]	-[b]	-[b]
Total		**13,375,000**		

[b]The biogas plant was withdrawn from the project after leakages were identified and prior to quantification of methane emission from the leakages.

1.5.2 Development of a method for identification of methane leakages

For identification of methane leakages at biogas plants a FLIR GF 320 optical gas imaging camera was taken into use (*Figure 1*).

The camera was adjusted to a wavelength range between 3.2 and 3.4 µm. Due to the absorption of infrared radiation in this range by many hydrocarbons including methane can be visualised by the camera.

Two different types of cameras (GF 320, Flir and GasFundIR HSX, Flir) were evaluated by AgroTech to choose the best suitable for the specific conditions related to leak identification at biogas plants. The gas imaging camera (GF 320, Flir) was found to be the best suited for detection of methane leaks, as it is able to identify low concentration of methane in atmospheric air and thereby to localize the exact position of methane leaks

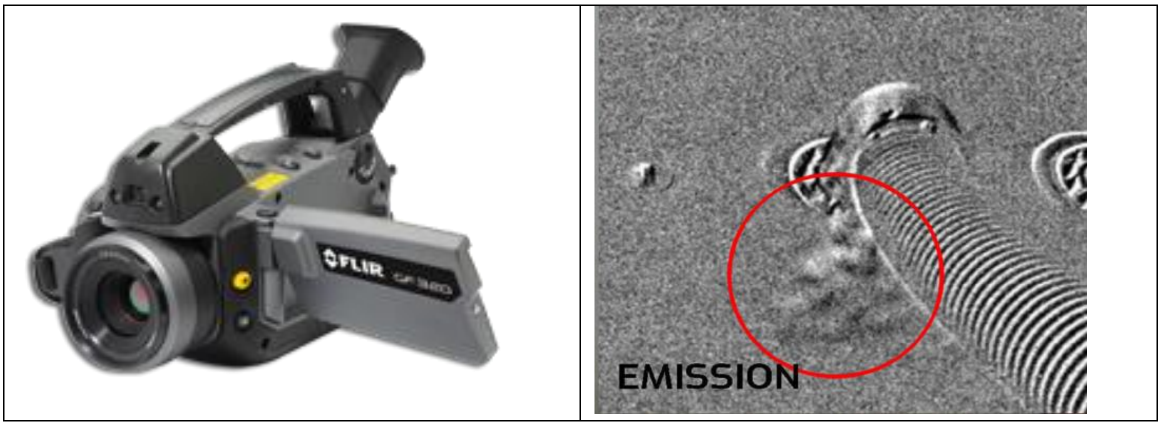

Figure 1. Optical gas imaging IR camera (FLIR GF 320), and visualization of a small methane leakage by use of gas imaging camera.

1.5.3 Identification of methane leakages at biogas plants

During autumn 2013 and spring 2014 selected biogas plants were scanned with the optical gas imaging camera (FLIR GF 320).
Before the identification measurements were initiated, the managers of the selected biogas plants were interviewed about annual methane production, the number of expected leakages, and the expected loss of methane due to the leakages (Table 2). In general the reported expectations did not correspond well with the results of the subsequent measurements.

In total more than 50 leaks were identified at 9 of the 10 biogas plants inspected (Table 2). One biogas plant owner decided to withdraw the plant from the project after the initial leak detection and results from this biogas plant are therefore not integrated in the project. The leakages were found to vary considerable in type, design and location. See examples in Figure 2.

Figure 2. Examples of detected leaks. Top, left: Leakage though a box covering a mixer on the roof of a covered digestate storage tank. Top, right: Leakage through a hole in a covered digestate storage tank. Bottom, left: Leakage through a pressure safety valve. Bottom, right: Leakage through the assembly between the concrete wall and the membrane roof at a digestate storage tank.

1.5.4 Quantification of methane leaks

When a leakage of biogas was detected by the IR camera (*Figure 1*), the amount of leaking gas was determined. This was done by collecting and measuring the amount of methane emitting from the leakage. The development of the operational method for identification and quantification of methane leakages at biogas plants is described in detail in section 1.5.5.

After identification and quantification of methane leakages were completed, individual reports were sent to the participating biogas plants. The report included pictures and videos of the methane leaks identified at the plant. An example of an individual report, written in Danish, can be seen in 1.12 (Example of individual measurement report).

1.5.5 Development of an operational method for quantification of methane leakages at biogas plants

The project developed a sampling system suited for quantification of methane leakages at biogas plants. The main parts of the sampling system were an air blower unit and various types of sampling devices suited for the types of leakages identified at biogas plants (Figure 3).

