POLITECNICO DI MILANO

School of Industrial and Information Engineering

Master of Science in Energy Engineering

OPPORTUNITIES FOR BIOGAS PLANTS IN EMILIA ROMAGNA REGION: ENERGETIC AND ENVIRONMENTAL ANALYSIS

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Master of Science Thesis by:

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To my parents,

with unwavering gratitude for economic support.

To my determination and perseverance,

when everything seemed difficult and impassable.

To my friends,

for having recommended and supported.

To my fellow students,

for having accompanied along this path.

To my Supervisor and Professors,

for their patience and dedication.

Abstract

Italy experienced a proliferation of biogas energy plants. In Northern Italy the number of plants has grown incredibly and in Emilia Romagna bioenergy production caused repulsion of locals and incompatibility with Parmigiano Reggiano cheese chain production. This thesis analyses the impacts of biogas development in Emilia Romagna region from a social, energetic and environmental perspective by direct depositions of operators, farmers and owners working in biogas energy production context. The study compares biogas production by using cattle manure and energy crops by taking into account all the corn cultivation process stages, transportation and digestate post-treatment in order to highlight biogas plant impact in terms of CO_2 emissions and primary energy consumption. Ten plants in Reggio Emilia, Modena and Piacenza province were investigated and analysed.

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Introduction

This thesis originates from a deep interest towards renewable energy field not fully developed nowadays, and still in its early stage which is biogas sector. Despite the huge growth in the last few decades, this technology has a large expansion margin which would require a homogeneous spread all over the Italian territory and not only in Northern Italy as it was experienced in last few years.

This work has been carried out following different steps. The first one involved a "fieldwork" in some biogas plants, cooperatives and dairy farms operating within Piacenza, Reggio Emilia and Modena countrysides. At the beginning some Google form questionnaires have been emailed to be able to gather technical information and figures. Later on, visits and surveys have been achieved in the above-mentioned companies. The high openness and willingness shown by all the operators and owners have been really crucial for the completeness of this thesis.

The second step has been characterized by a wide bibliographic research concerning scientific papers aiming at finding a feedback about what was previously seen in the international research context. The structure of the thesis has not been thought "a priori" but it has been a sort of "work in progress" during visits and extracurricular experiences.

In Chapter One I have tried to give a brief overview of Italian situation of biogas and its incentives evolution. Throughout the plants surveys and interviews to respective operators, several kinds of layout facilities have been captured; each of them presents its own peculiarity and features.

Being too onerous reporting all the biogas energy production basics and all related theory, I have decided to provide an overview concerning the most remarkable plant components by neglecting chemical theory about what happens inside fermenters just emphasizing the most relevant equipment in Chapter Two.

Considering the deep personal passion towards engines and my gained experience inside engine-manufacturing company, I have thought along with my supervisor to devote all the Chapter Three to the cogenerative engine (CHP) where a worldwide literature review has been carried out.

Chapter Four points out other energy conversion forms such as Fuel cell, Stirling engines etc and it takes into account the future perspective to inject biomethane into natural gas grids by upgrading systems. Moreover it underlines biogas impact inside electric network and the micro-grids evolution.

Eventually, Chapter Five and Chapter Six stress the experimental aspect of this work through the descriptive and listed collection concerning all the depositions given by biogas operator; furthermore they focus on the energy analysis of some biogas chain production stages accentuating important but not neglactable results in terms of primary energy consumption/saving.

All thinghs considered this thesis is the outcome of a careful reading about papers linked to personal considerations of people like operators and farmers who spend their everyday activities exploiting biogas sector.

1 Biogas in Italy

In recent years, Italy has witnessed a proliferation of agricultural biogas plants. This chapter highlights as institutional factors have played an important role in their diffusion. It describes the state and evolution of agricultural biogas in Italy, and then investigates the extent to which institutional pressures have been influential in shaping organizational models of biogas production. Further comments about future perspective and possible future incentives will be treat forward.

1.1 Biogas Evolution in Italy

Italy experienced a proliferation of biogas energy plants particularly between 2008 and 2012. In only a few years, the number of plants has grown from ten to nearly nine hundred [1] as we can see in Figure 1-2. Several connected factors have spurred this growth, all of them resulting from the confluence of three crises: in energy, the environment and intensive agriculture. These three crises are closely bound up with each other. The energy crisis has prompted rising prices for the supply of fossil fuels, dependence on potentially unreliable energy supply from unstable regimes, and negative environmental consequences stemming from greenhouse gas emissions. One of these consequences, climate change, is the main component of the environmental crisis, with clean and renewable energy resources being seen as a way to mitigate it. Intensive agriculture both contributes to the causes and suffers from the effects of climate change). Agriculture is not only being squeezed by the possible effects of climate change and related mitigation efforts, but it is also faced by a substantial squeeze due to energy price increases. Liquid fuel prices have more than doubled in the past few years, and this has had an influence on both agricultural production costs and prices to consumers.

Furthermore Italian sugar beet sector crisis is to be considered as well. EU policies totally destroyed the Italian market and in ten years sugar beet production decreased around 80% and 20000 jobs were lost all around the Europe. EU directives proposed and financed the conversion of sugar factory in biomass energy conversion plants and this brought the Italian producers at a very important juncture: start the conversion towards green electricity production or invest to try to survive in a more and more competitive market without any government support from 2020. [2] To counteract these forces, farmers need new ways to diversify their production, as well as environmentally friendly solutions. Biogas is one such solution: it produces clean and renewable energy, reduces the need to import fossil fuels, and provides a new stream of income to farmers. Thanks to the energy production of biogas farms, farmers are not only fighting the squeeze on agriculture, but also greening their farming systems.

1.1.1 The state of biogas production in Italian countryside

Accordingly last GSE report [3] in 2014 the RES production reached the record value of 120.679 GWh and bioenergy production counts for 18.732 GWh (Figure 1-1). Concerning electric sector, about 656.000 RES plants installed in Italy (total rated power of 50.594 MW) produced in 2014, about 121 TWh of electric energy and bioenergy sector contributes for 15%. Regarding to thermal sector, in 2014, about 9,9 MToe of thermal energy produced by RES was consumed, whose just 970 kToe as derived heat that is the thermal energy recovered from RES energy production (DH). As we can see in Figure 1-3 size plant distribution depends on RES typology and most of biogas plants in Italy (75.8 %) are included in 200 kW- 1 MW range.

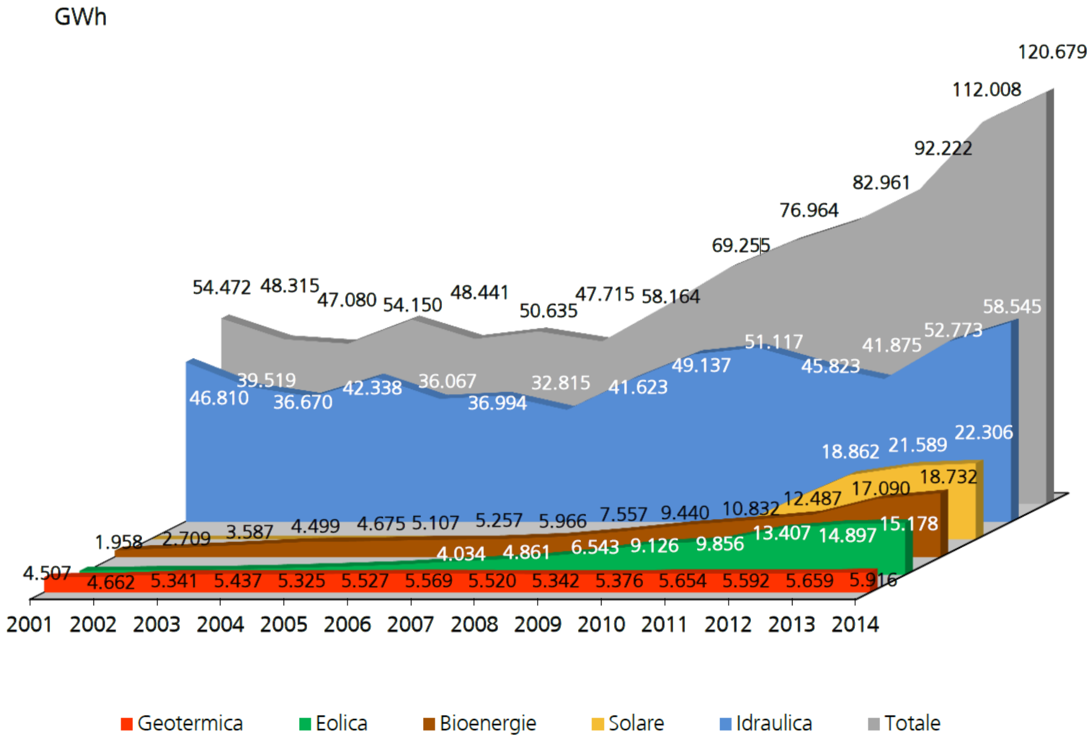


Figure 1-1: RES production evolution in Italy. Up to 2008 hydraulic source was preminant but in the last decade “new RES” were involved to the energy production contribution. (Source: [3])

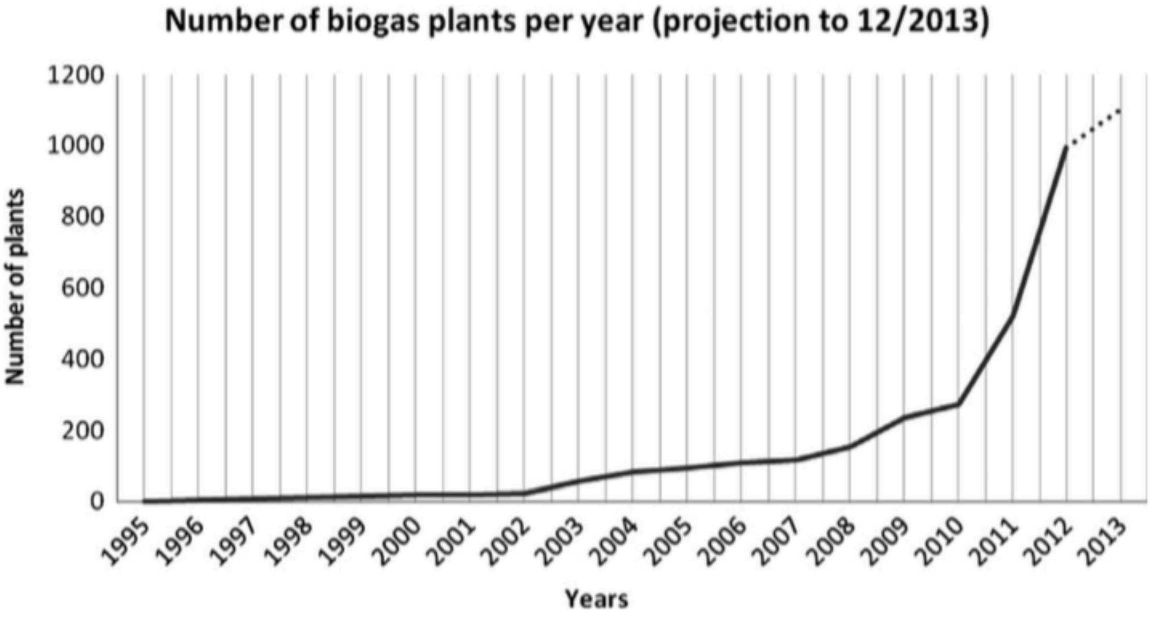


Figure 1-2: Number of biogas plants per year in Italy from 1995 to 2012. The dotted line indicates the projection in 2013. (Source: [4])

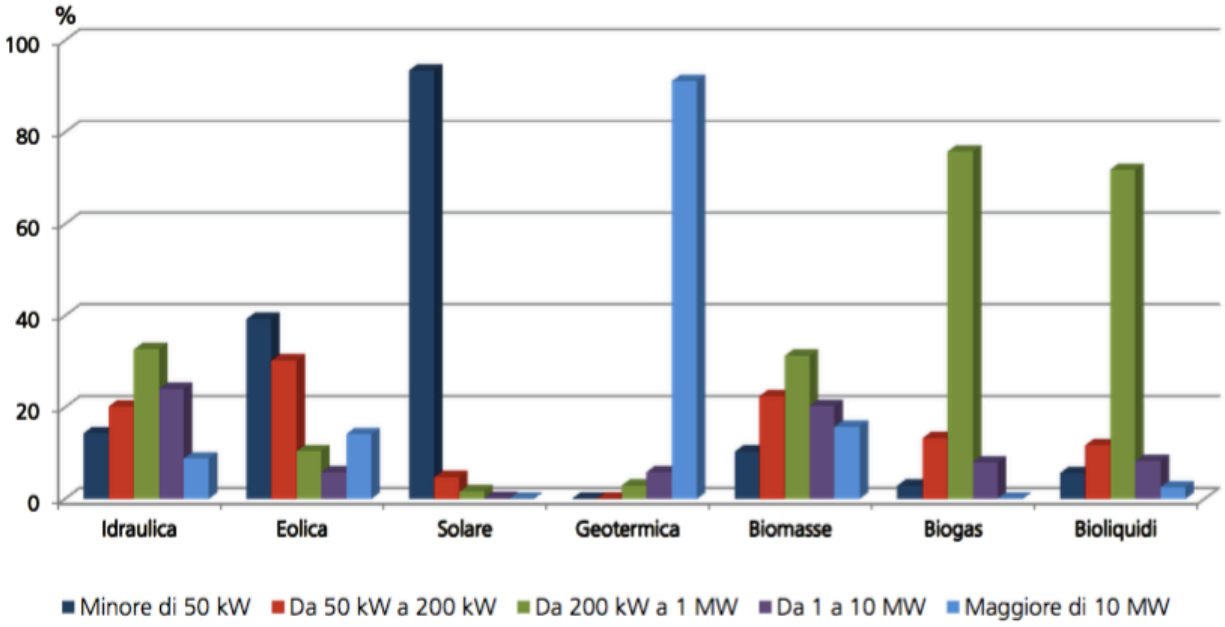


Figure 1-3: Plant size distribution accordingly RES typology. (Source: [3])

Between 2001 and 2014 electricity generation by bioenergy increased on average 19% year by year passing from 1.958 GWh to 18.732 GWh as shown in Figure 1-4, where biogas production counts for 43,8% of the total production. It is relevant to highlight the biogas production growth, moved from 1.665 GWh in 2009 to 8.199 GWh in 2014. According to the last official census [1] in 2013, there were 1054 biogas plants operating in Italy. Among them, 994 were managed by farmers, using energy crops and livestock manure. The others were located in organic waste landfills. This thesis focuses exclusively on plants managed by farmers.

Most of these plants are located in the Po Valley, where the concentration of large livestock farms is very high. 55% of livestock is located in Northern Italy, for a total of 5 milion to 7 million cattle and pigs; 75% of the animals bred in Italy. This area is characterized by intensive livestock production, high nutrient surpluses, and the intensive cultivation of cereals. Of the 994 existing plants in Italy, 882 are located in the northern regions and such uneven distribution is represented in Figure 1-5.

The Po Valley is the largest flat area of Italy and it comprises the most industrialized regions of the North (Piedmont, Lombardy, Emilia Romagna and Veneto). Owing to the presence of the River Po, the largest in Italy and flowing across the plains, the Po Valley is also Italy's most important agricultural area. Most of the agroindustry is located in this area, with major chains producing Parma ham and Parmigiano Reggiano cheese.

Established in this intensive agricultural region are biogas plants which use cereals, energy crops, and livestock manure as the main fuels for biogas digesters. 17.7% of plants use only livestock manure; 20.1% use only energy crops and cereals; and 62.2% make use of both types of fuel . The choice is dictated by the organizational model of the farm, but also by the installed power capacity. During the fermentation process, livestock manure is less caloric than cereals. Feeding a digester with a capacity of 1000 KWe requires cereals or a mix of fuel. Of the plants censused by [1], 65.5% had an installed power capacity between 500 KWe and 1000 KWe, 2.4% above 1000 KWe, 24.5% between 100 and 500 Kwe, and 7.6% less than 100 KWe.

At present, Italian biogas plants do not distribute natural gas through the network; rather, they use the gas to produce electricity directly. In almost all cases, the heat produced during gas burning is lost, with only a portion used within the farm. At best, the heat used consists of only 10% of the total heat energy produced.

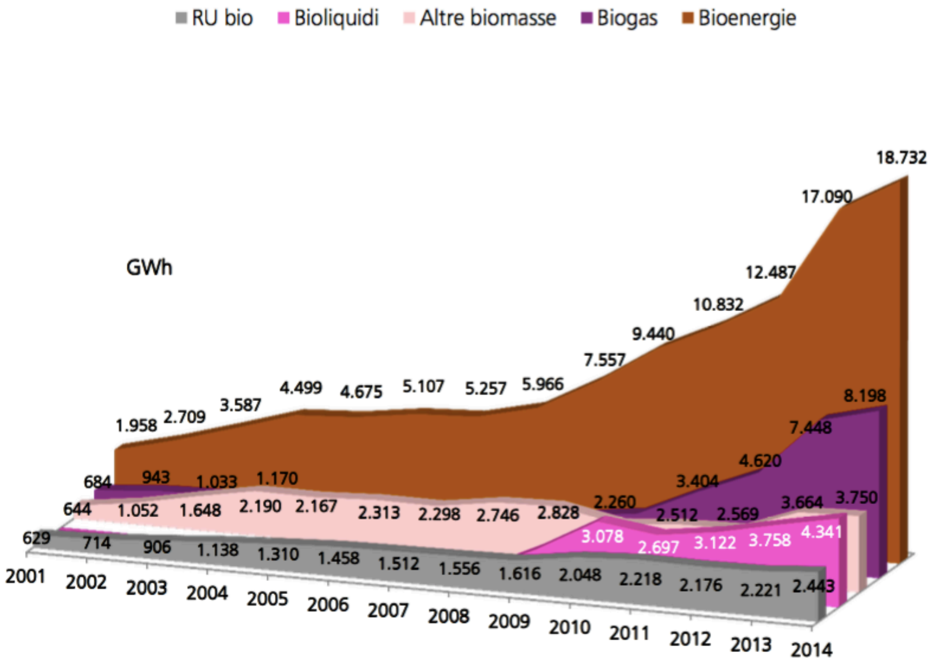


Figure 1-4: Bioenergy production evolution. (Source: [3]).

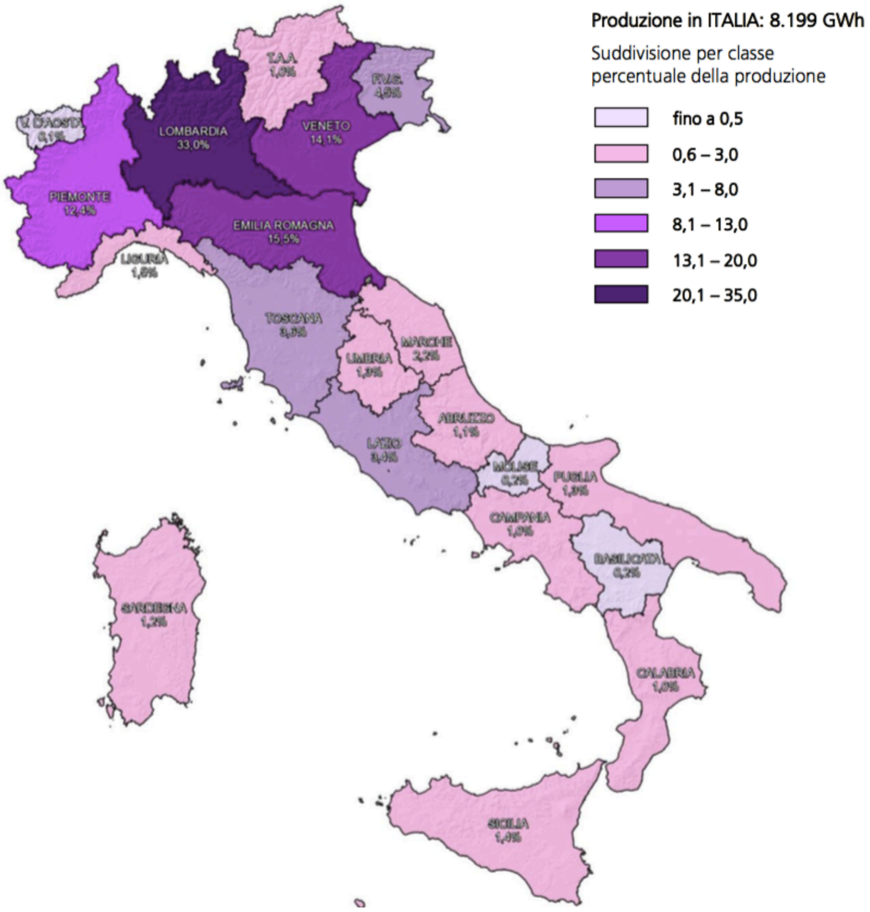


Figure 1-5: Regional distribution of biogas production in 2014. (Source: [3])

1.2 Regulatory Framework for biogas

Production values recently achieved in Italy are just a fraction of potentials: [5] estimated that animal breeding sewage digestion alone could generate up to 3.6TWh /year, which is approximately twice as much as total production levels in 2011. In the near future, it would thus be technically feasible to expand agricultural biogas generation beyond current production levels. Whether expanding agricultural biogas generation would also be economically feasible depends largely on promotion schemes. In fact, several studies from different countries confirm that, even considering co-benefits from cogenerated heat or digestate exploitation, power generation from agricultural biogas plants is profitable only when some form of incentive is available. Indeed, in the recent expansion of agricultural biogas in Italy, incentives were decisive.

1.2.1 Support programs ante 2013

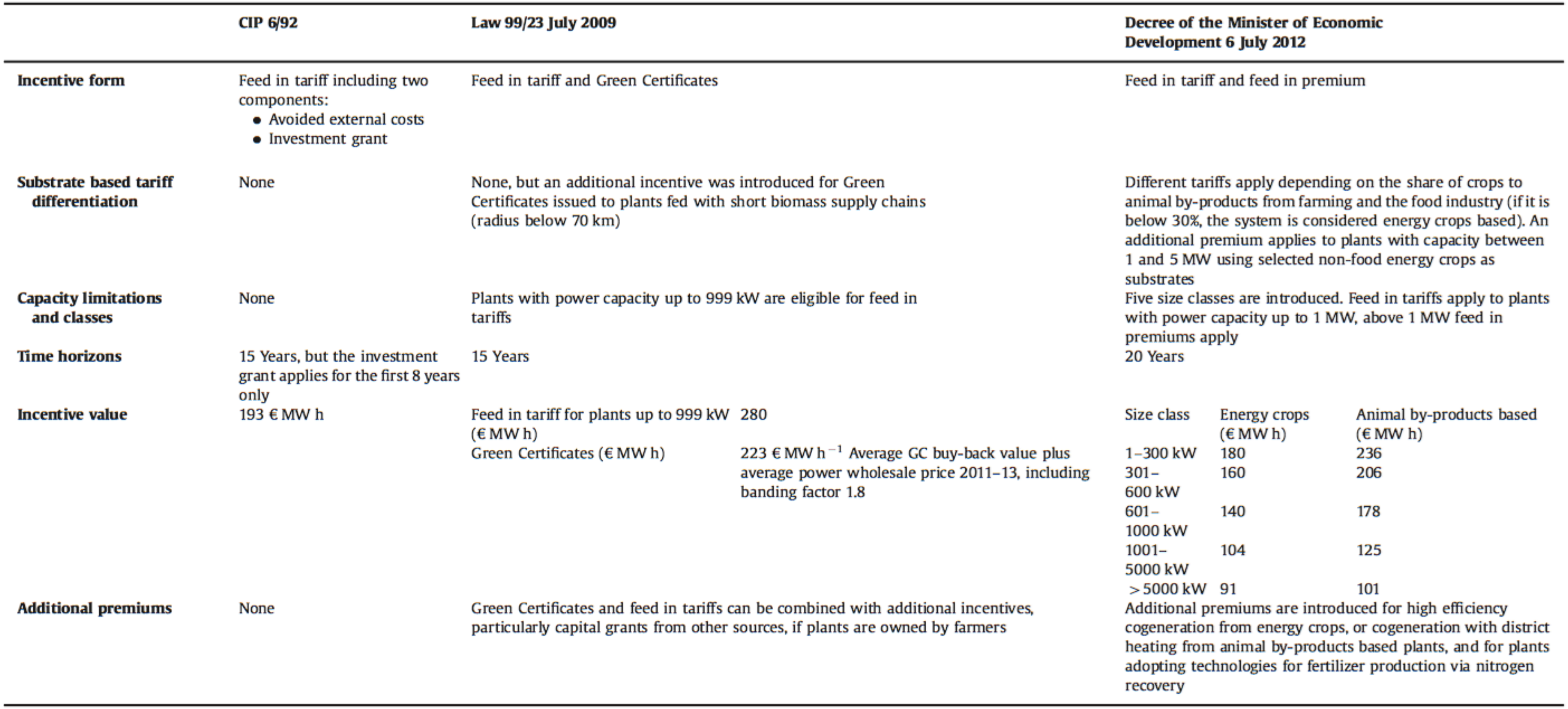
The first incentives for electricity generation from agricultural biogas were introduced in Italy before the liberalization of energy markets with the resolution known as CIP6 (Provvedimento CIP6/1992, April 29, 1992). As summarized in Table 1-1, the subsidy consisted of a feed in tariff (FIT) made up of an avoided cost and an investment grant component. The CIP6 program initiated biogas generation in the country, with an increase from nearly zero before 1992 to some 400 GW h in 1997, almost completely from landfills. Agricultural biogas generation remained almost nil until a first substantial rise in the early 2000s, determined by the transposition of the European Directive 96/92/EC into Italian Law with Decree Law 79/99 of February 19, 1999. A quota-obligation-based renewable energy support mechanism was started with the introduction of Tradable Green Certificates (TGCs). The regulation of the agronomic use of livestock effluents, implemented between 1999 and 2006 to transpose the European Directive 91/676/EC, also contributed to the development of digesters. However, not until the introduction of the feed in tariff and its final determination at 280 € /MWh with the Law 99/23 July 2009 did agricultural biogas production receive a real boost, mirrored by the three-figure percent growth reported for the years 2010 and 2011.

As summarized in Table 1-1 the same regulations also modified TGC by extending their validity period to 15 years and by differentiating their value by technology, introducing a banding factor of 1.8 for bioenergy from short supply chains (supply radius below 70 km). As a result, according to data from the GSE on certificate buyback prices and on power wholesale prices, average remuneration for biogas power between 2011 and 2013 was 223 € /MWh. While the TGC option was also theoretically available for plants below the FIT eligibility threshold of 1 MW, FITs were clearly preferable both for the sake of profitability and of lower risk.

Recommendations for RES support reported in the [6] suggest that distortions may arise when profitability expected at low risk (as in the case of FITs) is higher, resulting in higher additional costs finally paid by consumers. Indeed, an analysis of the Italian biogas market highlighted that in recent years very similar typologies have become dominant in Italy, i.e., 999 kW_e plants using a mix of animal feedstock and energy crops (mainly maize) as substrates.

De facto this system was very lucrative, and almost all plants below 1 MW_e choose to enter this mechanism, the forms of support were biased toward the production of electricity. There were no incentives for injection into the gas grid or for heat distribution. Also authorization procedures set the installed capacity of 1 MW_e as the threshold for distinguishing the type of process. Whilst for a system up to 999 kW_e, it was sufficient to possess a municipal authorization; those of larger size required an Environmental Impact Assessment.

Table 1-1: Policy changes in agricultural biogas support in Italy. (Source: [43])



	CIP 6/92	**Law 99/23 July 2009**		**Decree of the Minister of Economic Development 6 July 2012**		
Incentive form	Feed in tariff including two components: • Avoided external costs • Investment grant	Feed in tariff and Green Certificates		Feed in tariff and feed in premium		
Substrate based tariff differentiation	None	None, but an additional incentive was introduced for Green Certificates issued to plants fed with short biomass supply chains (radius below 70 km)		Different tariffs apply depending on the share of crops to animal by-products from farming and the food industry (if it is below 30%, the system is considered energy crops based). An additional premium applies to plants with capacity between 1 and 5 MW using selected non-food energy crops as substrates		
Capacity limitations and classes	None	Plants with power capacity up to 999 kW are eligible for feed in tariffs		Five size classes are introduced. Feed in tariffs apply to plants with power capacity up to 1 MW, above 1 MW feed in premiums apply		
Time horizons	15 Years, but the investment grant applies for the first 8 years only	15 Years		20 Years		
Incentive value	193 € MW h	Feed in tariff for plants up to 999 kW (€ MW h)	280	Size class	Energy crops (€ MW h)	Animal by-products based (€ MW h)
		Green Certificates (€ MW h)	223 € MW h $^{-1}$ Average GC buy-back value plus average power wholesale price 2011–13, including banding factor 1.8	1–300 kW	180	236
				301–600 kW	160	206
				601–1000 kW	140	178
				1001–5000 kW	104	125
				>5000 kW	91	101
Additional premiums	None	Green Certificates and feed in tariffs can be combined with additional incentives, particularly capital grants from other sources, if plants are owned by farmers		Additional premiums are introduced for high efficiency cogeneration from energy crops, or cogeneration with district heating from animal by-products based plants, and for plants adopting technologies for fertilizer production via nitrogen recovery		

1.2.2 Support programs post 2013

While previous support schemes had been effective in promoting investment, changes were required as an intense debate about incentives arose in the Italian media. At a time of economic stagnation, public opinion focused on allegedly high costs of renewable energy support charged to consumers. Targets for electricity generation from RESs for 2011 according to the national implementation of EU Directive 2009/28/CE was exceeded for most sources. RES-E targets had been fixed as shares of the total gross consumption of electricity, where growth was below forecasts due to the decline of the Italian GDP and of industrial production from 2008 onwards. Absolute values of solar electricity production and of biogas electricity production were, however, larger than expected, although the latter remained well below 2020 targets.

In this climate, the Decree of the Minister of Economic Development of 6 July 2012 introduced an incentive structure more in line with those in force in Germany, Austria and The Netherlands. In fact, as summarized in Table 1-1 and ad remarked in [7], the new biogas support policy includes:

- A stepped technology specific feed-in-tariff (third column of Table 1-1) for twenty years;
- An augmented tariff for plants using a minimum share of 30% manure, resembling similar bonuses or constraints in Austria and Germany;
- An additional bonus for high efficiency cogeneration of 40 €/MWh;
- An additional bonus of 40 € /MWh for high efficiency cogeneration plants adopting nitrogen recovery technologies to produce fertilizers;
- Special bonuses for plants with capacities between 1 MW and 5 MW using non-food energy crops only (20 € /MWh).

The new policy also entails a phase-out of Green Certificates. Plants commissioned before 2012 will receive proceeds from the wholesale of Green Certificates until 2015, when the Green Certificates will be replaced by a fixed feed-in premium calculated with current banding factors and equations, and with reference to current power wholesale prices.

In general, the 2012 incentive scheme is more complex than previous schemes. Basic tariffs are more generous than corresponding incentives in other countries and cogeneration is encouraged with higher bonuses rather than required as an eligibility constraint. As to [8], the new decree of 2012 deeply affected the convenience of biogas plant creation and its development in Italy. Basically the decree detached attention towards plants with rated power more than 600 kW and facilitates animal by-products farming in other words small farms using their biomass and exploiting very small production chain are favoured. The future diffusion of biogas plants will concern only small plants and a severe reduction of big energy power plants is already occurring. Further comments and analyses about this kind of policy support will be argued in Chapter 6.

1.2.3 Actual situation: 23-06-16 DM

On the 30th of June 2016 was published the ministerial decree of 23 June 2016 to encourage the production of electricity from plants using renewable sources, not with photovoltaic technology, which starts their operation from January 2013. The decree is the continuation of the incentives established by the Ministerial decree of July 6th, 2012 and arrived after a long wait from the operators also and above all because of the interaction between national institutions and the European Commission, which had to confirm the compatibility of the draft decree with the European guidelines on State aid.

Two different ways are expected for the access to the incentives, depending on the power of the plant and the category of intervention, managed by GSE exclusively by electronic means:

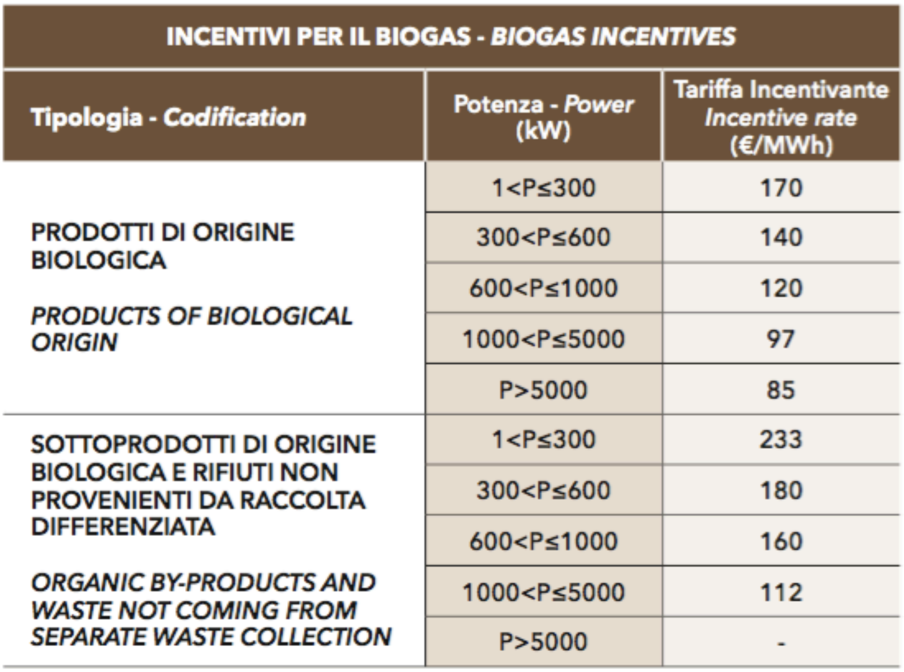
1. Direct access, following the entry into service: in the case of new plants, subject to full reconstruction interventions, reactivation, upgrading or renovation, with input below specific limit values, differentiated by type of source: in the case of biogas the limit is set equal to 100 kW.

2. Subscribing to Register and subsequent request for access to incentives for plants permitted in good position: in the case of new plants, subject to full reconstruction interventions, reactivation, upgrading, with power beyond the aforementioned limit and not more than 5 MW power beyond which it is necessary to access the auction procedures.

In continuity with the DM July 6, 2012, it is encouraged the production of net electricity supplied to the grid by the plant (calculated as the lower of net production and actually fed electricity into the grid). In this regard there are two different incentive mechanisms:

- a comprehensive incentive rate (Figure 1-6) (To) for power plants up to 0,500 MW, calculated by adding to the eventual rewards to which the facility has the right based incentive fee (Tb). The compensation paid includes the remuneration of energy that is withdrawn by the GSE;

- an incentive (I) for power plants exceeds 0,500 MW, equal to the difference between the basic feed-in tariff (Tb) -to which must be added any award to which the facility has the right- and the price for hour referred to the energy zone. The energy produced remains in the owner’s availability.



INCENTIVI PER IL BIOGAS - *BIOGAS INCENTIVES*		
Tipologia - *Codification*	**Potenza - *Power* (kW)**	**Tariffa Incentivante *Incentive rate* (€/MWh)**
PRODOTTI DI ORIGINE BIOLOGICA ***PRODUCTS OF BIOLOGICAL ORIGIN***	1<P≤300	170
	300<P≤600	140
	600<P≤1000	120
	1000<P≤5000	97
	P>5000	85
SOTTOPRODOTTI DI ORIGINE BIOLOGICA E RIFIUTI NON PROVENIENTI DA RACCOLTA DIFFERENZIATA ***ORGANIC BY-PRODUCTS AND WASTE NOT COMING FROM SEPARATE WASTE COLLECTION***	1<P≤300	233
	300<P≤600	180
	600<P≤1000	160
	1000<P≤5000	112
	P>5000	-

Figure 1-6: Incentives rate classification accordingly size plant and substrate typology defined in D.M. 23/06/16). (Source: [9])

2 BIOGAS TECHNOLOGIES

This chapter focuses briefly the technologies used to produce biogas. Only a basic understanding is given and no chemical part is investigated. Particular attention towards agricultural digester this chapter is oriented since the high number of visited plants in agricultural context.

