Action reference no.: TEKES/30.3.99/6

“Biogas production in farms, through anaerobic digestion of cattle and pig manure. Case Studies and research activities in Europe”

Prepared by:

Guillermo J. Escobar and Matti A. Heikkilä, STEs. BESEL, S.A.

For:

TEKES, OPET Finland

BESEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
CONTENTS

1. Summary.

2. Background.
   2.1. Energy recovery from pig and cow manure.
   2.2. The anaerobic digestion process.

3. European Projects.
   3.1. Introduction.
   3.2. Current development.
       3.2.1. Small and Medium Scale Farm Plants.
       3.2.2. Large Scale Farm Plants.
       3.2.3. Community Plants.

4. Case studies.
   4.1. Centralised manure digestion Plant.
   4.2. Energy from animal waste using anaerobic lagoon digesters.
   4.3. Biogas recovery from chicken manure for electricity and heat production.
   4.4. Collective Biogas Plant in Deersum.
   4.5. Skinnerup on-farm biogas plant with gas storage.
   4.6. Electricity and heat from anaerobic digestion of farm waste.
   4.7. Centralised biogas plant from animal, industrial and municipal wastes.

5. Current R & D.

6. Performance and Investment indicators.


ANNEX

   Annex I. References.
   Annex II. Press snippets

BESEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
1. SUMMARY.

AD systems are well known and now widely used throughout the world. The factor most strongly influencing the economic merit of an AD facility is maximising the sales of all usable co-products. Advanced technology end-use applications can increase the economic value of biogas, but only after sufficient production scale has been achieved to significantly reduce the unit cost of ownership.

The use of more sophisticated AD processes for industrial waste treatment will increase. AD can decompose some organic toxic and hazardous materials in co-digestion schemes and this potential will be realised. For the future, the driving forces for the use of AD will probably drift away from energy production. Organic stabilisation, pathogen reduction, and the production of a high-quality soil improver will be important reasons to use AD in developing countries. Energy savings in operation and minimal sludge production from AD versus aerobic treatment will become more important in energy and landfill deficient areas.
2. BACKGROUND.

2.1. ENERGY RECOVERY FROM PIG AND COW MANURE.

Currently, the use of pig and cattle manure in farms for energy is mainly made through anaerobic digestion. There are other technologies based on direct combustion for heat production, though they need the addition of dryer co-fuels, like straw, wood chips or poultry litter.

2.2. THE ANAEROBIC DIGESTION PROCESS.

In the presence of dissolved oxygen, aerobic micro-organisms decompose biodegradable organic matter to CO2 and water with release of heat to produce a natural compost process.

In the absence of dissolved oxygen, aerobic micro-organisms tend to ferment biodegradable matter to carbon dioxide and methane. This mix gas can be collected and used as fuel. This process is called anaerobic digestion.

It occurs naturally wherever high concentrations of wet organic matter accumulate in the absence of dissolved oxygen. This process is common in the bottom sediments of lakes and ponds, in swamps, peat bogs, intestine of animals and in the deep layers of landfill sites.

The overall process of anaerobic digestion occurs through a combined action of a consortium of different types of micro-organism:

<table>
<thead>
<tr>
<th>Hydrolytic</th>
<th>Break down complex organic wastes into their components sub-units.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentative</td>
<td>Transform these submits into short chains of fatty acids and carbon dioxide and hydrogen.</td>
</tr>
<tr>
<td>Syntrophic</td>
<td>Bacteria convert the short chains of fatty acids to acetic acid with release of heat, CO2 and hydrogen.</td>
</tr>
<tr>
<td>Methane</td>
<td>Bacteria produce large quantifies of methane and CO2 from acetic acid, and combine the available hydrogen with CO2 to produce more methane.</td>
</tr>
<tr>
<td>Sulphate-reducing</td>
<td>Bacteria reduce sulphates and other sulphur compounds to hydrogen sulphides. The hydrogen sulphides react with present heavy metals to form insoluble salts. Nevertheless, always is remaining some hydrogen sulphide.</td>
</tr>
</tbody>
</table>
The biogas production yield depends on the composition and biodegradability of the waste feedstock, but its rate of production depends on the population of bacteria, their growth conditions and the temperature of the process.

At ambient temperature, the biogas production is very slow. The rate is greatly increased by operating at mesophilic temperature range (35-40º C), or thermophilic temperatures range (50-60º C). The second thermal level reduces the time taken by the process (12-14 h.).
3. EUROPEAN PROJECTS.

3.1. INTRODUCTION.

In January 1996 there were 470 biogas plants in Europe for digesting animal manure.

<table>
<thead>
<tr>
<th>Country</th>
<th>No. Of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>200</td>
</tr>
<tr>
<td>Denmark</td>
<td>28</td>
</tr>
<tr>
<td>Switzerland</td>
<td>90</td>
</tr>
<tr>
<td>Austria</td>
<td>50</td>
</tr>
<tr>
<td>Italy</td>
<td>20</td>
</tr>
<tr>
<td>France</td>
<td>15</td>
</tr>
<tr>
<td>Great Britain</td>
<td>30</td>
</tr>
<tr>
<td>Sweden</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 1.

About 150 new plants (120 of them in Germany) have been built in Europe during the past 7 years. As many as 20 may have been closed during this same period.

Most of European Plants are small or medium sized farm scale plants that use 1-20 m³ substrate per day. Nine large farm-scale plants in Germany use more than 20 m³ per day. There are also several plants of this size in concentrated livestock areas of northern Italy, the Netherlands, and Denmark.

Germany and Denmark are the most dynamic countries regarding their development.

3.2. CURRENT DEVELOPMENT

Three main types of biogas plants are currently being developed in Europe:

- Small and medium-sized individual plants.
- Large-scale individual from plants (high tech., industrially built).
- Community plants that collect manure from individual farms (high tech., industrially built).
3.2.1 Small- and Medium –Scale Farm Plant.

The small-and medium-sized farm plants represent about 70% of the existing plants (and about 80% of the actual annual growth). They have been in use for about 60 years, and the oldest plant (located in southern Germany) has been operating for 36 years.

Most plants in Switzerland, Austria, France, and Great Britain are small farm plants. About half of the existing 28 plants in Denmark are small or medium-sized plants. About 190 of the plants in Germany are small-or medium sized. Germany has seen the strongest growth of such plants during the past 2 years, with 25 new plants built during this period.

Technical achievements.

More than 100 plant designs can be distinguished in Europe. Many solutions (only a few of which have been used for series production) have been invented and constructed.

Plant building boomed in southern Germany (especially Bavaria), Switzerland, and Denmark, between 1973 and 1984. About 60 plants were built in Bavaria, 80 in Switzerland, and 10 in Denmark. Many designs (concrete or steel, vertical or horizontal) were offered by companies that emerged as biogas plants. In Germany more than 10 manufacturers, most of which had built tanks of slurry equipment, suddenly offered biogas plants. Only a few built more than one plant and only one built more than 10. Technical difficulties and falling oil prices forced most to withdraw from the market. Today only one company is offering medium-scale plant.

Fortunately, before and during the boom years many farmers built their own plants. With help from scientists at the agricultural school at Weihenstepahn in Bavaria and from ecological groups, the farmers’ expertise could be gathered and disseminated.

