PROCEEDINGS OF ECOS 2012 - THE 25TH INTERNATIONAL CONFERENCE ON
EFFICIENCY, COST, OPTIMIZATION, SIMULATION AND ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS
JUNE 26-29, 2012, PERUGIA, ITALY

FEASIBILITY STUDY TO REALIZE AN ANAEROBC DIGESTER FED WITH VEGETABLES MATRICES IN CENTRAL ITALY

Umberto Desideri[a], Francesco Zepparelli[a] (CA), Livia Arcioni[a], Ornella Calderini[b], Francesco Panara[b] and Matteo Todini

[a] University of Perugia, Dept. of Industrial Engineering, Perugia, Italy, zepparelli@tre-eng.com
[b] CNR IGV Perugia, Italy, ornella.calderini@igv.cnr.it

Abstract

In the present paper we have analysed the possibility to realize an anaerobic digester in a bio-Energy Park located in Città della Pieve, a small town in Central Italy. The use of anaerobic digesters is quite common in Europe for reducing the environmental impact of manure in a co-digestion procedure with vegetables materials. In addition, for several areas of Central Italy there is the need to find alternative productions to improve farmer's incomes, as traditional cropping systems are loosing convenience. An interesting alternative seems to be cultivation of energy crops because of the favourable conditions of the electric energy market. We are suggesting a low input cropping system to be implemented in areas where low input food/feed crops are no more profitable.

In particular our case-study is an example based on the use of a forage legume, alfalfa (Medicago sativa L.), together with other crops, like sorghum, to realize small-size bio-digesters plants.

Alfalfa: is a highly sustainable crop as it is able to fix nitrogen and therefore it does not require this fertilization with the consequence of avoiding underground water pollution. Moreover alfalfa residual products are nitrogen rich thus improving soil structure and fertility more than popular graminaceous energy crops such as corn. Beside, alfalfa mostly does not need irrigation in the typical Central Italy environment, all these traits make it one of the species with the lowest energy needs for growing.

The aims of this feasibility study are: i) optimization of plant materials feeding the bio-digester, ii) typology of bio-digester, iii) size of bio-digester in relation with land availability for growing energetic cultures, iv) the utilization of bio-gas produced by bio-digester plant to produce electric and thermal energy using cogeneration engines, vi) disposal of waste-water produced according to regional and national laws.

The final aim of this study is to verify the possibility to develop an alternative economical use of marginal soils in relatively dry areas of Central Italy that would be replicable in other European areas with a similar climatic situation.

Keywords:

Alfalfa, Anaerobic digestion, Digestate, Silage, Sorghum.

1. Introduction

Anaerobic digestion is an appropriate technique for converting biomass such as ensiled energy crops into renewable energy. In addition, since the digested residue can be used as a fertilizer, a cropping system based on energy crops has favourable traits of sustainability.

The interest in using ensiled crops for anaerobic digestion is increasing. In Europe the development of anaerobic digestion began in the sector of civil sewage treatment plants for the stabilization of sludge and currently it is estimated that there are more than 1600 operational digesters.

At the moment this technique is considered to be one of the best for the treatment of the wastewater from agro-industrial complexes with high organic content. As early as 1994 there were about 400 business and consortium biogas units while now there are more than 3500 anaerobic digesters operating on livestock effluent in all countries of the European Union. The highest number is in Germany followed by United Kingdom and Italy. There are currently about 450 active plants for the recovery of biogas from MSW landfills with a high concentration in Great Britain. This type of treatment is being increasingly supplemented in recent years by the treatment of the organic fraction deriving from the differentiated collection of municipal waste (bio waste), digested with other organic industrial waste and livestock slurries. In Denmark alone there are now 21 centralized co-digestion plants of this type, treating about 1,750,000 tons of livestock slurry and 450,000 tons of organic industrial waste and bio waste.