2.1 Anaerobic Digestion Technology

2.1.1 Degradation anaerobic process

Some strains of bacteria produce a combustible gas when they digest biomass in the absence of oxygen. This, essentially, is the anaerobic digestion (AD) process and it is chemically very complex as we can see in Figure 2-1. The process works best on biomass with high moisture content, frequently up to 95% water. It uses a mixed population of bacteria types to break down the organic materials slowly, first into sugars, then acids. The acids subsequently decompose into biogas – comprising methane, carbon dioxide and hydrogen sulphide – with an average heat value of 20,3 MJ/m^3. The inert residue left behind contains high levels of nutrients and organic matter that can be further processed into compost, fertilisers and a range of soil conditioners.

Anaerobic Digester (AD) is the core of a biogas plant and it is the "container'" in which the anaerobic digestion process takes place in a controlled environment. It should be designed and operated to favour the AD process, by guaranteeing:

- Adequate and stable temperature
- Sufficient mixing to enhance the effective contact between bacteria and substrates
- Optimal residence time to support a stable microbial population and to achieve the expected degradation
- Reliable and effective biogas capture

2.1.2 Digestion unit design

The digestion unit is composed of one or several digesters, including feeding, agitation and heating systems. A pre-digestion tank and a post-digester may complete the unit. The technological possibilities are vast, with choices depending mainly on feedstock characteristics such as dry matter content, degradation rate, contaminant and inhibition risks. The main options and designs of different plant components are described in Table 2-1.

2.1.2.1 Feeding Systems

Feeding systems bring the substrates from their storage place into the digester, making the transition from aerobic to anaerobic conditions. They can be simple structures for substrate transport, but there are also elaborate systems that simultaneously allow intermediate storage, mixing, milling, weighing and feed-in control with full automation. The degree of technological advancement is mainly dependent on budget. Pre holding tanks, screw conveyors and piston systems are the main available technologies but for more exhaustive reading, [10] is suggested. Feeding management has a significant influence on the fermentation process. Sudden high loads of organic matter or abrupt substrate changes disturb the microbial community and result in a reduction in gas production.

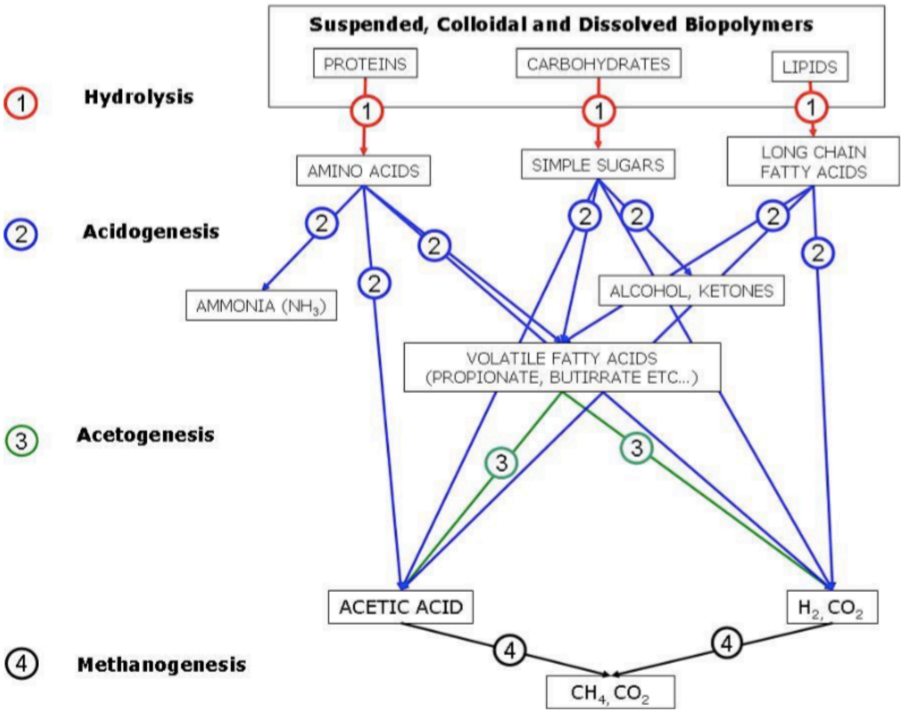
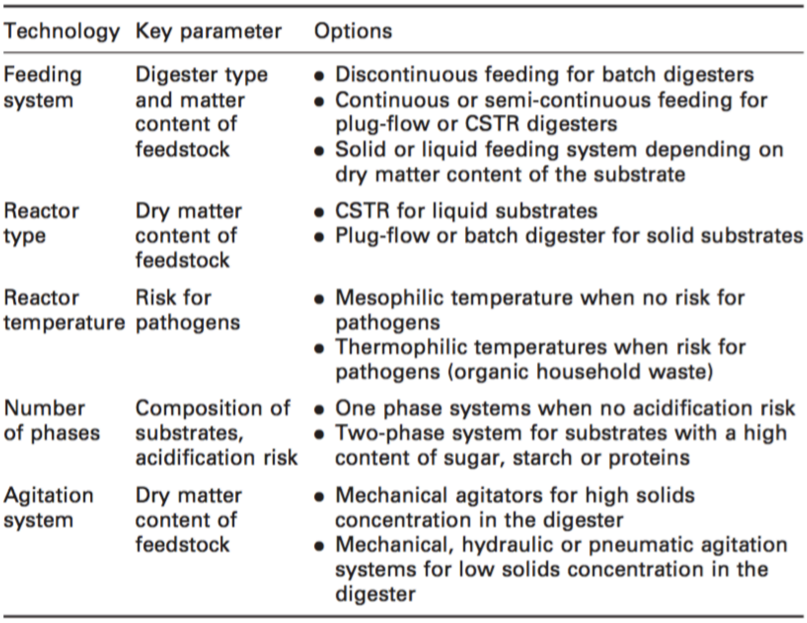


Figure 2-1: A schematisation of anaerobic degradation process occurs inside digesters into a biogas plant.

Table 2-1: Processing options. (Source: [10])



Technology	Key parameter	Options
Feeding system	Digester type and matter content of feedstock	• Discontinuous feeding for batch digesters • Continuous or semi-continuous feeding for plug-flow or CSTR digesters • Solid or liquid feeding system depending on dry matter content of the substrate
Reactor type	Dry matter content of feedstock	• CSTR for liquid substrates • Plug-flow or batch digester for solid substrates
Reactor temperature	Risk for pathogens	• Mesophilic temperature when no risk for pathogens • Thermophilic temperatures when risk for pathogens (organic household waste)
Number of phases	Composition of substrates, acidification risk	• One phase systems when no acidification risk • Two-phase system for substrates with a high content of sugar, starch or proteins
Agitation system	Dry matter content of feedstock	• Mechanical agitators for high solids concentration in the digester • Mechanical, hydraulic or pneumatic agitation systems for low solids concentration in the digester

2.1.2.2 Reactor Type

Digestion reactors are characterised by the feeding mode (batch or continuous) and by the mixing type (CSTR or plug-flow). The choice of reactor type is strongly dependent on feedstock characteristics. Batch reactors (usually garage-type systems) are exclusively used for solid feedstocks. As there is no mixing, impurities or fibrous substrates do not disturb the process, which is an advantage of this system. Distribution of micro-organisms happens through water sprinkling from the digester ceiling. If the substrates are too compact, dry zones may appear. Structuring materials such as wood chips and branches help efficient water percolation. Continuous reactors are either plug-flow or CSTR systems. Plug-flow reactors are used for solid feedstocks. The entering substrates push material through the digester, and this plug-flow effect can be achieved when the dry matter content of the substrate mix is above 20% at the entrance of the digester. CSTRs are used for low dry matter content substrates. Solid substrates can be introduced as long as the dry matter content of the substrate mix in the digester stays below 15%. Above this level, complete mixing of the reactor contents cannot be guaranteed. In plants with more than one digestion tank, plug-flow digesters and CSTRs can be combined and substrates can go through one or both of them depending on their dry matter content and degradation rate.

2.1.2.3 Number of phases

Most biogas plants function within a one-phase system, which means that all the steps of microbial degradation take place in the same tank. The advantages of this method are simple processing and lower investment costs. By contrast, a two-phase system separates the hydrolysis stage from the process (in a separate tank); pH, temperature and retention time can be optimised for each phase. This leads to better degradation kinetics and is recommended for substrates with a high content of sugar, starch or proteins. During the hydrolytic phase, these easily degradable substances produce large amounts of acids, which inhibit methane formation in a one-phase system.

2.1.3 Agricultural Digesters

These kinds of digesters are investigated because interviews and analysis involved farmer producers and this typology of reactors. Agricultural digester treat animal wastes (piggery /poultry manure), agricultural residues (e.g. wheat straw, maize, sorghum, stalks) and energy crops. We will discuss briefly about main technologies by underlining main features.

The oldest and simplest form of AD technology is the uncovered, un-mixed lagoon as shown in Figure 2-2. A **lagoon** may have a retention time of weeks or months. HRT (Hydraulic Retention Time) quantifies the average time that a soluble molecule fed into the reactor spends inside it, that is also the time available to microorganisms to degrade it.

$$HRT\ [days] = \frac{V_{digester}[m^3_{digester}]}{Q_{in}[\frac{m^3_{fed\ to\ digester}}{day}]} \qquad \text{Equation 2-1}$$

Where Q_{in} is the influent volumetric flow rate. If HRT is too low biodegradation results incomplete and degradable substrate leaves the digester whereas if it is too high, the digester is under loaded, biogas production is suboptimal and can be increased.

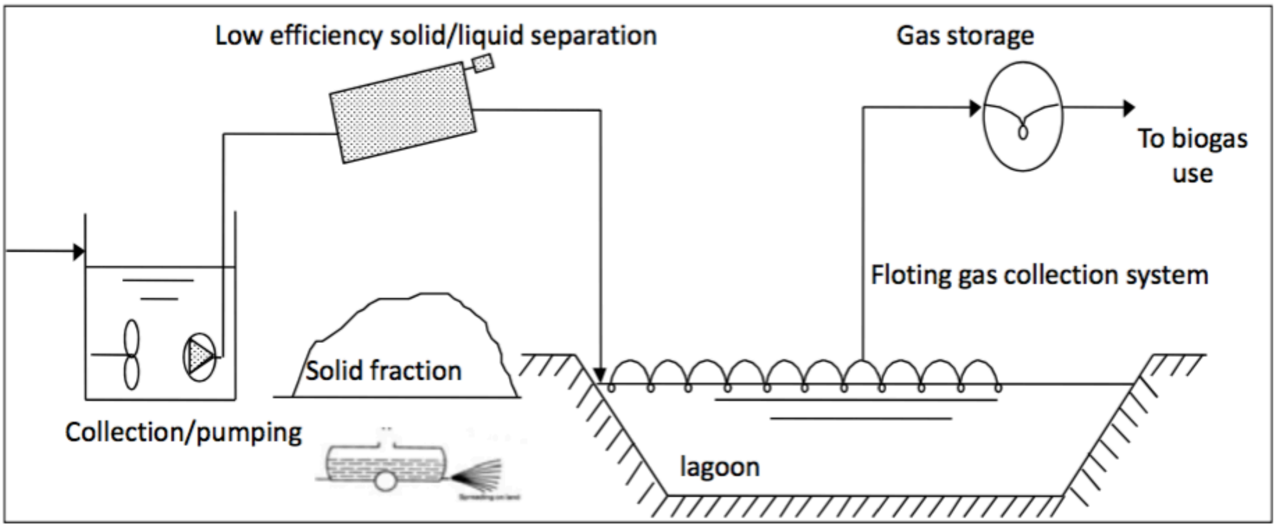
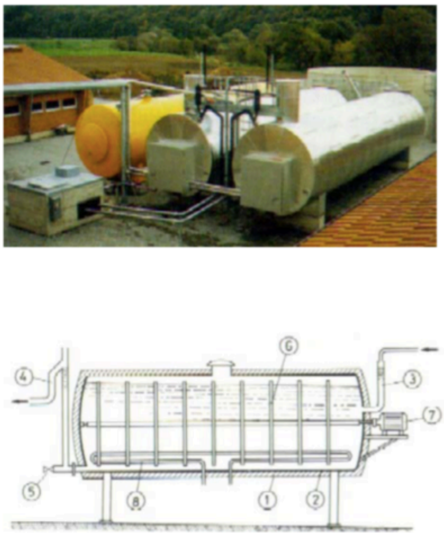


Figure 2-2: A lagoon is the simplest solutios that take advantage of in-farm already existing large storage tanks.

Because of odours and the need to control emissions, principally of methane, engineered membrane cover is usually added to collect biogas. This type of mixed and covered lagoon is now widely used around the world for the treatment of industrial wastes. The most famous and popular digesters are **complete contact** type. Completely stirred (mixed) tank reactors (CSTRs) contains a mixer that allows close contact between the biomass and the organic material being digested. With much greater space efficiencies than lagoon technology, and a retention time of days rather than weeks or months, the technology is fast taking hold in biogas industry. We may have horizontal digesters (Figure 2-3) or cylindrical compact tanks (Figure 2-4). A constant temperature in the digester is essential for a stable digestion process; digesters are therefore insulated and heated in order to reduce and compensate heat losses. Feedstock may also be heated before entering the digester, which helps to avoid temperature fluctuations. As a rule of thumb, aimed heat transfer values are 0.3W/m^{2}K for mesophilic reactors (35-42°C) and 0.2W/m^{2}K or less for thermophilic reactors (50-55°C). The resulting insulation thickness is 10–18 cm. Agitation of the digestion material is important for distributing the substrates, micro-organisms and heat; it also helps to drive out gas bubbles and avoid the formation of floating or settling layers. Agitation is done at intervals, with the length and frequency of the intervals being determined for each plant. There are three main forms of agitation techniques – mechanic, hydraulic and pneumatic but for detailed reading [10] is strongly suggested.

2.2 Gas Storage

Fluctuations and peaks in biogas production commonly occur. To dampen the effect of variable gas production and to allow a controlled flux to the transformation unit, biogas is gathered and temporarily stored. Due to this buffer volume, irregular consumption (e.g. by CHP units) can also be counterbalanced. Storage facilities need to be gas tight and resistant to pressure, UV irradiation, temperature variations and harsh weather conditions such as hail. The storage system also needs to be equipped with a sensor to detect over- or under-pressure.



Horizontal digesters and gas holding tank

1. Stainless still tank
2. Insulation
3. Feeding inlet
4. Digestate outlet
5. Heavy particles outlet
6. Horizontal Mixer
7. Mixing engine
8. Heating system

Figure 2-3: Horizontal agricultural digesters.

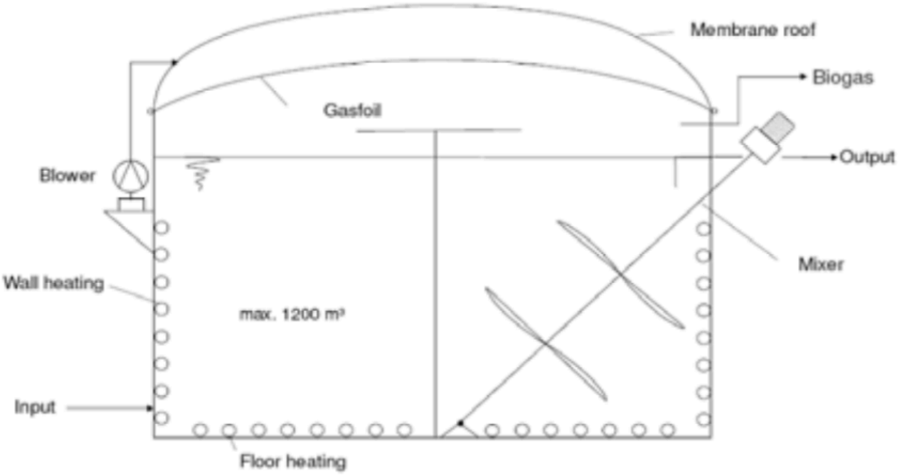


Figure 2-4: The most diffuse AD for agricultural biogas production.

2.3 Flares

Understanding the combustion process provides an insight into the benefits of one flare type over another. It also provides a basis for emission standards and performance criteria used in the regulation of flares. The basic reaction that releases the majority of the energy within the biogas is the combustion of methane:

$$CH_4 + 2O_2 = CO_2 + H_2O \qquad \text{Equation 2-2}$$

Designs should aim to maximise the conversion of methane in order to minimise the release of unburned methane and any products of incomplete oxidation such as carbon monoxide.

This is not the only unwanted bi-product of biogas combustion. Other species may be formed depending not only on the ratio of air: fuel but also the temperature and kinetics of the combustion reactions. Therefore in order to maximise the desirable reactions and minimise the undesirable ones we need to provide the following conditions within the flare:

- Temperature range 850-1200C;

- Residence time minimum of 0.3 seconds;

and it these two parameters, temperature and residence time, that form the performance specification for most advanced flares.

The temperature within the flame is governed by the amount of air added to the biogas. The theoretical relationship between excess added air and flame temperature based on the heat released from methane combustion is shown below. Mapping the desired temperatures and typical biogas concentrations onto this plot and taking account of heat loss provides an operating range for flares, given by the blue envelope.

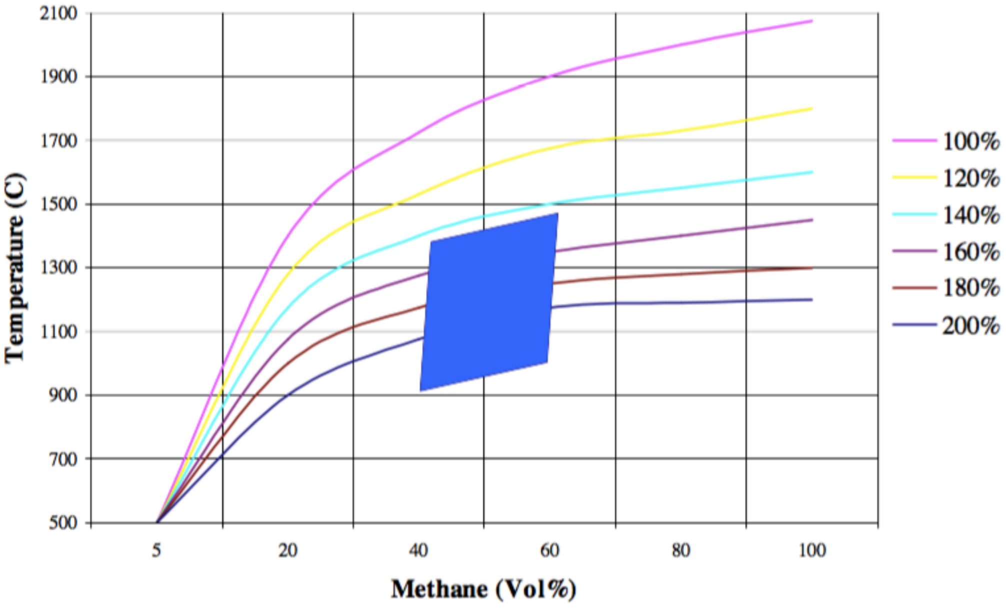


Figure 2-5: Flame Temperature (C) for CH4/CO2 Gas Mixture for a Range of Excess Added Air Concentrations (Source: [11]).

Biogas flares usually operate at the right hand side of the envelope at CH_4 >50% with the excess air to biogas ratio of the order of 10-15 volumes of air : biogas. Under these conditions the air is employed to both oxidise the biogas and cool the flame – it also propagates more turbulence and mixing. Mixing within the burn is crucial to ensure that all the biogas is burned uniformly and under ideal conditions.

Regulation of flares is piecemeal and this is an anomaly. A flare burning biogas containing 50% methane burning 1000 m^3/h of biogas is releasing 5 MWT_h of heat and this is comparable with a reasonably sized plant or incineration process where there is well defined and detailed regulation and control. A number of countries have standards applying to flares and these usually take the form of operational standards or emission controls or both.

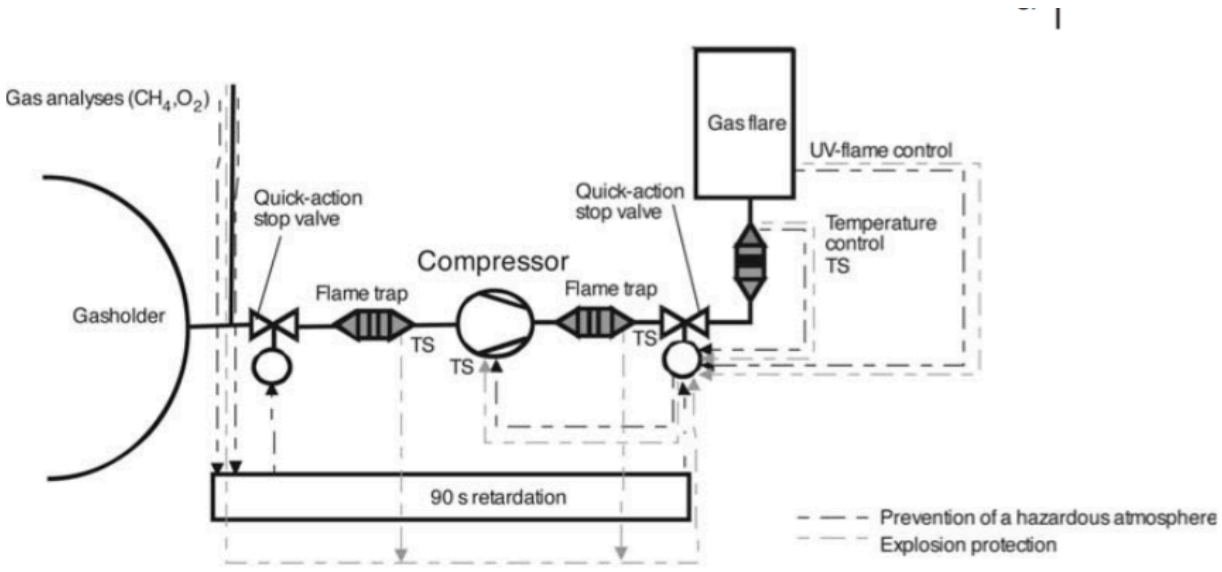


Figure 2-6: Safety devices around gas flare (Source: [12])

Biogas plants are often equipped with a gas flare, so that in case of emergency CH_4 can be burned and does not escape into the atmosphere. However, this enhances the risk that the flame from the gas flare strikes back into the plant and sets fire to the whole plant. Therefore the safety devices shown in Figure 2-6 are prescribed in the gas pipe before the gas flare.

3 CONVERSION TO ELECTRICITY BY ENGINE

Theoretically, biogas can be converted directly into electricity by using a fuel cell. However, this process requires very clean gas and expensive fuel cells. Therefore, this option is still a matter for research and is not currently a practical option. The conversion of biogas to electric power by a generator set is much more practical. In contrast to natural gas, biogas is characterized by a high knock resistance and hence can be used in combustion motors with high compression rates.

In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity. The design of an electric generator is similar to the design of an electric motor. Most generators produce alternating AC electricity; they are therefore also called alternators or dynamos. Appropriate electric generators are available in virtually all countries and in all sizes. The technology is well known and maintenance is simple. In most cases, even universally available 3-phase electric motors can be converted into generators. Technologically far more challenging is the first stage of the generator set: the combustion engine using the biogas as fuel. In theory, biogas can be used as fuel in nearly all types of combustion engines, such as gas engines (Otto motor), diesel engines, gas turbines and Stirling motors etc.

3.1 Appropriate Combustion Engine

3.1.1 External Combustion Engine

Stirling Motors: In such motors, biogas is combusted externally, which in turn heats the stirling motor through a heat exchanger. The gas in the stirling motor hence expands and thereby moves the mechanism of the engine. The resulting work is used to generate electricity. Stirling motors have the advantage of being tolerant of fuel composition and quality. They are, however, relatively expensive and characterised by low efficiency. Their use is therefore limited to a number of very specific applications.

In most commercially run biogas power plants today, internal combustion motors have become the standard technology either as gas or diesel motors.

3.1.2 Internal Combustion Engine

Diesel Engines operate on biogas only in dual fuel mode. To facilitate the ignition of the biogas, a small amount of ignition gas is injected together with the biogas. Modern pilot injection gas engines (“Zündstrahlmotoren”) need about 2% additional ignition oil. Almost every diesel engine can be converted into a pilot injection gas engine. These motors running in dual fuel mode have the advantage that they can also use gas with low heating value. But in that case, they consume a considerable amount of diesel. Up to engine sizes of about 200kW the pilot injection engines seem to have advantages against gas motors due to slightly higher efficiency (3-4% higher) and lower investment costs.

Gas Motors with spark ignition (Otto system) can operate on biogas alone. In practice, a small amount of petrol (gasoline) is often used to start the engine. This technology is used for very small generator sets (~ 0.5-10 kW) as well as for large power plants. Especially in Germany, these engines have advantages, as they do not need additional fossil fuels that would lead to lower feed-in tariffs according to the Renewable Energy Law (EEG).

Gas Turbines are occasionally used as biogas engines especially in the US. They are very small and can meet the strict exhaust emissions requirements of the California Air Resources Board (CARB) for operation on landfill and digester gases. Small biogas turbines with power outputs of 30-75 kW are available in the market. However, they are rarely used for small-scale applications in developing countries. They are expensive and due to their spinning at very high speeds and the high operating temperatures, the design and manufacturing of gas turbines is a challenging issue from both the engineering and material point of view. Maintenance of such a turbine is very different from well-known maintenance of a truck engine and therefore requires specific skills.

Today, experience of the use of combustion motors to produce electricity from biogas is extensive; this can be regarded as a proven standard technology. Over 4,000 biogas plants with internal combustion motors are in operation in Germany.

However, it has taken lengthy and determined effort to make this technology as durable and reliable as it is today. Internal combustion motors have high requirements in terms of fuel quality. Harmful components - especially hydrogen sulphide (H2S) in the gas can shorten the lifetime of a motor considerably and cause serious damage.

This must be addressed in two ways:

- Production of clean biogas
- Use of appropriate and robust motors and components.

In theory, most engines originally intended for cars, trucks, ships or stationary use can run on biogas as fuel and are available almost everywhere within a power range between 10 and 500 kW. This holds true especially in the case of dual fuel use. Robust engines with a certain sulphur resistance are mostly free of non-ferrous metal (German: “Buntmetalle”), as these materials are highly prone to damage through sulphur-rich biogas.

Before proceeding a very basic description of an engine and its way of functioning is necessary to provide ageneral knowledge for a mechanic, technician or a person willing to engage in the modification and operation of a biogas engine.

3.2 Some Basic Definitions and Relations

3.2.1 Engine Volume

The "displaced volume" of one cylinder Vd,c (1, cm3) is the volume displaced by the piston between its lowest position, the "bottom dead center", BDC, and its highest position, the "top dead center", TDC. The total displaced volume of a multicylinder engine, Vd,e , is the volume of one cylinder multiplied by the number of cylinders, i:

$$V_{d,e} = V_{d,c} \cdot i \qquad \text{Equation 3-1}$$

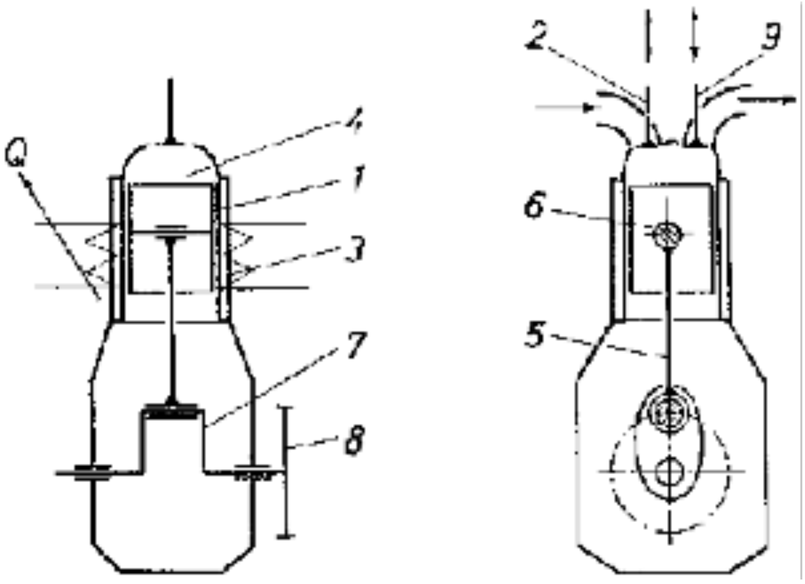


Figure 3-1 : Principal scheme of a 4-stroke engine.1 piston, 2 inlet valve, 3 cylinder, 4 combustion chamber, 5 connection rod, 6 gudgeon pin, 7 crankshaft, 8 flywheel, Q head rejected (cooling).

The volume of the combustion or compression chamber Vc is the volume into which the air or an air/fuel mixture is compressed when the piston has reached TDC. The total cylinder volume Vtot is the sum of the displaced volume and the combustion chamber volume of one cylinder:

$$V_{tot} = V_{d,c} + V_c \qquad \text{Equation 3-2}$$

3.2.2 Engine Speed

The engine speed describes the number of total (360°) revolutions of the crankshaft in a certain period of time, usually per one minute, i.e. 1/min or rpm.

3.2.3 Power

In most cases the power specified for an engine is the mechanical power, which is the mechanical energy (here "torque") transmitted by the crankshaft or flywheel within a certain period of time:

$$P = \frac{torque\ (kJ)}{time\ (s)} = \ torque\ \cdot speed\ (kW) \qquad \text{Equation 3-3}$$

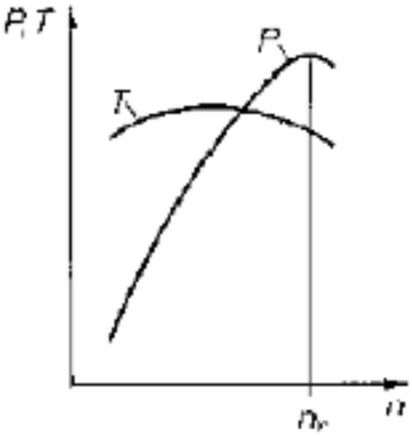


Figure 3-2 : Engine power output P and torque T as a function of engine speed n: nr marks the rated speed.

With a change in engine speed, i.e. the time for one cycle, the power output of the engine changes also. The diagram in Figure 3-2 demonstrates in principle the course of the torque (i.e. work) and power as a function of engine speed.

Heat energy, delivered by an engine through its exhaust and cooling water/air (normally 60-70%), is often wasted but may also be used for heating or process purposes especially in stationary engines as biogas energy plant.

3.2.4 Compression Ratio

The compression ratio gives the relation between the total cylinder volume at BDC (Vd,c + Vc) and the volume left for the compressed fuel/air mixture at TDC (Vc). The compression ratio should not be confused with the pressure rise during the compression stroke.

$$c = \frac{V_{tot}}{V_c} = \frac{V_{dc} + V_c}{V_c} = 1 + \frac{V_{dc}}{V_c} \qquad \text{Equation 3-4}$$

3.2.5 Isentropic Exponent

The isentropic exponent γ is a specific constant of a gas or a gas mixture and is defined as

$$\gamma = \frac{C_p}{C_v} \qquad \text{Equation 3-5}$$

The exponent describes the theoretical behavior of a perfect gas during a thermodynamic process, e.g. compression and expansion. The theoretical processes are however assumed to be reversible and adiabatic, i.e. have no losses or other influences from out" side, unlike natural processes.

3.2.6 Polytrophic Exponent

A technical process like an engine process involves losses. heat transfer and other irreversibilities and cannot therefore be described by the isentropic exponent γ. The polytropic exponent n is used instead. It is a function of the type of gas or gas mixture, the heat transfer from and to the cylinder walls, the mixture of fresh gas with the rest of the burnt gases, etc. Actual values for the polytropic exponent of air and air/fuel mixtures range from n = 1.30 . . .1.36.

3.2.7 Pressure after compression

$$p_c = p_s \cdot e^n \qquad \text{Equation 3-6}$$

The suction pressure Ps is the actual pressure in the cylinder at BDC and is not equivalent to the ambient pressure Pa due to pressure losses in carburetor throttle as well as the inlet channel and valve.

3.2.8 Effective Torque and Power

Torque and power define the engine performance: torque measures its ability to do work, while power indicates the rate at which work is done. Instead of starting from the ideal cycle and gradually arriving to predict the actual performance of the engine (as done in the previous chapters for others fluid machines) here *actual* or *effective torque and power* are operatively defined, specifying how to measure them.

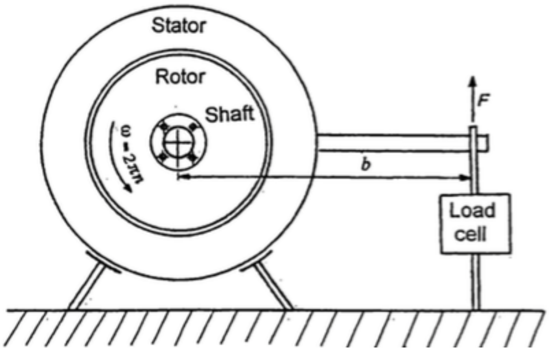


Figure 3-3 : Schematic representation of a dynamometer for test bench

The engine is set on a test bench and its shaft is connected to a *dynamometer.* This is a device able to absorb and (normally) waste the mechanical energy generated by the engine, simulating the behaviour of the real user (transport device, electric generator, etc..). It is basically composed (Figure 3-3) by a rotor coupled hydraulically or electro-magnetically to a stator, which is supported by low friction bearing. The engine drives the rotor, which in tum tries to drive the stator. A load cell measures the force F necessary to prevent stator rotation, while the rotor is steady turning.

When the group is dynamically balanced, the *effective torque Me,* developed by the engine, is:

$$M_e = F \cdot b \qquad \text{Equation 3-7}$$

while the delivered *effective power Pe* is the product of the torque by the angular speed ω:

$$P_e = M_e \cdot \omega = 2\pi n M_e \qquad \text{Equation 3-8}$$

3.2.9 Indicated Cycle

During the engine test many other parameters can be measured. In particular, a *pressure transducer*, directly facing the internal wall of the combustion chamber, and a transducer of the volume, actually available inside the cylinder for the working fluid, allow to generate a p-V diagram such as shown in Figure 3-4.

This diagram is traditionally called indicated cycle, because the early devices, used to create such a cycle, were named indicators (of the actual physical conditions inside the cylinder). These data can be used to calculate the indicated work Li per unit cycle (per cylinder), transferred from the gas to the piston, by integrating along the cycle curve, to obtain the area enclosed on the diagram:

$$L_i = \int pdV \qquad \text{Equation 3-9}$$

Notice that this area is a positive quantity (work transferred from the cylinder gases to the piston), if the along the integration line is clockwise (such as area A in Figure 3-4), while it is a negative quantity (work transferred from the piston to the cylinder gases), if the movement along the integration line is anticlockwise (such as area B in Figure 3-4, called also pumping work). Figure 3-4 shows the indicated cycle of a naturally aspirated four-stroke engine, at partial load. Here the pumping work transfer is negative, but it may be also positive, if the exhaust stroke pressure is lower then the intake pressure, which is normally the case of supercharged engines.

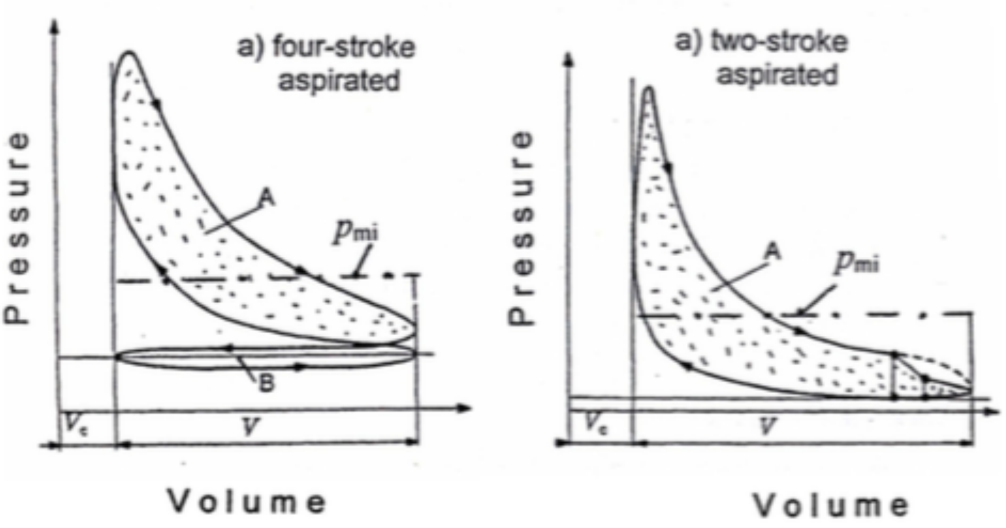


Figure 3-4: Indicated Cycles of Naturally Aspirated Four and two strokes engine

Knowing Li, the indicated power Pi transferred from the cylinder gases to the piston is the product of Li by the cycle frequency :

$$P_i = L_i \cdot f_c = L_i {}^{n}/_{\varepsilon} \qquad \text{Equation 3-10}$$

Both the indicated work Li and the power Pi depend on engine size, therefore it is useful to introduce a relative measure of the engine performance (i.e. independent on the specific engine), dividing the work per cycle by the cylinder volume displaced during the cycle:

$$p_{mi} = \frac{L_i}{V} = ({}^{1}/_{V}) \int pdV \qquad \text{Equation 3-11}$$

This parameter is called mean indicated pressure Pmi , because it is the mean ordinate of the area shown in Figure 3-4. The geometrical meaning of Pmi is emphasized in Figure 3-5, where it is presented as the difference between the areas A (useful work) and B (pumping work) of the indicated cycle, which is equivalent to a rectangle of base V and height Pmi .