Several engineering offices, which support farmers in building their own plants, were formed from the ecological groups. Most plants built in Germany since 1985 are based on this self-construction design, which succeeded because the technique was simplified, standardised, and combined with individual plant planning. The planning principle consists of the following parts:

- A specialised engineer performs individual planning.
- The prefabricated parts are delivered as a building kit.
- Local craftsmen and workers are hired.
- The possibility also exists to “do-it-yourself”
Two main plant types were developed:

Horizontal follow-through steel digester, using a standard steel tank, often previously used as a gasoline tank.

Vertical storage digester, using standard slurry storage tank as the digester.

The horizontal steel digesters generally range from 50 to 100 m³, and occasionally to 150 m³. A stirring axle and arms reach each square foot, making this digester usable for all substrate types. Because of its limited volume and time-consuming construction, it is currently used mostly for problematic substrates such as chicken and other solid manures.

The vertical concrete digester is based on a standard concrete slurry tank as used in southern Germany. These tanks are series products that provide low-cost volume. They can be insulated and made gaslight, and are often built underground, thereby reducing space demand. The volumes range from 250 to 600 m³, but some are 800 to 1200 m³ and range in depth from 3 to 6 m and measure 8 to 16 in diameter.

Depending on the substrate, some stirring systems also handle substrates such as solid manure with a high fibre content. Special gas-tight stirrers have been developed based on a standard slurry stirrer. These can be handled from the outside and adjusted to the optimum working level.

Until 1985, most individual farm plants used gas for heating purposes only. Today most plants use it for cogeneration, with electricity as the main product and heat as a by-product; however, it is also used to heat homes and water.

The gas is stored in balloons and protected in containers, silos, or shelter huts: The storage capacity is 60-100 m³. The biogas is stored at night, when the biogas engine is not running.

Substrate Characteristics.

The main substrate is liquid slurry from cattle, pigs, and chickens. One-third of the German plants also uses solid manure that includes straw and is liquefied in special mixing devices with slurry or water.

During the past 2 years, many biogas producers began adding organic matter from the food processing industry to their manure. Most types of organic water from food processing can be used in biogas plants including wastes from slaughterhouses, oil and fat from frying, spoiled food, etc. In areas that have many biogas plants, there is already a shortage of industrial waste material.
Economic Aspects.

There have been only two company-made turnkey plants built in Germany, and two in Austria, during the past 2 years. However, more than 25 self-constructed plants have been built during this same period. In Switzerland there are only company-built plants. In recent years only one or two of these have been built each year. The same applies to Denmark.

In Germany, electricity from biogas can be sold to the grid for $0.10 (U.S.) per kWh. The gas can also be cogenerated to provide heat from the farmhouse for $2,000 (U.S.) per year. During the summer a great deal of excess heat is lost. The cost of a self-constructed plant for 100 cows (a typical size for southern Germany) is $100,000-$120,000 (U.S.). Subsidies are granted in most German states for biogas plants at rate of 20%-25%. A reasonable return on investment can be achieved under these conditions. Few company-built plants are built because they cost 50%-100% more than self-constructed ones.

3.2.2. Large-Scale Farm Plants.

These plants are built by industrial contractors at large farms that have a high concentration of livestock. They use high-technology to treat and reduce the volume of slurry. During the past 5 years, five such plants have been built in Germany, and a few have been built in the Netherlands, Great Britain, and Denmark. A demonstration project was initiated to cover 50% of their costs, however, the overall costs were proven to be too high. The former Deutsche Demokratische Republik (East Germany) had seven such plants in operation, the largest of which is in Nordhausen, which produced more than 20,000 m3 of biogas per day. This plant now produces half that volume, as the volume of livestock has decreased by half. Today five plants, which depend on the cogeneration of industrial waste, still operate.

3.2.3. Community Plants.

Community plants use the manure from many farmers in a particular area. The first such plant began to operate 11 years ago. Today 14 plants, which use up to 80 manure deliverers and up to 440 tonnes per day of substrate, are in operation.

Community plants are especially popular in Denmark for the following reasons:
- Individual farm plants had minimal success in Denmark.
- The Danish culture stresses co-operation and community involvement.
- Most villages have heat distribution grids with central boilers that can make use of the waste heat produced from biogas cogeneration systems.

The first three plants were built in Jutland (in the far north) during 1986 and 1987. At that time, numerous technical and economic problems interfered with their success. However, the Danish Energy Agency started an action program for centralised biogas plants that repaired or rebuilt existing plants and constructed new ones. Under the Agency’s supervision, builders and engineers applied lessons learned from previous constructions and tested new technologies without damaging the plants.

**Technical Achievements.**

The manure is collected from individual farms by lorry tankers. Up to now, mesophilic digestion has been used over thermophilic digestion by a 10:5 ratio. However, four of the next five plants schedule to be built will use thermophilic digestion.

The development of effective and cleanable heat exchangers for the slurry allows high process temperatures to be used hygienically while the plant’s process heat demand remains below 20%. A major task of the plant is to sanitise the substrate (eliminate pathogens), as slurry from many farms is collected and redistributed, therefore, each plant either operates at thermophilic temperatures or includes a thermophilic step performed at 55º C or higher for several hours. When sewage sludge or house waste is co-digested with manure, a sanitising step performed at 70º C for at least 1 hour must be included.

Each of the 14 plants has a different digester design and stirring system. Some use horizontal steel cylinders or vertical steel tanks assembled by welding or bolting the concrete plates. Some plants use large, central, slow moving stirrers; some use fast-turning propellers. Some new plant use vertical steel constructions and slow-turning central stirrers. Gas may be stored in high-or medium-pressure tanks, in bell-type gasometers, in balloons, or in pressureless or double membrane systems.

The gas in most plants is used for cogeneration, and the heat is delivered to a municipal heating grid. The gas line can reach consumers up to 8 km away. Low-pressure systems have proven to be the most economical for storing and transporting gas.

**BESEL** is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
Substrate source.

The substrate is the decisive element for all community plants. The first plants were constructed to use only livestock manure, but their survival depended on adding industrial and household waste. Today all plants depend heavily on municipal and industrial waste. Slaughterhouse waste, fish oil, frying oil, bentonite filter mass, household waste, and other food processing waste are added in quantities up to 37% of the total input. Gas production can thus be doubled or tripled, and the process can be stabilised.

The slurry is collected from farms within a 10-km radius of the plans by lorry tankers, which allows the area’s manure to be well managed. The farms with surplus manure can send the products to farms that need more fertiliser. One of the plant staff’s central tasks is to carry out the logistics of slurry transportation. The manure is stored, sanitised, homogenised, evaluated for nutrient content, and distributed to farms or fields. This enables the improved fertilising qualities of the digested manure to be used where needed. See Table 2.