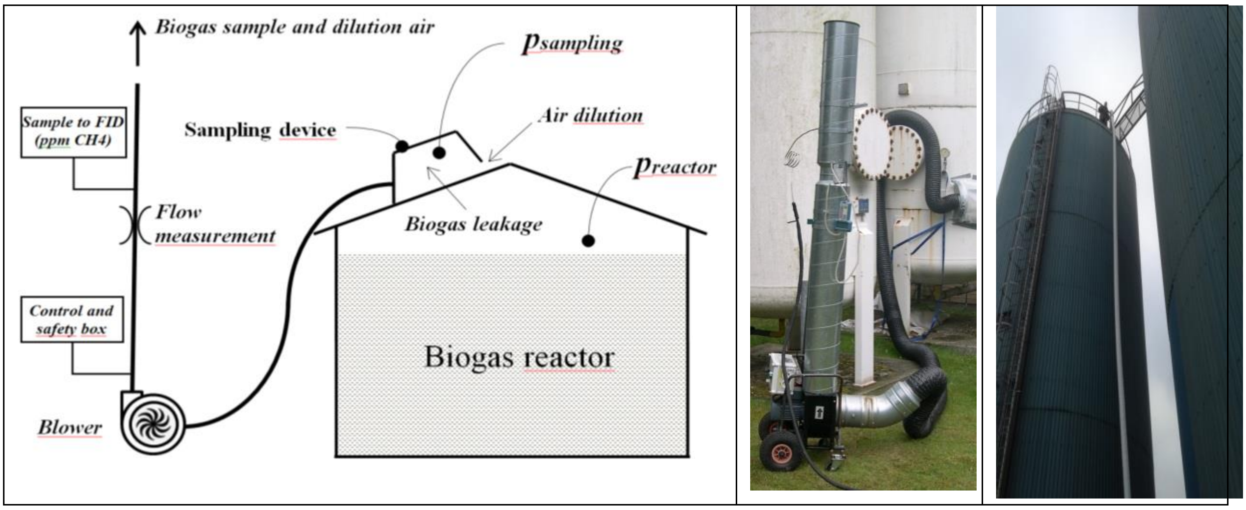

Figure 3. Sketch (left) and picture (middle) of the method applied for quantification of a methane leakage at biogas plants. The sampling of leaking gas at the top of a biogas reactor is seen at the right picture.

A detailed description of the sampling system can be seen in 1.13 (Quantification of methane losses). However, to give a brief overview, a short description of the developed methods and the sampling systems main components are described in the following.

The sampling system consists of a dynamic chamber measuring system. This system involves the following components.

- ATEX approved air sucking ventilator (air blower)
- Air flow regulating system
- Air flow measurement system
- Flexible antistatic air hose
- Sampling devises
- Gas concentration measuring system (FID or photo acoustic multigas sampler)

The sampling devices used in the study were partly open to the surroundings to prevent that a pressure drop inside the sampling device affected the leakage of methane from the methane source. The sampling devises were designed for the different type and designs of the leakages and its surroundings. Various types of sampling devises were therefore developed and taken into use (Figure 4)

Figure 4. Examples of sampling devises suited for measuring methane leakages. Top left: Sampling devise suited for leakages from pressure relief safety valves. Top right: sampling devise for measurement of a leakage on a curved surface. Bottom left: sampling device for sampling a leakage in biogas digester cover. Bottom right: Sampling devise designed for measurement of methane emission from a mixing pump cover box situated above a digestion tank.

The air blower unit was developed to deliver an air flow sufficient to prevent that the leaking gas is escaping the sampling device.
The amount of leaking gas was subsequently determined by measuring the flow of sampled air and the concentration of methane in the sampled air
The leakage of methane was calculated as

$$V_{CH_4} = V_{gas} \cdot C_{CH_4}$$

Where
V_{CH_4} is the flow of leaking methane
V_{gas} is the air flow removed by the blower
C_{CH_4} is the methane concentration in the sampled air/biogas mixture

1.5.6 Quantification of the emission factors of methane emission at Danish biogas plants

The project performed identification and quantification of methane leakages at 10 Danish biogas plants. The biogas plant owners were subsequently informed about the identified leakages and the amount of methane leaking through the leakages. The plant owner then had the opportunity to repair the leakages identified before a second identification and quantification campaign were performed at the biogas plants. The second measurement campaign was only performed at biogas plants that had performed repair of identified methane leakages. In the following the methane emission from biogas plants before and after maintenance is presented.

