


# Biogas from Slurry in a Farm with 100 Dairy Cows

## Cogeneration from an Innovative Small Capacity Biogas Plant

Case Study - Biogas

AGRI for ENERGY II

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## The Agricultural Farm

The *La Sisile Agricultural Farm of Zanello Giovanni and Graziano* is an animal farm where ~200 Italian Simmental (dual-purpose breed) and Friesian dairy cattle heads are raised for milk production. The lactating cows are 100, the dry cows are ~10 heads, whereas the internal replacement is guaranteed by about 60 female calves and 20 heifers. The milking phase is carried out in a 5+5 herringbone parlor. The milk daily production is approximately 28 $L*day^{-1}*head^{-1}$ on average (~2.8 tons $day^{-1}$ for the whole dairy barn), sold to *Latterie Friulane* cheese factory (Campoformido, Udine). The cows are raised in a head-to-head cubicle house with chopped straw as bedding material. The female calves are raised on fully slatted floor. The faeces and urine are excreted in the concrete passageways between the rows of cubicles or under the slatted floor (female calves). The passageways are cleaned at least three times per day, by an automatic scraper. The manure is removed from the building as slurry and it is stored in a manure pit which has become a reception pit after the construction of the biogas plant. The total production of slurry is ~12 $tons*day^{-1}$ (4,380 tons $year^{-1}$), characterized by a high Total Solids content (13÷14% TS). The slurry is spread on 100 ha of Utilised Agricultural Area of the farm ($UAA_{total}$), of which partly belong to the farm (~30 ha) and partly consist of leased land (~70 ha).

## Biogas Plant – Technical Data

The construction of an innovative and economic anaerobic digestion (AD) plant relies on the farmer's management choices of not use vegetable crops as the main energy sources, thus making the most of the Biochemical Methane Potential of the slurry (BMP as $Nm^3$ of biogas or $CH_4$ per kilogram of Volatile Solids, $kg_{VS}$, contained in the cow slurry). The total amount of slurry produced by the dairy cow farm is utilised. It is possible to have a small integration with other organic substrates characterized by higher BMP, e.g. maize crushed grains (produced exclusively in the agricultural farm), glycerol, molasses from sweet sorghum, etc.

The innovative anaerobic digestion (AD) plant is manufactured by *Bio4Energy*, a German-Austrian Company devoted to biogas plant construction. The AD plant has an installed electrical power of 50 $kW_{el}$ and a nominal thermal power of 86 $kW_{th}$ (depowered to 40 $kW_{el}$ and ~69 $kW_{th}$ for electrical and thermal power, respectively). The CHP unit consists of an Otto cycle endothermic engine, manufactured by *MAN SE* (engine E0836 E312). The digester operates in a plug-flow mode and its design and construction elements are standardized. It is formed by two chambers (K1 and K2) cylindrical, made of concrete, concentrically arranged and connected to the bottom. The biogas production occurs in the chamber K1. This cause a movement of organic material from K1 to K2. When the biogas pressure exceeds a specific value, the valve opening allows to equalize the level of organic material between K1 and K2 (digestate stirring).

An innovative thermo-gas-lift system (TGL) is installed for both mixing and heating (thus avoiding the use of mechanical stirrers and mixers), since the AD plant operates under mesophilic conditions (40÷42 °C). The effects of the TGL can be summarised as follows:

- Airlift pump by introducing compressed air at the lower end of the TGL in K1 and biogas at the upper end of TGL in K2. The compressed air injection has also a desulphurisation effect;
- Air bubbles rising;
- Convective flow of heat due to the presence of hot water in the double wall of the pipe.

**Input and Output of AD Plant**

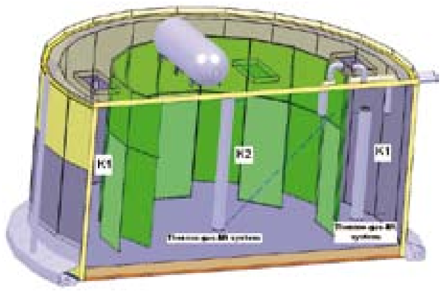
| | |
|---|---|
| Input per year | 4,418 tons |
| Total Solids (TS as % of Fresh Matter) | 14.3% |
| Organic load (VS as % of TS) | 85.7% |
| Organic Load Rate, OLR[a] | 3.9 kg $VS*m^{-3}*d^{-1}$ |
| Biogas produced per year | 189 thousand $Nm^3$ |
| $CH_4$ produced per year | 119.5 thousand $Nm^3$ |
| Electric energy gross production per year[b] | 327 thousand kWh |

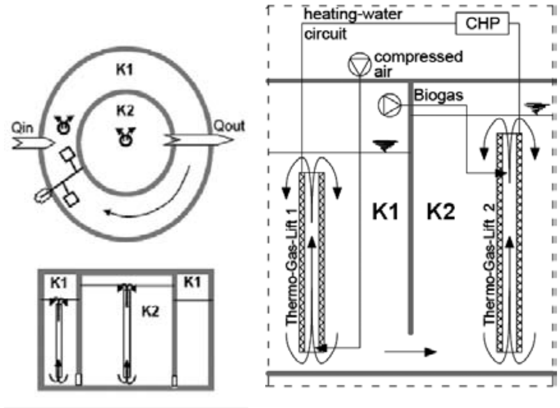
[a] OLR estimated taking into account approximately 382 $m^3$ digester tank.
[b] EE gross production estimated assuming 8.000 $h*yr^{-1}$ CHP annual operation hours at a load factor of 100%.