In 2010, primary energy production from biogas had an impressive increase of 31,3%. Biogas produced more than 10.9 Mtoe in 2010, which is an additional 2.6 Mtoe in just twelve months, and energy was primarily channeled into electricity production. The power output from this source should be as much as 30.3 TWh in 2010, which is 20.9% more than 2009 [1].

The country that developed anaerobic digestion at the highest degree in the last ten years is Germany, particularly in the livestock sector: the German biogas association reports that the country had 7,100 methanation plants in 2010 with 2,780 MW of electrical capacity. [1]

In 2010 Italy should become Europe's number three biogas producer, with primary energy production estimated at 478.5 ktoe. This is the result of the policy of incentives adopted by the national government which, in addition to providing a contribution for the investment, pays a price for electrical energy from biogas which may reach 0.28 €/kWh over a period of 15 years.

Central Italy is characterized by a great percentage of farmland localized in marginal areas. These kinds of areas are suffering to a greater extent of the general crisis of the primary sector due to lowering of incomes, abandoning of farms and the scarce appeal to the new generations. Eurostat reports a reduction of farmer's income of 3.3% in Italy. Energy from biomasses has become an interesting alternative to food/fodder crop production in the last years. The majority of power plants settled in Italy are based on biogas production in medium-large scale farms with animal husbandry. Because of the general Italian condition for farming this occurs mostly in Northern Italy. Anyway due to constant loss of income for traditional crops, farmers from marginal areas in central Italy are seeking an alternative to improve the profitability of their land. The present study analyse the possibility to suggest a model for biogas production in typical medium-small size farm in marginal areas where animal husbandry is not as common as it used to be. We are suggesting the use of two low/modest input crops with a special emphasis on alfalfa. Calculations are based on literature data but experimental analysis is in progress to test crop yield and biogas profitability in our conditions.

The present work takes into account the *"Regolamento regionale 4 maggio 2011, n. 4"* of Regione Umbria, concerning the management of facilities for the treatment of livestock manure and biomass for biogas production and utilization [2]. The new regional framework, in twenty articles, establishes: 1) the requirements for operation and management of anaerobic digestion plants and company, 2) inter-treating livestock manure and/or biomass to produce electricity and heat from biogas power up to 1 MW, 3) the terms of the agronomic use of the resulting digestate from anaerobic digestion.

In particular, the regulation sets that the materials to be treated must not come from more than thirty kilometres from the plant and that the same distance should be respected for the transport of digestate from the plant to the land of the company (art. 9). With articles 10 and 11 regulates the management and agronomic use of digestate and possible further treatment.

2. The anaerobic digestion process

Anaerobic digestion is an appropriate technique for converting biomass such as ensiled energy crops into renewable energy. The system proves its sustainability also because the digested residue can be used as a fertilizer.

Methane can be produced from biomass by either thermal gasification or biological gasification: biological gasification is commonly referred to as anaerobic digestion. A consortium of several different anaerobic bacteria carries out the process using a wide range of temperatures from 10°C to

over 100°C and at a variety of moisture contents from around 50% to more than 99%.. Bacteria living optimally at temperatures between 35 – 40 °C are called mesophiles, those surviving warmer and more hostile conditions at 55–60 °C are called thermophiles.
In the absence of oxygen, anaerobic bacteria ferment biodegradable matter into methane and carbon dioxide, a mixture called biogas. Biogas contains 60–70% methane and 30–40% carbon dioxide depending on the feedstock type [3]. Trace amounts of hydrogen sulfide, ammonia, hydrogen, nitrogen, carbon monoxide, oxygen and siloxanes are occasionally present in the biogas. Usually, the mixed gas is saturated with water vapor.
Anaerobic digestion takes place in basically three stages. In the first stage, complex organic macromolecules are hydrolyzed into simpler soluble molecules. In the second stage these molecules are converted by acid forming bacteria to simple organic acids, carbon dioxide and hydrogen; the principal acids produced are acetic acid, propionic acid, butyric acid and ethanol. In the third stage, methanogen bacteria form methane, either by breaking down the acids to methane and carbon dioxide, or by reducing carbon dioxide with hydrogen [4].
The biogas produced in an anaerobic digestion energy plant consists of 55–80% CH_4, 20–45% CO_2, 0.0–1.0% H_2S, and 0.0–0.05% NH_3, and it is saturated with water [5].