1.5.6.1 Identification and quantification of leakages before maintenance was conducted at the biogas plants

During autumn 2013 the first study campaign was performed at the ten selected biogas plants. It was found by the study that both number of leakages identified, and the amount of methane leaking from the leakages varied considerably between the individual biogas plants. Another finding was that the number of leakages identified and the amount of methane leaking were different from what the plant owners expected before the initiation of the first measurement campaign (Table 2).

Table 2. Plant owner's expectations regarding number and amount of methane leakages at their biogas plant, and the number of leaks identified and amount of methane leaking from 10 Danish biogas plants.

Biogas plant	Leaks expected (Plant owner)	Number of leaks identified	Expected methane emission (plant owner) [1000 m^3 methane/year]	Measured methane emission [1000 m^3 methane/year]
1	Yes	10	Unknown	1.6
2	No	5	10	3.9
3	No	0	Unknown	0
4	Yes	4	2-5 %	4.4
5	Yes	2	0.6	10.1
6	No	3	Unknown	28.0
7	No	14	Unknown	276
8	Yes	3	25	123
9	Yes	11	170	131
10	-[b]	-[b]	-[b]	-[b]
		52		**579**

[b]The biogas plant was withdrawn from the project after leakages were detected and prior to quantification of methane emission from the leakages.

Both number of leakages and the total methane emission varied considerably between plants. The number of leakages identified at the nine participating biogas plants varied from 0 to 14 for the different plants and the total amount of leaking methane was found to vary between 0 and 276,000 Nm^3 methane/year. The total methane loss corresponded to between 0 and 10 % of the total methane production at the individual biogas plants. The average leakage loss at the nine plants was found to constitute 4.2% of the total methane production. See Table 3 for further details.

Table 3. Number of leakages and measured methane emission from 10 Danish biogas plants at the first round of measurements (before maintenance of identified leakages)

Biogas plant	Type of plant	Total methane production, [10^6 m^3/year]	Number of leaks identified	Measured methane emission [10^3 m^3/year]	Methane emission [% of total methane production]
1	Farm scale	0.3	10	1.6	0.6
2	Farm scale	0.5	5	3.9	0.9
3	Farm scale	0.1	0	0	0.0
4	Farm scale	0.5	4	4.4	0.9
5	Farm scale	0.9	2	10.1	1.1
6	Centralised	1.3	3	28.0	2.1
7	Centralised	4.9	14	276	5.7
8	Centralised	1.2	3	123	10.0
9	Centralised	3.9	11	131	3.4
10[b]	Centralised	-[b]	-[b]	-[b]	-[b]
		14	**52**	**579**	**4.2**

[b]The biogas plant was withdrawn from the project after leakages were detected and prior to quantification of methane emission of the leakages.

1.5.6.2 Identification and quantification of leakages after maintenance was conducted at the biogas plants

During summer 2014 the managers of the biogas plants had the opportunity to repair the identified leakages. Not all plants performed repair of identified leaks (Table 4). The manager's reasons for not repairing identified leakages were that they found that the leaks were too difficult and/or too expensive to repair, or that the measured emission from the identified leaks was low.

A second round of identification and measurement of methane emission were performed at the biogas plants that had repaired the identified leakages. The second round of measurements were performed the same way as in the first round including a leak detection with the optical gas imaging camera (FLIR GF 320) and subsequent quantification of the methane emission from each individual leak.

Plants which had not repaired the identified leaks were not subjected to a second round of measurements. For these plants it was assumed that the methane emission found in the first round of measurements was equal to the findings if a second measurement had been performed.

The methane emission was in general considerably reduced after maintenance and repair of identified leakages (Table 4).

Table 4. Number of leakages and measured methane emission from ten Danish biogas plants at the second round of measurements (methane emission is shown before and after repair of identified leakages).

Biogas plant	Number of leaks identified	Repair conducted after leak detection	Methane emission before maintenance [10^3 m^3 methane/year]	Methane emission after maintenance [10^3 m^3 methane/year]	Methane loss after maintenance [% of production]
1	10	No	1.6	1.6[c]	0.6
2	5	No	3.9	3.9[c]	0.9
3	0	Not relevant	0	0[c]	0.0
4	4	??	4.4	22.0	4.4
5	2	??	10.1	9.7[c]	1.1
6	1	Yes	28.0	0.9	0.1
7	15	Yes	276	60.0[a]	1.2
8	7	Yes	123	9.3[a]	0.8
9	3	Yes	131	2.3	0.1
10[b]	-	-	-[b]	-	
	47		**579**	**110**	**0.8**

[a]Including a single leak

[b]The biogas plant was withdrawn from the project after leakages were detected and prior to quantification of methane emission from the leakages

[c] No measurements performed at the second round of measurements

The repair of identified leakages were conducted differently ranging from very quick and cheap to more expensive and time consuming solutions (Figure 5). Most leaks that were considered relatively easy and cheap to repair were repaired. Only a few leaks were not repaired, primarily leaks through assemblies.