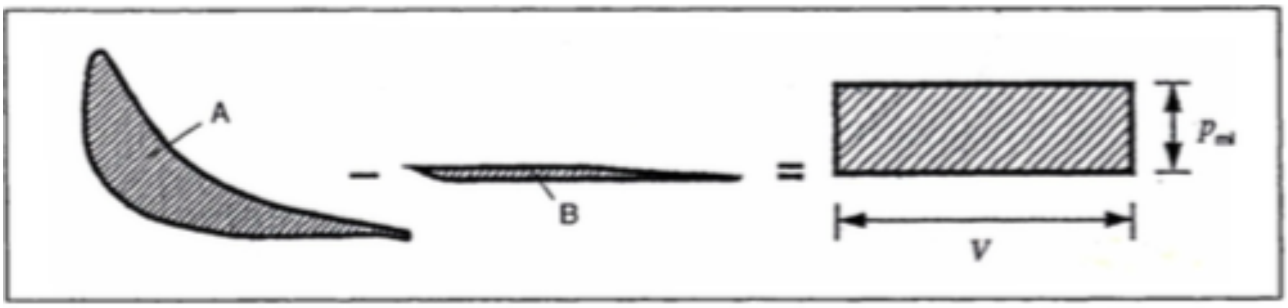


Figure 3-5 : Geometrical Meaning of the mean effective pressure

From the physical point of view Pmi can be considered as the pressure that, acting constantly on the piston during the only expansion stroke, would produce the whole indicate work Li . Indeed it is:

$$L = F \cdot s = (p_{mi} A_{pis}) S = p_{mi} V = L_i \qquad \text{Equation 3-12}$$

Then the Equation 3-10 gives:

$$P_i = p_{mi} V \, {}^{n}/_{\varepsilon} \qquad \text{Equation 3-13}$$

which allows to express the indicated power generated by a given engine, as a product of the following three parameters:

1. p_{mi} is a measure of the *effectiveness* of the pressure cycle
2. V is the volume displaced by the piston during its stroke
3. n/ε is the number of useful cycles, operated per unit time

3.2.10 Organic efficiency

The *organic efficiency* η_0 is the coefficient that allows to derive the *effective quantities* from the indicated power and torque, considering that part of the energy, transferred by the working gases to the piston inside the cylinder, must be spent to overcome the friction of many kinematic connections and to drive engine auxiliaries. In terms of powers, the organic efficiency is defined as the ratio:

$$\eta_0 = {}^{P_e}/_{P_i} \qquad \text{Equation 3-14}$$

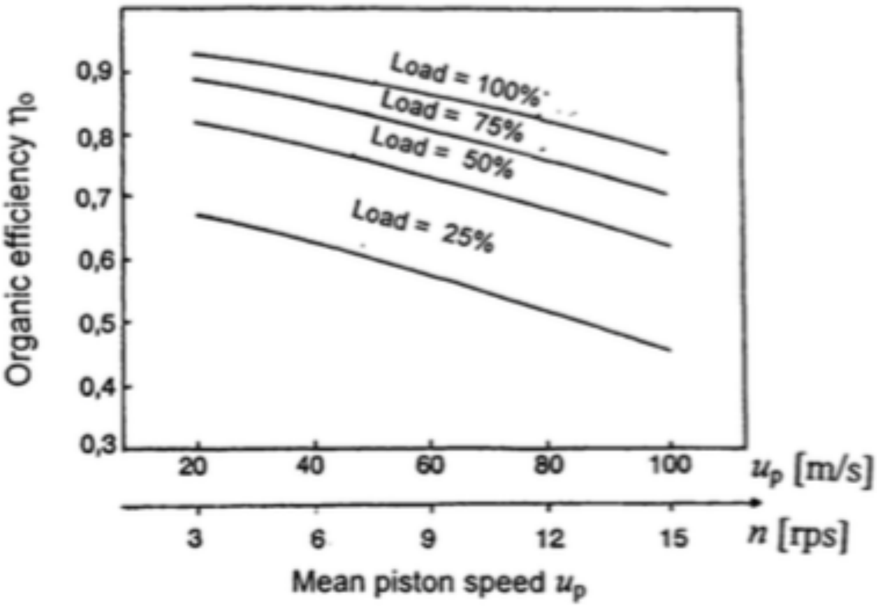


Figure 3-6: Organic Efficiency versus mean piston speed and engine load

It depends on many design and operating parameters. For a given engine, it decreases (Figure 3-6) when the mean piston speed up incre·ases (higher inertial forces, loading kinematic connections) and when the engine load decreases (proportionally, the energy spent to drive the auxiliaries becomes more important).

Then it is possible to define a mean effective pressure p_{me}:

$$p_{me} = \eta_0 p_{mi} \qquad \text{Equation 3-15}$$

as the effective work per unit cycle and unit volume displaced by the engine. It measures the ability of the engine designer in exploiting the available volume displaced by the pistons. Typical values for the mean effective pressure are:

- p_{me}= 0,8-1, 1 MPa in naturally aspirated engines
- p_{me}= 1,2-4,0 MPa in supercharged engines.

Then the expression Equation 3-13, Equation 3-14 and Equation 3-15 give:

$$P_e = \eta_o \cdot P_i = p_{me} V \, {}^{n}/_{\varepsilon} \qquad \text{Equation 3-16}$$

which is the correspondent Equation 3-13 and is widely used, for design calculations, to predict the expected power, assuming appropriate values for the Pme of that particular engine.

3.2.11 Air Fuel Ratio

During an engine test, the air mass flow rate m'_a and the fuel mass flow rate m'_f, used by the engine to generate the effective power *Pe,* can also be measured. The ratio of these two flow rates gives the *actual air/fuel ratio* α of the working mixture:

$$\alpha = \frac{m'_a}{m'_f} \qquad \text{Equation 3-17}$$

which is a function of: fuel characteristics, mixture formation process and load control system. The parameter a greatly affects the combustion process (that is: power, efficiency and quality of the burned gases).

The stoichiometric (or chemically correct) air/fuel ratio $\alpha_{stech}$is the minimum quantity of air, including just enough oxygen for conversion o f the unit mass o f fuel into completely oxidized products. It depends on fuel composition and typical values are: α_{stech}= 14,6 for gasoline, α_{stech}= 14,5 for diesel fuel, α_{stech}= 17,2 for methane, α_{stech}= 34 for hydrogen, etc ...

Because the actual a used by the engine is greater, equal or smaller then α_{stech}, an important parameter for defining mixture composition is the equivalence ratio ϕ:

$$\phi = \frac{\alpha_{stech}}{\alpha} \qquad \text{Equation 3-18}$$

which defines the richness in fuel of the mixture (ϕ <1: fuel-lean, ϕ = 1: stoichiometric, ϕ >1: fuel-rich mixture).

While the inverse of ϕ is the air excess coefficient λ:

$$\lambda = {}^{1}\!/_{\phi} = {}^{\alpha}\!/_{\alpha_{stech}} \qquad \text{Equation 3-19}$$

which defines the richness in air of the mixture (λ <1: fuel-rich, λ = 1: stoichiometric, λ > 1: fuel-lean mixture).

In conventional spark ignition engines (filled with homogeneous charge) the optimization of the combustion demands a near stoichiometric mixture (λ = 0,8-1,2 , but in today car engines strictly stoichiometric operation is imposed by the after-treatment of combustion gases) and a load control based on the variation of mixture quantity. In Diesel engines, instead, where the combustion process allows to control the load by changing the quality of the air-fuel mixture, the equivalence ratio varies greatly, depending on the load.

3.2.12 Specific Fuel Consumption

A useful parameter to monitor how efficiently the engine uses the supplied fuel, in producing the mechanical energy, is the *specific fuel consumption* c_{sf}per unit work produced:

$$c_{sf} = {}^{m'_f}\!/_{P_e} \qquad \text{Equation 3-20}$$

strictly correlated to the running costs of the engine. The specific fuel consumption, however, is not a dimensionless parameter. In practice it is traditionally expressed in ((g/h)/kW], that is [g/kWh] (common best values are: 200-220 g/kWh for spark ignition engines, 160-190 g/kWh for Diesel engines). In congruent units of the International System Csf, being the mass of burned fuel per unit work produced, it should be measured in [kg/J] or better, to avoid numbers very small, in[g/MJ] (where: I g/kWh = 1000/3600 g/MJ = 0,2778 g/MJ).

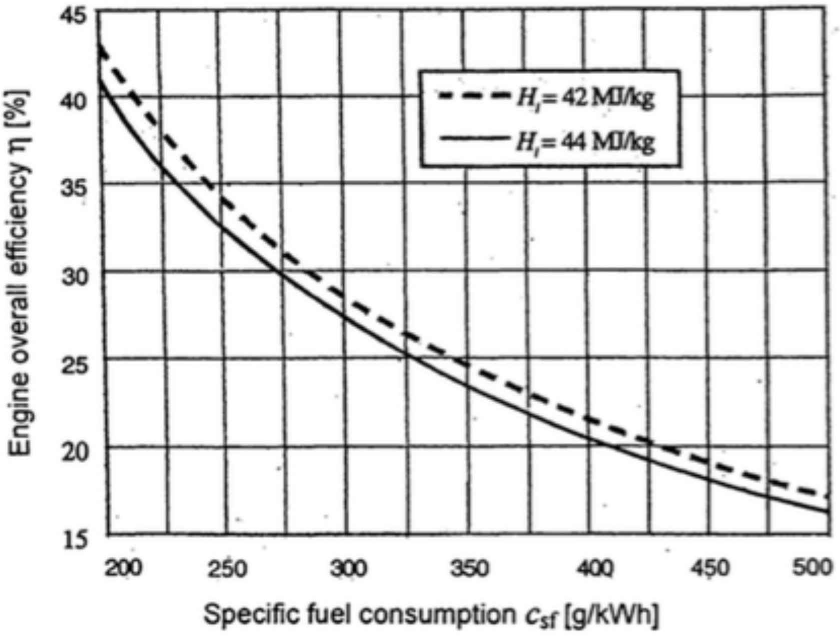


Figure 3-7: Specific Fuel Consumption versus Engine overall Efficiency

A dimensionless parameter, that avoids all these complications in using measure units, is the specific energy consumption c_{se}per unit work produced. It is defined as the ratio of the available thermal power released in the combustion process by the fuel supplied to the engine ($m'_f \cdot LHV$ where LHV is the lower calorific value of the fuel) and the effective mechanical power generated:

$$c_{se} = m'_f \, {}^{LHV}/_{P_e} = c_{sf}LHV$$

Equation 3-21

Finally, the inverse of $c_{se}$is the overall efficiency η of the engine:

$$\eta = {}^{1}/_{c_{se}} = {}^{1}/_{(c_{sf}LHV)}$$

Equation 3-22

It measures the conversion efficiency in mechanical work of the thermal energy released by fuel combustion (common best values are: η = 37-41 % for spark ignition engines, 43-50 % for Diesel engines).

For a given fuel (with its LHV) the Equation 3-22 shows that the overall efficiency η is in inverse proportion to specific fuel consumption , as reported in Figure 3-7 two typical fuels, which delimit the range of LHV (42-44 MJ/kg) of commercial gasolines and Diesel fuels.

3.3 Relevant Engine Types

In principle all internal combustion engines can be operated with liquid fuels (which are in vapor/gaseous form when they ignite) or with gaseous fuels. The given framework of this thesis however calls for the narrowing of the scope of engines towards types that can be modified and operated with acceptable efforts:

- Engines considered should be based on standard engine types produced in larger series;

-2-stroke engines, as the smaller types do not nave a very good reputation for long engine life and often use lubrication in a mixture with the liquid fuel. This excludes the use of a gaseous fuel. (Larger 2-stroke diesel engines range at power outputs of 500 kW and more and are usually individually projected and expensive units);

- No gas turbines as they are comparatively expensive and require sensitive operation and maintenance;

- No rotary piston (Wankel) engines because of generally bad reputation for reliability and engine life;

- No turbocharged engines because of their relatively sophisticated control systems.

The engine types to be considered here are therefore:

- Otto (gasoline) engines, 4-stroke;

- Diesel engines, 4-stroke.

3.3.1 Diesel Engine

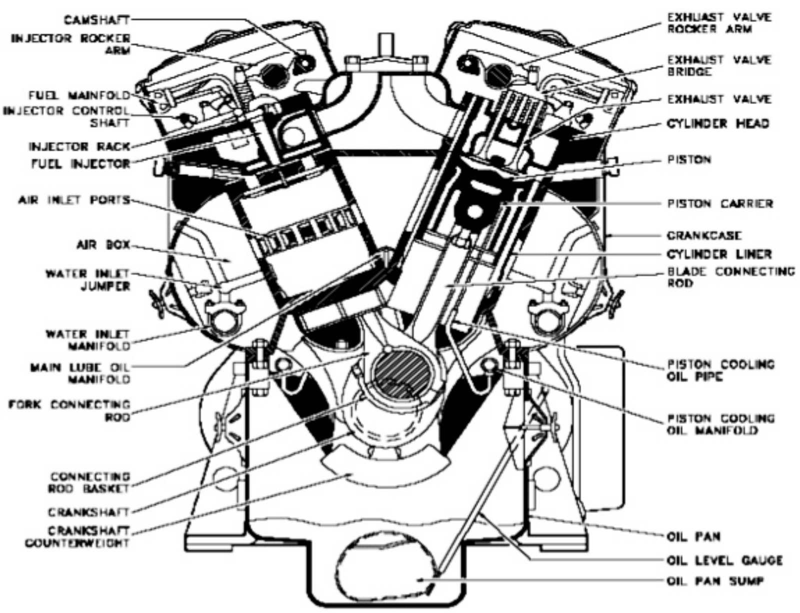


Figure 3-8: Cross Section of a V-type 4-stroke Diesel Engine

3.3.1.1 The Diesel Process

The diesel engine and its process are shown in the Figure 3-8. The engine sucks air at ambient conditions and compresses it to a pressure around 60 bar and above whereby the air reaches temperatures around 600°C. Shortly before the piston reaches TDC, fuel is injected and ignites immediately at these conditions. An external source for ignition is usually not necessary. Only at low ambient temperatures a"glow plug" is sometimes used to facilitate the start-up. The point or crank angle of injection is chosen (about 25°) considering that the pressure rise through combustion reaches a peak shortly after the piston has passed TDC.

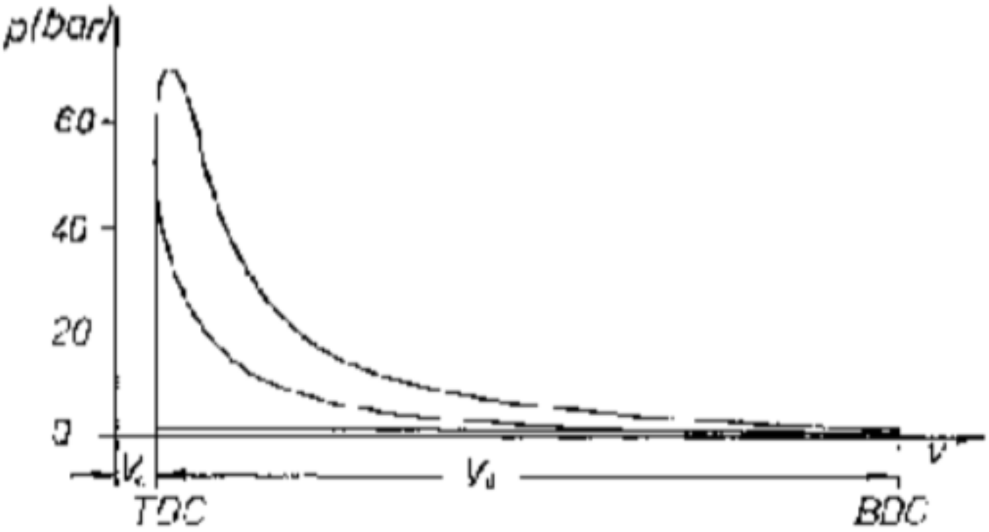


Figure 3-9: Simplified p-V diagram of a Diesel process

3.3.1.2 Operational Parameters and Controls

Diesel engines use fuels of low volatility, which have to be injected into the combustion chamber. Sufficiently large injection pressures are required to obtain a spray of suitable characteristics (in terms of droplet sizes, tip penetration and jet spreading angle) to be mixed with the air charge and burned in the time available for the combustion process.

In Diesel engines a compression ignition o f a heterogeneous charge occurs, because the fuel is atomized in small liquid droplets in the air trapped inside the cylinder and most of the fuel is still in a liquid state when the combustion begins. The physical states of reactants are different, therefore they can not be premixed before the combustion start. Most of the fuel burns mixed with the air in a heterogeneous form (form the point of view of reactant physical state). This presents some draw-backs (low combustion velocity, pollutant (particulate and nitric oxides) formation, etc...) , but also the advantage o f allowing to the Diesel an efficient load control.

Practically, the injection system of a Diesel engine carries out the following main tasks:

I. control the engine load, metering the required mass of the fuel to be injected per cycle,

2. distribute the fuel equally to each cylinder (in the case of a multi-cylinder engine) and per each cycle,

3. decide the optimum time o f the injection in the power cycle, for each engine running speed and load,

4. modulate in time the fuel flow rate, splitting the total fuel injected in different parts, to control the combustion evolution,

5. obtain a spray of suitable characteristics to be mixed with the air charge and burned in the time available for combustion.

Practically the above tasks are even more difficult when the mass of injected fuel is very small (of the order of few cubic millimeters).

An electronically controlled injection system allows to precisely manage the injection timing, the mass of fuel injected and the modulation in time of the injection law. This means that the total fuel injected in each cycle can be split in several parts, to obtain the most favorable evolution in time of the injected flow rate, in order to optimize the global combustion process.

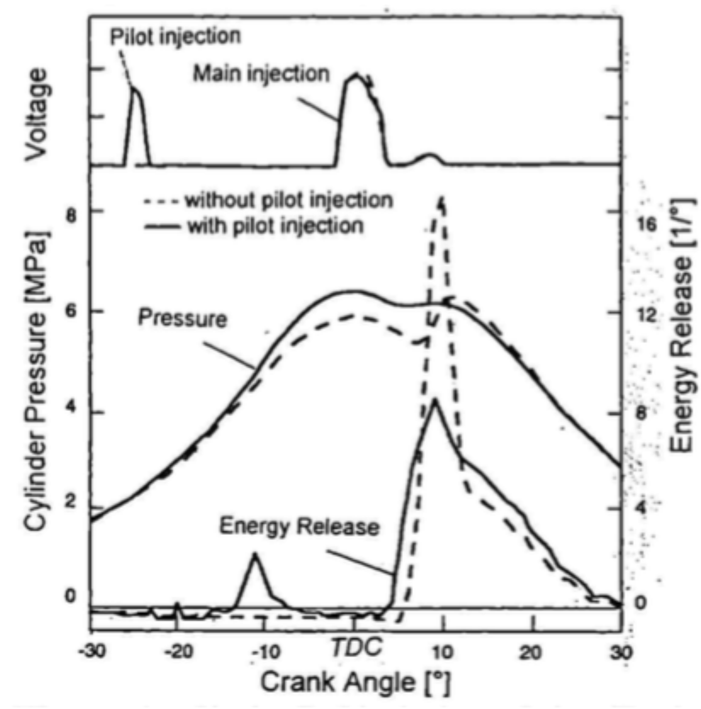


Figure 3-10: Effects produced by the pilot injection in a typical Diesel car engine

Indeed, the complex injection law, allowed by the actual injection systems, was gradually achieved. The first step was the introduction of a pilot injection o f a small amount (1-5 mm^3) of fuel in advance of the main injection. The injected fuel vaporizes and partially burns, increasing air temperature and pressure inside the cylinder. This leads to a reduction of the ignition delay of the main injection and to a softer combustion, with reduced pressure rise and lower pressure peak. These effects reduce the combustion noise and, in many cases, the fuel consumption as well.

The effects produced by the pilot injection are clearly shown in the example reported in Figure 3-10 referring to a typical car Diesel engine running at low rotational speed (1500 rpm) and 20% of load. In these conditions the pilot injection of 1 mm^3 of fuel produced a reduction of 50% in the peak of energy release and a cut of 6 dBA in the global engine noise.

3.3.2 Otto Engine

Otto engines or also called Spark-ignition engines use fuels sufficiently volatile to be easily vaporized and mixed with air, before the combustion is started by the spark plug *(premixed charge).* Therefore in these engines the task of the fuel metering system is mainly reduced to the control of the fuel mass, necessary to obtain the *air/fuel ratio* a required by the engine in each point of its operating map.

3.3.2.1 Mixture Requirements

The optimum air/fuel ratio α for spark-ignition engines depends on the engine performance which has to be optimized. Figure 3-11 shows that the maximum power, at wide-open throttle with a given filling coefficient, is obtained with a slightly rich mixture ($\phi = {}^{\alpha_{stech}}/_{\alpha} \approx 1.1$), while the maximum efficiency (or minimum specific fuel consumption) requires a lean mixture ($\phi = {}^{\alpha_{stech}}/_{\alpha} \approx 0.9$). **Error! Reference source not found.** proves that the minimum amount of carbon monoxides, unburned hydrocarbons or nitric oxides in the exhaust gases are achieved with different optimum values of air/fuel ratio.

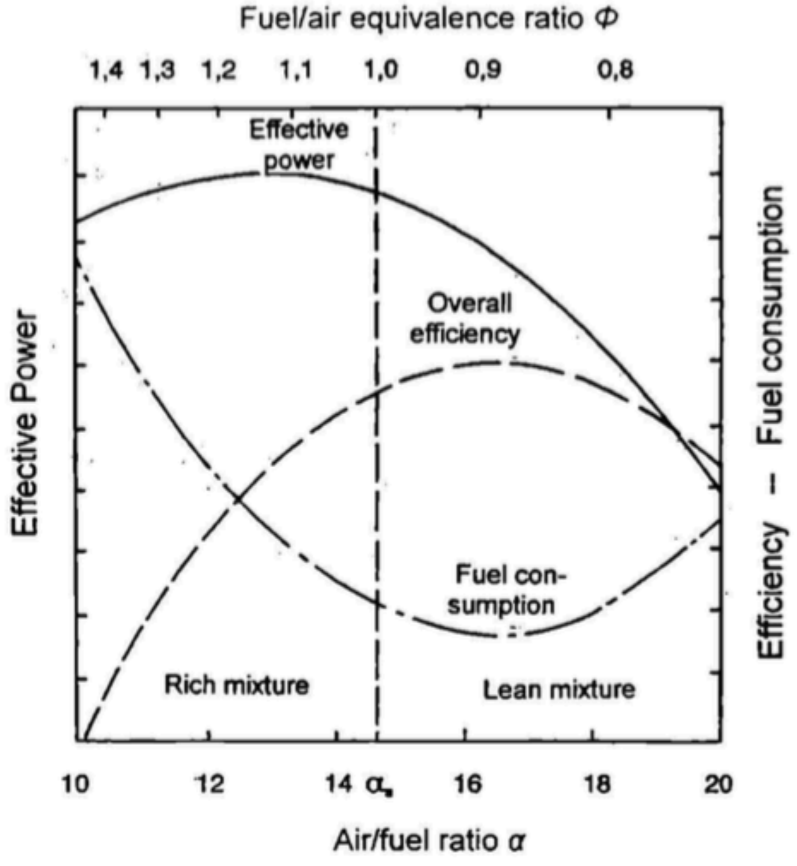


Figure 3-11: Influence of the air/fuel ratio on Power and Efficiency in a SI engine

3.4 Biogas and its Properties as a Fuel for Internal Combustion Engines

3.4.1 What Biogas is

Biogas originates from bacteria in the process of biodegradation of organic material under anaerobic conditions. It consists of a varying proportion of CH_4 (methane) and CO_2 (carbon dioxide) and traces of H_2S, N, CO, O, etc. The content of CH_4 and CO_2 is a function of the matter digested and the process conditions like temperature, C/N ratio, etc. Methane is the most valuable component under the aspect of using biogas as a fuel; the other components do not contribute to the calorific ("heating") value and are often "washed out" in purification plants in order to obtain a gas with almost 100% $CH_{4.}$

3.4.2 Energy Content of Biogas

The useful part of the energy of biogas is the calorific value of its CH4 content. The other components have strictly speaking an energy content also but they do not participate in a combustion process. Instead of contributing they rather absorb energy from the combustion of CH4 as they usually leave a process at a higher temperature (exhaust) than the one they had before the process (mainly ambient temperature).

The following are the thermodynamic parameters of CH4 at standard conditions (i.e. 273 K, 1013 mbar=0.1013 MPa):

- specific treat cp = 2.165 kJ/kg K,

- molar mass M = 16.04 kg/krnol,

- density ρ =0.72 kg/m3,

- individual gas constant R =0.518 kJ/kg·K,

- lower calorific value LHV = 50000 kJ/kg,

The actual calorific value of the biogas is a function of the CH_4 percentage, the temperature and the absolute pressure, all of which differ from case to case. The calorific value of the biogas is a vital parameter for the performance of an engine, a burner or any other application using biogas as a fuel.

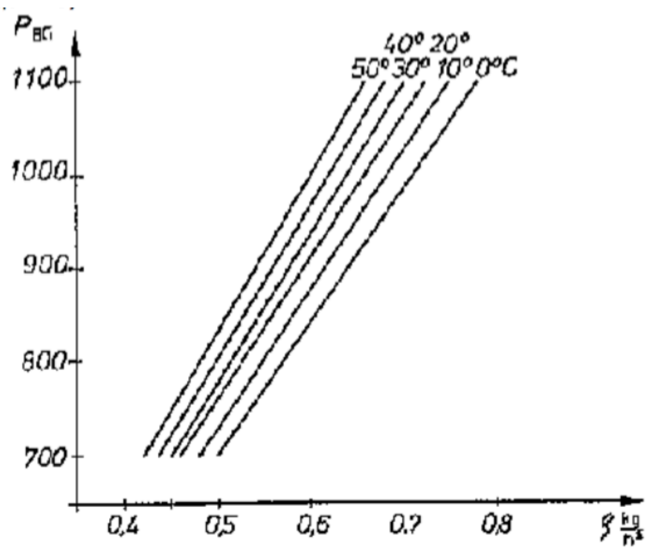


Figure 3-12: Density ρ of CH_4 as a function of biogas pressure and temperature

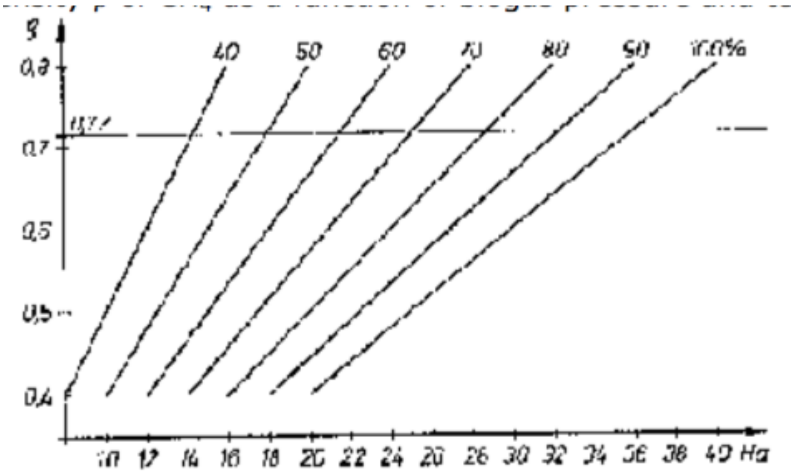


Figure 3-13: Calorific value of biogas as a function of the density and volume %-age of its CH_4 content
($\rho = 0.72$ is the density at standard condition)

The graphs (Figure 3-12 and Figure 3-13) will facilitate an easy determination of the density of the CH4 component in a first step and the calorific value of the biogas in a second step. Use the diagrams as follows:

- Determine the actual density ρ of the CH4 in the biogas using the actual biogas temperature and pressure (ambient pressure + biogas plant pressure (gauge) or pressure measured at inlet to the mixing device).
- FindT the actual calorific value using the density and the percentage of CH4 in the biogas mixture.

A precise calculation of the calorific value can be done following the example below.

Example:

Calculation of the calorific value of biogas at the following conditions:

- *Composition*
  CH_4 = 60%$_v$

CO2= 40%$_v$

Traces of other components negligible

- *Temperature*

  T=298 K

- *Pressure*

  P_a= 950 mbar (ambient pressure)

  P_p= 20 mbar (biogas plant pressure)

<u>Step 1: total pressure of biogas</u>

P_t = 950 + 20 = 970 mbar

If humidity of biogas was not considered in the gas analysis so far, the value has to be corrected using the diagram in Figure 3-14 and the related example.

<u>Step 2:</u>

Density ρ of CH_4 in mixture at actual pressure p and temperature T, calculated on the basis of the table values at standard conditions

- Temperature correction:

$$\rho_2 = \rho_1 \frac{T_1}{T_2}$$

- Pressure correction:

$$\rho_2 = \rho_1 \frac{P_2}{P_1}$$

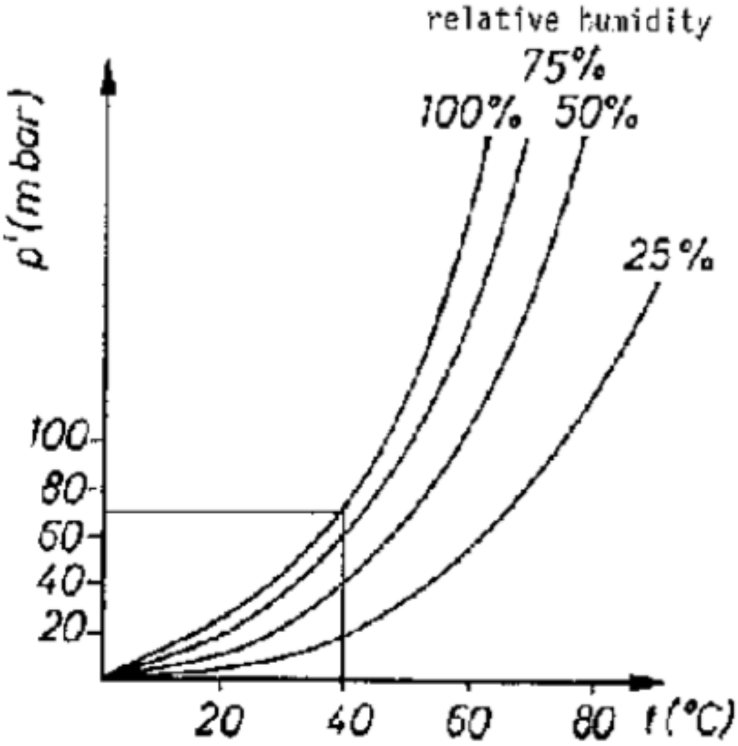


Figure 3-14: Partial pressure of water vapour in a mixture with biogas as a function of a biogas temperature and relative humidity

3.5 Generation of electricity in a four-stroke engine and a Diesel engine

Today's four-stroke biogas engines were originally developed for natural gas and are therefore well adapted to the special features of biogas. Their electrical efficiency normally does not exceed 34–40%, as the nitrogen oxide output NO_X has to be kept below the prescribed values. There are, for example, four-stroke engines with electrical efficiencies above 40% working with a recuperator as we can appreciate in Figure 3-15. The capacity of the engines ranges between 100KW and 1MW and the lifetime is given as ca. 60000h.

The engine operates at 1500 rpm and consists of:

- Engine block with crankshaft, crankshaft bearings and seals, housing, piston rod, piston with piston rings, cylinder, oil sump, flywheel housing
- Cylinder head with cylinder head gasket, cam shaft, valves, tappet, rocker arm.

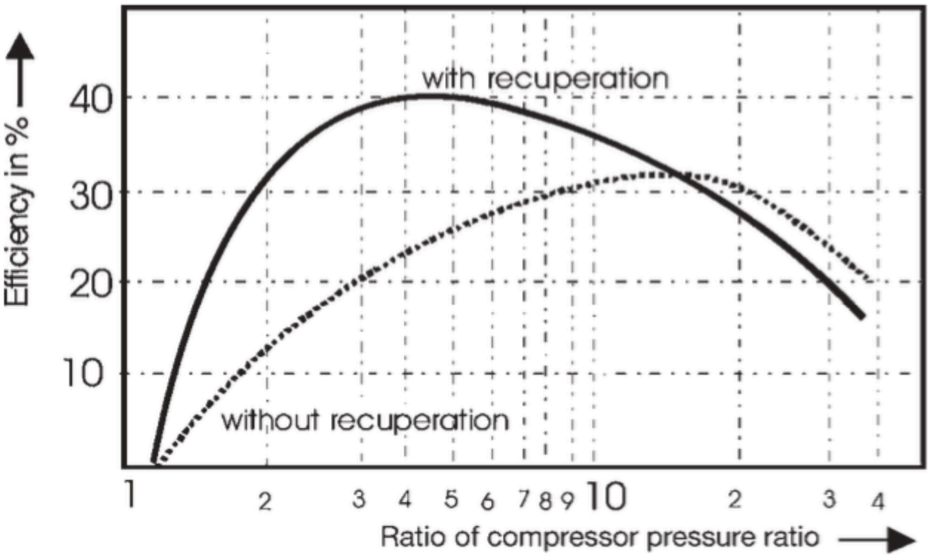


Figure 3-15: Efficiency depending on the pressure ratio of the compressor.

The air/fuel mixing is accomplished in the gas engine by a suction nozzle depending on the drawn-in air volume. Because of the outside regulation of the mixture, gas engines have longer response times to nominal and actual values of the rpm or the capacity. This is to be considered, particularly when the engine is operated in isolation from the electrical network.

Four-stroke biogas engines are used preferably with precompression of the gaseous fuel (turbocharger). By precompressing and subsequently cooling the mixture, the efficiency can be increased by the factor 1.5.

In general the efficiency decreases with an increase of the CO_2 concentration in the biogas. Because of the CO_2 content of the biogas and the consequently increased anti-knock properties, the compression ratio can be raised technically from 11 to 12.5 (as with a propane gas engine), whereby the efficiency rises ca. 1–2%. Four-stroke biogas engines working in CHPs are equipped with digitally operated spark ignition, actuated by capacitor discharge, which do not have wear parts and which deliver a high-energy, time-exact ignition, whereby low waste gas emissions and long service lives of the spark plugs result. The microprocessor-controlled ignition makes it easy to adjust the engine to different kinds of gas or varying gas quality. The timing of the ignition can be changed, e.g., depending on the analog signal of a methane analyzer or a knocking monitor. Usually a power adaption is made at the same time.

3.5.1 Operating conditions and exaust emissions features

Four-stroke biogas engines often run in the lean-burn range (ignition window $1.3 < \lambda < 1.6$) where the efficiency drops. The efficiency of lean-burn engines with turbocharger is ca. 33–39%. The NO_x emissions can be reduced, however, by a factor of 4 in comparison to ignition oil Diesel engines, and the limiting values38) can be met without further measures. Regulation is then made by a butterfly valve in the suction pipe.