2.1. Digester Technology in Europe

In Europe digesters are mainly made of concrete with a steel skeleton or just steel. Their sizes vary between 500 and 3,000 m , although there are still smaller units for small users. The digesters have usually a cylindrical form standing upright in most cases. Not only because of the climatic conditions in Europe but also in order to control temperature conditions inside the digester tanks are equipped with an insulation and a heating system. Digesters are also equipped with a system to agitate or to stir the digesting slurry. There are many systems available to stir the system: some with slow moving propellers stirring for longer periods or such with fast turning propellers switched on only for short periods. The biogas is collected either in an external plastic bag or in the space above the slurry covered with a plastic membrane [6].
The digesters are flow through systems, which are fed several times per day. In the case of agricultural biogas plants the slurry comes directly from the stables or is collected in small storages before entering the digester. There is often a premixing pit where other feedstock can be added to the slurry. Sometimes the bulk feedstock can be added directly to the digester through an extra input system. The outlet works in parallel to the inlet. The digested slurry is often pumped to a post digester and/or to a storage tank. These storage tanks must have the capacity to store the slurry for several, often six to nine, months [6].
The average retention time in the main digester is usually approximately 28 days, but it can be easily demonstrated that, especially if crops and crop residues were added, biogas production can be detected still after 90 days. Therefore many biogas plants work with a post digester and/or the slurry storage tank is also covered with a foil, which works as gas storage. During post-digesting process and storage, approximately 30% of the total biogas evaluation is captured [6].
In addition to the described technology of wet anaerobic digestion there is a growing interest in dry anaerobic digestion [7]. The wet technology works with slurries of less than 12% dry matter content whereas the dry process can handle dry matter contents of 30% and more which would enable the user to use mainly crops and crop residues as feedstock. In the past dry anaerobic digestion was limited to waste processing biogas plants. Dry continuous-flow systems are very expensive and the income from waste disposal fees was necessary for an economic business.

2.2. Crops characteristics

Different crops are being used for bioenergy production; in our system we want to stress the presence of low input crops to be able to enhance production of energy from biomasses in agricultural areas where cash crops are not profitable anymore. This will avoid competition with food/fodder cultivation and at the same time it will sustain farmer's income. We are focusing on alfalfa and sorghum, two commonly cultivated crops in Italy.

Alfalfa is a polyannual (2-5 years) plant species used as forage crop. In the last year work from different laboratories suggested its alternative use as a source of biomass for biofuel production [5]. On average its dry matter yield is 8-10 tons/ha, which is rather competitive with other crops more widely used for bioenergy such as giant cane (Arundo donax) or Mischantus. In fact the input needed by an alfalfa field is very limited in terms of irrigation and fertilization, in particular, due to its ability to fix nitrogen, it has a widely acknowledged ability to improve the organic matter content and structure of the soil. Therefore alfalfa can be suggested as a highly sustainable alternative to commonly used grasses for bioenergy production, in particular in Italy where it is a well-adapted crop more than the mentioned grasses.

The initial establishment of the field that depends on the soil preparation and the availability of deep ground water, enhance alfalfa productivity. Anyway according to literature, a satisfactory productivity can be obtained also in low rainfall regimes. It has to be considered that maximum productivity generally occurs in the second and third year of establishment. An average dry matter yield that is considered in our system for this period is 8-10 tons/ha. To provide a continuous supply to the biodigestor we assume the storage of plant biomass as silage. Data from literature suggest that alfalfa silage provides a dry matter yield of 11.5 t/ha [9], with 69.5% moisture, 5.7g protein, 1g fat, 8.8g fiber, 2.4g ash.