Figure 5. Examples of leakages repair. Top (left): Leakages identified at the cover of a digestate storage tank. Top (right): The identified leakages after being repaired with sealants. Middel (left): A leaking box covering a mixer situated on the roof of a covered digestate storage tank. Middel (right): The covering box was later replaced by a new box. Bottom (left): Leakage in a membrane covering a digestate storage tank. Bottom (right): The membrane was later replaced by a new membrane.

1.5.7 Development of a maintenance handbook describing the general types of leakages and their repair

The aims of the maintenance handbook were to identify and describe the general types of leakages, their significance and their repair. The hand book was targeted at the biogas owners and managers. The handbook (written in Danish) can be seen in appendix 1.14 (Maintenance handbook: Identification and repair of methane leakages); however, a short description of the handbook can be seen in the following.

1.5.7.1 Type of membrane leaks identified.

The different leakages identified at the participating biogas plants were classified into the following three categories

1. Leakages by assemblies between concrete wall and membranes at biogas reactors, concrete elements and pipe connections
2. Leakages through safety pressure relief valves
3. Other types of leakages

1.5.7.2 Methane emission from the different types of leakages identified.

Leakages by assemblies were in general found to cause lower emission than the other type of leakages. The average methane emission from this type of leakage was 713 Nm^3 methane/year/leakage, which was lower than the measured average leakage through safety valves and other types of leakages (Table 5)

Higher emission was measured from leakages in the category leakages through safety valves and other leakages. The average emission measured from leaking safety valves summed up to about 7,500 Nm3 methane per year/leakages, while the average emission measured from other leakages made up to 25,246 Nm3 methane/year (Table 5).

The repair of identified leakages had a significant effect on the emission level, especially the repair of leakages through safety valves and other leakages. The methane emission through safety valves and other leakages was reduced by more than 90 % following identification and repair, whereas the emission from leaks by assemblies was only marginally reduced from 713 to 709 Nm^3 methane/year in average per leak. In fact, an increase from 13,547 to18,421 Nm^3/year in the total methane emission was observed from this category. The increase was due to identification of new leaks at the second measuring period (Table 5).

More detailed information of different types of leakages and their maintenance and repair can be found Stefanik et al. (in press) and in 1.14 (Maintenance handbook: Identification and repair of methane leakages).

Table 5. Number of leaks and methane emission before and after maintenance of leakages identified at the first measurement period. The leakages are separated into the different categories of leaks: leaks by assemblies, leaks by pressure relief safety valves, and other leakages.

Type of leaks	No of leaks (+ No of new leaks identified at the 2. measurement campaign)	Measured methane emission [m^3 methane/year]			
		Before maintenance		After maintenance	
		Total	Average/leak	Total	Average/leak
Leaks by assemblies	19 (+7)	13,547	713	18,421	709
Leakages through safety valves	15 (+3)	113,158	7,544	8,952	597
Other leakages	18 (+4)	454,433	25,246	39,311	2,184
Total	**52 (+14)**	**581,138**		**66,684**	

It was observed that leakages could occur through assemblies of newly installed membranes. This indicates that it is advisable to check new installations with an optical gas imaging camera before the final handover from the supplier.

1.5.8 The environmental effect of methane leakages at biogas plants

Leakages at biogas plants cause undesirable methane emissions. As methane is a greenhouse gas, the emission affects the climatic impact of the biogas production. The project has therefore conducted an investigation of the methane leakages at biogas plants and how it influences the climatic effects of the biogas production.

A detailed description of the climatic effect of methane leakages can be seen in Hansen et al. (in press) and in appendix 1.16 (Climatic impact of methane leakages at biogas plants). However; a brief overview of the climatic consequences of leakages can be seen in the following.

Biogas production has a positive greenhouse gas effect. The positive effects is due that the biogas produced substitutes the use of fossil fuels, and that the biogas process reduces the methane emission from manure storage facilities (Fødevareministeriet, 2008; Miljøstyrelsen, 2014). However, the positive greenhouse gas effect is reduced when methane is leaking from the biogas plants.

It was found that methane was leaking from the majority of the biogas plants studied. The leakage loss from the plants investigated varied considerably between plants, but at average

4.2 % of the methane produced at the plants was lost due to leakages (Jørgensen et al. 2014; Jørgensen & Kvist, in press).