The CO content in the exhaust gas must be kept below 650 mg Nm^{-3} according to European regulations. This can be achieved by cooling the exhaust gas below ca. 400 °C in water-cooled collectors, because at lower temperatures the oxidation from hydrocarbons to CO (a post-reaction in the tail pipe) is slowed down. But the lower temperature brings the efficiency down to 27–35% before the turbocharger. A low CO value in the exhaust gas can also be achieved with an oxidation catalyst. The catalyst makes an activated charcoal filter essential in the suction pipe to the CHP to retain catalyst poisons (siloxanes, sulfur compounds). The efficiency rises ca. 3%, and emissions of SO_2 (formed by reaction of sulfur and oxygen to SO_2 in the engine) are prevented in the exhaust gas.

Since the engines can tend to knock with varying gas qualities, a methane content of at least 45% should be ensured.

All parts of the engine which come into contact with sulfur compounds and can corrode (copper, chrome), must be corrosion-protected, using best available materials which are easily replaceable. The corrodibility can be decreased by using specially designed bearings (Sputter bearings) instead of ball bearings.

In order prevent the drastic reduction of oil change intervals and considerable wear of the cylinder heads due to the sulfuric acid in the biogas, special lubricating oils are used which are ash-poor and ensure a long-term high alkalinity. Addition- ally, CHPs designed for biogas are equipped with large lubricating oil tanks (200 L) to allow a higher capacity for impurities and and a longer running time of the oil. Regular oil analyses are indispensable, depending on the sulfur content of the biogas. Regular means at intervals of 160–2000 h, on the average every 465 h.

In small agricultural plants, ignition oil Diesel engines with ca. 4dm3 piston displacement are frequently installed. These engines are more economical and have a higher efficiency than four-stroke engines in the lower capacity range. But their NOx-emissions are high. Their lifetime is given as 35 000 h of operation.

In general, gas Diesel engines work by direct injection, because pre-chamber engines develop hot places, resulting in uncontrolled spark failures with biogas. Because of the internal formation of gas mixtures Diesel engines can be faster controlled.

The ignition oil Diesel engine is operated ideally at a air/fuel ratio of $\lambda < 1.9$. The efficiency is then up to 15% better than in a four-stroke engine.

Biogas is usually inhomogeneous. High temperatures of combustion can lead to increased NO_x emissions, low temperatures to incomplete combustion and unburnt carbon in the exhaust gas. The engine can knock because of a too early self-ignition of the mixture with high methane contents. These problems are exacerbated by NH3 in the biogas. The variation of the biogas quality can be compensated by varying the feed of ignition oil. For an adequate biogas quality, feeding of 10–18% of ignition oil is recommended. When the methane content in the biogas is low, more ignition oil must be added.

If the Diesel engine remains a so-called self-ignition engine, the fuel can ignite a biogas air mixture which is sucked in, equivalent to a strong ignition spark. The limited values for NO_x can then be kept at lean burn with small ignition oil feed. Otherwise the NO_x value can only be kept low with an catalyst.

Operation with mineral ignition oil requires special storage and in Germany monitoring by the customs. The ignition oil consumption, the operational data of the engine, and the quantity of electricity fed into the electricity network must be registered continuously. If the operator of the plant sets a value on environmental protection, vegetable oil and/or biodiesel (rapeseed methyl ester) can be fed instead of mineral ignition oil. If then the regulation of λ is replaced by a gas supply technology, an even leaner air/fuel ratio compared to the Diesel process can be used. Advantages of renewable ignition oils are the lower carbon monoxide emissions, the sulfur-free exhaust, and the biological degradability. Only if biodiesel (RME) or vegetable oil is used as ignition oil, in Germany a special promotion is granted.

3.6 Literature Review

Biogas as a fuel for internal combustion engines (ICEs) has several advantages including lower fuel cost, reduced levels of harmful exhaust emissions, and being carbon neutral; this has led to much recent interest in ICE technologies using biogas.

Biogas also has applications in power generation; gases obtained from biomass can be used to generate electric power using a gas turbine or a gas engine. Large-scale gas turbine engines exhibit thermal efficiencies of 40%, and medium- and small- scale gas turbine engines of about 20–35%. Spark ignition (SI) and dual-fuel systems are widely used for power generation, and the thermal efficiency of these engines is around 30%.

It is challenging to use biogas for compression ignition (CI) engines due to a low cetane number; therefore, ignition methods such as SI, surface heating and dual- fuel auto-ignition are typically applied in reciprocating piston engines.

3.6.1 Combustion and emissions characteristics

Kim, Kawahara , Tsuboi and Tomita [13] investigated the effects of the composition of biogases on the combustion and emission characteristics of ICEs, with the aims of improving efficiency and reducing harmful emissions. In this study, the engine load was varied up to the maximum output power of the system; combustion analyses were carried out over a wide range of operating conditions, considering engine efficiency and exhaust emissions.

Figure 3-16 shows a schematic diagram of the micro co-generation engine system used in this work. An SI engine with three cylinders was used, the specifications of which are listed in Table 3-1.

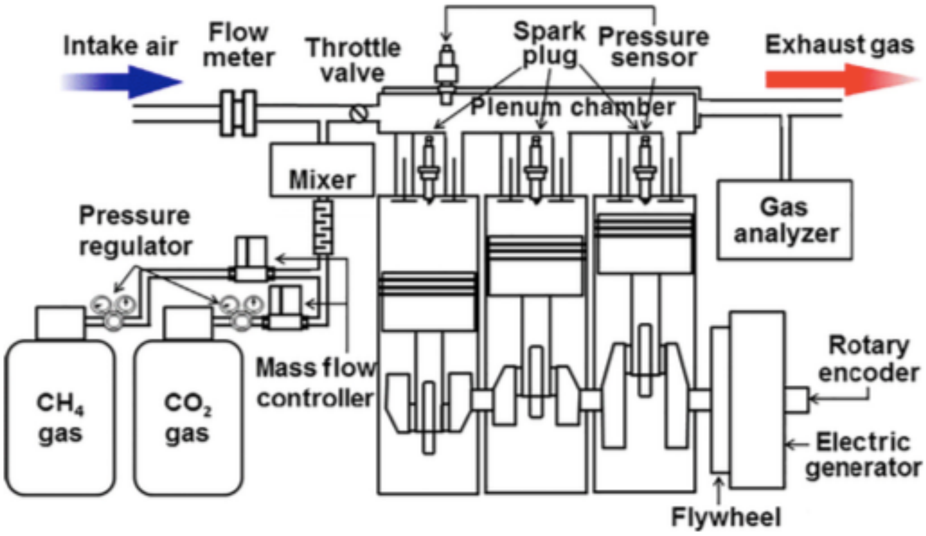


Figure 3-16: Experimental Engine System used by Kim, Kawahara,Tsuboi and Tomita in their study

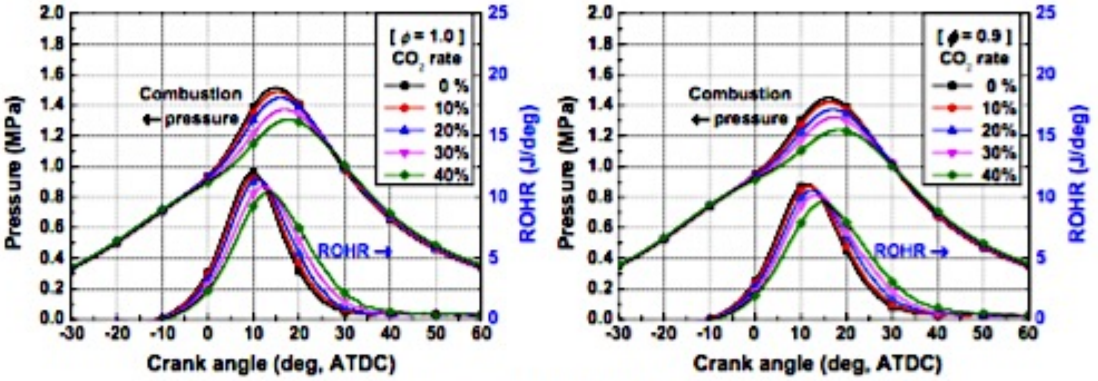
Table 3-1:Experimental engine specifications

Experimental engine specifications.

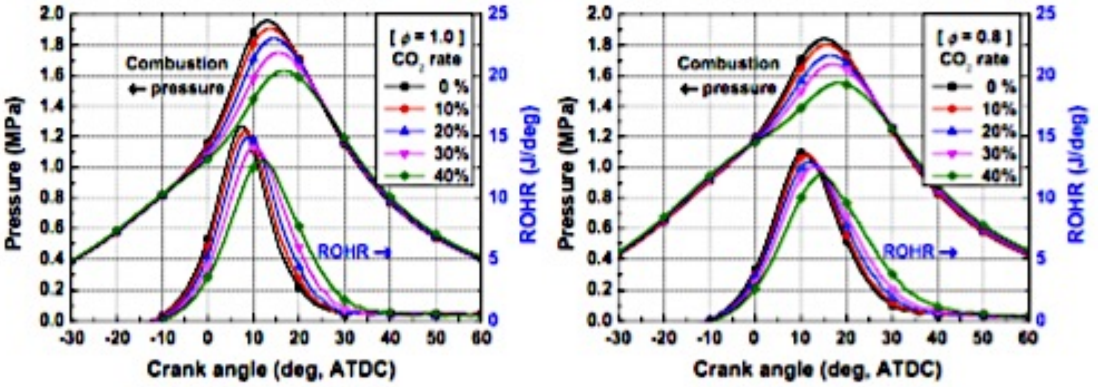
Engine type	4-stroke, 3-cylinder
Combustion chamber	Bowl-shaped
Bore × Stroke	88 × 90 (mm)
Displacement	1642 (cc)
Compression ratio	12:1 (geometric)

To investigate the effects of the composition of the biogas on the combustion characteristics and NOx emissions, four different engine load conditions were investigated while maintaining the engine speed at 1700 rpm. The equivalence ratio was initially set to the stoichiometric air–fuel ratio and then varied through 0.9, 0.8, 0.775, and 0.75 for electrical output powers of 1.85, 3.20, 4.55, and 5.90 kW. Those equivalence ratios were selected based on results near the lean limit for each load.

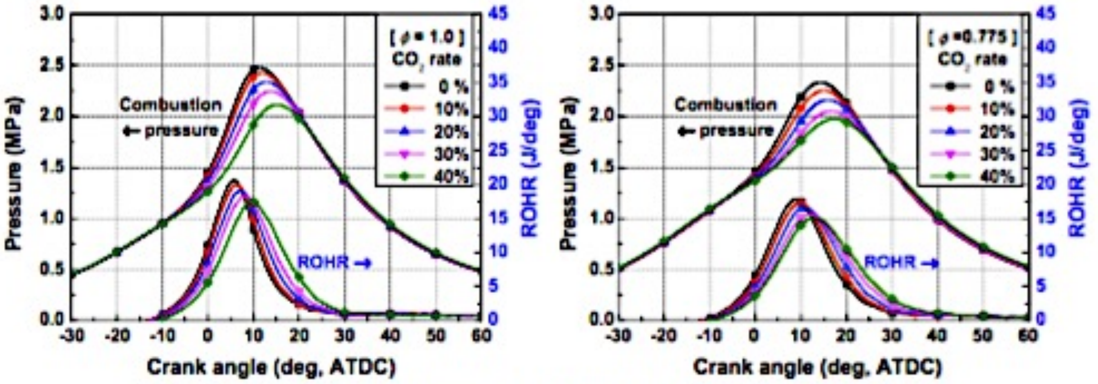
Figure 3-17 shows the combustion pressure and rate of heat release (ROHR) as a function of the crankshaft angle for various fuel com- positions, engine loads, and equivalence ratios. The combustion phases became more retarded and wider under lean burn conditions compared with the stoichiometric air–fuel ratios. As the CO_2 concentration of the fuel increased, the peak combustion pressure and ROHR decreased. This can be explained by considering that the CO_2 behaves as an inert gas. Furthermore, a reduction in the combustion noise and NO_x emissions may be expected from the use of biogas due to the lower peak combustion pressure and temperature.



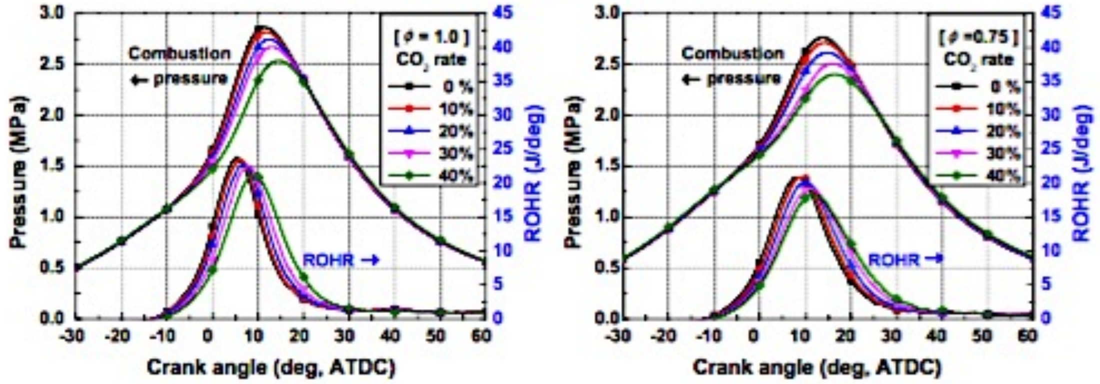
(a) Output power: 1.85 kW ($\phi = 1.0, 0.9$)



(b) Output power: 3.20 kW ($\phi = 1.0, 0.8$)



(c) Output power: 4.55 kW ($\phi = 1.0, 0.775$)



(d) Output power: 5.90 kW ($\phi = 1.0, 0.75$)

Figure 3-17: Combustion pressure and ROHR for each condition

Figure 3-18 shows the NO_x emissions as a function of the CO_2 content of the fuel for various engine loads. As the CO_2 content increased, the NO_x emissions decreased significantly for all engine loads. In particular, with a stoichiometric air–fuel ratio and at higher loads (i.e., 4.55 and 5.90 kW), the NO_x emission exceeded the upper level of the measurement equipment for low CO_2 contents; however, as CO_2 fraction increased, the NO_x emissions decreased markedly. In general, for a given engine load, the NO_x emissions can be reduced using a lean burn strategy and can be further reduced using a fuel containing CO_2. During combustion, NO_x forms primarily when a mixture of gases containing nitrogen and oxygen is heated. The large specific heat of CO_2 and its inert nature leads to a reduction in the peak combustion temperature. The effect is similar to that achieved using exhaust gas recirculation (EGR), and, as with EGR, the lower combustion temperature also negatively affects fuel consumption.

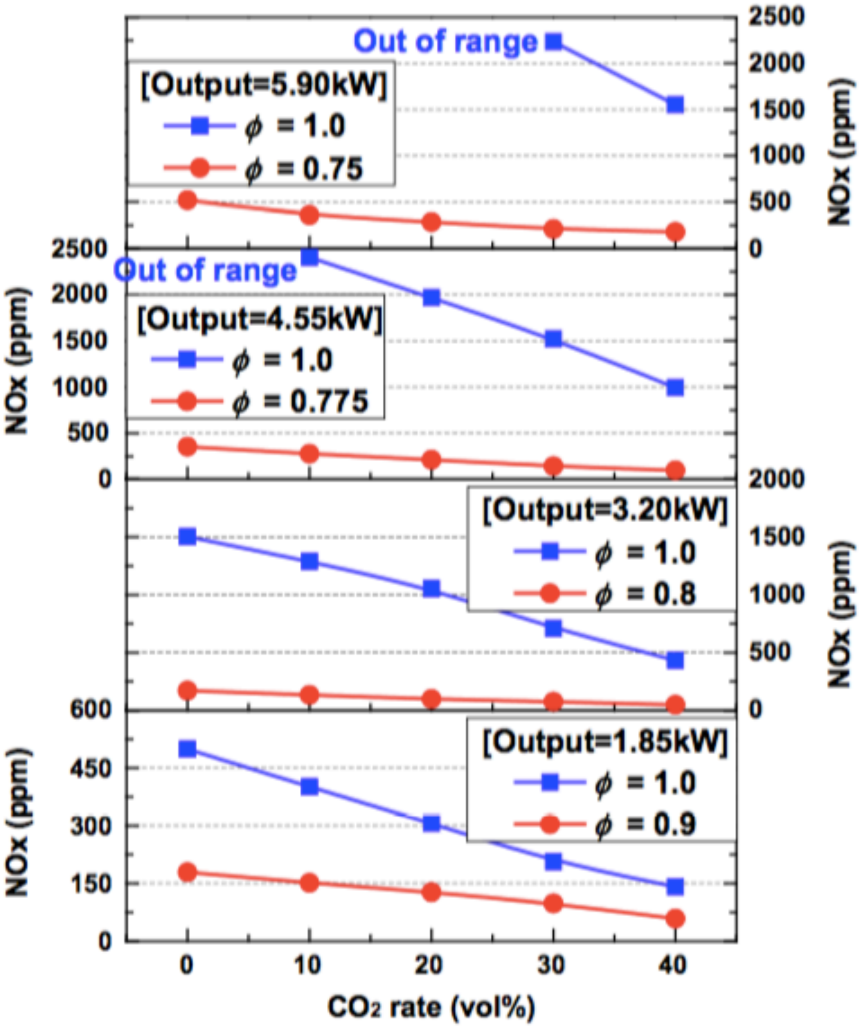


Figure 3-18: NO_x emissions as a function of CO_2 content for various engine load

Again, Crookes [14] found that biogas burned in a SI engine emitted less NOx and more HC compared with natural gas. The experimental facilities used for the spark-ignition engine tests , are shown schematically in Figure 3-19 A Ricardo E6 variable-compression ratio research engine and dynamometer, fitted with a computer-based cylinder pressure display and processing system, was employed.

Tests were performed at an engine speed of 2000rpm with relative air:fuel ratio1 ranging from rich to the lean misfire limit, and compression ratios of 11:1 and 13:1 (before the onset of detonation). The composition of the natural gas used in the experiments is as given in Table 3-2.

The CO2 was taken from a high-pressure gas cylinder, having a regulator fitted with an electric heater. The biogas was simulated by introducing various metered fractions of CO_2 and natural gas into a mixing device.

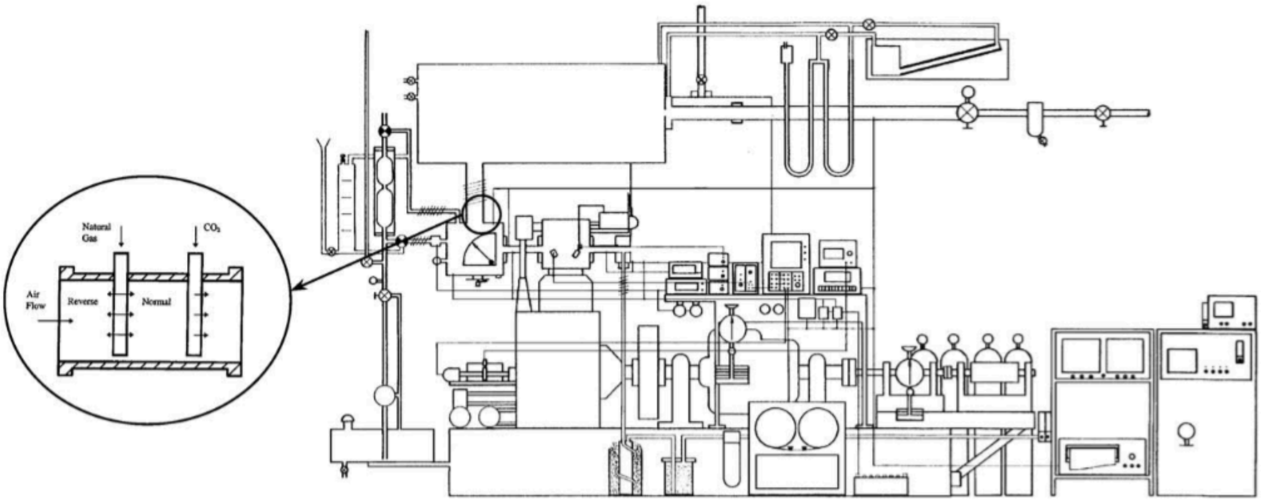


Figure 3-19: Experimental set-up for biogas tests in spark ignition engines

The mixing device (see Figure 3-19) consisted of a flanged pipe insert with two gas inlet tubes and was located in the metered air supply immediately upstream of the carburettor. The CO2 content of the simulated biogas (given by volume or mole fraction in the mixture of natural gas and carbon dioxide) was adjustable over the full range used. In some tests N_2 was used as the biogas inert diluent, having different thermo-physical properties to CO_2.

Table 3-2: Composition of Natural Gas used in Crookes experiments

Composition of NG	Percentage
Methane	93.25
Ethane	3.26
Nitrogen	2.15
Propane	0.65
Carbon dioxide	0.33
Isobutane	0.27
Other trace gases	0.09

Figure 3-20 provides a baseline data set of emissions for the SI engine tests with natural gas at 2000 rpm and 11:1 compression ratio showing the expected variation with relative air-fuel ratio. The effect of adding increasing fractions of CO_2 on the regulated emissions, NO_x and both CO and unburnt HC is shown in Figure 3-21 and Figure 3-22 respectively, with results given as brake-specific (b.s.) values, i.e. mass emitted relative to brake power.

The effect of adding CO_2 is to reduce specific NO_x values from about 7 g/MJ, by about 50% and increase unburnt HC while CO values are principally governed by air-fuel ratio. This effect is, however, displaced to a relatively richer condition. Though brake power (b.p.) is relatively unchanged by the CO2 fraction, minimum specific fuel consumption (s.f.c.) is increased, from a minimum of about 0.07kg/MJ, by too excessive an addition of CO_2.

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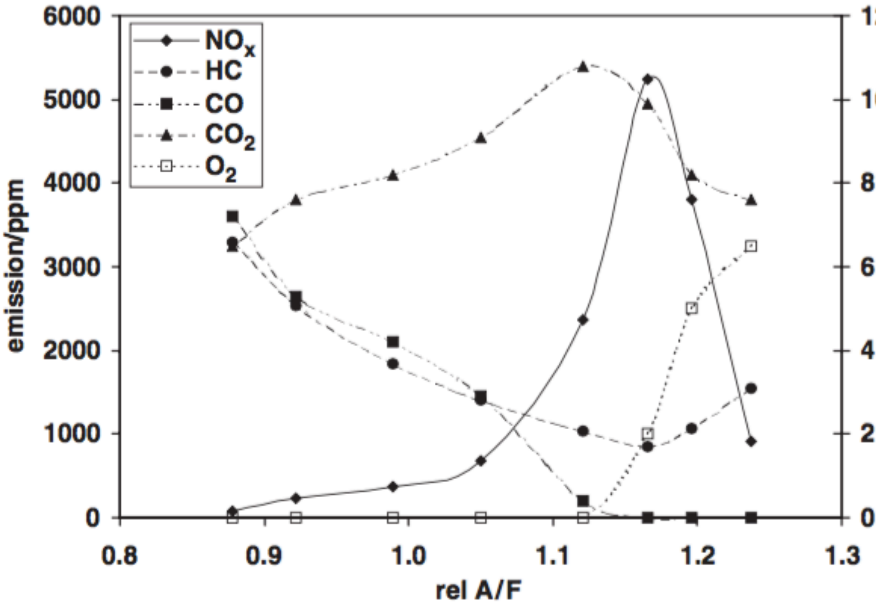


Figure 3-20: Variation with relative AFR of exhaust emissions for natural gas

To clarify whether the mechanism by which CO_2 affects the emission of NO_x is physical or chemical, tests with the same volume fraction of N_2 nstead of CO_2 were conducted. Figure 3-23 and Figure 3-24_present data for N_2 dilution alongside those for natural gas with and without CO_2 dilution. The changes are not noticeably different to those described earlier for CO_2. NO_x is reduced by a slightly lesser amount (except for the highest N_2 addition, when NO_x apparently increases again).

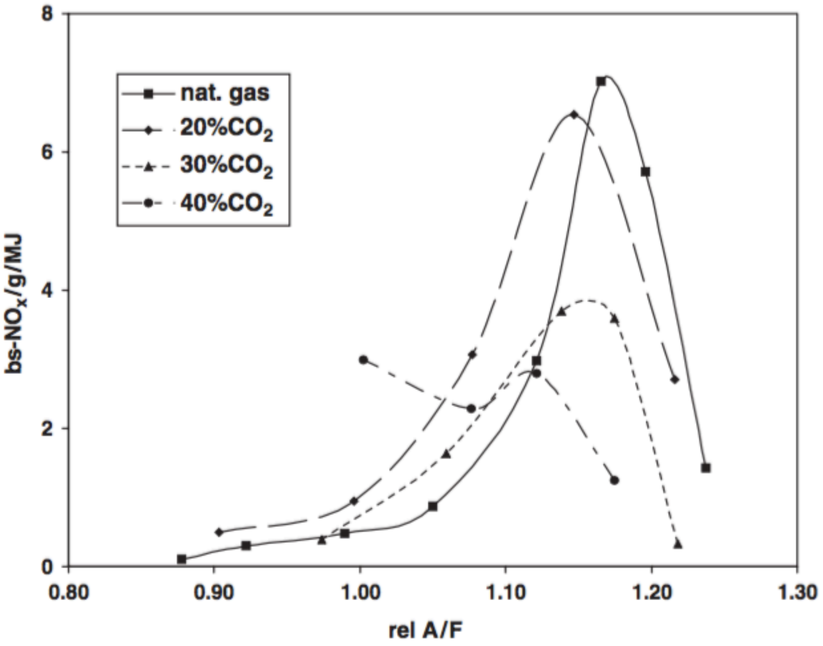


Figure 3-21: Effect of biogas carbon dioxide fraction on a break specific oxides of nitrogen

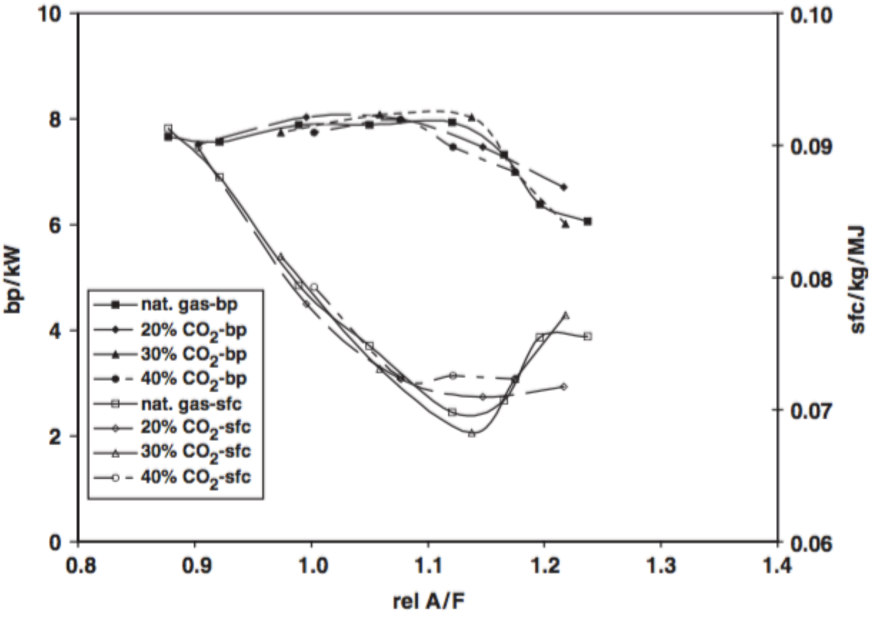


Figure 3-22: Variation of brake power and specific fuel consumption with relative AFR for different biogas composition

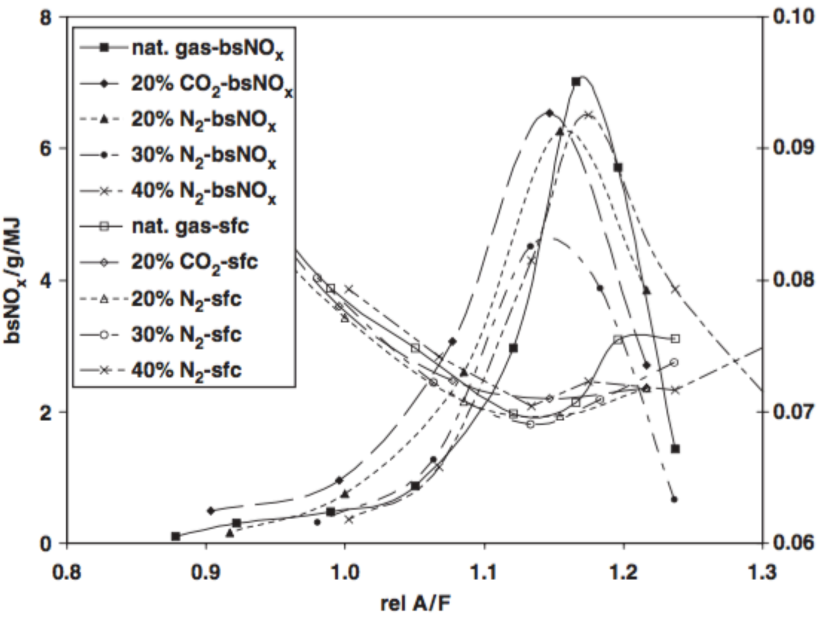


Figure 3-23: Effect of bio-gas composition on brake-specific oxides of nitrogen and specific fuel consumption with nitrogen addition

Unburnt hydrocarbons are increased, the reduction of CO with increasing relative air-fuel ratio is also shifted to richer conditions and the minimum specific fuel consumption is again somewhat raised by high fractions of N_2. Such similar findings with addition of CO_2 and N_2 are thus not likely to be of chemical origin and are more compatible with the thermal effect of the use of ‘‘additional’’ exhaust gas re-circulation (EGR) to raise the heat capacity of the charge to reduce NO_x.

As with EGR, there is likely to be an optimum level above which combustion quality will be impaired. The inert effect would be expected to be more evident with the CO_2 than the N_2, having a higher relative molar mass.

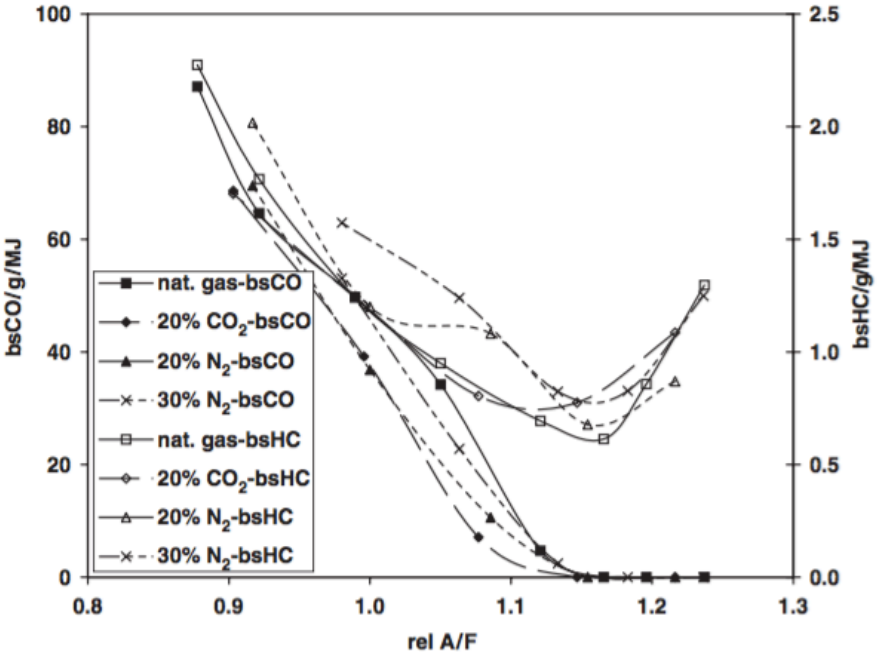


Figure 3-24: Effect of bio-gas composition on brake-specific carbon monoxide and unburnt hydrocarbons with nitrogen addition

It was also studied the effect of compression ratio and we know raising the compression ratio has the effect of increasing in-cylinder temperature and NO_x and HC. In tests with the compression ratio increased to 13:1, NO_x was again found to be able to be reduced by dilution with either CO_2 or N_2, except at the highest fraction of N_2.

3.6.2 Conclusions

1. Spark-ignition engine operation with biogas containing significant fractions of inert gases such as CO_2 and N_2 exhibit penalties of performance compared with natural gas or gasoline.

2. In general, as the CO_2 content of the fuel increased, the peak of combustion pressure and the ROHR decreased, and both the initial and main combustion periods became longer. Moreover, the combustion phases became retarded and wider under lean-burn conditions compared with the stoichiometric air–fuel ratio.

3. As the CO_2 concentration increased, the NO_x emissions decreased significantly for all operating conditions. The reduction in NO_x emissions due to the presence of CO_2 was greatest with the stoichiometric air–fuel ratio.

4. Specific fuel consumption is comparable with spark-ignition engine operation with biogas and specific NOx emissions are lower.

4 BIOGAS GRID CONNECTED

4.1 Potential of Biogas into the grid

The volume of biogas produced in agricultural areas is expected to increase in coming years. An increasing number of local and regional initiatives show a growing interest in decentralized energy production, wherein biogas can play a role. Biogas transport from production sites to user, i.e. a CHP, boiler or an upgrading installation, induces a scale advantage and an efficiency increase. Therefore the exploration of the costs and energy use of biogas transport using a dedicated infrastructure is needed.

The roles in the energy market are changing. Traditionally the electricity and natural gas markets have been dominated by large- scale producers, traders and distributors. In addition to these large- scale firms, small-scale initiatives developed. Local government, at municipal and provincial level, have adapted policies to reduce CO2-emissions in line with the national targets. Often villages and cities even have a higher ambition, striving to an energy or CO2 neutral community.

In this new development biogas can play its role as a local source of energy. Biogas is less fluctuating and more controllable in comparison to solar and wind and can, to a certain extent, be used as balancing power.

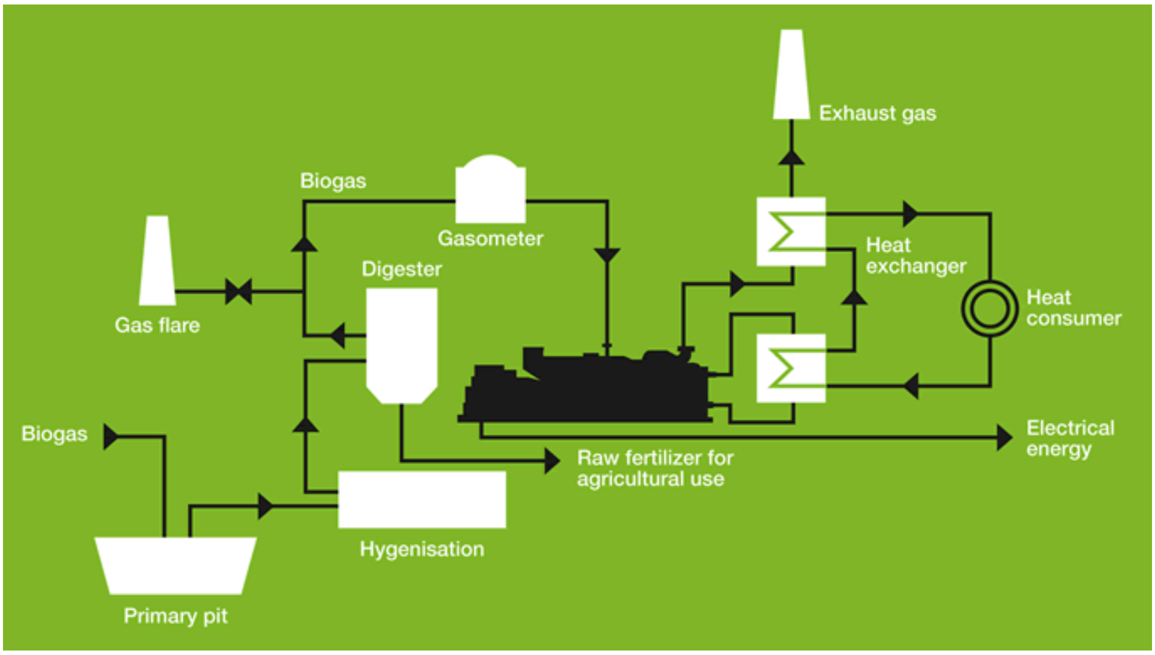


Figure 4-1: Simple Scheme of Biogas plant Energy Flows and Connections

In Figure 4-1 we can appreciate the simplest scheme of biogas plant that produces both thermal energy end electrical energy injected into the grid. Biogas is a promising renewable source of energy. It can be directly converted into electrical power, e.g., in a fuel cell. It can be burnt, releasing heat at high temperature. It can be burnt in a CHP for the simultaneous production of heat and power. Finally, it can be fed into the natural gas network for energy saving purposes or it can serve as fuel for vehicles, being distributed by gas stations. Often the biogas has to be transported over long distances and has to be purified before it can be further utilized.