The study conducted by Heiermann et al. [3, 10], investigates the suitability of various field crops for anaerobic digestion included alfalfa, thanks to laboratory scale batch anaerobic digestion tests under mesophilic condition.

Production on a continuous basis and an almost homogeneous feedstock is indispensable to enable an uninterrupted supply of crops for anaerobic digestion. Focusing on biogas production ensiling is the favorable and common method of whole crop preservation.

Legumes such as alfalfa have been ensiled but ensiling has relatively recently become a common means of conservation (Albrecht and Beauchemin, 2003).

Considering that chemical composition and structure of crops change during their growth, harvest time also plays a major role with regard to silage quality and maximum yield per hectare.

Fiber and sugar sorghum has been suggested as well suited for energy production. Sorghum itself is another low requirement crop and it is particularly interesting for its high resistance to drought and parasites. It is characterized by a high level of rusticity, growing well in different types of soil with a vegetative cycle of 95 - 120 days. Its dry matter yield on average is around 12-18 t/ha. Sorghum silage DM yields is 18 t/ha [2].

Energy outcome of the two crops is considered to be on average 530 l/kg biogas/organic DM for alfalfa silage ([5, 6], P. Weiland pers. comm) and 610 l/kg biogas/organic DM for sorghum silage (P. Weiland pers. comm).

We have considered cultural cost for the two crops as in the following table (sorghum data are from Contagraf, University of Padova, 2010, alfalfa data referred to a 4 years cycle, are from Rinaldi, 2005).

Table 1. Sorghum and alfalfa cultural costs

	sorghum, €/ha	*alfalfa*, €/ha
Seed bed preparation	230.00 – 250.00	90.00 – 100.00
Seed and sowing	160.00 – 170.00	50.00 – 60.00
Fertilization	130.00 – 150.00	50.00 – 60.00
Weed control	50.00 – 60.00	60.00 – 70.00
Harvest/ensiling	350.00 – 400.00	250.00 – 300.00
Total	930.00 – 1,030.00	500.00 – 600.00

As equipment for harvesting of sorghum, a combined forage harvester (mowing, chopping, loading) was accounted, for alfalfa swathing, raking, chopping of windrows and loading operations were considered.
We have used a combination of data from different literature sources to proceed with the calculations reported in the following parts of the paper.

4. Feasibility study

The chain for producing methane through anaerobic digestion from energy crops is presented in Fig. 1, from the production and harvest of crop biomass, to storage and pre-treatment of the biomass, production and utilization of biogas, storage, post-methanation and post-treatment of the digestate, and finally returning the digestate back to the crop production areas as fertilizer and soil-improvement medium [12].