As mentioned earlier, the methane leakages at biogas plants reduce the positive climatic effect of the biogas production. A previous study has calculated the climatic effect of biogas produced by various types of biomass combinations (Fødevareministeriet, 2008). They found that anaerobic digestion of a biomass consisting of cattle and pig slurry, and the fibrous fraction of pig slurry results in a positive reduction of greenhouse gas emission equal to about 40 kg CO_2 per m^3 slurry digested. When the measured methane emission found in the present study was related to the above assessment, it was found that the measured methane loss reduced the positive climatic effect of the biogas production from 40 to about 31 kg CO_2 per m^3 slurry digested.

Many of the identified leakages can be repaired at a relative low cost (Kvist et al., 2014; Stefanik et al., in press). A study of the methane leakages before and after repair and maintenance of identified leakages showed that the maintenances of identified leakages reduced the average leakage loss from 4.2 to 0.8% of the total methane production at the studied biogas plants.

The reduction of the positive climatic effect of biogas production was considerably reduced following identification and maintenance of leakages identified at the studied biogas plants. Following maintenance of identified leakages, the reduction of the positive climatic effect of biogas production was found to be reduced from about 40 to 38 kg CO_2 per m^3 animal slurry digested. Identification of leakages at biogas plants is therefore considered to be an effective method to ensure a high positive climatic effect of biogas production.

1.5.9 The economic impact of methane leakages

Another aim of the project was to quantify the economic impact of the identified methane leakages in order to improve the economical profitability of the biogas plants.

A full report of the estimated economic impact of methane leakages at biogas plants can be seen in 1.15 (Economic impact of identified methane leakages). However; to give a brief overview, a short description of the preconditions for calculating the economic impacts and main economic impact of methane leakages at biogas plants can be seen in the following.

The environmental impacts of methane emissions have been addressed previously. However, leakage of methane has also economical aspects, as lost methane represents a value that could otherwise be capitalized as a profit to the farmer or biogas company. As both costs of the biogas production and the need for process energy have been paid already, the full value of the saved methane can be realized by the biogas plants.

In the following the potential improved profit of reduced methane leakages at biogas are estimated. To do so a number of economical preconditions have to be set.

1.5.9.1 Preconditions for calculation of the economic impact of methane leakages

Most new biogas engines have energy efficiencies close to 40 % for electricity and 50 % for heat. This means that app. 4 kWh electricity and 5 kW heat can be produced by 1 Nm^3 methane.

Most farm scale biogas plants are only able to utilize a limited amount of the heat production. Most likely they are therefore not able to capitalize the full value of the extra heat production caused by reduced methane leaks. On the other hand most centralized biogas plants sell their heat to district heating systems. In many situations, however, the demand for heat is lower than the heat production during summer periods, which mean that only a part of the heat production normally can be utilized and capitalized. Centralized plants are therefore likely to be able to put value to about 50 % of the increased heat production caused by a lower leakage loss of methane.

At an electricity price of 1.15 DKK/kWh, the sale of the electricity produced by the methane amounts to 4.60 DKK/Nm^3 methane. The heat production is often sold to district heating companies for approx. 600 DKK/MWh. Therefore, if 50% of the heat production is utilized, the extra heat production generated by 1 Nm^3 methane will amount to approximately 1.50 DKK/Nm^3 methane.

In other words, if the estimated methane leaks could be avoided, farm scale plants are likely to profit from additional electricity sales, and centralized plants from additional electricity sales and half of the amount of extra heat sales.

Farm scale plants are therefore likely to realize 4.6 DKK/Nm^3 reduced methane emission, while centralized plants are likely to realize 6.1 DKK/Nm^3 reduced methane emission.

1.5.9.2 The calculated economic impact of identified methane leakages

The above preconditions were used to calculate the anticipated lost annual profits as a consequence of methane leaks, which at the same time, represent a potential for increased profits (Table 6).

Table 6. Number of leaks and the measured emission loss at different biogas plants, and the calculated lost annual profits/potentially improved profits at each plant.

Biogas plant	Type of biogas plant	Number of leaks identified	Annual methane production Nm^3 CH_4	Measured annual loss of methane Nm^3 CH_4	Rate of lost methane %	Lost annual profits DKK
1	Farm scale	10	300,000	1,600	0.6	7,360
2	Farm scale	5	500,000	3,900	0.9	17,940
3	Farm scale	0	100,000	0	0.0	0
4	Farm scale	4	500,000	4,400	0.9	20,240
5	Farm scale	2	900,000	10,100	1.1	46,460
6	Centralized	3	1,300,000	28,000	2.1	170,800
7	Centralized	14	4,900,000	276,000	5.7	1,683,600
8	Centralized	3	1,200,000	123,000	10.0	750,000
9	Centralized	11	3,900,000	131,000	3.4	799,100

Lost annual profits due to methane leakages were found to vary between 0 and 1.7 mio. DKK per biogas plant.