Table 2. First 10 Centralised biogas Plants, 1994.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Input (m³/day)</th>
<th>Manure (%)</th>
<th>Organic Waste (%)</th>
<th>Digestion Temperature (°C)</th>
<th>HRT (days)</th>
<th>Gas Production (m³/day)</th>
<th>Gas Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Hjermitslev</td>
<td>44</td>
<td>63</td>
<td>37</td>
<td>37</td>
<td>34</td>
<td>4400</td>
<td>CHP**</td>
</tr>
<tr>
<td>Vegger</td>
<td>58</td>
<td>73</td>
<td>27</td>
<td>56</td>
<td>15</td>
<td>4500</td>
<td>CHP</td>
</tr>
<tr>
<td>Skovsgård</td>
<td>53</td>
<td>70</td>
<td>30</td>
<td>35</td>
<td>29</td>
<td>3100</td>
<td>CHP</td>
</tr>
<tr>
<td>Davinde</td>
<td>27</td>
<td>86</td>
<td>14</td>
<td>37</td>
<td>28</td>
<td>900</td>
<td>Boiler</td>
</tr>
<tr>
<td>Sinding</td>
<td>132</td>
<td>70</td>
<td>30</td>
<td>52</td>
<td>16</td>
<td>7100</td>
<td>CHP</td>
</tr>
<tr>
<td>Fangel</td>
<td>152</td>
<td>77</td>
<td>23</td>
<td>37</td>
<td>21</td>
<td>7100</td>
<td>CHP</td>
</tr>
<tr>
<td>Revninge</td>
<td>37</td>
<td>75</td>
<td>25</td>
<td>44</td>
<td>15</td>
<td>1200</td>
<td>Network</td>
</tr>
<tr>
<td>Ribe</td>
<td>401</td>
<td>84</td>
<td>16</td>
<td>53</td>
<td>12</td>
<td>11800</td>
<td>CHP</td>
</tr>
<tr>
<td>Lintrip</td>
<td>385</td>
<td>67</td>
<td>33</td>
<td>37</td>
<td>20</td>
<td>11400</td>
<td>CHP</td>
</tr>
<tr>
<td>Lemvig</td>
<td>453</td>
<td>79</td>
<td>21</td>
<td>52</td>
<td>17</td>
<td>14800</td>
<td>CHP</td>
</tr>
</tbody>
</table>

* Progress report on the economics of centralised biogas plants, February 1995, Danish Energy Agency.
** Combined heat and power.
Economic aspects.

Biogas energy in Denmark costs about $0.28 (U.S.) per m3 when used to cogenerate combined heat and power (CHP). This stipulates methane content of 65%. Once the biogas is converted into heat and electricity, its value increases to $0.42 (U.S.) per m3. Transporting manure and industrial waste feedstock to centralised biogas plants constitutes 35%-50% of the plant’s total operating costs. All plants own the vehicles; outside transporters are employed for most industrial wastes.

The first community plants needed a substantial subsidy (30%-40%), but new plants require less than 20% (0% in some cases) to achieve economic balance. During the past 8 years construction has improved and prices have decreased; however, the long-term challenge for centralised biogas plants will be economic viability without industrial wastes or investment grants. Organic wastes comprise almost 90% of the substrate; already, organic wastes are being imported from Germany. Biogas plant costs must be reduced by 15%-20% if they are to be able to operate economically on manure alone.
4. CASE STUDIES.

Following, four case studies are presented. It allows to have a look on recent (even not completed projects) in the relevant sector.

4.1 CENTRALISED MANURE DIGESTION PLANT.

Location: Ribe; Denmark

General Description
Stringent environmental legislation concerning the storage and spreading on land of animal manure, combined with an official energy policy which insists on a number of CHP plants based on domestic fuels, has increased the interest in centralised biogas plants and 15 plants have now been in operation for several years. Ribe Biogas Plant is one of these 15 plants.

The plant is owned by a limited company. Shares are held by, among others, local farmers supplying manure, a group of slaughterhouses, the regional electricity supply company and a public pension fund. The objects of the company are to establish and operate a biogas undertaking and to develop and disseminate biogas technology.

The Ribe Centralised Biogas Plant project was initiated in 1987 and production started in July 1990.

The European Union and the Danish Action Programme chose the project as a demonstration plant for Centralised Biogas Plant. Substantial information and experience on management, processes and the economy of centralised biogas plants have been derived.

Technical Data
80 farms supply manure as slurry, primarily from dairy cattle. The slurry is transported to the plant on their own lorries and fed into digesters where the gas is generated. The slurry is co-digested with slaughterhouse waste and other organic wastes. The balance between manure, slaughterhouse waste and other organic wastes varies depending on season and year. In total 400 tonnes are digested daily producing 11,000-12,000 cubic metres biogas. The plant is thermophilic in operation, the biomass being degassed at approximately 53°C, which offers two advantages: the process takes only 12-14 days (compared to a longer reaction time in mesophilic digestion) and the high temperature ensures a satisfactorily sanitary output.
The effluent is returned as fertiliser, partly to the farms that supply fresh manure, partly to other crop farmers. There are 22 decentralised liquid manure tanks with a total volume of some 45,000 cubic metres. These tanks, which each serve anything from one to nine farms, are sited near the purchasers of the annual surplus of approximately 4,000 cubic metres of liquid manure produced by the company.

The biogas is piped and sold to a CHP station, which is a part of the town of Ribe's district heating system.

Performance Data

Operation of the plant is satisfactory and stable with production as expected, although due to variations in the amount of manure and its composition output can vary. Operation costs are more or less as expected apart from maintenance of transport equipment.

Economic Data
(Note: DKK is the Danish crone).

The operation of the centralised biogas plants can result in several secondary economic advantages to the waste suppliers (industries or municipalities) and the farmers involved.

Key figures on invested capital and financing are shown in the table.

Invested capital and financing (in DKK 1990 prices)

<table>
<thead>
<tr>
<th>Invested Capital</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-Biogas plant</td>
<td>28,950,000</td>
</tr>
<tr>
<td>-Equipment for slurry transport</td>
<td>3,700,000</td>
</tr>
<tr>
<td>-Slurry Storages</td>
<td>12,600,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45,250,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Financing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-Public investment grant</td>
<td>17,700,000 (Grant, % of total investment 39%)</td>
</tr>
<tr>
<td>-Indexed mortgage loan</td>
<td>24,750,000</td>
</tr>
<tr>
<td>-Own capital (shares)</td>
<td>2,800,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45,250,000</strong></td>
</tr>
</tbody>
</table>
Plant Economy DKK - 1996 prices

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>4,378,000</td>
<td>6,603,000</td>
<td>6,858,000</td>
<td>7,189,000</td>
<td>7,910,000</td>
</tr>
<tr>
<td>Operating costs</td>
<td>2,198,000</td>
<td>2,844,000</td>
<td>2,436,000</td>
<td>2,569,000</td>
<td>2,875,000</td>
</tr>
<tr>
<td>Staff expenses</td>
<td>1,708,000</td>
<td>1,529,000</td>
<td>1,772,000</td>
<td>1,726,000</td>
<td>1,805,000</td>
</tr>
<tr>
<td>Ordinary result</td>
<td>472,000</td>
<td>2,230,000</td>
<td>2,649,000</td>
<td>2,895,000</td>
<td>3,232,000</td>
</tr>
<tr>
<td>After interest</td>
<td>-454,000</td>
<td>1,668,000</td>
<td>1,688,000</td>
<td>2,235,000</td>
<td>2,648,000</td>
</tr>
</tbody>
</table>

**Project Details**

Project Type: Demonstration  
Start date: July 01, 87  
End date: July 01, 90

**Organisation(s) and Contact(s)**

Organisation: Ribe Biogas Plant  
Role: Host Organisation  
Address: Koldingvej 19, Ribe DK 6760  
Tel.: +45 75 41 04 10  
Fax: +45 75 42 32 45  
Contact: Jensen, Else  
Tel.: +45 75 41 04 10  
Fax: +45 75 42 32 45