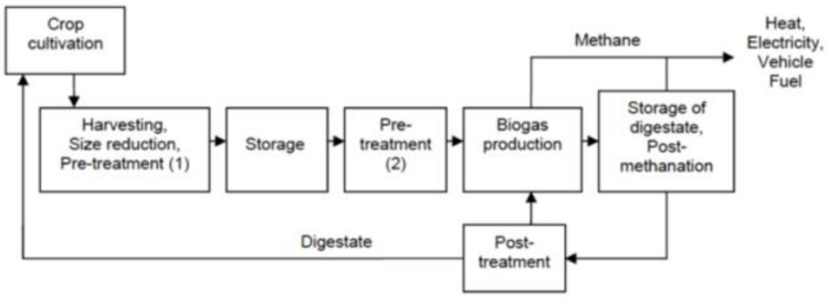

Fig. 1. Biogas production chain

Energy crops and crop residues can be digested either alone or in co-digestion with other materials, employing either wet or dry processes. In the agricultural sector one possible solution to processing crop biomass is co-digestion together with animal manures, the largest agricultural waste stream. In addition to the production of renewable energy, controlled anaerobic digestion of animal manures reduces emissions of greenhouse gases, nitrogen and odors from manure management, and intensifies the recycling of nutrients within agriculture. Animal manures typically have low solids content (<10% TS), and thus, the anaerobic digestion technology applied in manure processing is mostly based on wet processes, mainly on the use of continuously stirred tank reactors (CSTRs).
In co-digestion of vegetable matrices and manures, manures provide buffering capacity and a wide range of nutrients, while the addition of plant material with high carbon content balances the carbon to nitrogen (C/N) ratio of the feedstock, thereby decreasing the risk of ammonia inhibition. The positive synergy effects often observed in codigestion, due to the balancing of several parameters in the co-substrate mixture, have offered potential for higher methane yields.

The most important parameter in choosing crops for methane production is the net energy yield per hectare, which is defined mainly by biomass yield and convertibility of the biomass to methane, as well as cultivation inputs. Energy crops should be easy to cultivate, harvest and store, tolerant to weeds, pests, diseases, drought and frost, have good winter hardiness and be able to grow on soil of poor quality with low nutrient input.

Due to the problems related to the animal manure management, the present feasibility study concerns a co-digestion of vegetable matrices, in particular alfalfa and sorghum.

The co-digestion of two vegetable matrices may create problems in regard to the activation of the anaerobic digestion process. Because of this it may be necessary to make an inoculum of slurry to help the activation process.

Table 2. Methane and gross energy potentials of energy crops and crops residues

Substrate	*Methane potential*				*Gross energy potential*	*Ref.*
	($m^3 CH_4 kg^{-1} VS_{added}$)	*($m^3 CH_4 kg^{-1} TS_{added}$)*	*($m^3 CH_4 t^{-1}$ ww)*	*(m^3 CH_4 ha^{-1} a^{-1})*		
Forage beet	0.46	n.r.	n.r.	5800[a]	56[ac]	1
“	0.36	0.32[c]	55[c]	3240[b]	34[b]	2
Alfalfa	0.41	n.r.	n.r.	3965[a]	38[ac]	1
“	0.32	0.28[c]	56[c]	2304[b]	24[b]	2
Potato	0.28	n.r.	n.r.	2280[a]	22[ac]	1
Maize	0.41	n.r.	n.r.	5780[a]	56[ac]	1
Wheat	0.39	n.r.	n.r.	2960[a]	28[ac]	1
Barley	0.36	n.r.	n.r.	2030[a]	20[ac]	1
Rape	0.34	n.r.	n.r.	1190[a]	12[ac]	1
Grass	0.41	n.r.	n.r.	4060[a]	39[ac]	1
“	0.27	0.24[c]	46[c]	1908[b]	20[b]	2
“	0.27-0.35	0.25-0.32	64-83	n.r.	n.r.	3
Clover	0.35	n.r.	n.r.	2530[a]	25[ac]	1
“	0.14-0.21	0.12-0.19	24-36	n.r.	n.r.	3
Marrow	0.26	n.r.	n.r.	1680[a]	16[ac]	1
kale	0.32	0.28[c]	42[c]	2304[b]	24[b]	2
Jerusalem artichoke	0.27	0.24[c]	49[c]	2862[b]	30[b]	2
Sugar beet	0.23	0.19[c]	n.r.	n.r.	n.r.	4
tops	0.36-0.38	0.29-0.31[c]	36-38[c]	n.r.	n.r.	5
Straw	0.25-0.26	0.23-0.24	139-145	n.r.	n.r.	3
“	0.30[c]	0.25[c]	n.r.	n.r.	n.r.	6

[a] in Germany, [b] in Sweden, [c] Values calculated from the data reported, a = year, n.r. = not reported. 1: Weiland 2003, 2: Brolin et al. 1988, 3: Kaparaju et al. 2002, 4: Gunaseelan 2004, 5: Zubr 1986, 6: Badger et al. 1979.