Lot of consideration, comments and research have been investigated in recent years and in this chapter the main conclusions inherent impact of biogas plant on Distribution Network (DN) will be given. Furthermore it will be provided a description about all the forms of energy supplied by biogas plant (District Heating, Electric Energy, Bio methane) and its possible layout to better improve efficiency and cost. Energy conversion by engines was already mentioned in the previous chapter therefore just energy generation by other technologies will be reported before analysing various researches and actual studies.. Finally a perspective on the potential role of biogas in smart energy grids will be taken into account.

4.2 Biogas to Energy

Biogas can be used either for the production of heat only or for the generation of electric power. When current is obtained, normally heat is produced in parallel. Such power generators are called combined heat and power generation plants (CHP) and are normally furnished with a four-stroke engine or a Diesel engine. A Stirling engine or gas turbine, a micro gas turbine, high- and low-temperature fuel cells, or a combination of a high-temperature fuel cell with a gas turbine are alternatives.

Biogas can also be used by burning it and producing steam by which an engine is driven, e.g., in the Organic Rankine Cycle (ORC), the Cheng Cycle, the steam turbine, the steam piston engine, or the steam screw engine. Another very interesting technology for the utilization of biogas is the steam and gas power station.

Figure 4-2 shows the range of capacities for the power generators which are available on the market as pilot plants or on an industrial scale. The efficiency indicates the ratio of electrical power to the total energy content in the biogas. Efficiency figures are given for different manufacturers. Small-capacity engines can result in lower efficiencies than high-capacity engines.

The generated current and heat can supply the bioreactor itself, associated build- ings, and neighboring industrial companies or houses. The power can be fed into the public electricity network, and the heat into the network for long-distance heat supply. The power or the heat can sometimes drive vehicles.

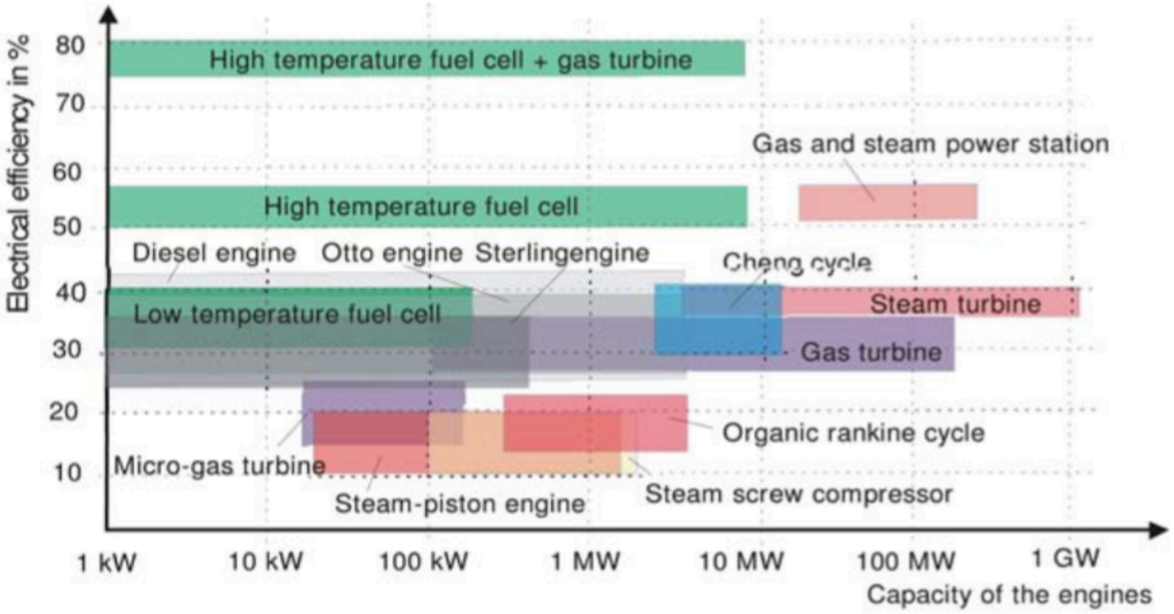


Figure 4-2: Efficiency and Capacity correlations for various Technologies

4.2.1 Supply of current to the public electricity network

The mode of operation of a gas engine varies in principle according to whether it:

- covers peak load
- covers base load
- supplies its own needs and only feeds the surplus into the network

The mode of operation is determined by local conditions, especially the price of electric power.

Different plant designs are needed for covering a constant basic load and for covering peak loads for certain periods of the day only. Peak load covering requires complex and expensive gasholders for longer periods and larger and more expensive power stations.

The worldwide ongoing system of promoting renewable energy, as from biogas, does not especially consider whether the power is generated for basic or for peak load and at what time of day the current is fed into the network. Therefore biogas plants are normally designed to cover the basic load, although the produced power depends on the activity of the microorganism and therefore varies.

Biogas plants are usually constructed at places, where the power network is not available and special efforts are required to connect the CHP to the public power network.

Usually special adjustments with synchronizing control, switching devices, network failure control and compensation of short-circuit power, power failure and wattless current are required.

4.2.1.1 Generators

For power generation, asynchronous or synchronous generators can be used. The application of an asynchronous generator is only reasonable if the generated electrical power is less than 100 KW because of the necessity for wattless current. However, even then they are not chosen for isolated operation. Much more often, synchronous generators are used.

4.2.1.2 Current-measuring instruments

For feeding the current into the public electricity network, a transformer with attached voltage measurement is necessary. Outgoing and incoming current are measured in a so-called 4-quadrant enumerator. For this, a mean voltage measurement is essential.

4.2.1.3 Control of synchronization

The electrical power unit may be connected to the public electricity network only if the generator voltage is adapted to the net; i.e. mains voltage must be provided by all three phases and must reach a value in all three power lines above the tripping value of the voltage decrease protection. This is controlled by the low-voltage protection of the current net failure registration. Nevertheless, the connection of the CHP is always slightly retarded.

The connection of an asynchronous generator happens automatically at a rotational frequency of 95–105% compared to a synchronous generator. The connection of a synchronous generator is done when the following three conditions are fulfilled:

Variation of the voltage: +/−10% of the nominal voltage

Variation of the voltage frequency: +/−0.5 cycles per second

Difference in the phase angle: +/−10°.

The frequency, the voltage and the phasing of the net and the generator are measured by appropriate sensors and controlled digitally by a synchronization device. The generator is controlled and adjusted within the limits of tolerance by signals in the range of 0–10 V. Only then does the PLC (programmable controller) release a signal for connection, with a slight time delay.

4.2.1.4 Switching devices

For connection of the generator to the electricity network, off-load switches should be used, in particular for capacities up to 100KW circuit-breakers with upstream safeguard load disconnecting switch and for capacities above 100KW circuit- breakers with electric drive.

4.2.1.5 Network Failure Registration

The generator is disconnected when the values under-run or over-run the limiting values stipulated below:

1. Low-voltage protection: 80% of the rated voltage
2. High-voltage protection: 110% of the rated voltage
3. Decreasing frequency protection: 49 cycles per second
4. Increasing frequency protection: 51 cycles per second.

For monitoring the frequency and the voltage, a three-phase relay is used. With synchronous generators, in place of the frequency monitoring a vector jump relay is used, which registers much faster disturbances like short breaks in the network due to its very short response time. During short breaks (duration of 150–500ms) the synchronous generator runs freely. With return of the mains voltage a wrong phase position could occur, which could lead to the destruction of the synchronous generator. The vector jump relay compares the current phase positions between the generator and the network (Figure 4-3). If these deviate by more than ca. 10°, then within 100 ms a signal is given to cut off of the generator connection. Thus, out-of-phase connection of the network to the generator is prevented.

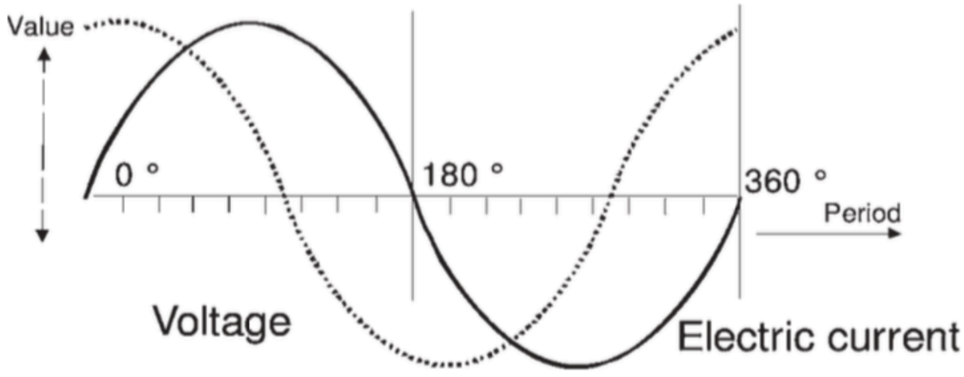


Figure 4-3: Phase difference between electric current and voltage

4.2.1.6 Short Circuit Protection

Generators usually produce a short-circuit current of 1.5–4 times the nominal current. Fuses or switches are not available on the market, which react to short- circuit current. Only special current guards can measure the short-circuit current. These have an adjustable time of retardation, so that they do not react when load is connected.

4.2.1.7 Wattless current compensation

Synchronous generators produce wattless current due to a phase shift. The phase shift cos\ of a generator, which is to be connected to the electricity network, should be within the limits of 0.9 capacitively to 0.8 inductively in the case of withdrawal and supply of power. Generators are equipped with an automatical cos\ controller even for varying power generation. Additional compensation is not necessary. With asynchronous generators, compensation capacitors are necessary. These may not be switched on before connecting the generator and have to be switched off at the same time as the generator is disconnected. The capacity of the capaci- tors should be ca. 75% of the rated output (in kVA) of the generator.

4.2.2 Supply of heat

The economics of a biogas plant are highly dependent on the utilization of the heat produced from the biogas (Figure 4-4). It must be borne in mind that the heat is produced over the whole year and not only in the winter, when it can be easily used. The heat could be used, e.g., for:

- heating swimming pools and/or industrial plants
- heating stables as for the breeding of young animals under infrared emitters
- the treatment of products or for drying processes.
- heating greenhouses
- cleaning and disinfection of the milking equipment
- Transformation of warmth in cold e.g. for milk cooling

A remarkable step forward could be the use of the heat for operating an absorption refrigerator. The cold could then be used in agricultural plants for cooling purposes, e.g., for stables or for milk. The heat generated, e.g., in a CHP, partly escapes with the exhaust gas and has to be recovered in the exhaust heat exchanger for further use. But it can only be regained to a certain extent, because the exhaust gas is at a minimum temperature of 120–180°C. The heat is partly transferred to water in the cooling water heat exchanger. The heat of the lubricating oil is mostly dissipated to the engine cooling water. But heat losses of the entire biogas plant and radiation losses of the CHP cannot be avoided.

Engines with a turbo charger are usually equipped with an intercooler or with a mixture radiator if they are gas engines. Depending on the design, the heat generated therein is transferred to the cooling water or to a separate water cycle. The water in the cycle, which transports the heat from the biogas burner to consumers, is normally heated to 90–130°C and flows back to the burner at a temperature of 70–110°C.

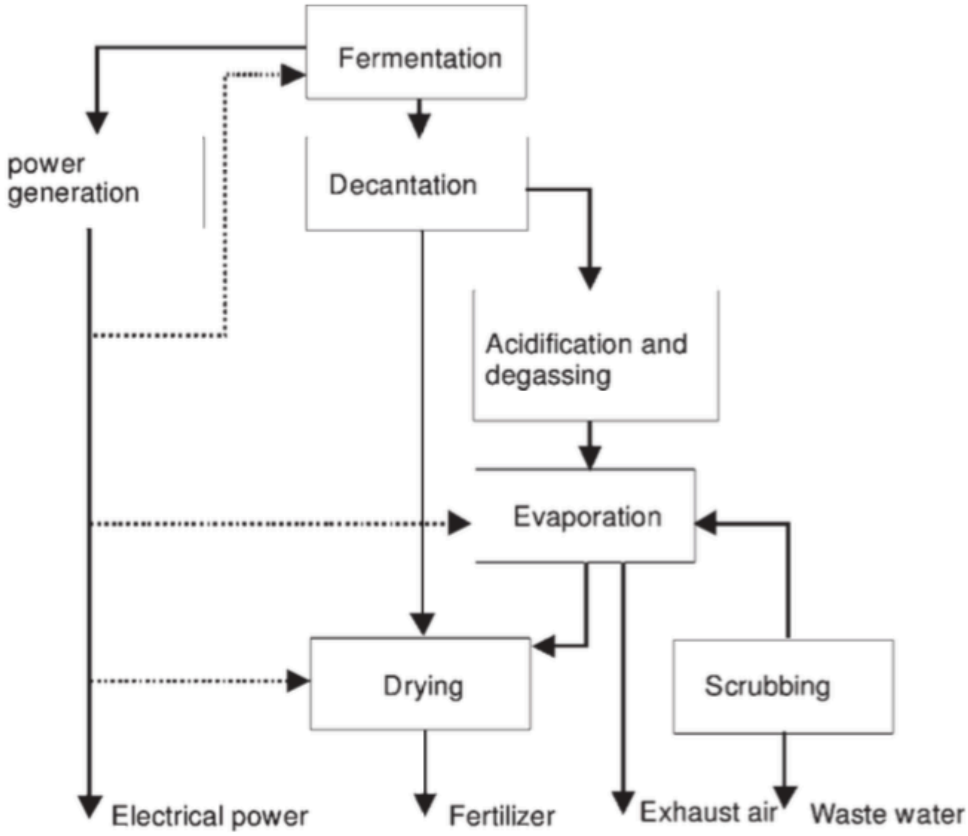


Figure 4-4: Utilization of heat generated in the biogas plant itself (dotted lines)

4.2.2.1 Combined heat and power generation (CHP)

CHPs are very common in biogas plants (see Figure 4-5). In parallel to the generation of current, a more or less high percentage of heat is developed in CHPs, depending on the power generator technology.

Approximately 50% of the CHPs installed in biogas plants in Europe run with four-stroke engines and about 50% with ignition oil Diesel engines. More modern technologies like fuel cells or micro gas turbines are very seldom to be found.

The total efficiency, i.e. the sum of the electrical and thermal efficiencies, is within the range 85–90% with modern CHPs. Only 10–15% of the energy of the biogas is wasted. But the electrical efficiency (maximum 40%) is still very low: from 1m3 biogas only 2.4KWh electric current can be produced.

The equipment of a complete CHP includes

- a generator set consisting of drive unit and generator

- a waste gas system

- a ventilator for the supply of the combustion air on the one hand and on the other hand for the removal of the radiant heat of the engines, generators, and pipework

- a sound-damping hood

- an automatic lubricant supply.

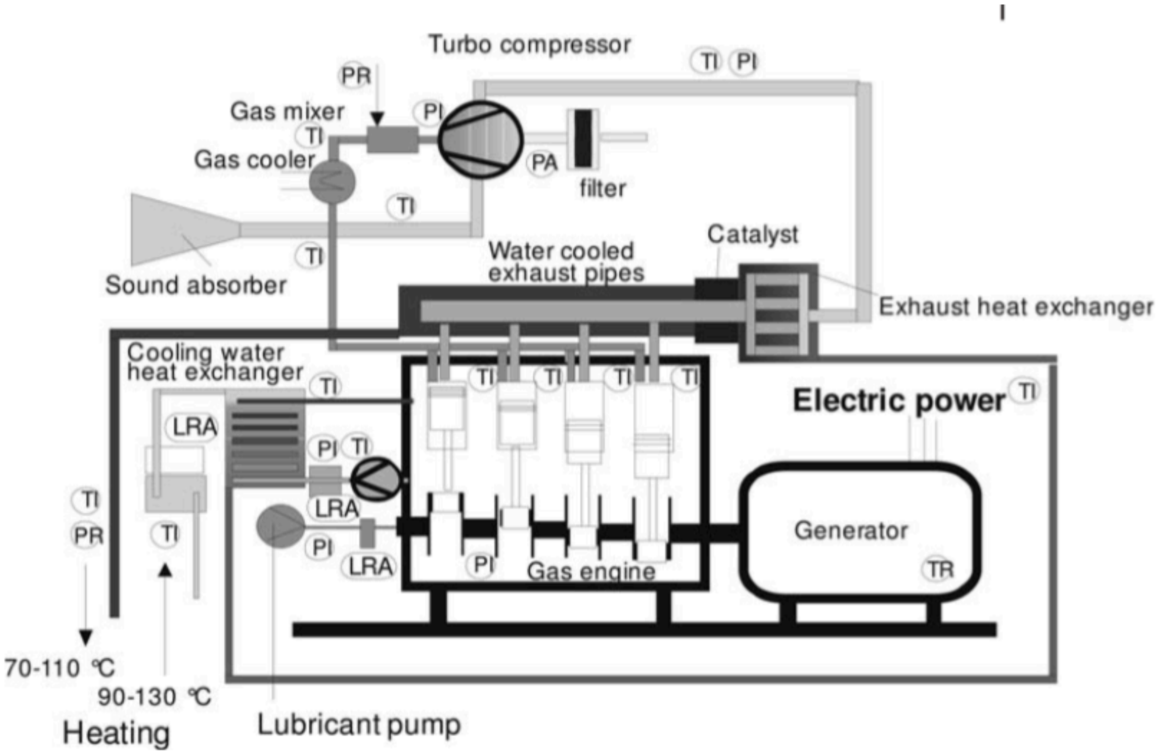


Figure 4-5: CHP instruments: Control instruments (for cooling water temperature at motor inlet and outlet, cooling water temperature at the exhaust pipes, cooling water pressure, heating water temperature inlet and outlet, pressure of the lubricant, pressure in the crank case, pressure in the exhaust pipe, charging air pressure, gas mixture temperature before and after cooler, exhaust temperature after each cylinder, after turbo compressor, and after heat exchanger, voltage of the lambda probe on both sides, pinging signal). Contactor for (level of lubricant, level of cooling water, contamination of the intake filter). Digital indicator for (temperature of the electric coil, low voltage of the starting battery, missing heating water, overpressure of heating water, level of lubricant, level of cooling water, over-current for all electrical motors, minimum gas pressure, tightness of all gas pipes).

4.2.3 Supply of electricity by other technologies

4.2.3.1 Generation of electricity in a Stirling engine

An alternative to the commonly used four-stroke engine and/or the Diesel engine is the Stirling engine. The efficiency of the Stirling process is closest to that of the ideal cycle. In the Stirling engine, heat and cold must be supplied alternately to the working medium once per cycle. Because of the slow-acting heat transfer through the walls of the combustion chamber, external heat exchangers are installed in which a special driving gas is heated and cooled. The driving gas moves between two chambers, one with high and one with low temperature.

In stage I, the driving gas is to be found uncompressed in the cold chamber. When the driving piston moves upwards (see Figure 4-7), the driving gas is compressed (stage II) and then forced to the warm chamber. On its way it is heated in an external heat exchanger. The heated driving gas presses the displacement piston downwards by its expansion pressure (stage III). The displacement piston is taken downwards with the driving piston (stage IV). Then the displacement piston moves upwards again, forced by the rhombus gear with which both pistons are connected. The displacement piston presses the driving gas downwards back to the cold chamber. On its way it is cooled in a cooling heat exchanger. Then the cycle starts again. The rotation of the rhombus gear can be used to run a power generator.

The Stirling engine was recommended for power generation for many years, but was seldom realized on an industrial scale because of technical problems in details. Industrial scale installations are not known in which power is generated from biogas in Stirling engines.

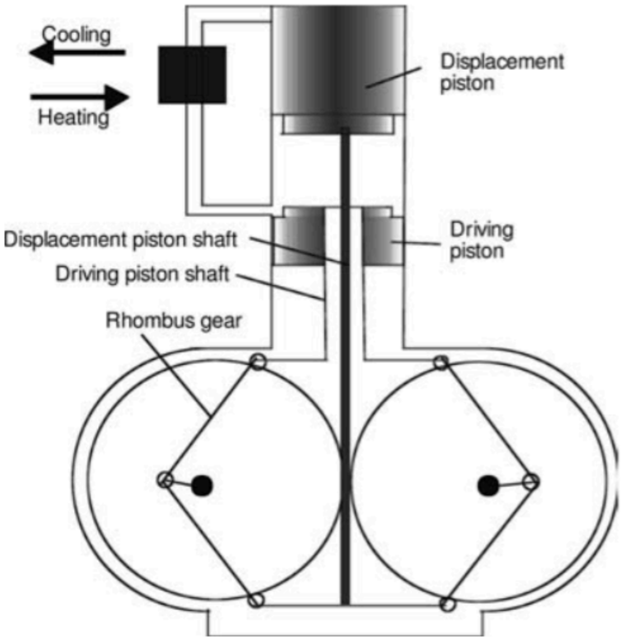


Figure 4-6: Design of a Stirling engine

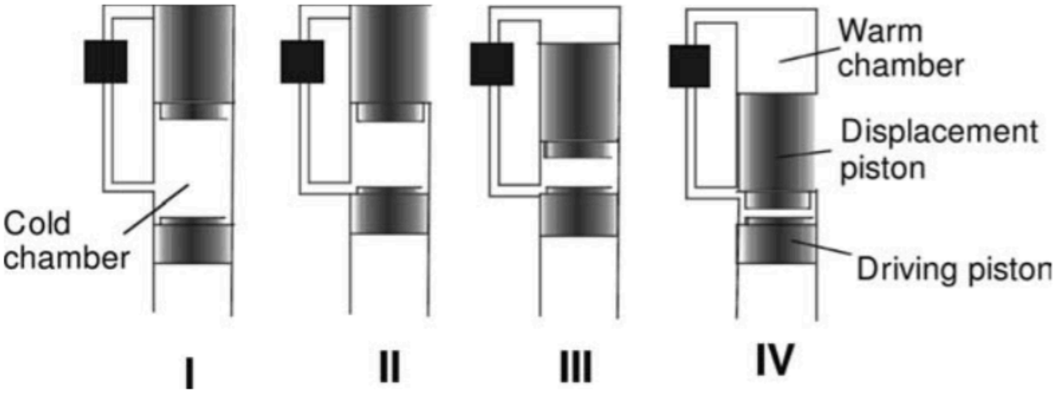


Figure 4-7: Working principle of a Stirling engine

4.2.3.2 Generation of electricity in a fuel cell

Compared to combustion engines, the fuel cell converts the chemical energy of hydrogen and oxygen directly to current and heat. Water is formed as the reaction product (Figure 4-8). In principle, a fuel cell works with a liquid or solid electrolyte held between two porous electrodes – anode and cathode as we can see in Figure 4-9. The electrolyte lets pass only ions and no free electrons from the anode to the cathode side. The electrolyte is thus "electrically nonconductive". It separates the reaction partners and thereby prevents direct chemical reaction. With some fuel cells, the electrolyte is also permeable to oxygen molecules. In this case the reaction occurs on the anode side. The electrodes are connected by an electrical wire.

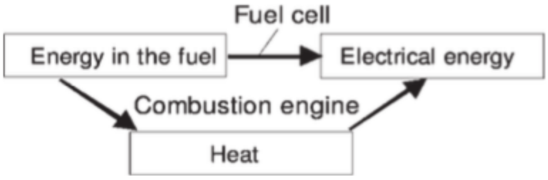


Figure 4-8: Energy conversion in a combustion engine in comparison to a fuel cell

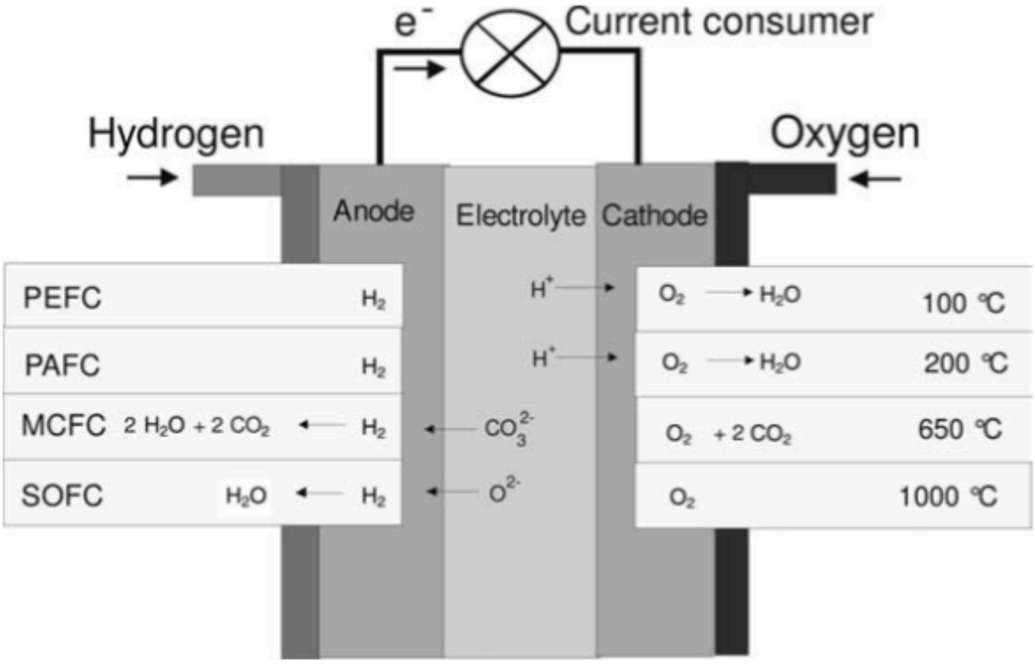


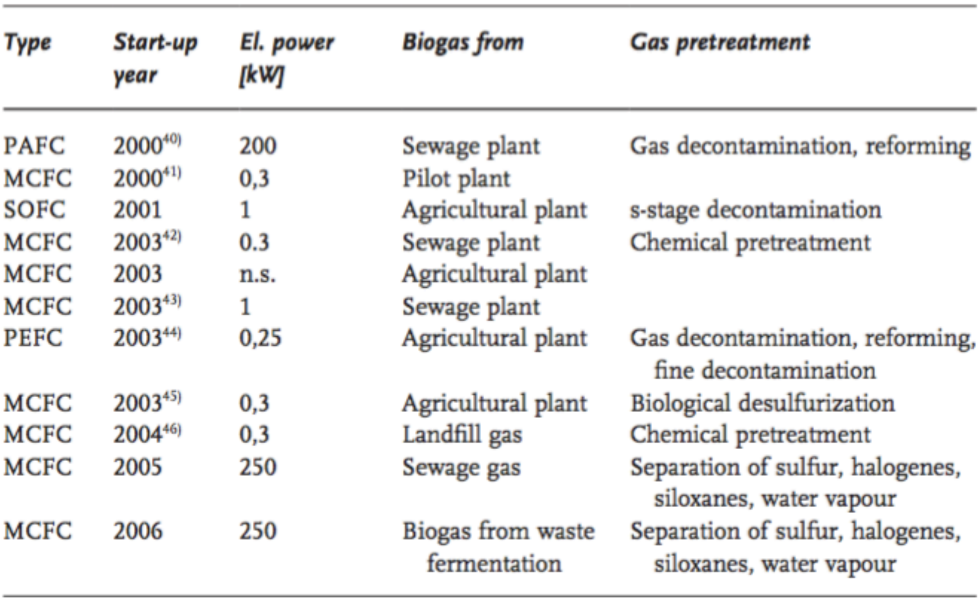
Figure 4-9: Fuel cell types

Both reaction partners are continuously fed to the two electrodes. The molecules of the reactants are converted into ions by catalytic effect of the electrodes. The ions pass through the electrolyte, while the electrons flow through the electric circuit from the anode to the cathode. Taking into account all losses, the voltage per single cell is 0.6–0.9 V. The desired voltage can be reached by single cells arranged in series, a so-called stack. In a stack, the voltages of the single cells are added. Depending on the type of fuel cell, the biogas has to be purified, especially by removing CO and H_2S, before feeding the fuel cell. Only a small number of fuel cell plants, mostly pilot plants, are in operation for the generation of electricity from biogas and they are listed in Table 4-1.

Figure 4-10 shows the flow patterns of complete fuel cell plants. Decontamination of the crude biogas is absolutely necessary with all fuel cells, which work in a temperature range up to 200°C. Subsequently, the methane from the biogas must be reformed to H_2. The hydrogen is fed into the stack. That part of the hydrogen which does not pass through the electrolyte is after-burned and used for the generation of heat.

In the MCFC cell, carbon dioxide serves as the cooling medium for the biogas on the anode side. Therefore, less excess air is necessary on the cathode side. The blower can be designed with a lower capacity. CO_2 slows the kinetics on the anode side to an insignificant extent, but accelerates it on the cathode side, so that a higher efficiency (ca. 2%) is observed when using biogas instead of pure hydrogen. Another type of fuel cell is the SOFC plant, shown in Figure 4-11, for providing houses with current and heat.

Table 4-1: Industrial scale and pilot plant fuel cells for biogas



Type	Start-up year	El. power [kW]	Biogas from	Gas pretreatment
PAFC	2000[40]	200	Sewage plant	Gas decontamination, reforming
MCFC	2000[41]	0,3	Pilot plant	
SOFC	2001	1	Agricultural plant	s-stage decontamination
MCFC	2003[42]	0.3	Sewage plant	Chemical pretreatment
MCFC	2003	n.s.	Agricultural plant	
MCFC	2003[43]	1	Sewage plant	
PEFC	2003[44]	0,25	Agricultural plant	Gas decontamination, reforming, fine decontamination
MCFC	2003[45]	0,3	Agricultural plant	Biological desulfurization
MCFC	2004[46]	0,3	Landfill gas	Chemical pretreatment
MCFC	2005	250	Sewage gas	Separation of sulfur, halogenes, siloxanes, water vapour
MCFC	2006	250	Biogas from waste fermentation	Separation of sulfur, halogenes, siloxanes, water vapour

Pilot plant tests have shown that in SOFCs operated with biogas a lower efficiency (max. 5%) is obtained in comparison to an SOFC fed with natural gas. Although fuel cells show significant advantages in comparison to other “engines” for generating current from biogas, there are still many doubts about their breakthrough on the market because of the high costs. Their main advantage is their very high electrical efficiency. It is expected that the assumed considerable decrease in costs when fuel cells are manufactured on a production basis will push their commercialization.

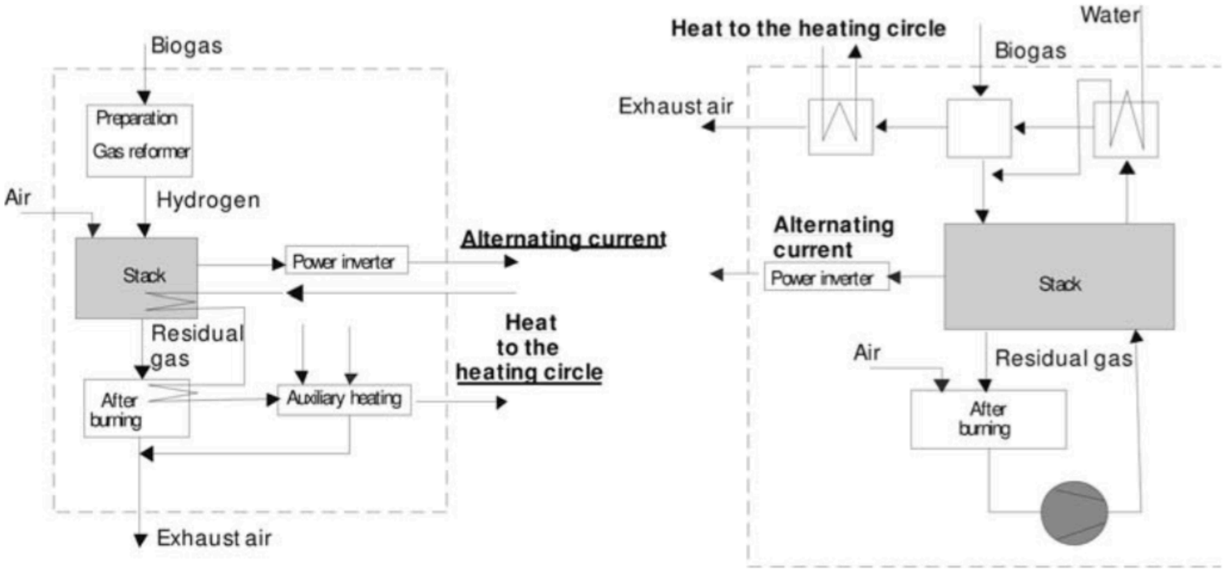


Figure 4-10: Flow chart of fuel cell plants: PAFC (left); MCFC (right)

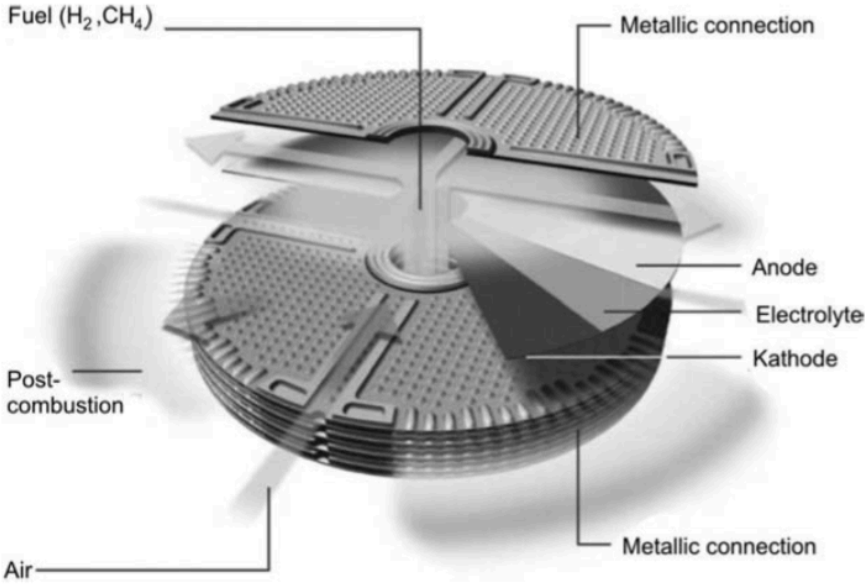


Figure 4-11: SOFC fuel cell type

4.2.3.3 Generation of electricity in a gas turbine

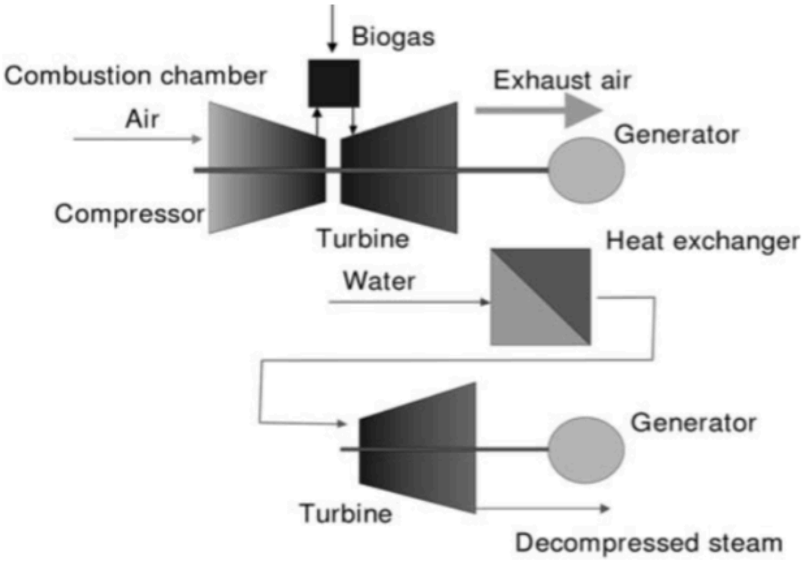


Figure 4-12: Gas turbine process with heat recovery in a steam turbine downstream

Biogas can be converted to current via gas turbines of medium and large capacity (20 MW_{el} and more) at a maximum temperature of ca. 1200 °C. The tendency is to go to even higher temperatures and pressures, whereby the electrical capacity and thus the efficiency can be increased. The main parts of a gas turbine are the compressor, the combustion chamber, and the turbine.