Organisation: Kruger A/S  
Role: Construction Company  
Address: Aldersrovej 22, Aarhus N DK-8200  
Tel.: +45 86 16 32 11  
Fax: +45 86 10 33 75
4.2. ENERGY FROM ANIMAL WASTES USING ANAEROBIC LAGOON DIGESTERS

Location: Southeast; United States of America

General Description
The Southeast Regional Biomass Energy Program (SERBEP), funded by the US Department of Energy, is developing information about anaerobic lagoon technology, including cost/size relationships, construction of lagoons, use of different animal manures (cattle, swine, and chicken), effect of climate, and institutional barriers. This technology has the potential to provide farmers and livestock handlers in the South-eastern United States with the capability to control their wastes (solids, water, and odour) while improving their economic bottom line by producing electricity, hot water, space heating, and cooling. Anaerobic lagoon digesters have much higher gas-recovery efficiencies than conventional stirred tank digesters due to longer retention times, and the biogas is 10%-15% richer in methane than conventional digesters. Projects which the SERBEP has supported include: (1) a 600 sow feeder pig operation (Martin Farms) in South Boston, Virginia. (2) the development of a hybrid lagoon concept by Georgia Tech to reduce lagoon size requirements (report available). (3) a 300-500 sow furrowing facility near Centerville, Arkansas. The project is now complete and the cover has been removed. (4) the design and installation of a heat recovery system for a covered lagoon (odour and solids control) at a meat-packing operation in Gaffney, South Carolina.

As an example, the Martin Farms project produces more than 80% of the electricity needed for the 600-sow facility. This is believed to be the first swine farm in the country to use covered-lagoon technology from the point of inception.

Technical Data
The covered Martin Farms anaerobic lagoon holds 389,000 cubic feet (2.9 million gallons) and is powered by a 25 kW H225 Chrysler marine engine with a Kato generator. This is a two-cell lagoon (primarily secondary) to treat the flushed waste from the barns. The primary lagoon is covered and contains a heat exchange grid in the base using heat from the engine cooling system to maintain lagoon temperature in the winter. Please note that the cover was replaced in 1997 to correct problems with the original design. The engine operation has not been resumed due to problems with water chemistry which is restricting gas production. The farm is evaluating the use of a gas combustor for hot water and winter heat.

Performance Data
The Martin Farms lagoon produces 11,780 ft3/day of gas and between 150,000 and 175,000 kWh annually. The digester loading rate is 0.14 kg volatile solids/m3/day. Electrical generation is expected to average 12-16 kW in the winter and exceed 25 kW during the summer. A study of anaerobic digestion of dairy animal wastes by North Carolina State University in Raleigh

BESSEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed of fifteen experts from all over the European Union and supported by the INNOVATION Programme.
concluded that anaerobic digestion of dairy and swine manure can be successfully accomplished from 10°C (50°F) to 23°C (75°F) for loading rates of 0.1-0.2 kg volatile solids/m³/day. Methane yield increases linearly over this temperature range.

**Economic Data**

(Note: $ is the US dollar)

Anaerobic technology is economically promising because it can be used to produce electricity for lighting, hot water, space heating and cooling. The capital costs of anaerobic lagoon digesters are roughly half those of conventional stirred-tank digesters.

Initial investment at the Martin Farms swine operation was $85,128.

Operation and maintenance is estimated to be $2,500. Unit energy costs are not yet available. A simple payback of 7.5 years is based on estimated $11,000 annual savings in electrical costs. Electricity to power the farm had been available from a conventional power generation source that produced 20 kW/hour at a selling price of $0.065/kWh. Normally, 80% to 90% of the facility's needs can be met through methane use. Additional monetary values or expenses of the system as they relate to odour control and lagoon clean-out will be evaluated as operations continue.

**Environmental Data**

The waste from Martin Farms swine operations will decompose to carbon dioxide and methane. The Martin Farms project captures and burns the methane and converts it to carbon dioxide, the less effective greenhouse gas. Although difficult to quantify objectively and economically, the covered lagoon inherently reduces odour. Effluent from the secondary lagoon is applied to the land in accordance with state regulations on farm property.

**Project Details**

Project Number US-94-518

Project Type Demonstration

Organisation Tennessee Valley Authority

Address PO Box 1010, Muscle Shoals Alabama 35662-1010 United States of America

Tel. +1 205 386 2499

Contact Stephenson, David

Tel. +1 205 386 3087

Fax +1 256 386 3799
4.3. BIOGAS RECOVERY FROM CHICKEN MANURE FOR ELECTRICITY AND HEAT PRODUCTION

Location: Nistelrode; The Netherlands

Project Description (Revised November 1997)
The Rijkers bv poultry farm in Nistelrode has built a biogas plant that uses chicken manure to generate electricity and to heat the house and poultry house. Part of the manure is fermented directly and part is dried to a dry matter content of 50%. In order to make the chicken manure pumpable, pig manure is also added. The methane gas extracted generates electricity by means of a gas engine and generator. The waste heat is used to heat the buildings and the fermentation tank.

Technical Data
The manure from approximately 45,000 laying hens is removed daily with a manure removal system and discharged into an 80 m³ cellar behind the poultry house. Since the manure has to be pumped it has to be made liquid. This is achieved by adding pig manure, flocculation silt and water or return fluid from the post-storage of the fermented manure. From the cellar, the manure is pumped to the fermenter. The digester itself consists of three compartments: the main digestion compartment (75 m³), a secondary digestion compartment (35 m³) above it and a channel connecting the two. In the main compartment, the manure begins to digest. A gas mixture of methane (64%) and carbon dioxide (36%) is formed, causing the pressure in the bubble above the fermenting manure to rise. The gas pressure passes part of the manure up through the channel into the secondary digester. When the liquid in the secondary digester reaches the overflow level, some of it flows out of the digester and into a storage bunker, while fresh manure is added to the main digester compartment. The gas valve is then opened and the manure in the secondary digester flows back into the main digester compartment. This causes the fresh load to be mixed with partially digested manure, and the process starts again. The fermented mixture is stored in a silo from which the fluid portion is returned to the mixing and metering pit. A balloon weighted with concrete ring floats in the silo containing the fermented manure. The gas is stored in the balloon for subsequent use by the combined heat and power plant. The gas drives a gas engine to which a generator is coupled. The heat generated by the engine is used for the heating system. The system also comprises a boiler fired by biogas or natural gas. This boiler heats the building and the manure fermenter. The level of gas production depends on the composition of the manure; it emerged that optimum production was obtained from a daily supply of 6.1 m³ of chicken manure, diluted with 2.3 m³ of pig manure, 1.9 m³ of flocculation silt and 2.3 m³ of return fluid.
Performance Data
During the measurement period, daily production of 932 m³ of biogas was achieved. The composition of the gas was approximately 64% methane and 36% carbon dioxide. The following estimates were made on an annual basis from 1986 data:

- Plant operating hours: 7,750 hours/year
- Electricity generated for own use: 310,600 kWh/year
- Electricity supplied to the national grid: 29,900 kWh/year
- Amount of heat produced: 689,750 kWh/year
- Heat used by the fermenter: 169,000 kWh/year
- Used for heating farm buildings: 163,000 kWh/year
- Heat extracted by the emergency cooler and not used: 358,000 kWh/year

Biomass mixture:
- Chicken manure: 1,970 m³/year
- Pig Manure: 742 m³/year
- Flocculation sludge: 614 m³/year
- Total: 3,326 m³/year

Biogas data:
- Maximum production: 295,545 m³/year
- Average production: 236,436 m³/year
- Average composition: 64% methane, 36% carbon dioxide
- Lower calorific value: 23 MJ/m³

Economic Data
(Note: NLG is the Dutch guilder)
In 1988, the average energy prices were NLG 0.14/kWh for electricity and NLG 0.5556/m³ for natural gas. This means that in 1988, the equipment saved about NLG 43,500/year in electricity and NLG 27,900 in natural gas. In addition, 29,000 kWh/year was sold at a price of NLG 0.0753/kWh, yielding a turnover of around NLG 2,300. The total revenue amounted to NLG 73,300/year. At a total investment of NLG 433,183 the simple pay-back time of the digester is 5.9 years. This could be improved if all the heat produced by the cogeneration unit could be sold.