This study assesses the sizing of the anaerobic digestion dimension plant, the quantification of the necessary agricultural area for the crops cultivation and for the agronomic utilization of the digested produced by the anaerobic digestion process.

We have considered a size of the CHP engine of 250 kW, which is a power that fits the needs of a typical medium-small size farm. In addition the following technical parameters are assumed:

- Mesophilic temperature range;
- Hydraulic retention time (HRT) equal to 28 days;
- Co-digestion of alfalfa and sorghum.

Following these assumptions, we have determined the amount of alfalfa and sorghum necessary to feed the 250 kW CHP engine. Considering a lower heating value of the biogas equal to 6.8 kWh/m^3, an efficiency of the engine equal to 36% and 7,500 operating hours for year, we obtain an amount of biogas equal to 766,544 m^3 per year.

In order to evaluate the amount of alfalfa and sorghum necessary for the production of biogas amount stated above, we have considered the parameters reported in table 3 (regarding alfalfa) and table 4 (regarding sorghum).

Table 3. Alfalfa silage parameters

Alfalfa silage	
Dry matter, DM	40%
Organic dry matter, ODM	85%
Biogas yield	0,55 m^3 biogas/kg ODM

Table 4. Sorghum silage parameters

Sorghum silage	
Dry matter, DM	30%
Organic dry matter, ODM	85%
Biogas yield	0,60 m^3 biogas/kg ODM

We have also assumed that anaerobic digestion of alfalfa produces 60% of the biogas, while 40% is produced by sorghum digestion.

The volume of the digester is calculated based on the following equation, given the amounts of the vegetable matrices and the hydraulic retention time:

$V = HRT * Q$

The necessary volume of the digester resulted of 407 m^3.

Given the vegetable yield/ha of the vegetable matrices it is possible to evaluate the amount of areas necessary to produce enough supply for the digester. Assuming alfalfa silage yield equal to 10.92 t/ha*year, and sorghum silage yield equal to 16.91 t/ha*year, and we have obtained that 225.23 ha are required for the production of alfalfa silage, and 118.51 for production of sorghum to feed the digester.

4.1. Digestate management

Digestate is a solid material remaining after the anaerobic digestion of a biodegradable feedstock and it is produced both by acidogenesis and methanogenesis with different characteristics.

Digestate is an easy product to handle and to apply and it can be used successfully as a substitute of mineral fertilizers. The fertilizer value of digestate depends on the nutrients present in the feedstock. However, digestate is the result of a living process and therefore has characteristics that are specific to each digester tank.

In the present study we have assumed that the digestate produced by the digester is stored in a specific waterproof lagoon, that as to be dimensioned to contain the amount of digestate produced in 150 days. The storage device of the digestate also envisages a frank minimum safety of at least

fifty centimeters. The design must include all the necessary measures to minimize odorous emissions [2].
In fact, the application of digestate at times of the year when there is little plant uptake, for instance autumn and winter, can result in nutrient leaching and runoff into ground and surface waters (e.g. of N and P). Digestate must therefore be stored until the correct time of application.
Digestate applications should be matched with crop nutrient requirements; this will minimize any unintended negative impact to the environment and also maximize farmers' profits. Table 5 reports application rates (especially for nitrogen), length of storage periods, and timings for applications that must also comply with national limits.

Table 5. National limits regulating nitrogen loading on farmland, required storage capacity and its spreading season

	Maximum nutrient load	*Required storage capacity*	*Compulsory season for spreading*
Austria	170 kg N/ha/year	6 months	28 feb – 5 oct
Denmark	170 kg N/ha/year (cattle) 140 kg N/ha/year (pig)	9 months	1 feb – harvest
Italy	170 - 340 kg N/ha/year	150 days	depends on the weather conditions
Sweden	170 kg N/ha/year	6 – 10 months	1 feb – 1 dec
Northern Ireland	170 kg N/ha/year	4 months	1 feb – 14 oct
Germany	170 kg N/ha/year	6 months	1 feb – 31 oct arable land 1 feb – 14 nov grassland