Loss of methane is loss of money. Therefore, if the methane leakages at biogas plants could be totally avoided many plants would achieve considerable profits.

Based on the estimation of the economic impact of methane leakages a regular screening for methane leakages at biogas plants is considered to be highly recommendable.

1.5.10 International evaluation of the developed methods

The project has contributed to an international evaluation of methodologies for measurement of methane emission from biogas plants, "Climate impact from biogas production, data collection and comparative study of measurement and calculation methods in Europa". The measurement systems developed within the project were in this project evaluated by means of a joint comparative international evaluation project taking place at the Linköping biogas plant, Sweden. The project and the results obtained are described in detail by a joint report (Holmgren et al. in press).

The measurement method developed by the present project and how it was integrated in the joint evaluation project are described in detail in appendix 1.17 (Measurement report. Methane emission from Svensk Biogas i Linköbing). However, a brief introduction of the evaluation project and its main results are described in the following.

The institutes involved in the joint international evaluation project were the following:

- DBFZ. Deutsches Biomasseforschungszentrum. German Biomass Research Centre.
- DGC. Dansk Gasteknisk Center. Danish Gas Technology Centre.
- DTU. Danmarks Tekniske Universitet. Technical University of Denmark.
- SP. Technical Research Institute of Sweden
- AgroTech. Institute for Agri Technology and Food Innovation

The project gathered some of the most experienced organizations and people in Europe regarding the measurement of methane emissions from biogas production plants. The project had two main objectives. The first objective was a literature study to gather existing data and knowledge, mainly in Europe, regarding methane emission measurement methods and results. The second objective was a comparison of some more or less established measurement methods during a joint comparative measurement campaign at a Swedish biogas plant, Tekniska Verken i Linköping. To our knowledge similar work has not been performed previously.

From the literature study it was concluded that a number of studies of the methane emissions from biogas plants have been performed in different countries, using different methods and approaches. The large variation in methods made it difficult to draw general conclusions from the existing data. A rather large variation between design, size and biomass use of typical plants in different countries makes the comparison even harder.

The evaluation part of the international project took place at the Tekniska verken in Linköping, Sweden between the 8 and the 12th of September 2014. Each of the institutes involved in the project performed individual leakages identification and measurements of methane leaking from the identified leakages. Subsequently each institute calculated the measured methane emission before methods and results were discussed and compared in a joint report (Holmgren et al, in press).

The conclusion of the comparison measurements in Linköping was that the general results from different methods and approaches involved in the comparative study are comparable (Figure 6). The total methane loss reported by the on-site measurement teams range between 0.6 – 1.1 % of the total methane production at the studied biogas plant. There were many and unknown uncertainties in all measurement results and they were due to both analytical uncertainties and time variation in emission sources.

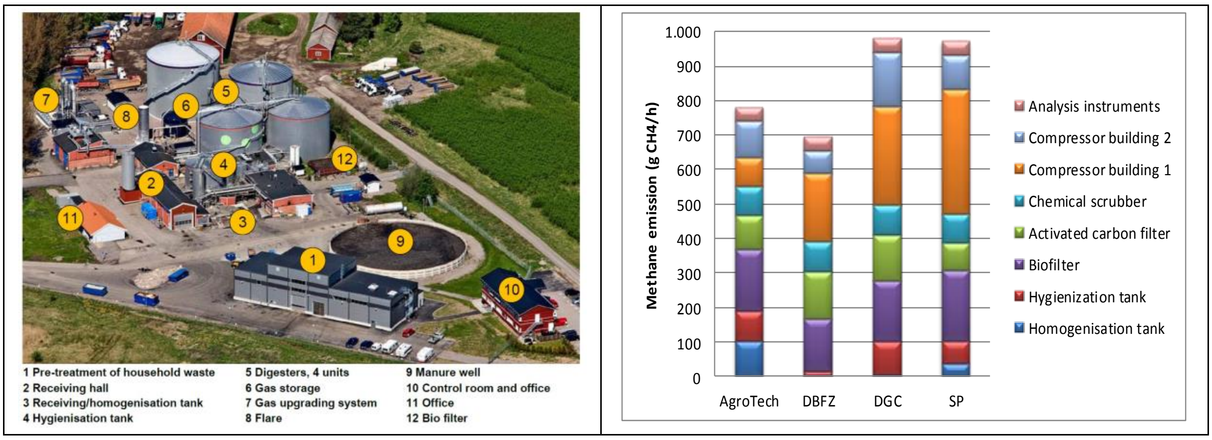

Figure 6. Methane emission sources at Linköping biogas plant, and comparison of estimated/hypothetic emission levels measured by the four different institutes measuring on-site at the different methane emission sources.