Project Details
Project Number NL-94-513
Project Type Demonstration
Start date June 01, 86
End date September 01, 86
Country The Netherlands

BESEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
4.4. COLLECTIVE BIOGAS PLANT IN DEERSUM.

**Location:** Deersum; The Netherlands

**Objective**
To design, construct, operate and manage a biogas plant to treat the manure of dairy cattle, located in several farms in the village of Deersum, Neth. The expected energy production is yearly of 63,000 m$^3$ biogas (210 GJ heat and 78 MWh). The simple payback time is equal to 12 years.

**General Description and technical data**
The manure collected from dairy cattle in several farms in the village of Deersum (Neth), which represent 3,950 m$^3$ manure yearly with a content in organic matter of 7%, will be stored in a storage tank of 275 m$^3$.

The methane digester will have a capacity of 210 m$^3$. It is constructed in polyester. The mixing will occur by gas recirculation.

The digester will be equipped with an internal heat exchanger.

The digestion process will be conducted in the continuous mode without recycle at the temperature of 35°C. The mean hydraulic residence time will be 20 days. The expected gas production rate is equal to 0.83 m$^3$ biogas per m$^3$ digester and per day.

The digester effluent will be stored in a silo of 2,000 m$^3$ capacity. The produced gas will be stored in a balloon gas-holder of 100 m$^3$ capacity.

The yearly gas production will amount to 63,000-m$^3$ biogas. H2S will be removed from the biogas by passing through iron oxides. Part of the purified gas (10,000 m$^3$ per year) will be used in a boiler yielding 210 GJ for farm housing heating. The remaining of the biogas will be used in a TOTEM cogenerator of 15 kW and is expected to yield yearly 78 MWh, that is 30% of the municipality demand. Part of the heat produced by cogeneration will be recycled to heat the methane digester.

Monitoring will include mass and flows balances around the biogas plant concerning the inputs and the outputs of the methane digester including gas, electricity and heat, and temperatures.

The innovative character of the project lies in the managing of a collective biogas plant, linked with a wind-turbine (subject of another contract : WE/607/84).
Achievements
During the first year of operation, the digester received 1,900 m$^3$ manure corresponding to 5.2 m$^3$ per day.

In all, it has produced 30,500 m$^3$ gas. Thus the specific rate of gas production has been 16 m$^3$ gas per m3 manure. The average volumetric gas production was 0.40 m$^3$ of digester capacity per day. Over 29,000 m$^3$ gas was delivered to the co-generation power plant, which generated 33,000 kWh of electricity and heat utilised to heat the digester plant. Thus, the specific electricity production amounted to 1.14 kWh per m$^3$ gas.

Various teething troubles were experienced with the digestion plant: repeated blockage of the manure pumps, which were remedied by installing a stirrer in the pump pit; malfunctioning of the mixing system (gas injection); high hydrogen sulphide (H2S) levels in the gas, necessitating a larger desulphurisation capacity; low specific electricity production of the power plant.

Also, scum formation was experienced in the digester from time to time. The first problems either seem surmountable or have meanwhile been resolved, whilst scum formation is combated by adding spent motor oil.

As a result of these problems, only 1,900 m$^3$ manure could be delivered to the installation per year, against 3,950 m$^3$ as initially foreseen. The co-operation between the farmers concerning the delivery and offtake of the manure gave no troubles.

During the measuring period (from early 1988 until early 1989), the electricity demand of Deersum amounted to 331,000 kWh per year and the aggregate windmill/digester electricity output amounted to 255,000 kWh per year. Of this, 69 % (176,000) was utilised in Deersum. Thus, the wind turbine and the digestion plant could meet half of the electricity demand of Deersum.

The balance was covered by the provincial energy utility PEB Friesland. Additionally, there were also savings on the weekly maximum power demand of Deersum.

The surplus electricity, 31 % or 79,000 kWh per year, was delivered to PEB Friesland.

The power plant of the digestion plant was put into operation during the peak loads of Deersum (between 7.30 and 9.30 h a.m., and 6.00 and 8.30 h p.m.) by means of a timer.

During the first year the Deersum Energy Project was not profitable. The average cost price of the electricity amounted to Dfl.0.33 per kWh. This can be reduced to Dfl. 0.18 (Dfl. 0.15 per kWh for the wind turbine and Dfl. 0.29 for the manure digestion plant) by increasing the manure feed rate to the digester; higher rates for the sale of electricity; choosing a cheaper site; and
assigning a higher money value to digested manure than to undigested manure because of the former higher fertilising value.

Through series production of the main equipment, the cost price could be reduced still further to Dfl. 0.12 per kWh (Dfl. 0.10 per kWh for the wind turbine and Dfl. 0.16 for the manure digestion plant). These figures do not take into account the beneficial effects in the way of employment opportunities and the environment.

**Project details**

Start Date : 1986-01-01  
End Date : 1988-04-01  
Project Status : Completed

Project Cost : 309462.00 ECU  
Project Funding : 123785.00 ECU  
Project Reference : BM./00606/84/NL/..

Prime Contractor:  
Organisation : MUNICIPALITY OF BOARNSTERHIM  
Address : POSTBUS 40  
Postcode : 9000 AA  
City : GROUW  
Country : NETHERLANDS  
Contact Person : Name: VAN NES  
Tel: +31-5662-9204
4.5. SKINNERUP ON-FARM BIOGAS PLANT WITH GAS STORAGE

Location: Skinnerup, Denmark

Project Description
In April 1996 a new on-farm biogas plant of the "Smedemester" type was put into operation near Thisted in Jutland. The innovative feature of this plant is a total gas storage of 465 m³, allowing the farmer to produce electricity at the time of the day when it is most valuable. A small 65 m³ gas storage was established from the beginning but a bigger storage (400 m³) was added in July 12-13 m³ of slurry and 300-500 litres of fish oil sludge is mixed in a prestorage tank every day. From there it is pumped into a digestion tank (200 m³) six times per day. At the same time a corresponding quantity of degassed slurry is displaced to a storage tank. The daily gas production varies from 300 m³ (slurry only) to 970 m³ (boosted with fish oil sludge). The gas is burned in a motor generator and the electricity sold to the public grid. Electricity production varies between 600 and 1,870 kWh/day.

The farm is almost entirely heated by biogas that saves about 75,000 litres/year of fuel oil. The farmer takes advantage of peak load electricity prices by storing the biogas at night and running the motor generator only during peak hours.