5. Conclusions

This study has assessed the opportunity to realize an anaerobic digester in a bio-Energy Park located in Città della Pieve, a small town in Central Italy.
We have chose to evaluate the anaerobic co-digestion of vegetable matrices such as alfalfa and sorghum silage and we have evaluated the principal process parameters.
In particular, assuming a 250 kW CHP engine, we have determined the biogas necessary, the volume of the digester, the amount of alfalfa silage and sorghum, and also the areas required to their production.
The area requested seems to be rather relevant, depending on the lower productivity of the crops chosen as alternative to the largely used energy crops for biogas production, such as maize. The economic feasibility is being currently investigated also taking into account smaller digester size and that marginal lands should be used. Further analysis including other low-input energy crops as suggested by latest literature in the field will be carried out.
Finally we have reported some important consideration about the digestate management, that could be a great opportunity but also a critical point of the system.

Nomenclature

CSTRs	Continuously Stirred Tank Reactors
HRT	Hydraulic Retention Time
ODM	Organic Dry Matter
TS	Total Solids
TVFA	Total Volatile Fatty Acids
VFA	Volatile Fatty Acids

VS Volatile Solids
ww wet weight

References

[1] Eurobserv'er, "The state of renewable energies in Europe". 2011 edition.

[2] Regolamento regionale 4 maggio 2011, n. 4 "Norme di attuazione dell'articolo 4, comma 1, lettera e) della legge regionale 10 dicembre 2009, n. 25 concernente la gestione degli impianti per il trattamento degli effluenti di allevamento e delle biomasse per la produzione di biogas e l'utilizzazione agronomica delle frazioni palabili e non palabili" Bollettino Ufficiale della Regione Umbria n. 21 del 11 Maggio 2011.

[3] M. Plöchl, M. Heiermann, B. Linke, H. Schelle. "Biogas Crops – Part II: Balance of Greenhouse Gas Emissions and Energy from Using Field Crops for Anaerobic Digestion". Agricultural Engineering International: the CIGR Ejournal 2009. Manuscript number 1086. Vol. XI. Month.

[4] R. M. Jingura, R. Matengaifa, Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe, Renewable and Sustainable Energy Reviews 13 (2009) 1116–1120.

[5] L. Xiaohui, N. Sugiura, F. Chuanping, M. Takaaki, Pretreatment of anaerobic digestion effluent with ammonia stripping and biogas purification, Bioresource Technology 100 (2009) 5478–5484.

[6] Plöch M., Heiermann M. "Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?". Agricultural Engineering International: the CIGR Ejournal. Invited Overview No. 8. Vol. VIII. March, 2006.

[7] Köttner M., Dry fermentation – a new method for biological treatment in ecological sanitation systems (ECOSAN) for biogas and fertilizer production from stackable biomass suitable for semiarid climates. In Proc. 3rd International Conference on Environmental Management, pp 16. Johannesburg, South Africa 2002.

[8] Chen F., Dixon RA Lignin modification improves fermentable sugar yields for biofuel production Nat Biotechnol 2007. 25(7):759-61.

[9] Borreani G, Tabacco E. Insilamento dell'erba medica per valorizzare le proteine. Terra e vita 2008, 14: 80-82.

[10] M. Heiermann, M. Plöchl, B. Linke, H. Schelle, C. Herrmann. "Biogas Crops – Part I: Specifications and Suitability of Field Crops for Anaerobic Digestion". Agricultural Engineering International: the CIGR Ejournal. Manuscript 1087 2009. Vol. XI. June.

[11] Candolo G. "Energia dalle biomasse vegetali: le opportunità per le aziende agricole" Agronomica 2006, 4:26-35.

[12] A. Nordberg, A. Jarvis, B. Stenberg, B. Mathisen, B. H. Svensson. "Anaerobic digestion of alfalfa silage with recirculation of process liquid". 2006.