Apart from that, a few lessons were learned from the comparison measurements in Linköping. When the time schedule for the measurements was set, it was deliberately set up to not have the measuring teams influencing or disturbing each other. Due to the large time variation in emission sources, this however made strict comparison of the results difficult or even impossible. Variations in plant operation during the week occurred which made it even more hard to compare results. For a future measurement campaign it is strongly recommended to have as many measurements as possible performed in parallel, and measurements should be complemented with intercalibrations with gas bottles with known methane content.

A suggested next step would be the development of a handbook regarding methane emission measurements from biogas installations. This handbook should aid the user in choosing a suitable measurement method and approach depending on the purpose of the measurement task. It should list advantages and disadvantages of the respective methods and approaches. Further, it should guide the user in analyzing and understanding reported values using different methods and approaches. The handbook would serve as an important reference to a future work on standardization of methane emission measurements from biogas installations.

1.6 Main results

- An operational method for identification and measurement of methane emission from biogas plants was developed and evaluated at commercial biogas plants
- In total more than 50 methane leaks were identified at nine commercial biogas plants
- Methane emitted by leaks summed up to 4.2 % of the total methane production at nine Danish biogas plants
- There is a large potential for economical savings by identification of methane leakages at biogas plants
- Many leaks are easy and cheap to repair
- The leakage of methane was considerably reduced following identification and quantification of methane leakage and subsequent repair of identified leakages
- Leaks were identified at biogas plants where the plant owners did not expect methane leakages prior to investigation
- The total amount of methane lost by leakage was in general higher than expected by the plant owner prior to investigation.

1.7 Dissemination of results

The results of the project have been published at relevant national and international conferences and workshops. A list of this is appended in the following.

Hansen M.N., Stefanek K. 2014. Presentation of AgroTech and measurement of methane emission from biogas plants. Presentation at the European Methane emission workshop, 4th September 2014 Kiel Germany. Inter Baltic Biogas Arena.

Hansen M.N., Stefanek, C., Rasmussen S.G. Metanemission fra danske biogasanlæg – Klimaeffekt af metanlækager på biogasanlæg. In press.

Gregersen K.J. Methane emission from Danish biogas plants – Economic impacts of identified methane leakages. In press.

Holmgren M.A., Hansen M.N., Reinelt T, Westerkamp T., Jørgensen L., Scheutz C., Delre A. Methane emission measurements from biogas production - Data collection and comparison of measurement methods. In press.

Jørgensen L, Kvist T. Methane emission from Danish biogas plants - Quantification of methane losses. In press.

Jørgensen L., Kvist L., Andersen S.D., Stefanek K., Hansen M.N., 2014. Methane emission from Danish biogas plants. Presentation at the European Methane emission workshop, 4th September 2014 Kiel Germany. Inter Baltic Biogas Arena.

Kvist T, Jørgensen L, Andersen S.D., Stefanik, K, Hansen M.N. 2014. Metanemissioner fra biogasanlæg. Indlæg ved biogas økonomiseminar 8. dec. 2014, Koldkærgaard Agro-Tech.

Kvist T. 2014. Når biogasanlægget lækker gas. FiB No. 50 dec. 2014, Biogas. http://www.biopress.dk/PDF/nar-biogasanlaegget-laekker-gas

Stefanek K. 2014. Når biogasanlægget lækker gas. Nyhedsbrev om bioenergi, brint & brændselsceller nr. 40, februar 2014 p. 2 http://www.biopress.dk/PDF/nar-biogasanlaeg-laekker-gas/view

Stefanek K., Hansen M.N., Rasmussen S.G. Metanemission fra danske biogasanlæg – Håndbog. Identifikation og reparation af lækager. In press.

Stefanek, K. Jørgensen L., Kvist T., Andersen S.D., Rasmussen S.G., Hansen M.N., 2014 Methane Emission from Danish Biogas Plants, 22nd European Biomass Conference and Exhibition, Hamburg, 25th June 2014, http://programme.eubce.com/search.php?idses=173

The results obtained at the identification and quantification studies performed at the Danish biogas plants involved in the study were summed up in individual reports. These reports were sent to the individual biogas plants. An example of an individual biogas reports can be seen in appendix 1.12.

1.8 Utilization of project results

1.8.1 The project participant’s utilisation of results

Within the project, the participants have by means of the project developed competences and methods for identification and quantification of methane leakage at biogas plants. The project partners have built up commercial activities aiming to help biogas plants, the energy sector and the waste water treatment plants to reduce methane leakage from biogas and natural gas energy systems. The market potential of the developed commercial activities is not yet known.