Economic Data
Electricity prices vary as follows: (including a government subsidy (tax refund) of DKK 0.27/kWh (Note DKK is the Danish krone).

<table>
<thead>
<tr>
<th>Electricity Load</th>
<th>Price DKK/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.77</td>
</tr>
<tr>
<td>intermediate period</td>
<td>0.64</td>
</tr>
<tr>
<td>off peak</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Technical Data
Digestion tank: 200 m³ (vertical steel tank)
Process temperature: 40 - 48 °C
Average digestion time (1996): 12 days
Biomass consumption (1996):
- Slurry: approx. 370 m³ per month
- Fatty agricultural waste: approx. 12 m³ per month
Gas storage:
- Small: gasbag in container: 65 m³
- Large gas storage in round arch hall: 400 m³

BESSEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
Caterpillar motor/generator set 87 kW (electricity)
Accumulator tank for heat 10 m³
Substituted fossil fuels 75,000 litres fuel oil

Performance Data
Calculated annual electricity production 350,000 kWh

<table>
<thead>
<tr>
<th>1996 month</th>
<th>Gas m³</th>
<th>Electricity kWh</th>
<th>Electricity sold DKK</th>
<th>Sales price DKK/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>5,500</td>
<td>10,000</td>
<td>5,100</td>
<td>0.54</td>
</tr>
<tr>
<td>June</td>
<td>11,500</td>
<td>26,700</td>
<td>15,400</td>
<td>0.57</td>
</tr>
<tr>
<td>Jul</td>
<td>11,850</td>
<td>23,700</td>
<td>15,000</td>
<td>0.64</td>
</tr>
<tr>
<td>August</td>
<td>16,000</td>
<td>31,000</td>
<td>20,500</td>
<td>0.66</td>
</tr>
<tr>
<td>September</td>
<td>13,000</td>
<td>24,100</td>
<td>16,000</td>
<td>0.67</td>
</tr>
<tr>
<td>October</td>
<td>20,000</td>
<td>32,700</td>
<td>22,800</td>
<td>0.70</td>
</tr>
<tr>
<td>November</td>
<td>19,000</td>
<td>26,500</td>
<td>16,900</td>
<td>0.64</td>
</tr>
<tr>
<td>December</td>
<td>20,000</td>
<td>36,700</td>
<td>21,500</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Sales price was DKK 0.54/kWh in May but increased when the large gas storage was built in July and decreased in November and December when the large gas storage was out of order due to rebuilding.

Economic Data
Total investment DKK 2.1 million
Public investment grant DKK 600,000
Gas storage about DKK 70,000

Although electricity production reached its peak in December sales revenue was less than in October because the gas storage was out of order and electricity therefore sold at a lower price. Calculations show that the gas storage increases the value of electricity sales by about DKK 45,000/year. Calculated depreciation 5 years (with a production similar to 1996). Annual heating savings DKK 112,500

Environmental Data
Skinnerup biogas plant contributes to reduction of greenhouse gas emissions as the replacement of fossil fuels results in reduced CO2 emissions. Approximately 75,000 litre/year of fuel oil for heating is saved. Annual electricity production is expected to be approx. 350,000 kWh.

Long road haulage of manure and fertiliser is not needed at a decentralised plant. Petrol / diesel oil are thereby saved and heavy traffic on small roads avoided.

BESEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
Project Details
Project Number DK-97-520
Project Type Demonstration
Start date May 01, 95
End date March 01, 96
Country Denmark
4.6 ELECTRICITY AND HEAT FROM THE ANAEROBIC DIGESTION OF FARM WASTES

Location: Shrewsbury, Shropshire; United Kingdom

General Description
The 260 hectare mixed farm attached to Walford College near Shrewsbury, UK includes a 130 dairy cow herd, 160 sows and progeny, plus beef cattle and dairy young stock. These produce some 3,000 tonnes of organic manure per annum. Environmentally acceptable disposal of this waste presented a problem. In 1990, the college decided to introduce an integrated farm slurry management system based on anaerobic digestion to assess its advantages over the previous method of spreading raw manure directly to the land. Anaerobic digestion involves the breakdown of organic waste by bacteria in the absence of oxygen, by-products include a methane-rich gas which can be used as a fuel.

As part of a 3-year demonstration project, an anaerobic digestion system incorporating a combined heat and power (CHP) facility was installed in 1994. The system was rated at 35 kWe (electricity) and 58 kWth (heat output). Actual output has averaged 18.22 kWe for 19.5 hours/day. Approximately 30 kWth is harnessed to maintain the digester at the requisite temperature of 35-37°C. The system also produces 15 m3/day of treated liquid slurry or "liquor" and 3 tonnes/day of separated fibre. The liquor, which is odourless and easier to handle than raw manure, has an average analysis of 2.32 kg Nitrogen, 1.32 kg P2O5, and 5.3 kg K2O per 1,000 litres and is spread on grazing land. The fibre is made into compost for the college's own use and for sale to garden centres and other customers.

Technical Data
Slurry is fed from the pig and dairy units via flow channels to a reception pit. A chopper pump then pumps the slurry into a 335 m3 above-ground digester. Digestion takes 16-20 days. Digestion produces 450 m3/day of biogas that fuels the CHP unit driving an electricity generator. Heat is recovered from the engine's coolants and exhaust system. A stand-by boiler is used to heat the digester in the event of failure of the CHP unit. After digestion, the treated slurry is passed over a sieve separator. The fibre is removed to a composting shed and liquor is fed to a 950,000 litre storage tank.

Construction work began in February 1994 and the system was commissioned in October 1994.

Performance Data
The system requires no more than 1 hour/day attention from the farm-workers. The lack of slurry smells around the unit is noticeable and the area around the digester is cleaner than might be
expected.

**Economic Data**
(Note: £ is the UK pound)

Capital Cost

- Digester: £89,349
- CHP unit: £34,700
- Composting unit: £9,600 (incl. site infrastructure and connections)
- Total: £133,649

<table>
<thead>
<tr>
<th>Actual</th>
<th>Potential (Based on first 6 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>£10,374</td>
</tr>
<tr>
<td>Avoided spreading costs</td>
<td>£2,500</td>
</tr>
<tr>
<td>Fertiliser saving to grassland</td>
<td>£2,000</td>
</tr>
<tr>
<td>Compost sales</td>
<td>£400</td>
</tr>
<tr>
<td>Waste hot water</td>
<td>Nil</td>
</tr>
<tr>
<td>Annual income</td>
<td>£15,274</td>
</tr>
<tr>
<td>Running costs</td>
<td>£2,100</td>
</tr>
<tr>
<td>Net annual income</td>
<td>£13,174</td>
</tr>
<tr>
<td></td>
<td>£17,082</td>
</tr>
<tr>
<td></td>
<td>£2,500</td>
</tr>
<tr>
<td></td>
<td>£2,000</td>
</tr>
<tr>
<td></td>
<td>£14,600</td>
</tr>
<tr>
<td></td>
<td>£2,628</td>
</tr>
<tr>
<td></td>
<td>£38,810</td>
</tr>
<tr>
<td></td>
<td>£2,100</td>
</tr>
<tr>
<td></td>
<td>£36,710</td>
</tr>
</tbody>
</table>

**Environmental Data**
The system provides:
- Greatly simplified waste management;
- Alleviation of waste disposal problem;
- Savings in electricity costs;
- Full utilisation of anaerobic digestion by-products;
- Savings in grassland fertiliser costs;
- Potential farm-gate sales of the fibre;
- Reduced risk of pollution;
- Destruction of weed seeds in the manure.