Ambient air is compressed in the compressor and transmitted to the combustion chamber, where biogas is introduced and combustion takes place. The flue gas that is so formed is passed to a turbine, where it expands and transfers its energy to the turbine. The turbine propels on the one hand the compressor and on the other hand the power generator. The exhaust gas leaves the turbine at a temperature of approximately 400–600 °C. The heat can be used for driving a steam turbine downstream, for heating purposes, or for preheating the air that is sucked in (see Figure 4-12). The gas turbine is regulated by changing the biogas supply into the combustion chamber.

Gas turbines are characterized by very low emission values. When feeding decontaminated biogas, the NOx value in the exhaust gas is ca. 25ppm. The CO content can be considerably reduced by a catalyst downstream. Higher efficiencies can be obtained by higher turbine inlet temperatures, which presupposes particularly temperature-resistant materials and complicated technologies for blade cooling. Therefore gas turbines of the highest efficiency are relatively maintenance-intensive.

4.2.3.4 Generation of electricity in a micro gas turbine

Micro gas turbines are small high-speed gas turbines with low combustion chamber pressures and temperatures. They are designed to deliver up to ca. 200 kW_{el} electrical power. Nearly all micro gas turbine manufacturers offer turbines of radial design with combustion air compressor, combustion chamber, generator, and heat exchanger (Figure 4-13). Micro gas turbines are characterized by a single shaft on which the compressor, the turbine, and the generator are fixed. The turbine propels the compressor, which compresses the combustion air and at the same time the generator. Thus radial forces to the bearings and to the shaft are avoided, which allows a simple design; e.g., the bearings can be “gas-lubricated” because of the low load. The gas lubrication can be accomplished by passing compressed air through the bearings. Oil changes as required for normal turbines are not necessary because of the oil-free running of the micro gas turbine.

For normal operation, the turbine sucks in the combustion air. The fuel is normally supplied to the combustion air in the combustion chamber. When biogas with a low calorific value is used it can also be mixed with the combustion air before the turbine. In the latter case, a little biogas has only to be supplied directly to the combustion chamber for fine adjustment.

The up to 100000 rpm rotating generator produces high-frequency alternating current, which is converted in an electronic device (Figure 4-14) so that it can be fed synchronously into the power network.

The electrical efficiency of 15–25% of today’s micro gas turbines is still unsatisfactorily low. An attempt to increase the efficiency has been made by preheating the combustion air in heat exchange with the hot turbine exhaust gases. But great improvements are still necessary before micro gas turbines will penetrate the market of industrial biogas plants. However, already today the coupling of a micro gas turbine with a micro steam turbine to form a micro gas and steam turbine seems interesting and economical because of its high electrical efficiency (ca. 50%). Micro gas-turbines are regulated only by varying the fuel supply.

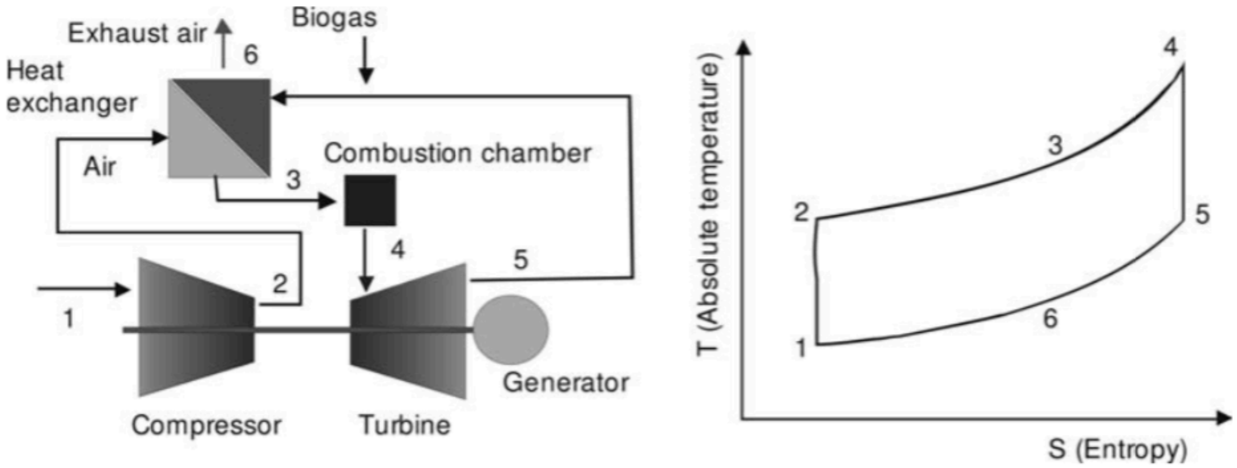


Figure 4-13: Micro gas turbine: scheme (left), thermodynamical process (right)

The maintenance interval can be as long as 2000–8000 h. It can be longer when the operating temperature is increased above the normal operating temperature of ca. 10°C. In the United States, many micro gas turbines are in operation for the generation of electricity from natural gas. The machines are well approved for low capacities. The machines are well approved for low capacities. Some experiments on the supply of biogas to micro gas-turbines have been made in Sweden (Table 4-2).

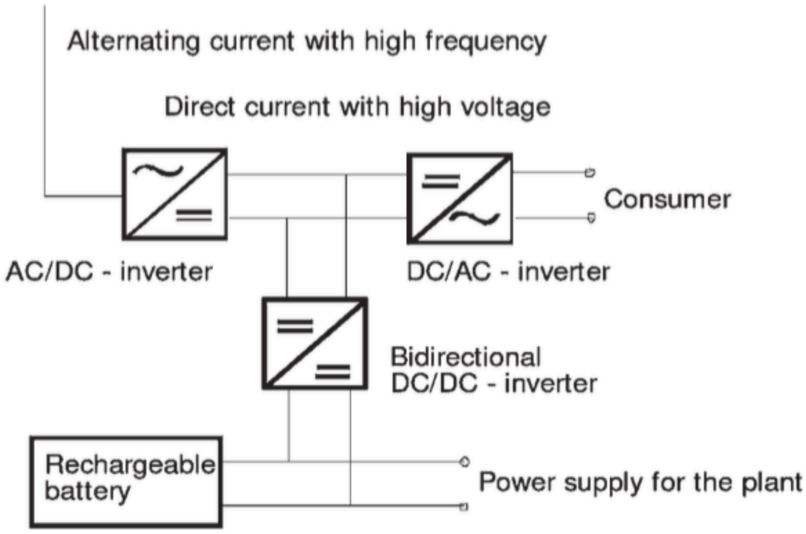
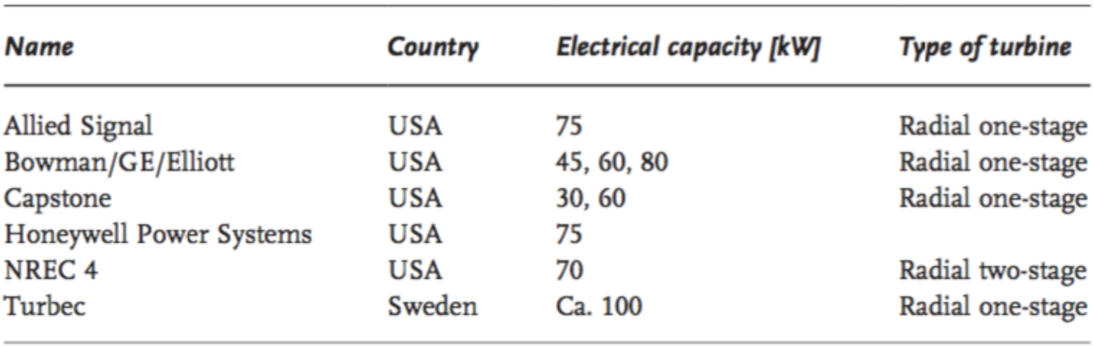


Figure 4-14: Electronic gear

Table 4-2: Some worldwide suppliers of micro gas turbines



Name	***Country***	***Electrical capacity [kW]***	***Type of turbine***
Allied Signal	USA	75	Radial one-stage
Bowman/GE/Elliott	USA	45, 60, 80	Radial one-stage
Capstone	USA	30, 60	Radial one-stage
Honeywell Power Systems	USA	75	
NREC 4	USA	70	Radial two-stage
Turbec	Sweden	Ca. 100	Radial one-stage

4.2.4 Biogas for feeding into the natural gas network

Apart from the local direct conversion of biogas to current and heat, there is the possibility to clean the biogas, to separate methane and carbon dioxide, and to feed the methane into the low-pressure natural gas network. Compared with other utilization paths of biogas, upgrading of biogas to biomethane offers several advantages and has thus become of increased relevance in the last decade, especially in Europe as we can appreciate in Figure 4-15. Biogas upgrading and grid injection of biomethane enables transportation of the gas to places where the complete energy (power and heat) is needed, thus offering the chance to increase the overall efficiency of gas utilization. In summary, biomethane offers the following advantages:

- temporary decoupling of production and utilization
- local decoupling of production and utilization
- storage capability
- flexibility regarding several utilization paths: electricity (combined with full utilization of heat); heat (combined with power or in natural gas burners); vehicle fuel (for natural gas vehicles); and primary product for the chemicals industry

To be able to inject biogas into natural gas grids or for direct utilization as vehicle fuel, it is necessary to clean and upgrade the raw biogas. Cleaning means the separation of undesired gas compounds and upgrading refers to the separation of CO_2. For sake of simplicity we will not focus on the technology about biogas cleaning before injection into grid but a discussion about the latest researches and the actual situation in some countries and the perspective in Italy will be made.

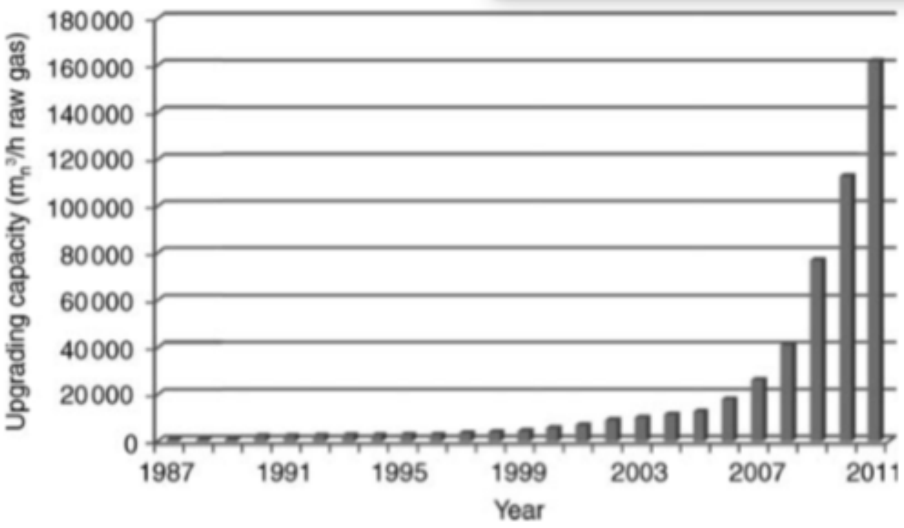


Figure 4-15: Upgrading capacity of European biogas upgrading plants in the period 1987–2011 related to raw biogas (Copyright:Fraunhofer IWES, 2012).

4.2.4.1 Some basis to feed biogas into grid

Before feeding the biogas into the natural gas network, the following features must be adjusted:

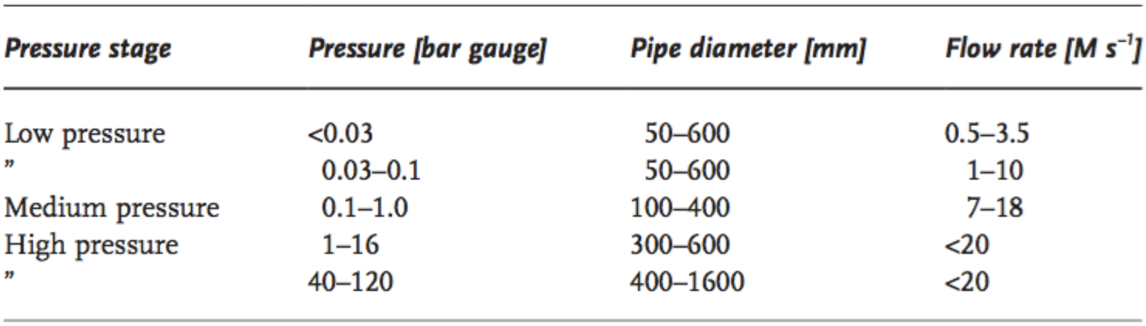
- Pressure
- Density
- Total sulfur
- Oxygen and humidity content
- Wobbe index.

The Wobbe Index (WI) or Wobbe number, as already discussed in previous chapter is an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and town gas and is frequently defined in the specifications of gas supply and transport utilities. If V_C is the higher heating value, or higher calorific value, and G_S is the specific gravity, the Wobbe Index is defined as:

$$I_W = \frac{V_C}{\sqrt{G_S}}$$

Depending on its quality, natural gas is divided into two groups that are characterized by the Wobbe Indices: L-Gas H-Gas groups and precise distinction can be observed in Table 4-3.

Table 4-3: Grid-type networks for the natural gas supply.



Pressure stage	***Pressure [bar gauge]***	***Pipe diameter [mm]***	***Flow rate [M s^{-1}]***
Low pressure	<0.03	50–600	0.5–3.5
”	0.03–0.1	50–600	1–10
Medium pressure	0.1–1.0	100–400	7–18
High pressure	1–16	300–600	<20
”	40–120	400–1600	<20

In some countries, the composition of the gas mixture at the feed point to the customers is decisive for pricing. In order to maintain the gas quality at the feed point, gas mixing is permitted as showed in Figure 4-16. Mixing devices are controlled by the calorific value or Wobbe index using the variables pressure, natural gas flow rate, and gas flow rate. In order to ensure a homogeneous mixture in the downstream network, the mixing devices have to be driven continuously. The addable rate of CO_2 depends on the CO_2 rate in the natural gas stream (normally not more than 2%) and the quantity of nitrogen in the natural gas. Wide variations in the composition of the biogas cause large expenditure on the regulation system and need a system which can give “attenuation” in the summer as well as raising the quality in the winter. A minimum calorific value at the feed point is a result of the use of natural gas only for heating and steam boiling in houses. The standard is difficult to keep up regarding techniques, even more in H-gas networks than in L-gas networks. But the minimum calorific value nowadays is less important than other features of the gas; e.g., for gas engines the methane number, which indicates the knocking behavior of gases. The methane number considerably influences the lifetime of the engine.

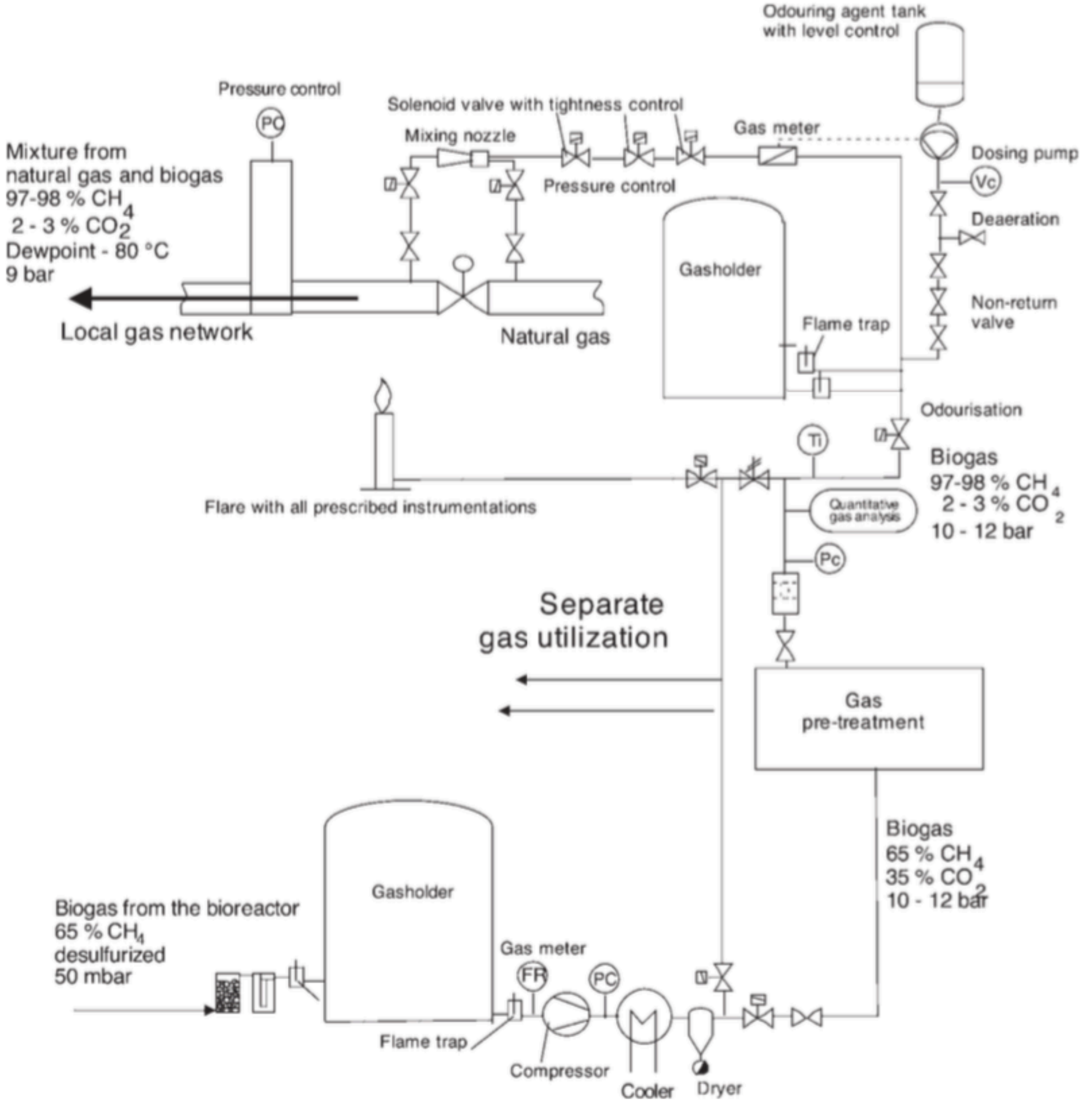


Figure 4-16: Plant for feeding biogas into the natural gas network – all pressures given in bar gauge

Biogas could be more easily fed into the natural gas network if the quality of the transported gas (natural gas + biogas) was what decided the price. Than the costumer has to pay for the energy taken and not for the gas flow rate of a certain quality.

If the biogas is not completely compatible with the natural gas distributed in the gas network, then the maximum feedable biogas rate is in general determined by the Wobbe index of the resulting gas mixture. In Denmark up to 25% biogas with a methane content of 90% may be fed to the natural gas network. Without any preparation, up to 8% by volume may be mixed with the natural gas if the biogas has a methane content of at least 60%.

There are special stations for the automatical supply of biogas into the natural gas network, depending on the quantity and quality of the gas. Such stations consist of:

- gas filters for the protection of the controlling system
- compressors, in order to safeguard the gas pressure in the network
- gas quality measuring instruments, e.g., a calibratable process gas chromatograph
- shut off device with ball valves in case of unexpected situations
- gas pressure controller to maintain the initial gas pressure
- sometimes a special gas mixing device.

Before connecting to the gas network, the following have to be installed:

- Two automatic shut-off valves with an intermediate tightness-checking device. In case of interruptions of the operation, incidents, and power failures, these valves must automatically close.
- One valve to be operated manually. This valve may only be opened by personnel responsible to the owner of the gas network for safety reasons.

Before feeding the gas into the network, it must be odorized. Because odorizing plants are very expensive, they are only installed in large biogas plants. For feeding of biogas from small plants it is recommended to odorize the main natural gas stream a little further upstream. The odorization can be done either by injection of the odorizing agents directly into the natural gas stream or by passing part of the gas flow through a container in which the odorizing agent evaporates.

Recently, tertiary butylmercaptan (TBM) was recommended as an odorizing agent. In comparison to tetrahydrothiophen (THT), it has the following advantages:

- high smell intensity
- low absorption rate at pipe walls
- easier disposability.

The lower the biogas pressure at the feeding point, the more advisable is the installation of a compressor plant.

4.2.4.2 Actual situation and future perspective

Europe has witnessed a substantial growth in power generation from biogas over the past few years: the gross electricity output from decentralized agricultural plants, centralized co-digestion plants and municipal methanization plants increased from approximately 17 TWh in 2006 to almost 36 TWh in 2011 [15].

Several countries in Europe also subsidized upgrading plants, which use suitable technologies [16] to remove carbon dioxide from biogas and yield bio-methane, having similar composition and heating value to natural gas and suitable for injection into the gas grid or for use as a vehicle fuel: some 200 plants exist in Europe, mainly located in Germany, Sweden, Austria, Switzerland and the Netherlands [16].

Since the end of the 1990s, a local gas network has been built up around lake Zurich (Switzerland), and a considerable percentage of this is supplied with biogas out of particular established biogas plants. Each of these is designed to produce more than 50 m^3 biogas per hour. The plants receive organic wastes from households, from industry, and from agriculture as well as industrial waste water, particularly from the food, animal feed, and paper industries. Since the heat produced during the generation of electricity cannot be used economically in the local networks, and since the biogas plant works continuously and cannot produce biogas only if a vehicle is to be refuelled, the decision was made to feed all prepared biogas into the natural gas network. This gas mixture is sold under the labelling “Naturgas” in the area around Zurich, because it does not completely meet the specifications of natural gas.

In a small town of Sweden, Laholm, in the year 1992 a biogas plant was constructed, mainly to contribute to the reduction of the eutrophication of Laholm bay, in which problems due to pollution by fertilizers were increasing. Other objectives of the project were the production of biogas for Laholm and the production of a biological fertilizer for the surrounding agriculture. The plant processes liquid manure as well as other waste materials, in particular from fifteen different food manufacturers. Biogas production reaches about 20–30 GWh annually, with a methane content of ca. 70%. Up to the year 2000 this biogas was used in a CHP, and about 300 dwellings were supplied with heat. When not enough biogas was available, the CHP could be operated with natural gas. A substantial disadvantage of the system was that in periods with low heat requirements almost 40% of the produced biogas had to be burnt in the flare. In the year 2001, therefore, a biogas preparation plant was constructed, which is able to prepare 250 m^3/h biogas with 60–65% methane content to natural gas quality. The prepared biogas is used in a CHP as in earlier times. When the heat consumption decreases, the prepared biogas is fed into the local low-pressure natural gas network and distributed in the city of Laholm [17].

Germany without any doubt is the most advanced country in the world from both biomethane and feed into grid biogas injection point of views. As we can see from Figure 4-17 and **Error! Reference source not found.**Figure 4-18 the most of plants are situated in Germany and Government is pushing towards further development and diffusion over all the country.

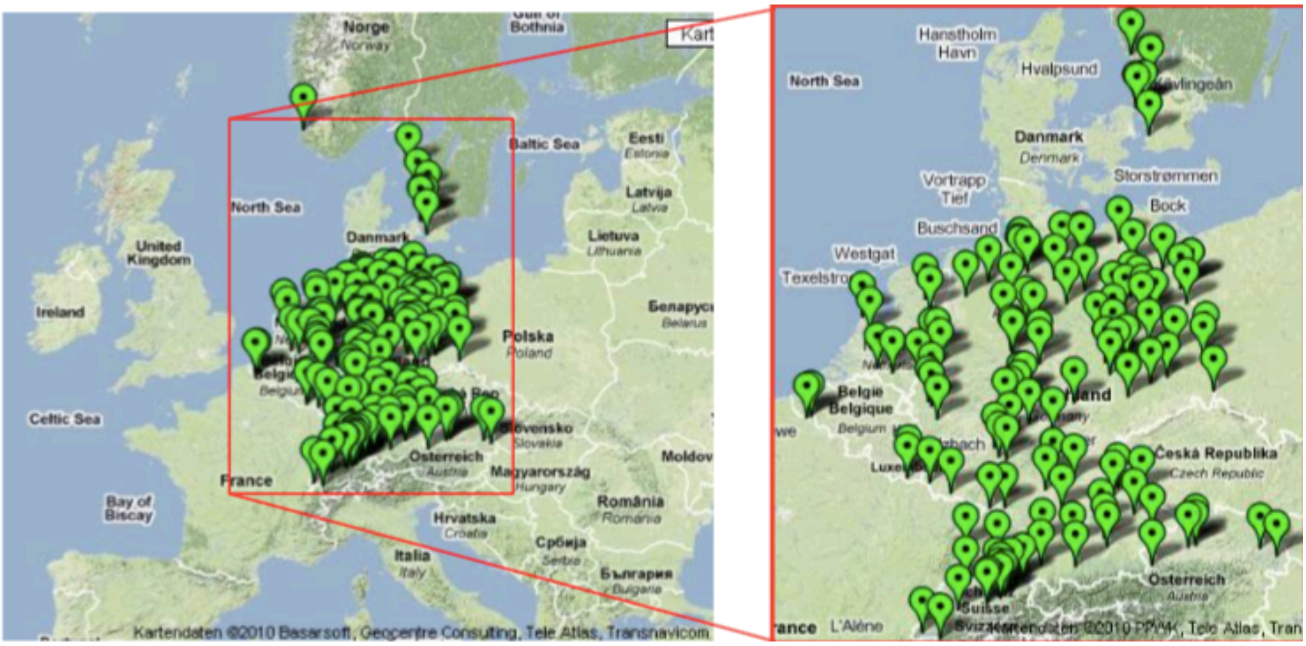


Figure 4-17: Biomethane production plants in Europe (Source: www.biogaspartner.de)

The first project in Stuttgart Mühlhausen was promoted by the European Union in the 1990s with the object of gathering experience in the preparation of sewage gas to natural gas quality. Before the project started, a basic calculation had shown that the preparation of biogas and its feeding into the natural gas network could be economical under the given circumstances. For the preparation of the sewage gas, the procedure of chemical absorption (scrubbing under pressure) in an MEA reactor (monoethanolamine) was chosen. The experiences with the plant were quite positive. Crude sewage gas was prepared at the rate of 400 m^3/h and was afterwards fed into the natural gas network for several years without problems. As can be seen from Table 4-4, the plant actually operated profitably.

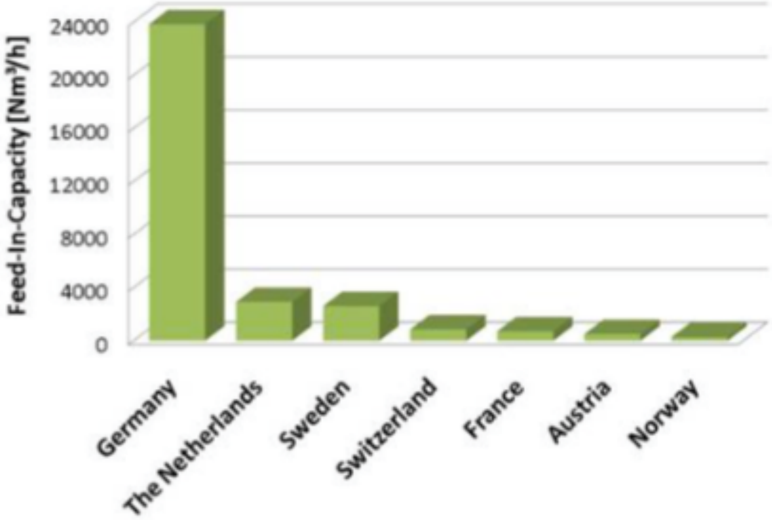


Figure 4-18: Feed-in biomethane capacity in Europe (Source: www.biogaspartner.de)

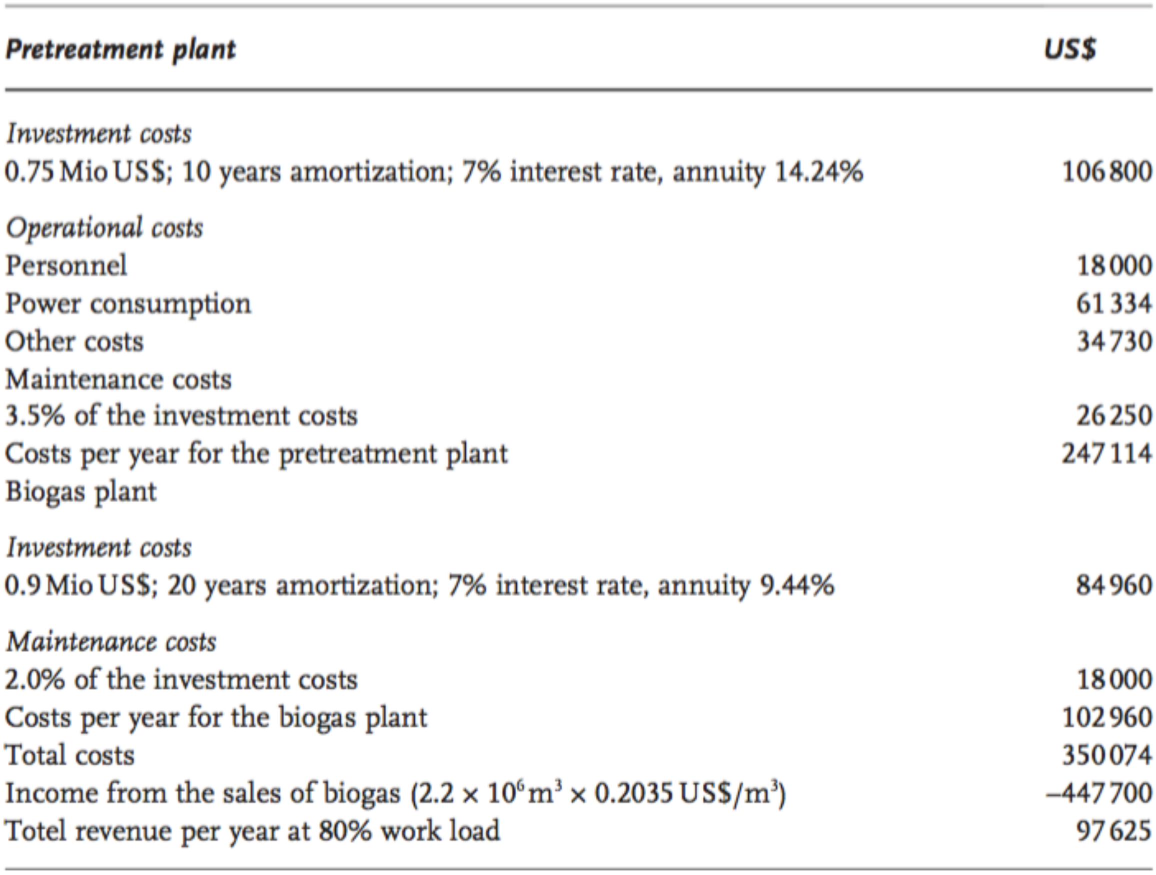
In Germany, the natural gas distributing companies have given up their initially discouraging attitude to biogas. Today it is assumed, according to a careful estimation, that in future 100 billion KWh biogas per year will be fed into the natural gas network, which is equal to 10% of the today's natural gas demand. In Plienigen, near Munich, starting from the year 2006, an agricultural biogas plant is feeding 3.9 Mio m^3 biogas per year into the natural gas network, equivalent to ca. 2.9MW.

The plant (is supplied with 32000–35000 Mg corn and energy- affording plants per year from surrounding farmers, who cultivate land of ca. 500 ha area. The residue is taken back to the farmers as fertilizer. Three horizontal bioreactors with a capacity of 1000 m^3 each are installed as well as three vertical reactors with a volume of 2700 m^3 each for after-fermentation. Two containers serve for residue disposal, with 10000 m^3 volume in total.

Figure 4-19: Plienigen Biogas Plant

The output is 920 m^3/h biogas. This biogas is first desulfurized, then dehumidified, and afterwards enriched to a methane content of approximately 96% by pressure swing adsorption (PSA). The PSA works with carbon molecular sieves. By the PSA procedure, the biogas volume rate is reduced to 485 m^3 /h with natural gas quality. A conventional natural gas compressor compresses the cleaned bio- methane to 40 bar. At this pressure the biogas is fed into the high-pressure gas network of the urban natural gas supply. [18]

Table 4-4: Economics of the sewage gas pre-treatment part of the sewage water treatment plant in Stuttgart-Mühlhausen.



Pretreatment plant	**US$**
Investment costs	
0.75 Mio US$; 10 years amortization; 7% interest rate, annuity 14.24%	106 800
Operational costs	
Personnel	18 000
Power consumption	61 334
Other costs	34 730
Maintenance costs	
3.5% of the investment costs	26 250
Costs per year for the pretreatment plant	247 114
Biogas plant	
Investment costs	
0.9 Mio US$; 20 years amortization; 7% interest rate, annuity 9.44%	84 960
Maintenance costs	
2.0% of the investment costs	18 000
Costs per year for the biogas plant	102 960
Total costs	350 074
Income from the sales of biogas ($2.2 \times 10^6 m^3 \times 0.2035 US\$/m^3$)	–447 700
Totel revenue per year at 80% work load	97 625

Studies concerning the upgrade of biogas to be injected into the natural grid have been done not just in Europe but also all around the world. In Egypt for example biogas is one of the promising renewable energy sources.

Egyptian biogas contains other acidic components (CO_2 and H_2S) where they must be removed before pumping the biogas into the natural gas network to meet the standards of these networks. Biogas sweetening is the process in which CO_2 and H_2S are removed in order to protect the pipelines network and power engines from corrosion due to acidic effect, and to raise the calorific value of the treated biogas. Most of biogas researches in Egypt focused only on biogas production from local resources and using it in thermal energy generation, however, there are only few researchers concentrated on the biogas quality enrichment. In [19] a simulation was done to determine the optimum working pressure, which can achieve the methane purity of the Egyptian biogas comparable to natural gas quality. The biogas treating process was accomplished inside Pressure Swing Absorber (PSA) where the feed sour gas enters the absorber at the CO_2 contents of 0.25, H_2S contents of 0.0004.

Figure 4-20 describes the typical complete acid gases removal cycle (sweetening cycle) which plugged in Aspen HYSYS 8.6 and used for natural gas NG upgrading and purification [20] in which the acid gas removal steps are performed.

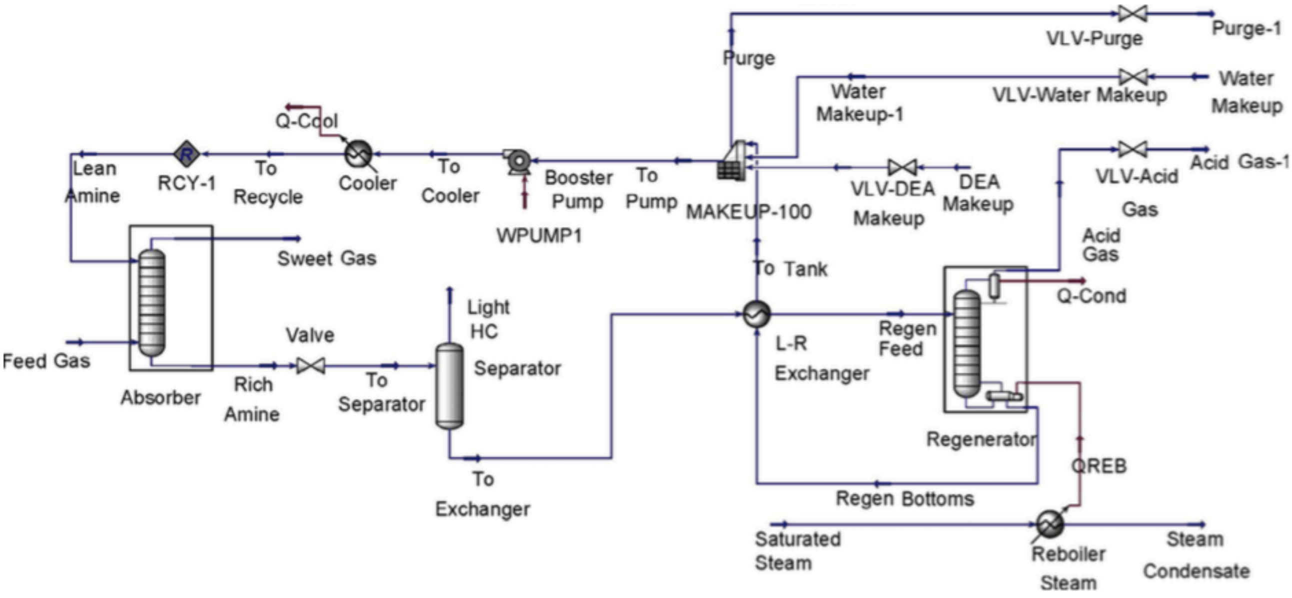


Figure 4-20: Complete acid gases removal cycle modelled in Aspen HYSYS 8.6 (sweetening cycle)

The feed Egyptian biogas which has the composition as mentioned in Table 4-5 enters the absorber at a temperature of 30 °C, a pressure of 1.1 bar and volume flow rate of 13 m^3/h from the bottom of the absorber column as showed in detail in Figure 4-21 .