Giving the small dimensions of the plant, including the CHP unit, the thermal energy yearly produced will be used mostly or exclusively for self-maintenance of the mesophilic conditions.

According to the technical specification of the plant manufacturing Company, the external diameter of the

| **Organic Materials Utilized in AD**<br>UAA = Utilised Agricultural Area | UAA [ha] | Production [$tons*ha^{-1}*yr^{-1}$] | Yearly input [$tons*yr^{-1}$] | Daily input [$tons*day^{-1}$] | Gross electric power [$kW_{el}$] | Electric power [%] |
|---|---|---|---|---|---|---|
| Cattle Slurry | | | 4,380 | 12.0 | 40 | 90 |
| Maize Crushed Grains | 2.5 | 15 | 37.5 | 0.1 | 4.5 | 10 |
| TOTAL | **2.5 ha** | | **4,418** | **12.1** | **44.5** | **100%** |




*Layout and flow scheme of the circular-shaped 2-chambers in two concentric cylinders, K1 and K2 separated by scum baffles.*

digester tank is 10.5 m (K2 inner diameter equal to 6.0 m) and the external height is 6.81 m (K2 maximum water level equal to 5.5 m). The resulting total gross volume is ~441 $m^3$ whereas the available volume is ~382 $m^3$. *[www.bio4gas.eu, 2011]*
The total Residence Time (RT) can be estimated approximately at 31÷32 days, which should ensure the full exploitation of the BMP, thus making the cover of the digestate storage tanks an inconvenient option if the latter aims only at the recovery of the residual biogas produced during the final storage.

## Economic and Financial Analysis

The results of the economic and financial analysis can be summarized as follows:

| **Capital Expenditure (CapEx)** | [€] |
|---|---|
| Civil works[a] | 100,000 |
| Civil works[b] | 40,000 |
| Electro-mechanical engineering | 116,000 |
| CHP unit | 60,000 |
| S/L separator | 20,000 |
| Excavations, electrical connections | 45,000 |
| Miscellaneous expenditure (administrative practices, project planning, etc.) | 80,000 |
| Regional funding (40% of the CapEx) | –184,400 |
| **TOTAL** | **276,600** |

[a] Related to the biogas manufacturing Company
[b] Slurry/digestate storage tank

| **Operating Expense (OpEx)[a]** | [€*$yr^{-1}$] |
|---|---|
| Repairs / maintenance | 4,640 |
| Biological service | 5,000 |
| Energy crop supply | 5,625 |
| Income loss (UAA required for biogas plant construction) | 5,000 |
| **Total** | **20,265** |

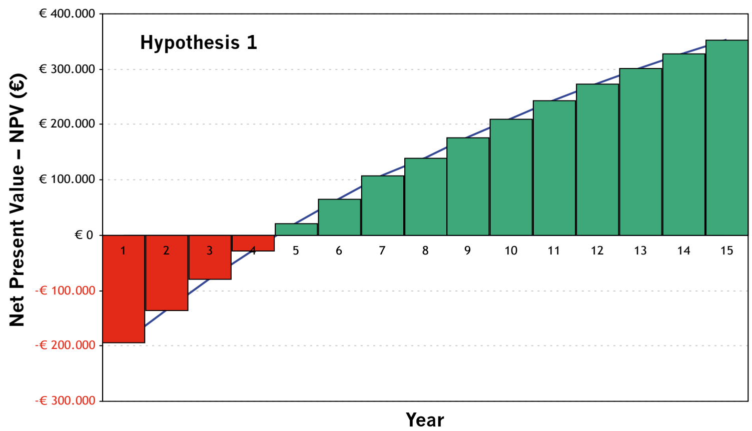
[a] The supplementary maintenance of the CHP unit has been added to the OpEx. This expenditure has been estimated and expected equal to € 15,000 in the 8th year.

The **Annual Revenues** result mainly from electricity sale, whose high value relies on the high incentives for electricity production from biogas (feed-in-tariff = 0.28 €/$kWh_{el}$). Notwithstanding, it should be examined in detail if the thermal energy may be suitable also for heating the water in the milking parlour. In this way, among other advantages (e.g. avoid a cost of ~3,000 € for $CH_4$ consumption), it should be possible to increase the ratio of the utilized thermal energy and the electricity fed in the electricity transmission grid.