**Project Details**

- Project Number: UK-96-504
- Project Type: Demonstration
- Start date: October 01, 94
- End date: [Not specified]
- Country: United Kingdom
- Organisation(s) and Contact(s):
  - Organisation: Walford College
  - Role: Host Organisation
- Address: Baschurch Shrewsbury SY4 2HL United Kingdom
BESEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
4.7. CENTRALISED BIOGAS PLANT FOR ANIMAL, INDUSTRIAL AND MUNICIPAL WASTES

Location: Sinding-Orre; Denmark

General Description
In 1984 the Sinding-Orre Civic Association discussed how to ensure a cost effective heat supply network for the small urban areas around the town of Herning based on alternative energy. A committee was appointed consisting of representatives from the civic association, farmers and municipality. After several meetings it was decided that the municipality of Herning should establish the biogas plant while a new supplier association (farmers) should be responsible for transportation and distribution of manure to and from the plant. The plant was built in 1987/88 and involved the production of biogas from the thermophilic digestion of pre-sorted and source-separated household waste.

Several problems were solved and identified during the first year of operation and a number of interesting features were implemented e.g. a method for treating source separated household waste (now in permanent use). Facilities for receiving and converting different types of industrial waste were also developed. The technique for using the organic fraction of household waste is now technically reliable and financially satisfactory. It includes pre as well as post sorting of plastics in order to ensure a clean fertiliser for the farmers.

Water and hydrogen sulphide are removed from the biogas before it is compressed, piped and sold for electricity and heat production to two local plants (a district heating plant in Sinding and a combined heat and power plant in Tjorring). The electricity is distributed through the electricity grid.

Technical Data
- Manure suppliers: 35
- Digestion tanks: 21,000 m³
- Process temperature: 53°C
- Process time: 15-16 days
- Annual consumption (1995):
  - Animal waste: 36,000 tonnes
  - Industrial and municipal waste: 16,000 tonnes
- Total: 52,000 tonnes

Emissions: Varying negligible amounts of SO2, NH3 and NOx
Performance Data
Annual biogas production in 1995 was 3,142,878 m³. Approximately 30% of the biogas is used as process heating at the biogas plant.

Economic Data
(Note: DKK is the Danish krone).
Investment: Excluding gas distribution, CHP plant and external storage
Plant DKK 20.8 million
Storage tanks DKK 2.9 million
Transport vehicle DKK 2.5 million
Total DKK 26.2 million

Environmental Data
Sinding-Orre biogas plant is part of an ambitious Danish demonstration and development programme of biogas. During 1996 almost 20 centralised biogas plants are in operation in Denmark. They produce about 40-50 million m³ of biogas per year corresponding to about 25 million m³ of natural gas. The Danish government's energy policy favours the use of non-fossil fuels in order to reduce CO₂ emissions and increase the use of renewable energy.

Project Details
Project Number DK-97-510
Project Type Demonstration
Start date June 01, 84
End date June 01, 88
Country Denmark
4.8. ANAEROBIC DIGESTION OF PIG SLURRY PROVIDES FUEL FOR ELECTRICITY AND HEAT

Location: Piddlehinton, Dorset; United Kingdom

General Description
In 1983, to alleviate an odour problem caused by the slurry produced by 12,500 pigs and to derive the maximum benefits from the slurry, Hanford's pig farms at Bourne Park decided to install and operate an anaerobic digester. Anaerobic digestion involves the breakdown of organic wastes by bacteria in the absence of oxygen. The methane-rich biogas generated can be used as a fuel, while the residue represents a valuable fertiliser.

The biogas produced by the Piddlehinton digester was initially harnessed to generate electricity for on-site use, with surplus electricity exported to the Grid at weekends and during some nights. In addition, low-grade heat recovered from the engines driving the generators provided space heating for Hanford's 460 m² (5,000 ft²) office building adjacent to the site, built in 1989.

Subsequently, Hanford submitted the project for inclusion in the first Non-Fossil Fuel Obligation (NFFO) Renewables Order, announced in 1990. The application was successful and, as a result, all the electricity produced is now sold to the grid for premium prices.

Technical Data
Slurry and food processing waste is pumped on a continuous basis from a reception pit into a 750 m³ insulated steel digestion tank, where it remains for around ten days at approximately 37-40°C. The biogas produced is fed to a store and then to two 45 kW modified spark-ignition six-cylinder Ford-Dover engines, each driving a 45 kVA asynchronous generator. Electricity is exported to the grid via a transformer. The system uses heat recovered from the engines' coolant water to heat the digester tank and supplies the surplus by pipe to the office block. Solids in the digested effluent are separated mechanically and the liquid residue is fed to a store before being spread on farmland. A diesel-fired boiler is used to heat the digester to operating temperature after a shutdown. Since commissioning, Hanford has made a number of improvements to the overall system as a result of R&D undertaken by the company.

The facility took six months to build and was commissioned in 1984. Hanford Construction, one of the Hanford Group of companies, built the digester and carried out all electrical and mechanical engineering work. The digester was designed by a firm of expert engineers.

Performance Data
Daily electricity production averages just over 1 MWh. The engines run at about 80% of capacity. Separated fibre production averages 2.1 tonnes/day that is ploughed into the ground.

BESEL is the co-ordinator of the Consortium for STA to the OPET Network in the field of RES, which is composed by fifteen experts from all over the European Union and supported by the INNOVATION Programme.
purely financial terms, the project operated at break-even prior to the award of the NFFO contract. Shutdown for cleaning and maintenance is necessary twice a year. The digester has also been closed down on two occasions to allow rectification of corrosion and sedimentation problems. In addition, the slurry feed system experienced minor difficulties but these were easily overcome.

**Economic Data**
(Note: £ is the UK pound)
Capital cost was approximately £213,000 (£144,000 for the digester and £79,000 for the generating plant, separator and site works). This has been fully depreciated, although further investment was necessary in 1989/90 to replace the generator sets and corroded sections of the digester tank.

Operating costs are approximately £15,000/year.

**Project Details**
Project Number UK-96-502
Project Type Demonstration
Start date September 01, 83
End date March 01, 84
Country United Kingdom
5. CURRENT R + D.

Production and usage of biogas has demonstrated their benefits from environmental and economical points of view.

The technology has reached the maturity age.

Currently, the subject is how to improve gas production and consumption from manure fermentation. In this sense, there are three main areas of Research and Development. They are the following:

• Improving fermentation efficiency by better process control and more efficient conversion of biogas into electricity and heat through monitoring of the slurry supply, the stirring of the fermenter contents, and heating and preheating of the fresh slurry.

• Biogas purification, by data collection on gas drying and three different purification techniques. Effectiveness, safety and costs are examined for the following methods:
  - Dry biogas purification with iron oxide.
  - Gas scrubbing with iron-containing ground-water.
  - Addition of iron chloride to fresh slurry.