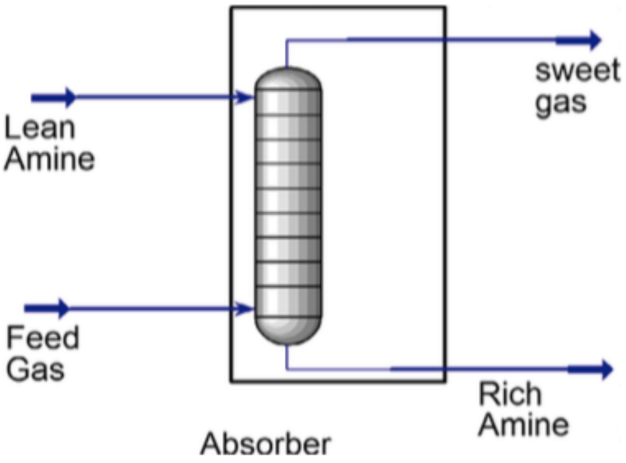
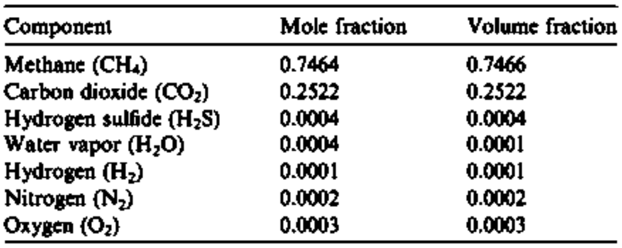


Figure 4-21: The absorber column used in the simulation to determine the optimal PSA (Pressure Swing Absorber). The absorber column was selected from Aspen HYSYS model pallet which has the internal construction containing 20 stages, each stage consists of one tray as having construction looks like a sieve.

Table 4-5: Feed Egyptian biogas composition in mole fraction



Component	Mole fraction	Volume fraction
Methane (CH_4)	0.7464	0.7466
Carbon dioxide (CO_2)	0.2522	0.2522
Hydrogen sulfide (H_2S)	0.0004	0.0004
Water vapor (H_2O)	0.0004	0.0001
Hydrogen (H_2)	0.0001	0.0001
Nitrogen (N_2)	0.0002	0.0002
Oxygen (O_2)	0.0003	0.0003

The simulation cycle was run to insure absorber conversion using Aspen HYSYS for the purpose of PSA working pressure optimization. All the numerical simulation conditions of temperatures, pressures and feed gas flow rates of the removal cycle are a result of running numerous simulation trials in order to get the highest methane purity from Egyptian biogas. The research stated the following considerations:

- There is a reverse proportion between PSA working pressure and CO_2% in the Egyptian biogas final product gas as depicted in Figure 4-22 . At the point, which is the absorber PSA working pressure to 5 bar, the CO_2 percentage equals to 0.0084. There is little (non economic) effect of PSA working pressure on the CO_2 contents if the pressure is more than 5 bar. Therefore, there is no need to increase the PSA working pressure to more than 5 bar to maintain the optimum initial cost for absorber construction.

- Also a reverse proportion between PSA working pressure and H_2S% in the Egyptian biogas final product was shown and it is represented in Figure 4-23. The H_2S contents can be removed completely from Egyptian biogas final product at the pressure of 1.1 bar. This leads to say that the pressure value of 5 bar which is needed to clean CO_2 from Egyptian biogas is sufficient to clean the CO_2 and H_2S gases simultaneously.

- Figure 4-24 shows the effect of the PSA working pressure on the methane purity of the biogas final product. At the point, which is the absorber PSA working pressure to 5 bar, the methane purity tends to be 95% which is the desired value of most of NG networks. There is more effect of PSA working pressure on the methane purity if the pressure is more than 5 bar.

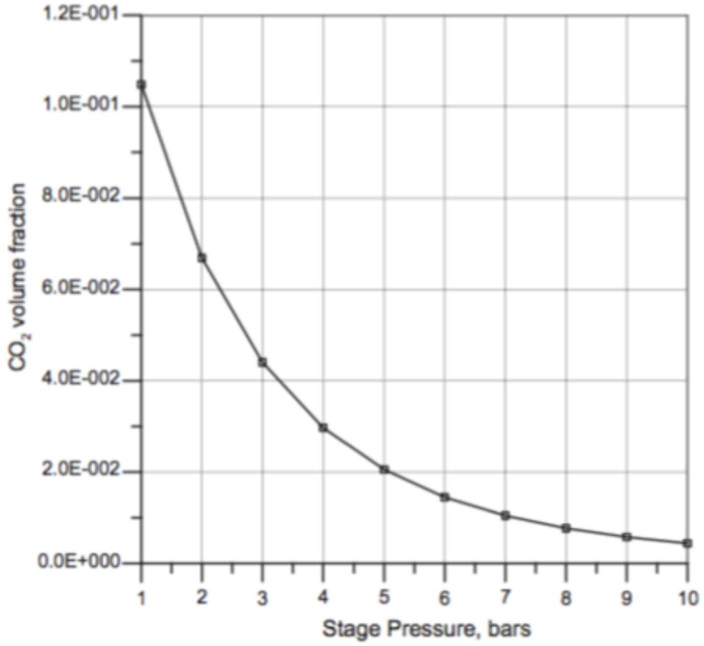


Figure 4-22: Effect of Egyptian biogas PSA working pressure on biogas final product CO_2 contents

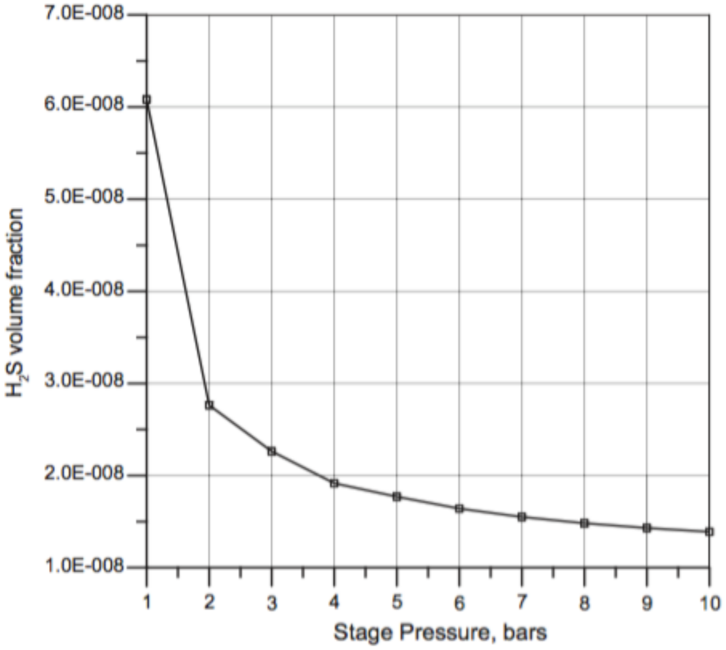


Figure 4-23: Effect of Egyptian biogas PSA working pressure biogas on final product H_2S contents

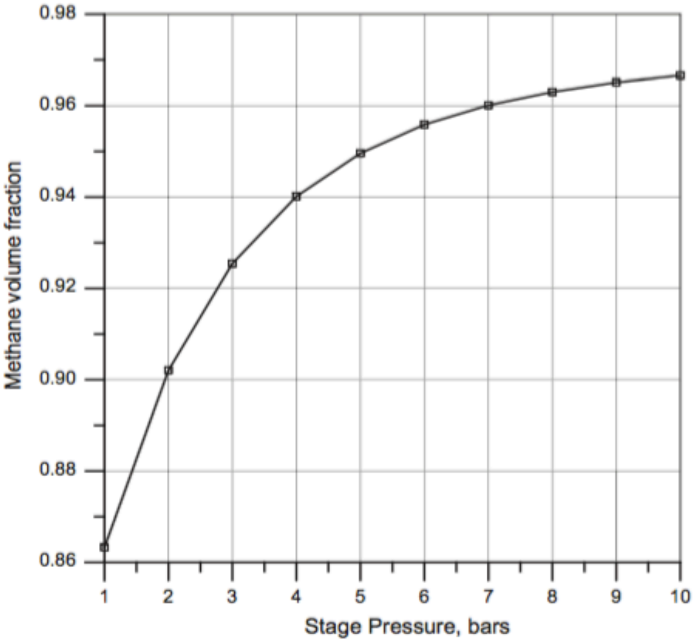


Figure 4-24: Effect of Egyptian biogas PSA working pressure biogas on final product methane purity

4.3 Impact of biogas plant in the Grid

As a distributed renewable energy, biogas power generation have many advantages including high efficiency, low investment cost, energy-saving, and high reliability. Distributed generation located close to demand delivers electricity with minimal losses. This power may therefore have a higher value than power coming from large, central conventional generators through the traditional utility transmission and distribution infrastructure. With the use of renewable distributed generation, the dependency on fossil fuels and on their price can be minimized. This step will also lead to a significant reduction of carbon dioxide emissions, which is required in several government programs. If, in addition, distributed generation and consumption in a certain area are integrated into one system, reliability of the power supply may be increased significantly, as shown in Figure 4-25.

In this paragraph we will discuss about Microgrid concept and the optimal ratio of installed capacity of biogas energy into the grid. Furthermore the potential of biogas to generate electricity flexible on demand will be investigated together the prospects of biogas transport grid and its impact to the local and global network. Finally a brief case study of district heating optimization will be analysed to be exhaustive about all the aspects.

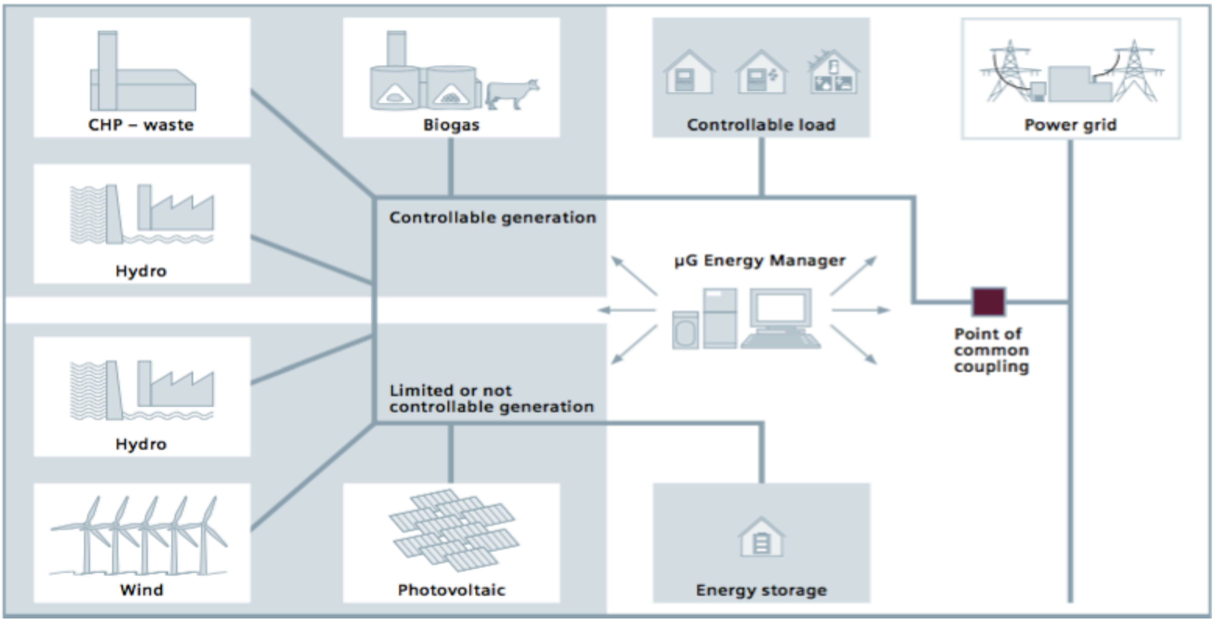


Figure 4-25: Microgrid with one common point of coupling to the utility grid [21]

4.3.1 Design of Microgrid with biogas power generation

A microgrid is a regionally limited energy system of distributed energy resources, consumers and optionally storage. It optimizes one or many of the following: Power quality and reliability, sustainability and economic benefits and it may continuously run in off-grid- or on-grid mode, as well as in dual mode by changing the grid connection status [22].

Micro-grid, which consists of distributed generations, loads, energy storage units and control devices, can make good use of renewable energy and improve the efficiency of fossil-energy utilization. It is especially important for the developing areas with relatively abundant photovoltaic and biogas power. With the application of the micro-grid, the stability-problem of renewable energy connecting to the power system can also be solved effectively [23].

In grid-connected mode, the microgrid operator can take economic decisions – such as to sell or buy energy depending on on-site generation capability, its cost, and the current prices on the energy market. In case of a utility power system outage, the point-of-common-coupling breaker will automatically open, and own generators will continue to supply power to loads within the microgrid. The idea of microgrids is not new. In the very beginning of rural electrification, several microgrid structures had been installed. Later, the economical benefits of an interconnected utility grid with large power plants led to today's power system structures.

Today, there are several industrial sites worldwide with on-site generation and islanding capability. The main reason for these constellations usually is the requirement for process optimization in a certain industrial site. For example, huge amounts of steam are required for chemical processes. In this case the process owner can decide to install its own steam turbine-based generation, which will increase power supply reliability and reduce the cost of energy. The generators in such an industrial sites usually cover exactly the demands of the site, generally to avoid possible generation and demand imbalance in case of islanding. This "classical microgrid" will be separated from the utility grid in case of a disturbance outside the microgrid, and its own generators will continue to supply the process load. The grid connection is a backup solution for the case that one or more on-site generators have to be disconnected, for example due to a fault or for maintenance purposes. The related investments can be justified through the calculation of economical losses caused by utility power system outages and energy cost reduction by the use of the steam, which is created for the chemical process anyway. Other on-site generation systems can achieve a high degree of efficiency through the application of combined heat and power (CHP) or combined cooling and heating power (CCHP) systems, if the heating and cooling can be reasonably used for own processes [24] .

A microgrid energy manager (MEM) as shown in Figure 4-25 is a monitoring and control software, which usually includes functions like SCADA (Supervisory Control and Data Acquisition), energy management, generator and load management, system reconfiguration and black start after a fault, system efficiency monitoring, carbon dioxide contribution analysis, system health monitoring and other functions. The microgrid energy manager generally has a communication link to all major generators and loads within the system. In addition, it may receive precise weather forecast data from a professional weather service for all locations of renewable power generators inside the microgrid. Merging this information with the physical characteristics of the generators, the microgrid energy manager can predict the available amount of renewable power generation for the near future. This information helps plan the utilization rate of the fossil-fueled generators within the microgrid.

In grid connected mode, distributed generators and battery systems within the microgrid will synchronize the frequency and magnitude of the voltage at the own terminals to the grid voltage and will optimize the energy supply, as required by the energy manager. Grid voltage and frequency stability is maintained by large rotating generators connected to the utility grid. In islanded mode, however, steady state and dynamic power balance between load, generation, and electrical energy storage, such as batteries, inside the micro- grid system must be achieved without any dependency on a central component or on a communication in- frastructure. This important requirement has been expressed and proven in successful research projects worldwide [25].The implementation of this feature is possible with intelligent local controllers for generators, battery systems, and load management units in a decentralized and autonomous infrastructure, for example using the classical “frequency droop control”, “voltage droop control” and “frequency dependent load control” principles.

In summary, the microgrid energy manager with its variety of functions described above helps operate a microgrid in a very efficient way, while local controllers of distributed generators, batteries and loads care

Microgrids can be considered the building blocks of a Smart Grid or an alternative path to the “super grid.” The most important feature of a microgrid is its ability to separate and isolate itself from a utility’s distribution system during power system disturbances and blackouts. This is referred to as “islanding.” [26].

Microgrids may be very different depending on market segment, size, and location. Some microgrid examples are discussed below.

4.3.1.1 Research and future perspectives

At present, some research has been done about micro-grid with photovoltaic and wind power. Some feasible control methods, protection strategies and reliability analysises have been proposed. However, there are few papers discussing about the micro-grid with biomass power. However, some issues about the development of biomass power have been studied. The evaluation indexes of the benefits from large biogas power generation has been analyzed in [27]. but the relation between the benefits and the installed capacity has not been considered.

Reference [28] introduces the gas production of different biogas raw materials and discusses the feasibility of generating waste heat utilization. But detailed description of the program has not been done. The status, problems and solutions of wind and biomass power has been presented in [29], but the strategies of maximizing benefits has not been discussed.

Structures and mathematical models of micro-grid were introduced in [30]. Then multi-complementary micro-grid operation strategy was analyzed. After that, the optimal ratio of the installed capacity of renewable energy in micro-grid has been presented when the cost and energy consumption are considered. An example is used to prove the feasibility of the proposed design method. At last, an example is used to prove the feasibility of the proposed design method.

[30] discusses the construction scheme of multiple complementary energy micro-grid with photovoltaic power generation and biogas power generation. The simulation results prove that it can improve the stability of the system, and reduce the operation and maintenance costs. In the simulation test, it was used the proposed planning method to solve the problem of environmental pollution resulting from burning of crop straw and livestock industry. The proposed method can also improve the stability and the economy of the micro network system. Figure 4-26 shows atypical micro-grid structure in the rural areas of China, where PCC is the common bus-line. The micro-grid is

connected with the power grid through a switch. The micro-grid contains photovoltaic power generation array, micro gas turbine cogeneration and energy storage device. With the application of micro gas turbines, the waste heat can be used for heating and hot water supply, which will improve the efficiency of fossil energy and the economy of the system.

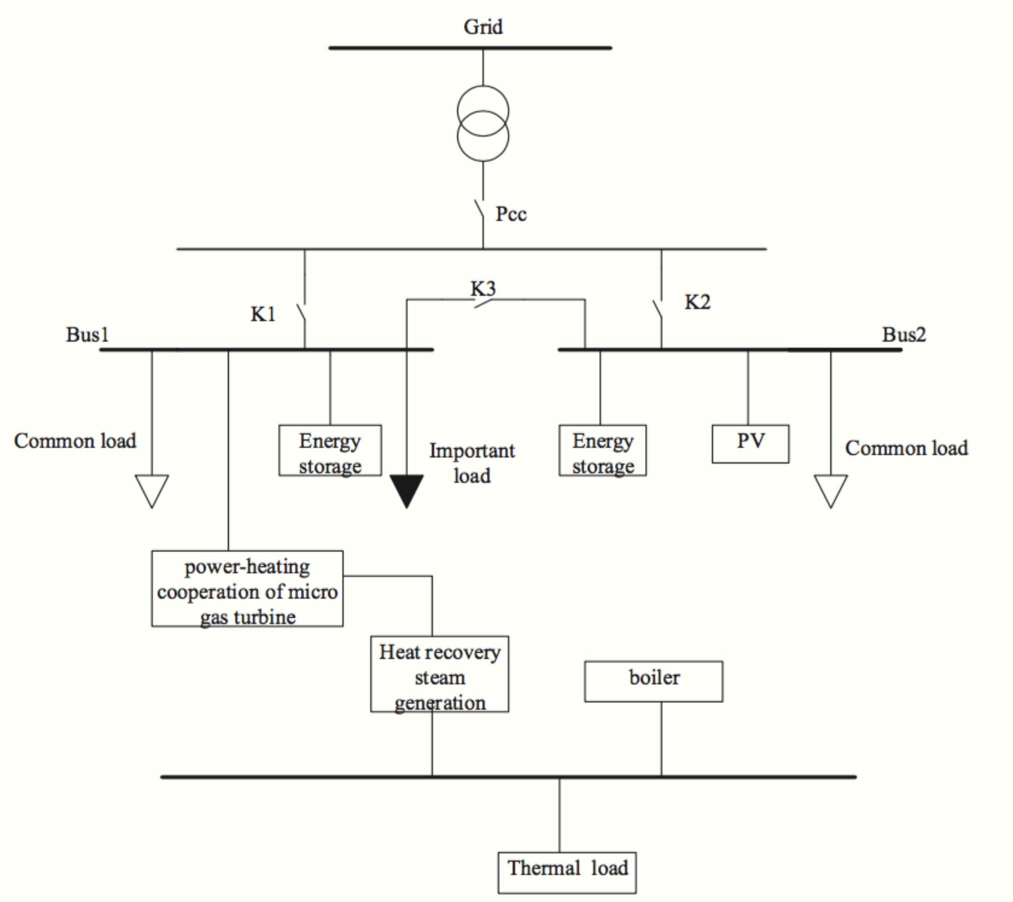


Figure 4-26: Micro grid structure used in [30]

4.3.1.2 Expected microgrid features

Microgrid components such as renewable or fossil-fueled generators, point-of-common-coupling breaker and its control, loads, energy storage systems, and others must meet several requirements to enable seam- less operation. Appropriate microgrid standards will be laid down, others will be revised. To support these activities, Lawrence Berkeley National Laboratory has identified some important top-level microgrid features [31] that should be considered in all research, development, prototyping, and standardization projects:

- **Autonomy**: Microgrids include generation, storage, and loads, and can operate autonomously in grid-connected and islanded mode. In the first case, a microgrid can independently optimize its own power production and consumption under the consideration of system economics such as buy or sell decisions. In both operation modes, the system can minimize CO2 emissions by maximizing renewable energy consumption and minimizing fossil-based generation. In islanded mode the system is capable of balancing generation and load and can keep system voltage and frequency in defined limits with adequate controls.

- **Stability**: Independent local control of generators, batteries, and loads of microgrids are based on fre- quency droops and voltage levels at the terminal of each device. This means that a microgrid can operate in a stable manner during nominal operating conditions and during transient events, no matter whether the larger grid is up or down. (Additional research is required, however, to achieve a high level of stability, for example to eliminate unnecessary reactive power exchange between rotating or inverter-based generators.)

- **Compatibility**: Microgrids are completely compatible with the existing utility grid. They may be considered as functional units that support the growth of the existing system in an economical and environmentally friendly way.

- **Flexibility**: The expansion and growth rate of microgrids does not need to follow any precise forecasts. The lead times of corresponding components (fossil-fueled and renewable generators, storage systems, and others) are short, and a microgrid can grow incrementally. Microgrids are also technology-neutral and able to cope with a diverse mixture of renewable and fossil-fueled generators.

- **Scalability**: Microgrids can simply grow through the additional installation of generators, storage, and loads. Such an extension usually requires an incremental new planning of the microgrid and can be per- formed in a parallel and modular manner in order to scale up to higher power production and consump- tion levels.

- Efficiency: Centralized as well as distributed microgrid supervisory controller structures can optimize the utilization of generators, manage charging and discharging energy storage units, and manage consump- tion. In this way energy management goals can be profoundly optimized, for example in economic as well as environmental respects.

- Economics: According to market research studies, economics of heat recovery and its application by CHP systems is very important to the evaluation of microgrids. In addition, the utilization of renewable energy resources will help reduce fuel costs and CO2 emissions.

- Peer-to-peer model: Microgrids can support a true peer-to-peer model for operation, control, and energy trade. In addition, interactive energy transactions with the centralized utility grid are also possible with this model. The proposed concept does not dictate the size, scale, and number of peers and the growth rate of the microgrid.

4.3.1.3 Microgrid Examples

4.3.1.3.1 Institutional/campus microgrid

Figure 4-27 shows an institutional/campus microgrid, which is continuously operated in island mode. Connection to the utility grid is a backup option. The biogas and CHP units are necessary for continuous energy supply, and also for heat for cold winter days. However, fluctuating energy of renewable resources like wind and solar systems can be stored, for example with an electrolysis system. This stored energy can then be used with the application of a fuel cell.

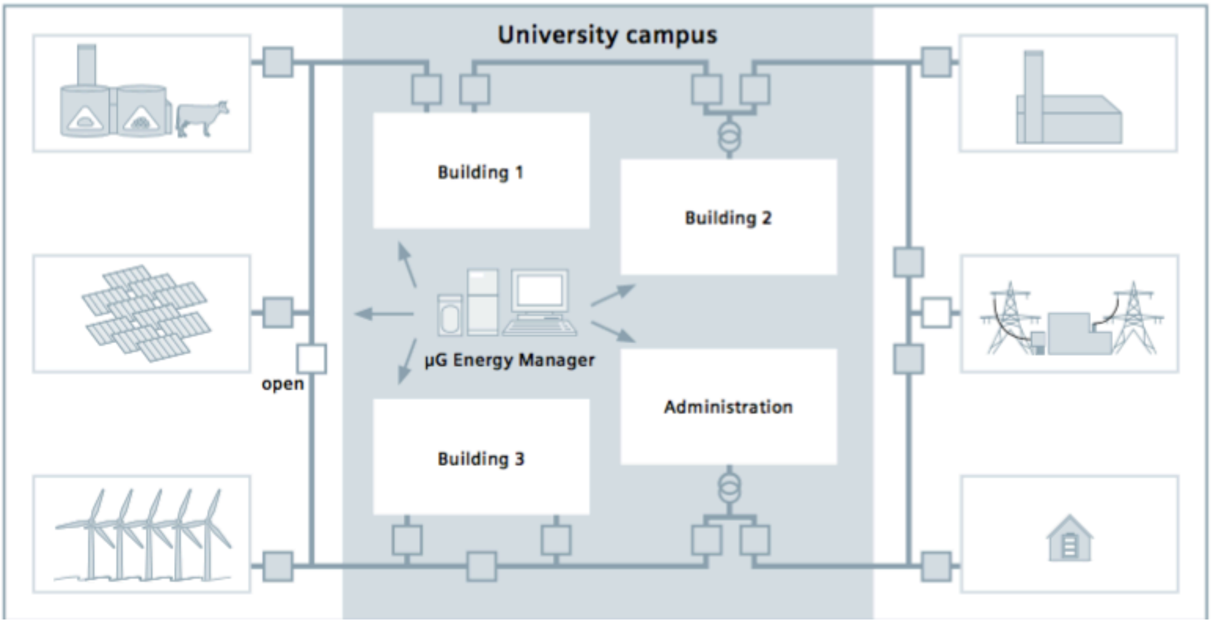


Figure 4-27 : Institutional/campus microgrid [21]

4.3.1.3.2 Industrial microgrid

Main reasons for the installation of an industrial microgrid are power supply security and its reliability. There are many manufacturing processes in which an interruption of the power supply may cause high revenue losses and long start-up times. Typical examples are chip manufacturing, the chemical industry, and the paper and foodstuff industries, for instance. Today, some industrial sites are installing uninterruptable power supplies if their utilization is economically justified. Microgrid structures may bring additional advantages, for example the combination of secure power supply with high energy efficiency and the utilization of renewable generation. A possible layout is represented in Figure 4-28.

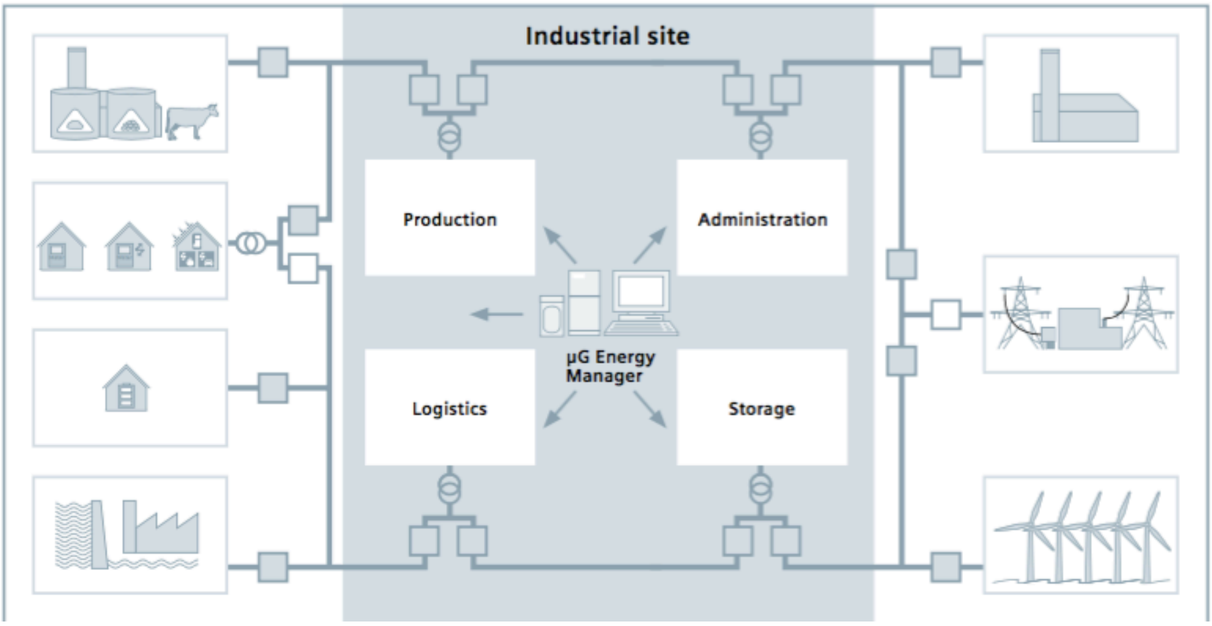


Figure 4-28: Industrial Microgrid [21]

4.3.1.3.3 Off-grid and Island microgrid

An “off-grid” microgrid as shown in Figure 4-29 usually built in areas that are far distant from any trans- mission and distribution infrastructure and, therefore, have no connection to the utility grid. Due to this, such a microgrid must have black start capability that is is the process of restoring an electric power station or a part of an electric grid to operation without relying on the external transmission network [32]. To provide a black start, some power stations have small diesel generators, normally called the black start diesel generator (BSDG), which can be used to start larger generators (of several megawatts capacity), which in turn can be used to start the main power station generators. Generating plants using steam turbines require station service power of up to 10% of their capacity for boiler feedwater pumps, boiler forced-draft combustion air blowers, and for fuel preparation. It is uneconomical to provide such a large standby capacity at each station, so black-start power must be provided over designated tie lines from another station. Often hydroelectric power plants are designated as the black-start sources to restore network interconnections. A hydroelectric station needs very little initial power to start (just enough to open the intake gates and provide excitation current to the generator field coils), and can put a large block of power on line very quickly to allow start-up of fossil-fueled or nuclear stations. Certain types of combustion turbine can be configured for black start, providing another option in places without suitable hydroelectric plants [33].

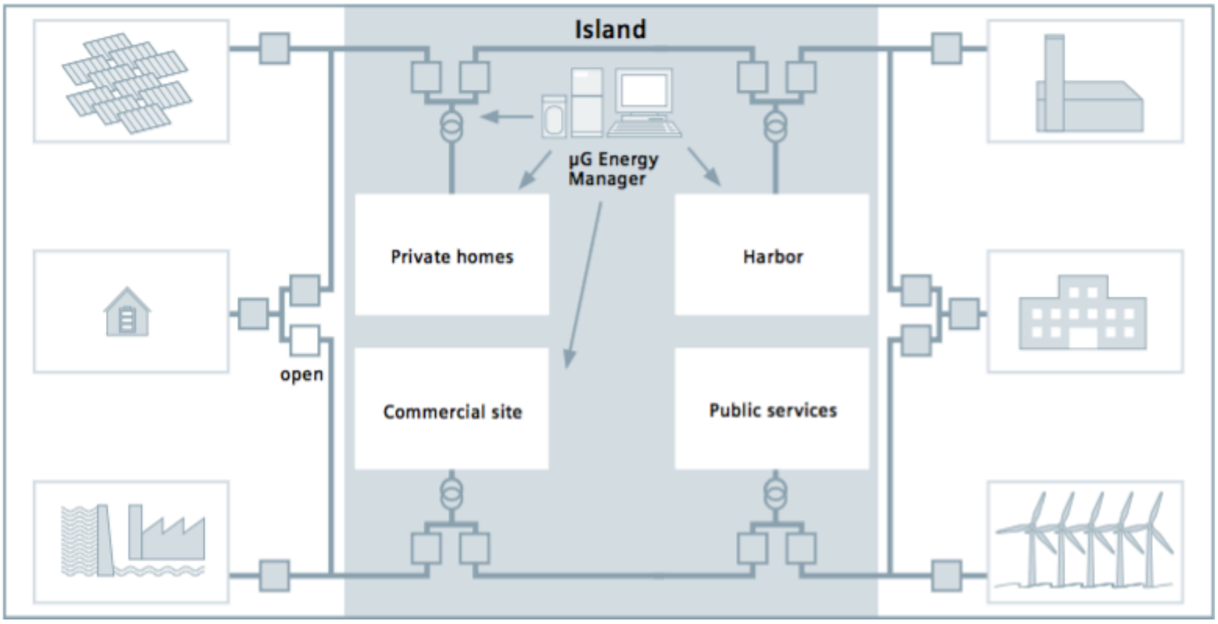


Figure 4-29: "Off-grid" microgrid [21]

4.3.1.3.4 Utility Microgrid

A utility microgrid may include a distribution feeder, a complete medium voltage distribution substation (Figure 4-30) or even several distribution substations in a large area. In the latter case, the energy flow from various generators within the microgrid to the loads and the energy exchange between different segments may become difficult to handle. Thus, the microgrid operation may require the installation of a distribution SCADA and a distribution management system (DMS), including distribution state estimation and power flow calculation. Additional operation, control, and automation systems such as an outage management system (OMS) and distribution substation and feeder automation may be required to keep the outage time short in case of a disturbance within the microgrid.

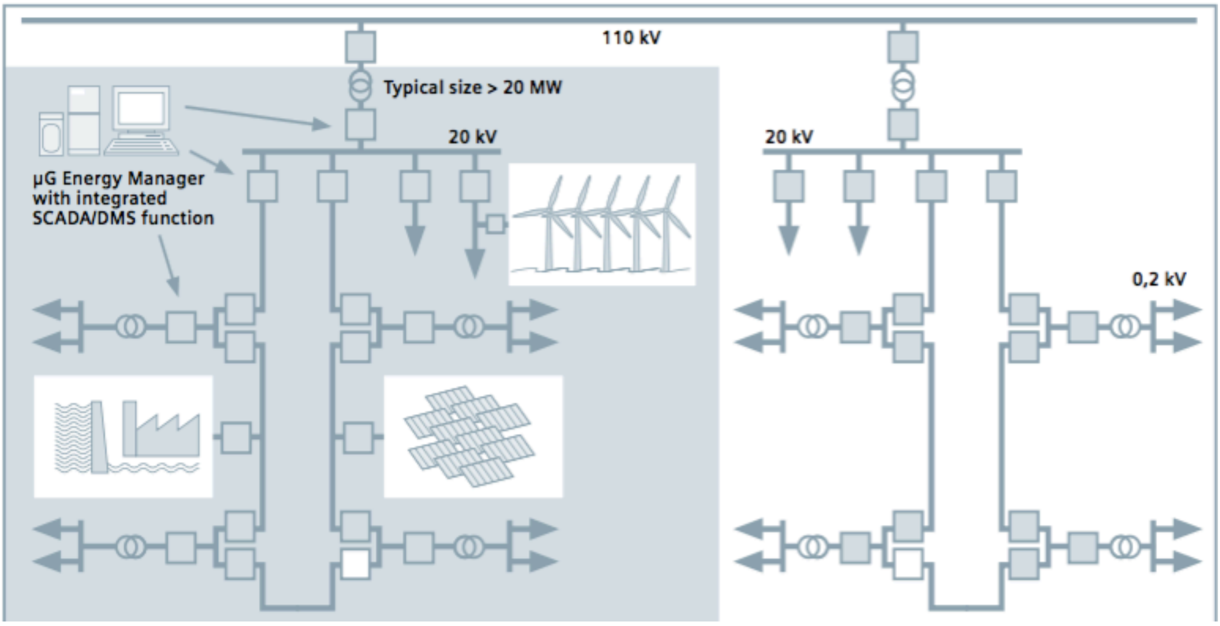


Figure 4-30: Utility Microgrid [21].