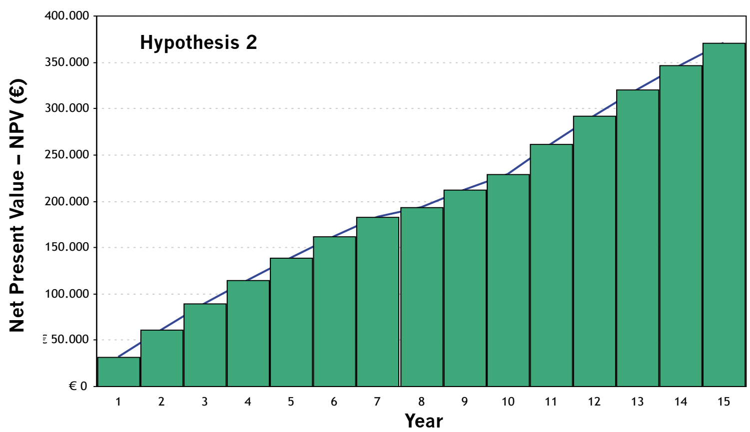
| **Annual Revenues** | [€*$yr^{-1}$] |
|---|---|
| Electricity fed in the electricity transmission grid, obtained from RES in biogas plants <1$MW_{el}$ | 85,100 |
| Digestate utilization on UAA (chemical fertilizer avoided cost) | 3,100 |
| **Total** | **88,200** |

[a] The CHP unit operating time has been assumed to be equal to 8.000 hours*$yr^{-1}$ and the electricity self-consumption has been estimated to be equal to 5%.

The Discounted Cumulative Cash Flow illustrates the economic viability of the investment into the biogas plant. On the basis of the Hypothesis 1, there is a disbursement at the 1st year of the investment, without having recourse to a bank loan and assuming a discount rate of 7%. The results can be summarised as follows:
**Payback time (PB) = 5th year**
**Net Present Value at the 15th year ($NPV_{15th\ year}$) = € 352,000**
**Internal Interest Rate at the 15th year ($IIR_{15th\ year}$) = 31.6%**




On the basis of the Hypothesis 2, there is a disbursement at the 1st year of the investment and a recourse to a bank loan of 12 years with a rate of interest on own capital (r) of 4%. The results can be summarised as follows:
**Net Present Value at the 15th year ($NPV_{15th\ year}$) = € 371,000**



# Adherence of the Case Study to "The Biogas Done Right" Principles

## Setting Up of Biogas and Biomethane Plants

*Available UAA must produce vegetable biomass which have to originate 70% minimum of the primary energy necessary for plant operation, excluding energy obtainable from animal manures and by-products:*

- Vegetable biomass, as above mentioned, must originate from owned or leased UAA, as it is recorded in the farm holding file; the average duration of leases must be 4 years minimum; the distance of UAA from the plant must be 70 km maximum (if UAA are not covered by framework contracts or sector agreements).
- Animal manures, as above mentioned, must be produced by the proposing agricultural firm or by members of the same agricultural firm or by third party, providing that average duration of contracts for manure supply is 4 years minimum and distance of manure production site from the plant is 70 km maximum.
- By-products, as above mentioned, must be produced by the proposing agricultural firm or by members of the same agricultural firm or by third party, providing that average duration of contracts for by-products supply is 4 years minimum.

## Land efficiency

*At least 70% of the primary energy necessary for plant operation must be produced from one or more of the following organic matrices:*

a) Animal manures produced by the proposing agricultural firm or by members of the same agricultural firm or by third party, providing that the distance of manure production site from the plant is 70 km maximum.

b) Agro-industrial by-products.

c) Agricultural residues and by-products.

d) Energy crops produced as first or second yearly harvest, before (yearly precession) or after (yearly succession) harvesting of feed and/or food crops.

e) Perennial crops (al least biennial).

## Carbon efficiency – Energy

*Efficient management of the CHP unit by fulfilling at least one of the following requirements:*

a) A quantity of the thermal energy which is produced yearly, corresponding to 20% minimum of the electricity which is fed in the electricity transmission grid, must be used for heating and/or cooling.

b) The thermal energy must be used in a suitable thermodynamic cycle in order to produce a supplementary quantity of electricity, which must be 5% minimum of the electricity which is fed in the electricity transmission grid.

## Carbon efficiency – Biology

*Efficient management of the biogas production plant by fulfilling at least one of the following conditions concerning the biomass pre-treatment and/or digestate post-treatment:*

a) Biomass mechanical pre-treatment (biogas production >15% compared to the situation without the treatment).

b) Biomass termo-mechanical pre-treatment (biogas production >15% compared to the situation without the treatment).

c) Biomass termo-pressure pre-treatment (biogas production >15% compared to the situation without the treatment).

d) Digestate post-treatment (by excluding Solid/Liquid separation) in order to enhance the fertilizer value and reduce nitrogen load on agricultural areas.

e) Digestate storage covers (30 day storage time minimum) and recovery of the residual biogas produced.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