• Measuring energy flows for different livestock sectors. First results (as expected) point the pig farms as having the best economic prospects.
6. DRAFT OVERVIEW OF THE AD SITUATION IN EUROPE AND NORTH AMERICA

AUSTRIA (1999-01-25)

Based on recent estimations the following plants are currently in operation:

- 88 Domestic sewage sludge digesters
- 31 Landfill gas reclamion plants (19 under construction)
- 20 Anaerobic Industrial waste water pre-treatment plants
- 50 Agricultural biogas plants
- 2(3) Domestic biowaste treatment plants

BELGIUM (1April 1997)

In Flandres, agricultural (mainly animal) waste management is of major concern because of intensive stock rearing and pig farming. (AD). Numerous digesters were built on individual farms in the ‘80s but it is thought that few of these are still operational.

CANADA

AD processes are currently used in some areas of Canada to treat municipal sludge, paper mill wastewater, potato processing plant wastewater, and cheese factory wastewater. These industries treat their wastewater to solve environmental problems and eliminate cohabitation problems. Energy recovery and utilisation is a secondary issue.

The main driving forces for AD in Canada are the environmental regulations.

DENMARK

Nineteen centralised biogas plants and 18 on-farm biogas plants currently operate in Denmark and further new plants are under construction or planned.
In total the centralised biogas plants currently produce 2.2 PJ.

Number of biogas plants:
- centralised 19
- on-farm 18

Figures of the centralised plants
- Biomass 10,000-160,000 ton per year, 30-450 ton per day
- Biogas production 1,000-20,000 Nm³ per day
- Digesters, size 750-7,900 m³
- Members, to deliver manure 6-80

**GERMANY**

At present 380 biogas plants are in operation throughout Germany, 250 plants have been constructed in the last 2-5 years. The average investment costs for a farm scale plant are DM 250,000.-. There are 11 large scale plants treating agricultural, agro-industrial or organic household with investment costs ranging from DM 5-20 Mil per plant.

**GREECE**

The estimated amount of manure produced by animals in Greece is 6.7 million tons. Dry animal waste production has been based on 1723 kg dry wastes/year for cattle, 199 kg dry wastes/year for sheep and goats, and 182 kg dry wastes/year for pigs (Loehr, 1974). The respective amount for chicken is 58.4 kg dry wastes/year.

A few attempts were made in the past through EC projects but they were not successful. The substrates were pig manure and whey from cheese factory

**ITALY**

At the end of the eighties, a new generation of simplified low cost plants for animal (mainly pig) wastes, usually obtained from covering anaerobic lagoons with flexible covers, arrived on the market. Their success is witnessed by the number of them -around fifty, from an...
unofficial survey carried out among manufacturers - built until now, the majority of which are still working.

After 1993-94, the farm market is more or less still, due to lack of public funds and the shortening of profit margins in animal husbandry. Nevertheless, a provision of the Italian government of 1992 that offered incentives for self-production of electric energy from biomasses, paying 270 ITL/kWh (0.135 ECU/kWh)

THE NETHERLANDS

Potential renewable energy in the Netherlands from anaerobic digestion of the 1.5 million tons available organic waste and 4.5 million tons of animal manure is 125 million m3 natural gas equivalent or a saving of 4 PJ.

The Netherlands has a sound knowledge on anaerobic digestion technology due to past projects and current projects in the field of anaerobic digestion of green waste, the chance of successful manure digestion plants is therefore relatively high. One key factor to success is effective, continued communication and co-operation with all interested parties. The establishment of a national interest group is therefore an essential start.

NORWAY

In spite of very little historic tradition in production and treatment of biogas, Norway has passed 60 biogas production units. Most of them were built in the last few years. Only 2 of the plants are in agriculture. Almost none of them are built for energy reasons - about 50% of the gas produced is flared.

Cheap electricity from hydropower and enough wood for personal heating has made no need of other/alternative energy sources.

PORTUGAL

In Portugal there are regions with high concentration of pig. In these regions there are operating 4 centralised biogas plants. About 90 farm scale plants are operating in the central and the southern part of the country.

The centralised biogas plants operate with not very satisfactory results, due to an inappropriate choice of treatment method.
SWEDEN

Over the period 1994-1997, five full scale plants have been constructed in Sweden and are currently in operation or in start up.

The amount of feedstock to be treated ranges from 26000 to 80000 tonnes per year. All of the plant are wet continuous digesters and are operated as mesophilic or thermophilic one stage, completely mixed, conventional reactors.

All plants are in the vicinity of major agricultural districts and the digester residue is distributed as a slurry fertiliser.

SWITZERLAND

About 100 farm scale biogas plants are in operation in Switzerland. Three installations are treating solid waste, all the others are running on liquid manure with addition of chopped straw (1.5 to 3 kg per animal and day).

The production of electricity became important when the price was fixed to SFr. 0.16 per kWh for renewable energy. Over 60 of the 100 digesters are equipped with CHP.

UNITED KINGDOM (April 1997)

Of the 45 units installed, only about 25 are currently operating. These farm-scale digesters have suffered from several problems. Some of the most common have been an inability to maintain a mesophilic temperature during the winter months, pipe blockages, digester pH instability and equipment failures. The two main causes of these problems have been inadequate design and lack of operator training, both of which should be relatively easy to rectify.

SPAIN

AD of animal manure is not very common in Spain due to a bad general opinion based on some unsuccessful projects implemented during the 80's. The reason why those projects faulted was the lack adequate bio-engineering work. The bacteria associations were not the most appropriate for the substrates to be digested. Besides, the already known problems (i.e., sulphur in gases, stirrers malfunctioning, etc.) were also found.
Nowadays the Spanish government is launching a Plan for the promotion of renewable energy sources. The objective is to produce 4,456 toe/year in 2005 and 7,427 toe/year in 2010 of biogas by AD of animal manure. The proposed tools to foster AD for energy projects mainly consist of: special price for electricity produced using biogas as fuel in CHP systems; partial de-taxation; public grants between 10-20% of initial investment; energy and environmental legislation leading to the reduction of organic wastes disposal.

U.S.A.

The status of the Farm-based digesters in the United States is the following:

<table>
<thead>
<tr>
<th>STATUS</th>
<th>TECHNOLOGY</th>
<th>Slurry</th>
<th>Plug</th>
<th>Mix</th>
<th>Lagoon</th>
<th>Other</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Not operating</td>
<td>0</td>
<td>18</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>Farm closed</td>
<td>0</td>
<td>11</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Under construction or planning</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Planned but never built</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>47</td>
<td>26</td>
<td>10</td>
<td>4</td>
<td></td>
<td>94</td>
</tr>
</tbody>
</table>

According the source, farmers base their decision not only on energy recovery, but also on environmental concerns and to reduce the amount of wastes to be eliminated as well as to facilitate their management.

A prove of the concern of the Federal Authorities regarding climate change, the AgSTAR pollution prevention programme has been expanded to livestock industry.
7. PERFORMANCE AND INVESTMENT INDICATORS.

The following tables show some economic figures averaged from the above case studies as well as from other not included in this document. Those figures may orient farmers on investment, operating and maintenance costs as well as energy production yields and economic savings coming AD projects.

The tables contain data from farms where cows, pigs, and hens are grown. AD systems running on mixed substrates have not been included to make a clearer picture of the performance and investment indicators.

For each kind of cattle, AD systems have been classified having into account the main technology. (tables 7.1, 7.3, and 7.5)

Besides, for each type of livestock, the indicators of different farms have been averaged in tables 7.2, 7.4, and 7.6