1.8.2 Patent

The project partners have not planned to patent the methodologies developed in the project.

1.8.3 The project contribution to realisation of the energy policy objectives

The project has contributed to development of a methodology and results that help the biogas companies improve the environmental impact and a more cost efficient biogas production. Improvement of the environmental and economic effects of biogas production is important for the future development of the Danish biogas production and thereby to meet the political objectives to reduce the use of fossil fuels by increased green energy production.

1.9 Transformation of results to other institutes

The method developed and the results obtained within the project have been disseminated to other relevant Danish and international institutes working with improvement of biogas production and reduction of the environmental impact of the biogas production facilities. The dissemination of methodologies and results obtained by the project has taken place at relevant workshops and conferences.
Further, the methodology developed by the project has been presented and evaluated by taking part in an international joint project hosted by the Swedish Energiforsk (the former

Swedish Gas Technology Centre) in the autumn of 2014 and spring of 2015. The institutes taking part of the evaluation were the following:

- Deutsches Biomasseforschungszentrum (DBFC) Germany
- The Danish Technological University (DTU) (Denmark)
- Sveriges Tekniska Forskningsinstitut (Sweeden)
- Swedish Energiforsk (former SGC) (Sweeden)
- Danish Gastechnology Centre (DGC) (Denmark)
- AgroTech (Denmark)

A list of the dissemination of projects methodology and results can be seen in section 1.7.

1.10 Project conclusion and perspective

The project has developed an operational method for identification and quantification of methane emission from biogas plants. The developed method was evaluated at Danish commercial biogas plants. At nine Danish biogas plants more than 50 leakages were identified. The total methane emission from these leakages summed up to 4.2 per cent of the total methane production at the studied plants.

The emission from the leakages varied considerable both between individual leakages and between individual plants. Leakages were identified at biogas plants where the plant managers did not expect methane leakages prior to investigation, likewise the total amount of methane lost by leakage was in general higher than expected by the plant managers prior to investigation. Many, but not all, identified leakages could be repaired at relatively low cost.

The leakage loss reduced the economic output of the biogas production. Besides, as methane is an important greenhouse gas, the methane leakages at biogas plants reduces the positive climatic effect of biogas production.

The leakage of methane was considerably reduced following identification and quantification of methane leakage and subsequent repair of identified leakages. Following repair, the measured emission of methane was reduced from 4.2 to only 0.8 per cent at the total methane production at the studied biogas plants. A periodical inspection of methane emission at biogas plants could therefore be a possible method to increase the economic output of biogas production and to optimize the environmental impact of biogas production.

Annex

Relevant links

Stefanek K. 2014. OL bioenergy får hul på besparelser.

http://agrotech.dk/cases/ol-bioenergy-faar-hul-paa-besparelser

Kvist T. 2014. Når biogasanlægget lækker gas. FiB No. 50 dec. 2014, Biogas.
http://www.biopress.dk/PDF/nar-biogasanlaegget-laekker-gas

Literature

Fødevareministeriet, 2008. Landbrug og Klima – Analyse af landbrugets virkemidler til reduktion af drivhusgasser og de økonomiske konsekvenser. Fødevareministeriet 2008.

Holmgren M.A., Hansen M.N., Reinelt T, Westerkamp T., Jørgensen L., Scheutz C., Delre A. Methane emission measurements from biogas production - Data collection and comparison of measurement methods. In press.

Jørgensen L, Kvist T. 2015. Methane emission from Danish biogas plants - Quantification of methane losses. In press.

Kvist T., Jørgensen L., Andersen S.D., Stefanek K., Hansen M.N. 2014. Methanemissioner fra biogasanlæg. Indlæg ved Biogas økonomiseminariet 8. december 2014. Koldkærgaard.

Miljøstyrelsen, 2014. Vurdering af virkningerne på miljøet (VVM) for biogasprojekter - drivhusgasser. Miljøministeriet, Naturstyrelsen 16. dec. 2014.

Stefanik K.; Hansen MN.; Rasmussen SG. Metanemissioner fra danske biogasanlæg – Håndbog: Identificering og reparation af metanlækager. In press.

1.11 List of Appendix

1.12 Example of individual measurement report

1.13 Quantification of methane losses

1.14 Maintenance handbook: Identification and repair of methane leakages

1.15 Economic impact of identified methane leakages

1.16 Climatic impact of methane leakages at biogas plants

1.17 Measurement report. Methane emission from Svensk Biogas i Linköbing