5 DATA COLLECTION

A data collection of some biogas producers in Emilia Romagna was conducted in March and April 2016. The farms and dairy producers visited are mainly situated within Reggio Emilia, Modena and Piacenza countryside. Ten biogas plants were investigated and depositions were released by operators, owners and farmers working into biogas plants. In some cases entire layout schemes and important figures were available.

5.1 Collaboration: the key to energy production

Why the collaboration and symbiosis between two figures in a production chain is very important, is explained by a experienced technician like D.M., worker in the biogas power plant close to the dairy farm: “Società Agricola Codeluppi” located in Campegine, a small town in Reggio Emilia province (Figure 5-1). The biogas power plant and the dairy farm are physically separated and independent entities but actually there is a strict collaboration from which energy production, and manure disposal and energy savings depend on.

Manure waste obtained from the livestock industries are one of the main organic waste which will be hazardous to environment if they are not managed suitably. Animal manure contains a high concentration of nitrogen (N) and phosphorus (P), which causes nutrient imbalance and pollution in environment. Furthermore, the livestock manure contains the residues of some harmful substances such as growth hormone, antibiotics and heavy metals. On the other hand, microorganisms in the animal manure could contaminate the environment, which in turn causes the outbreak of the human diseases. In this regard, it has been found that the disposal of the livestock manure has a polluting impact on the environment which contaminates air, soil and water sources. Hence, the treatment of animal manure and slurries by AD (Anaerobic Digestion) process has the beneficial outcomes of producing quality fertilizer, reduction of odours and microbial pathogens with the sustainable production of energy source as biogas converted in electrical energy and heat [34].

The biogas Power plant has a capacity of 250 kW and produces electrical energy by using just cattle and pig manure received by nearby farm that sells all the animal waste and during the hottest month like June, July and August maize flour is added as well together the substrate to feed the digester. This is due to the fact during the summer the feed-in manure comes from the farm almost fermented, therefore the “nutrition supply schedule” of digester includes also maize flour that is the same of cattle and pigs food. Around 1000 kilograms per day during the period od 2-3 months is added to substrate to favour the methanogenesis inside the digester and the important thing to delight is that it does not have to contain aflatoxines otherwise they would contaminate the digestate after AD and it could pollute the soil and the animal food as consequence, affecting permanently all the closed production chain.

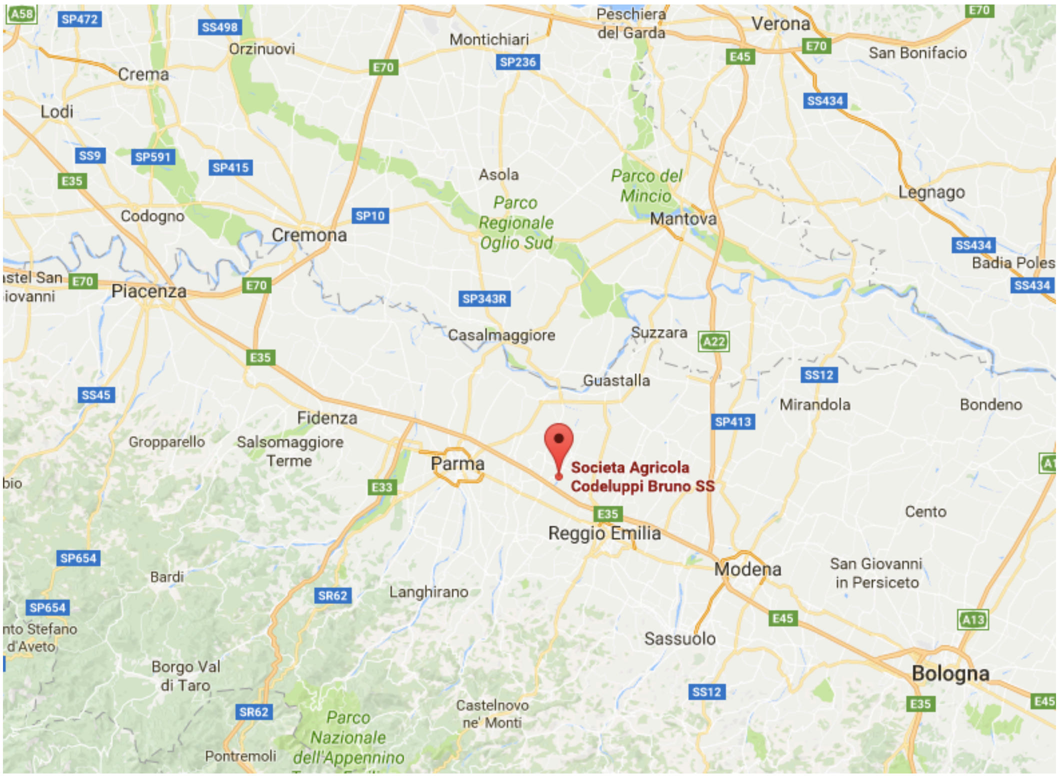


Figure 5-1: Geographical position of "Società Agricola Codeluppi" (Source: Google Maps)

"Società Agricola Codeluppi" owns 3200 head of cattle and around 5000-6000 pigs and by selling manure it earns 55000 – 58000 € per year, total 70000 € including maize flour supply to biogas plant and the transportation cost are on its own. The farm produces milk for the Parmigiano Reggiano production chain (FARE UN PARAGRAFO SULLA PRODUZIONE DI PARMIGIANO REGGIANO E LE SUE PECULIARITA) and it owns a photovoltaic plant but unfortunately it was not allowed to find information and details about it.

The total investment cost of Biogas Power plant was about 2 M€ and the payback time provision of 6 years was respected as we can see from Table 5-1. It was built 3 years ago (2013) and the layout is made of two digesters that are also gas holder and a final tank for digestate connected in series together in order to recover a small part of biogas. The CHP unit is a MAN 6 cylinder 150 kW and it runs 1500 rpm at maximum power. The two digester are equipped with grid that facilitate O_2 insufflation to reduce H_2S. Last year (2015) they experienced the grid damage into a digester due to the scaling process on the grid itself and this caused extraordinary stop of the plant and loss of energy production and income.

Another reason of frequent energy production interruptions is attributable to weather. The technician of the plant illustrated the possibility of "stop and go" during low pressure day particularly during storms. Indeed the pressure sensor inside the digester reads the outside pressure difference, therefore if the atmospheric pressure (1 bar) decreases a lot the sensor measures a sort of overpressure inside the digester and stops automatically the engine and the biogas plant is turned off. Basically it is a sort of self protection mechanism that put in place countermeasures to avoid further damages but in reality there is no kind of real problem in this case: the pressure inside the tanks is always the same but the sensor does not know it.

The two digester works in mesophilic condition around 40-42 °C and thermal power recovered by CHP is used to maintain the temperature constant inside the tanks for the correct methanogenesis process in order to maximize biogas yield. Close to the engine, into the container block showed in Figure 5-2, there is an heat exchanger with re-circulation valves where cogeneration is exploited: water exits the engine at 70-80 °C and it is mixed with outlet water comes from digester at 40-50°C and it reaches 60 °C end then it enters the tanks where biogas formation occurs.

Due to the origin of substrate the methane content into the biogas is not so high as other plants using maize or agro energetic cultivations. The plant reaches peaks of 56-57% but on average it is around 52 %. It varies along the days and along the seasons, totally dependent on the nutritional feed in schedule program set on a laptop daily. The technician decides and set how much volume flow rate of various substrates are to be inject. At the moment of the visit in the plant, it was set the following "diet":

- 26.8 m^3/day of pig manure (more liquid)
- 32 tonns/day of cattle manure
- 45 tonns/day of cattle sewage diluted with the pig manure to compact it

Make the correct "BioMix", the so called mixture of substrates that is fed into the digester, according D.M. is the most critical part of the entire biogas formation process. The manure is always different, with day by day various features dependent on weather, umidity, content and so on. The mixture is loaded into a plug screw rotating inside a stator therefore the risk of clogging is very high. Find the correct proportion of the substrates in order to have the appropriate mixture is not easy and just the experience can avoid clogging and damages to the rotor. For this reason a technician must be always present during manure injection and feed in phases and he has the task to control and regulate the power of engine of the screw and the mass flow rate of substrate. The electrical power of engine for such feed in process is obviously to be considered as energy self consumption, that in this plan is about 18-21% of the electrical energy produced.

Table 5-1: Technical and Economical Details of Biogas Power Plant in Campegine (RE)

Substrate Feed-in Typology	Animal manure (cattle, pig) and maize flour (summer)
Head of cattle quantity	3200 + 5000 pigs
CHP Power [kW_{el}]	1 x 250 kW
Self-consumption [%]	18-21
Thermal Power [kW_{th}]	n.a.
Thermal Power Usage	Mesophilic Temperature Digester and offices
Digester Number	2
Post Digester Number	1
$FeCl_2$/$FeCl_3$ supply	yes
Chiller	no
Activated Carbon	yes
Total Investment cost	2 M€
Incentives	0,28 €/kWh
Operating Cost [€/year]	70000 €
Insurance Cost [€/year]	7000 €
Estimated Payback Time	5-6 years
Respected Payback Time	yes
Ordinary Maintenance Cost [€/year]	30000 €
CH_4 Biogas Yield [%]	54-57 %
Annual operating hours [h /year]	8300
Total Energy Produced [kW / year]	

Figure 5-2: A view of two main digester, flare and CHP unit into "Azienda Agricola Codeluppi", situated in Campegine (RE).

5.2 The Cooperative: a way to produce biogas

“Valtrebbia Energia” is a farming cooperative that acts in the territory of Piacenza and built 1MW Biogas Power Plant in 2011 close to Quarto Gossolengo (PC), in the countryside of Emilia Romagna, between Piacenza and Fidenza (see Figure 5-3). Respect with other biogas plants in Italy, its main feature is to split the biogas formation processes, we can appreciate from the layout shown in Figure 5-5 that there is a starting tank where hydrolysis chemical process occurs. Therefore the entire digester line is a little bit longer and more complex compared other analysed plants.

In the first reactor where hydrolysis starts, we have very acidic environment: the substrate is attacked by bacteria and when the tank is full a vent permit the expulsion of acid gas, then the substrate is sent to digester line and it is already degradable and it continues the methanogenesis process, already started previously. The digesters are connected in series and the substrate can be fed into each one in a independent way by a pipe as we can see in Figure 5-5. For example at the time of the visit 8.5 m^3/h of substrate was injected into first digester, 7.5 m^3/h into second one and 2 m^3/h into the last one. Being connected the surplus of biogas enters the second digester and so on, basically it is as a unique tank divided by 3. At the end after the three digester there is a post digester, that is not directly fed with substrate but some biogas is produced during this phase as well.

Apparently we could think that the plant is too complex (see planimetry in Figure 5-7) , difficult to manage and with a too complex operating process but in reality accordingly granted opinion of the cooperative member, the plant is not so hard to run and just a know-how learning starting time is needed. As a matter of fact they experienced a problem during the start-up period due to inexperience: the produced biogas in the hydrolysis process resulted too acidic with a CH_4 percentage too low and the engine were not performing in the right way. In fact when the plant experiences rapid oscillations of methane value the engine runs unstably. They realized that the correct methane percentage should be 60-64% and this was found after first year of operations.

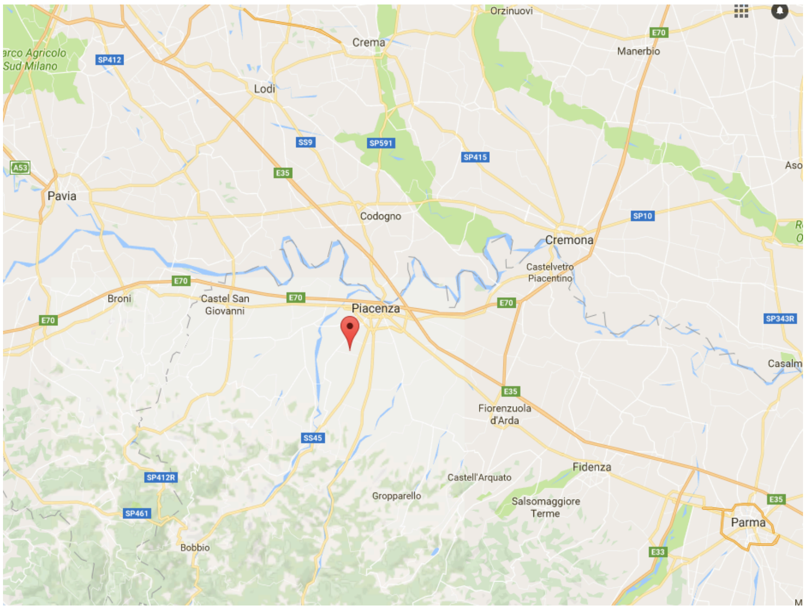


Figure 5-3: Geographical position of the Biogas Power plant owned by “Valtrebbia Energia” (Source: Google Maps)

Figure 5-4: A view from satellite of “Valtrebbia Energia” Biogas Plant. We can see clearly the line digester, the storage area of crop and the three CHP units. (Source: Google Earth).

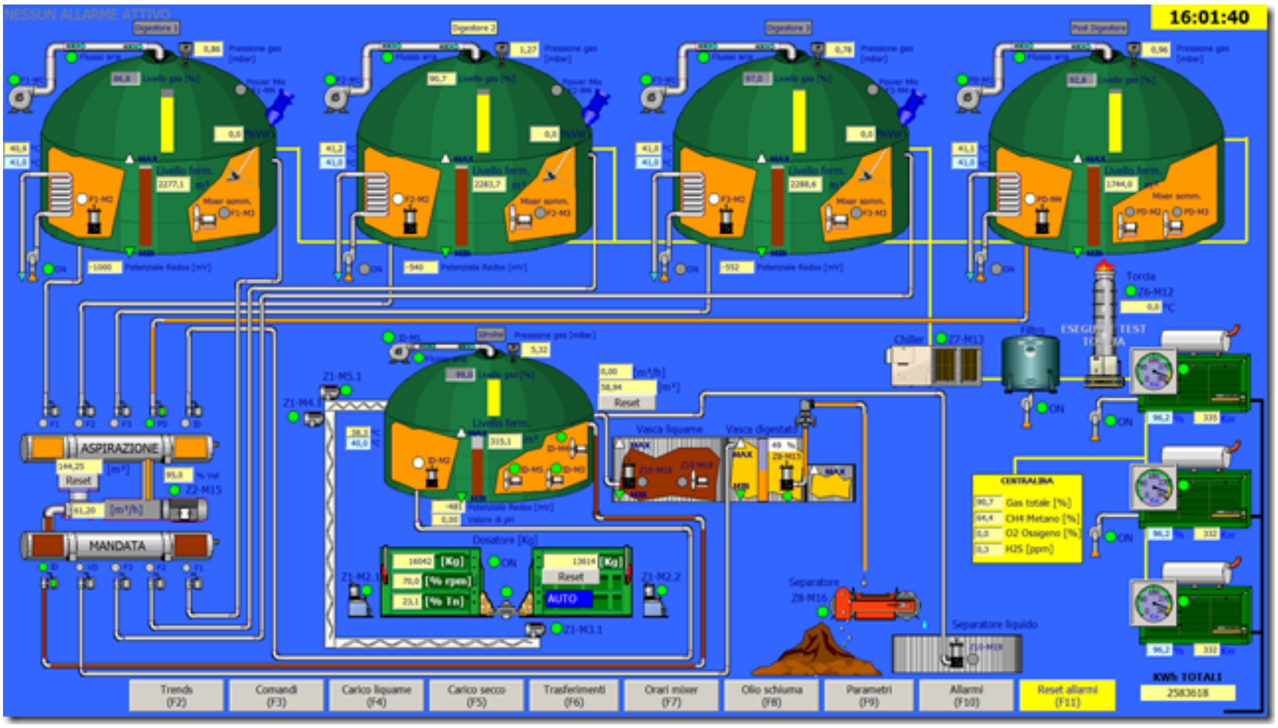


Figure 5-5: “Valtrebbia Energia” Biogas Plant Layout (Source: Valtrebbia Energia)

But the real characteristic of the plant is its management and cooperative members economic benefit. The cooperative is made of four business partners own respectively four farms which all the final product (substrate to feed into the plant) flows into the same point: the biogas plant. They produce two kinds of substrate: shredded corn and triticale that mix to obtain the correct substrate to be fed into the digester line. Firstly they adopt the 70:30 proportional ratio of corn/triticale, then they gradually decrease triticale share up to stocks end. Shredded corn has the maximum biogas yield because grain is larger compared as triticale one even they experienced a triticale high quality. At the beginning of the business activity they obtained a very humid green shredded corn and erroneously someone suggested them to do not worry about the colour or humid content by stating that in Germany there was no difference. Obviously the content of humidity of substrate strongly affect the methane percentage and biogas yield therefore the farms owners decided to change strategy. On average the percentage of methane is about 60-65 % with peaks of 70%.

The plant has three MAN CHP units (Figure 5-8) , each 333 kW; it was decided to adopt this configuration rejecting the 1 MW one engine solution or two 500 kW engines solution to avoid stop of production and have backup engines in order to prevent biogas burning with flare shown in Figure 5-6. The flare is never used and a remote control grants always the correct feed-in diet in order to avoid to waste surplus biogas and burn it. The engines produce both electrical energy and heat recovered only to maintain constant temperature inside the digester since there was no possibility to connect to DH (District Heating). The Figure 5-5 clearly shows the heating coils inside each reactor and the respective pump the sucks hot water from engine rooms (the green containers depicted in Figure 5-9. Water leaves the engines at 88°C and enters the digesters about at 41-42°C (mesophilic temperature).

Figure 5-6: Flare located into "Valtrebbia Energia" Biogas Plant. On background substrate storage tank can be appreciated.

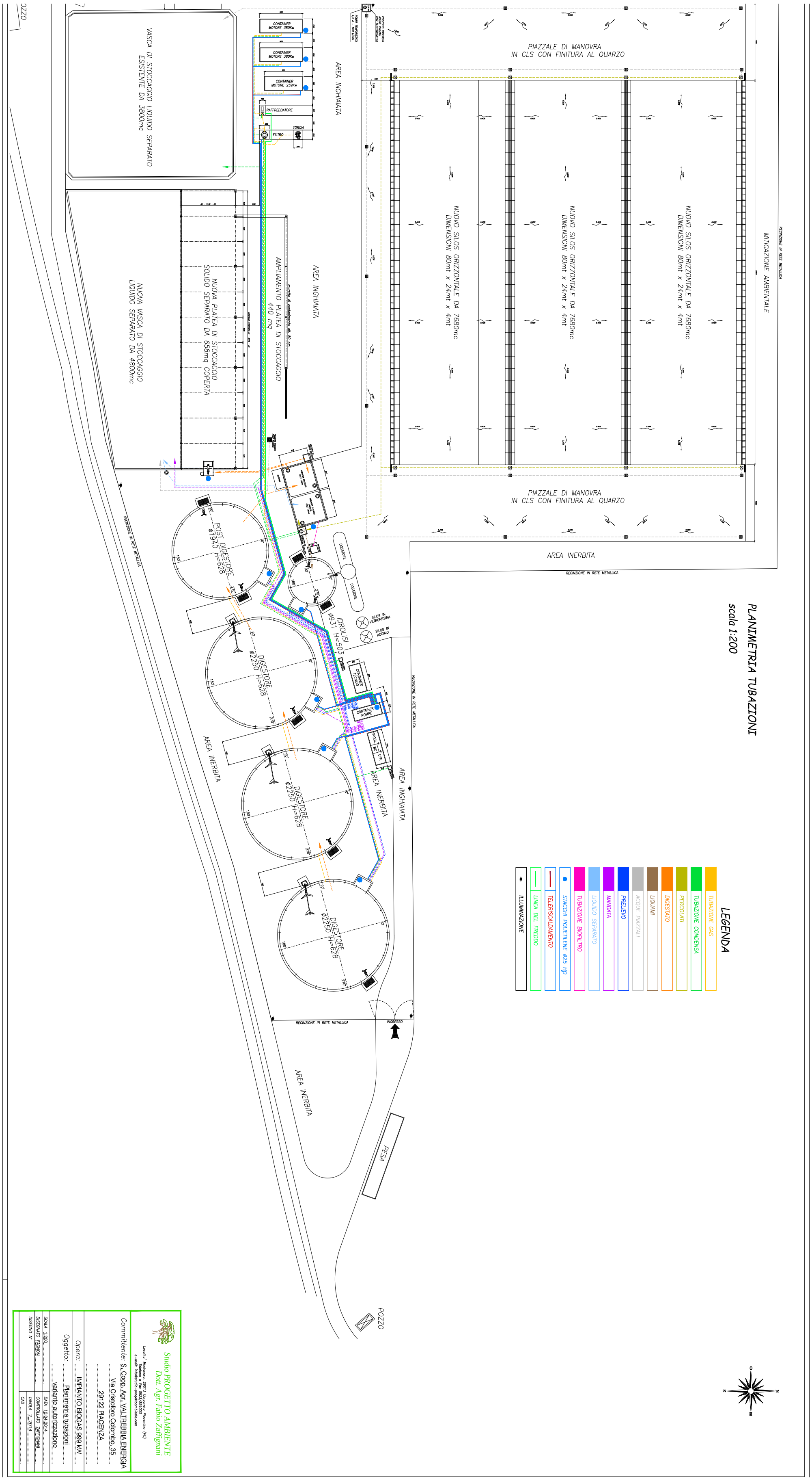


Figure 5-7: Planimetry of "Valtrebbia Enrergia" Biogas plant (Source: Valtrebbia Energia)

Figure 5-8: A view of Engine MAN 333 kW in “Valtrebbia Energia” Biogas Plant

Figure 5-9: Three 333kW MAN engines inside containers explosion proof

The plant injects all the produced electrical energy into the grid except the 8% of self consumption. There was a 10% of missed production (2% more) due to lack of experience at the beginning of the biogas plant operation because of clogging due to foam and lather but after the usual know-how learning time no problem occurred. They experienced also problem with water-inlet-into-digesters pumps togheter with normal operation of oil and seal cylinder head change operations therefore the plant is forced to stop the production and there is no income due to missing production.

Firstly the project of the plant was German company LUTE's but after its bankruptcy the plant was completed by MONTAGGI SPECIALI Srl and due to this inconvenience the total investment cost skipped from 4.5 M€ to 4.7 M€. Maintenance servize is managed by ELETTROAGEL and the business investors decided to sign the contract only for engines insurance (60000 €/ year) and not for the whole plant due to much expanses. The "by 24h service contract " provides an instant maintenance service in one day otherwise the missed energy production that was lost would be refunded. More economical datas are listed in Table 5-2.

The four business partners autonomously produce crop to be sent into the biogas plant and their profit comes from the auto selling of substrate at a higher price respect with market price. If they sold corn and triticale into the market they would be paid less (2.8-2.9 € / 100 Kgs for shredded corn)so the prefer sell to themselves at higher price (5.5 €/100 Kgs) in order to maximize incomes and achieve the estimated payback time.

Table 5-2: Technical and Economical details of "Valtrebbia Energia" biogas plant, Quarto Gosslengo (PC)

Substrate Feed-in Typology	**Shredded Corn, Shredded Triticale and some Animal Waste Manure**
Head of cattle quantity	-
CHP Power [kW_{el}]	3 x 333 kW
Self-consumption [%]	8-10%
Thermal Power [kW_{th}]	n.a.
Thermal Power Usage	Constant temperature digesters
Digester Number	3
Post Digester Number	1
$FeCl_2$/$FeCl_3$ supply	no
Chiller	yes
Activated Carbon	yes
Total Investment cost	4.7 M€
Incentives	0.28 €/kWh
Operating Cost [€/year]	65000 €/year
Insurance Cost [€/year]	n.a.
Estimated Payback Time	7 years
Respected Payback Time	yes
Ordinary Maintenance Cost [€/year]	60000 €/year (engines maintenance set)
CH_4 Biogas Yield [%]	64-67%

Annual operating hours [h /year]	8060 hrs
Total Energy Produced [TWh / year]	8 TWh/year
Substrate supply [Kg / day]	52000 Kg/day
Biogas production [m^3/h]	160 m^3/h

After the digester chain and the post digester the plant includes a separator (Cri-Man) that divide dry and liquid part. The liquid part is loaded in a storage basin and part of this is reintroduced in the biogas production chain in order to dilute the substrate. The dry part of digestate is loaded on a caterpillar tractor and spread all over the fields while the liquid part fills a tanker truck and spread as well. The digestate is reused as fertilizer and it was noticed to be an excellent one and one farmer even stopped to use common fertilizers avoiding to introduce chemical compounds. They built another storage basin as safety reserve in case of separator damage. Also some liquid cattle manure is added to corn and triticale substrate to enhance bacteria load and homogenize the feed in load but we are talking about small quantities (8.5 m^3/day) that are almost negligible. This animal waste comes from nearby farm totally free because it does not own storage basins for manure so it is more convenient "to donate" their by-product rather then dispose of it. The cooperative members wanted to add to the "feed-in diet" of digester tomato skin as well because the area surrounding the facilities is full of tomato production companies but ARPA did not approved such decision because of the priority usage as animal food. Anyway they think it was better do not use them because of their high humidity content and low methane yield.

Before approaching the engines, biogas is pre-treated by a chiller (see Figure 5-10) lowers down the temperature until 5.5 °C in order to decrease humidity content and facilitate the carburation and passes by an activated carbon filter (shown in Figure 5-11) which is heated by engines outlet hot water. Accordingly plant operators the choice to adopt such expansive configuration is legitimized by the longer engines life since H_2S content falls down dramatically and its corrosive power as well. The Chiller does not need any maintenance but AC filter (activated carbon) requires to be changed every 1.5 year at a price of around 5000 € and to be sent to Caorso for the disposal at a price of 1000 €. Further more they introduce a little bit of O_2 into the digesters by small compressors but they are evaluating to shut them down to decrease self consumption.

Figure 5-10: Chiller pretreats biogas before approaching engines in order to decrease H_2O content

Figure 5-11 : Activated Carbon Filter used as pre-treatment process in order to decrease H_2S biogas content

5.3 Biogas plant in Gazzata (RE): A perfect example of simplicity

If previously described plant is synonym of complexity, the biogas plant in Gazzata, a small town located between Reggio Emilia and Modena (Figure 5-12), represent outstanding simplicity and essentiality. “Kinexia” company ended the works in December 2012 and the plant started to produce electrical energy on January 2013 by operating with only one digester since the plant had to be put into operation to be registered with 0.28 €/kWh incentives. Kinexia is a listed company located in Milan and it owns also other plants in Italy: PV plants and wind farms in Aprila (Roma), Pavia etc…

As we can appreciate in Figure 5-13 the layout is extremely simple and essential: two digesters connected to respective digestate tanks and one CHP unit with a rated power of 999 kW producing electrical energy to inject into distribution network and cogenerating heat by exploiting the district heating and providing hot water to the nearby households. Even though DH connection, dwellings close to the facility are not so many and part of the heat has to be dissipated by radiator situated next to CHP unit.

The plant is fed by “food” cultivations like maize, sorghum and triticale and plant operators do not need to look for and purchase crops because a third party does it. It is unique and it has the tasks to harvest, to shred it and the delivery to the plant. At the moment of the visit (March 2016) it was fed just by maize but around April also triticale harvest would have be started. They cannot use stalks and dehydrated pulps because municipal authorization was not allowed but maize four usage is under evaluation since they have founded a very economical supplier, probably due to aflatoxines presence and the impossibility to be sold in Emilia Romagna region as animal food because of ARPA control for Parmigiano Reggiano production chain quality. Further more they will create a proper “digester diet” by exploiting the fields rotation and the seson dependence.

Figure 5-12: Geographical position of “Kinexia” Biogas plant located in Gazzata (RE) (Source: Google Maps)

About biogas yield when they feed the digester only by maize (around 50 tons /day) obviously they experience the maximum yield and the biogas production is about 500 m^3/h and the plant produces more or less 22-23 MWh/day. Self-consumption is around 9-10% and it is a little bit higher respect with other plants because they inject into the reactors dry mixture then the energy consumption is higher because mixers and stirrers have to work more to homogenize the substrate. There are three moveable stirrers of 11 kW each controlled by a CPU set by an operator and they works every 20 minutes (20 minutes work then 20 minutes stop and so on). Then there is a bigger central mixer of 17 kW has the task to turn over the denser bottom layer. It works at the same time of loading system: as the substrate is fed into the digester it starts to rotate for at least 45-60 minutes and this occurs every 2 hours because they inject the "digester food" 12 times per day.

As previously said engine cogenerates electricity and heat recovered for digester heating and DH but the plant has also a boiler able to supply hot water by exploiting hot exhausted gases from engines. The boiler was built because greenhouse construction was considered during the biogas plant planning phase and further heat provision was expected therefore now the plant has a surplus of heat that has to be dissipated by fans (energy consumption) and the boiler never works.

To abate H_2S oxygen is injected inside and then there are two AC (Activated carbon) filters with bypass pipe in case of filter change because during the maintenance just one filter may cause engine under-pressure and the CHP units could stop. Before filters, H_2S content is around 262 ppm and after around 75 ppm, the filters are changed every year. Other than AC filter a chiller is used to decrease humidity content as well. CH_4 percentage is on average 51% but at the moment of the visit the measurement was 48% due to maintenance operations: they had just substitute the agitator and the digester was opened so O_2 content was slightly increased by causing a fermentation degradation (since it needs anaerobic condition) and the engines run at very low speed: 600 rpm.

Figure 5-13: A Satellite view of the biogas plant on Gazzata (RE). It is immediate to understand layout simplicity with only two digesters and respective digester tanks. No separator and no post digester are present. (Source: Google Earth)

As we can see in Table 5-3 the total investment cost was 4 M€ and it has been working since 24000 hours. It produces electrical energy more or less 7000 hours/year. Oil check takes place every 500 hours carried out by an operator but no particular problems along the plant life occurred, just ordinary head cylinder, gaskets, mixer, sparks inspection after 17000 hours. They do their best to merge more inspections and maintenance operations to optimize and to avoid lost production.

Figure 5-14: A view of the storage area where shredded crops are clumped.

Table 5-3: Technical and Economical details of "Kinexia" biogas plant, Gazzata (RE)

Substrate Feed-in Typology	**Shredded maize, triticale and sorghum**
Head of cattle quantity	-
CHP Power [kW_{el}]	1 x 999 kW_{el}
Self-consumption [%]	9-10%
Thermal Power [kW_{th}]	-
Thermal Power Usage	DH, digester temperature
Digester Number	2
Post Digester Number	-
$FeCl_2$/$FeCl_3$ supply	no
Chiller	yes
Activated Carbon	yes
Total Investment cost	4 M€
Incentives	0.28 €/kWh
Operating Cost [€/year]	n.a.
Insurance Cost [€/year]	n.a.

Estimated Payback Time	n.a.
Respected Payback Time	n.a.
Ordinary Maintenance Cost [€/year]	n.a.
CH_4 Biogas Yield [%]	51%
Annual operating hours [h /year]	7000 hours
Total Energy Produced [TWh / year]	7 TWh
Substrate supply [Kg / day]	48000-50000 Kg/day
Biogas production [m^3/h]	500 m^3/h

5.4 The first certificated Biogas Plant in Italy

In September 2016 Italian Biogas Consortium (CIB) certificated for the first time in Italy and Europe the "CAT" Biogas plant located in Correggio (RE) (see Figure 5-15). CAT (Cooperativa Agroenergetica Territoriale) is made of 26 business partners decided to convert beet sugar production into energetic cultivations due to beet production chain crisis. At the beginning this decision met lot of opponents due to the absurdity to convert food in energy but year by year local population was thought by seminars and visit to the facilities and became conscious of what a biogas power plant really is.

The plant was built in 2010 with 0.28 €/kWh incentives and has 2 CHP units for the total rated capacity of 999 kW. The total investment cost was about 5 M€ paid by leasing option extended in 15 years. The annual income is around 2.2 M€ and the estimates payback time was 5-6 years. The business plan was almost correct, just engines maintenance required more economical effort than estimated one. During the planning phase it was chosen to utilize two engines of 500 kW each in order to sell excess heat to Encore, a wood gasification company, that with another 500 kW engine they should have provided heat to a residential and commercial area by DH but unfortunately the project never started. Therefore the surplus heat produced by engines is used for temperature digester maintaining, dryer operations and facilities heating. Dryer is used for bundles of hay formation and it needs auxiliaries as fans fed by PV plant built on the top roof of the barn. The PV plant was built in 2015 and injects electrical energy by on spot trading.

The 26 partners of the cooperative produce themselves the crops and deliver them to the plant and use the digestate as fertilizer therefore the chain is closed. The substrates feed the digesters are maize silage, triticale, soy and sorghum (300 hectares/year) and they do not have storage problems because they do not have livestock for the Parmigiano Reggiano cheese production so the aflatoxines and clostridium are not considered as a problem. Liquid manure (18 m^3/day) and stalks (2500 tonns /year) are added as well.

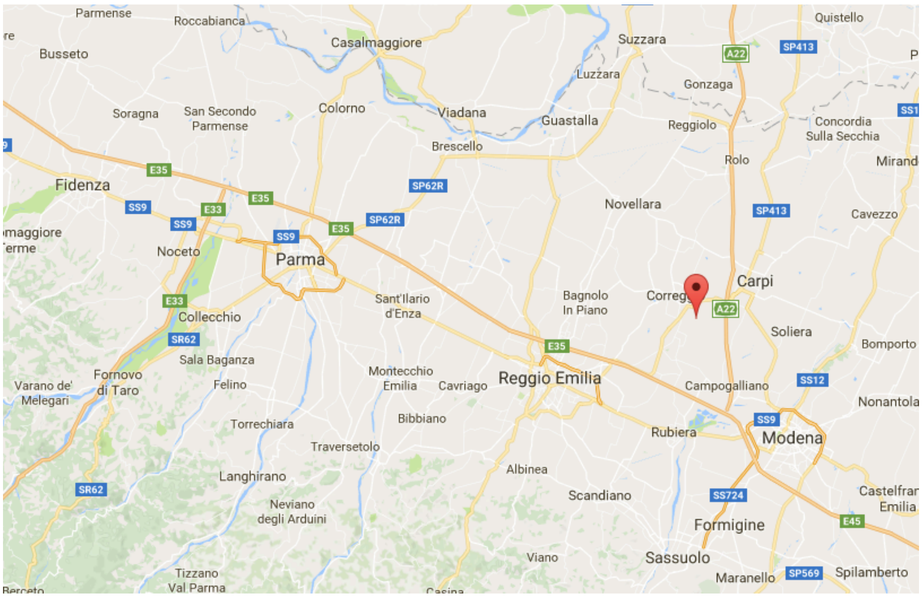


Figure 5-15 : Geographical position of "CAT" biogas plant, Correggio (RE). (Source: Google Maps).

Biogas yield oscillates but on average is 230-240 m^3 for one ton of maize, 170-180 m^3 for one ton of triticale, 160 m^3 for one ton of sorghum, 170-180 m^3 for one ton of compressed beet and 50-60 m^3 for one ton of stalks. The satellite view in Figure 5-17 clearly shows two digesters, post digester, final residuals tank and digestate liquid part container. They have a low efficiency screw as separator and the solid component of digestate is spread all over the cooperative members' vineyards where it is difficult to enter by tanker trucks. Now they are experimenting a bio cell in order to sanitize the digestate as some farmers use it in the cattles litter: the by-product is heated up to 75-80 °C for 1 hour and all the clostridiums and agriculture detrimental bacteria should be removed. In 5 years of experience and production chain evolution they went trough bad cheese wheel to a digestate even used as food for animals.

The plant works bout 8570 hours per year by selling energy to GSE for the total amount of 2.2 M€. For further details see Table 5-4. They do not use Activated Carbon as pre-treatment of biogas because they had some problems. A chiller and a depuration system shown in Figure 5-16 (20.000 € of initial cost) are present in the layout.

Figure 5-16: The pre-treatment unit for biogas in CAT biogas plant in Correggio (RE).

Figure 5-17: Satellite view of CAT biogas plant in Correggio (RE). (Source: Google Earth)

Table 5-4: Techcnical and economical details of "CAT" biogas plant, Correggio (RE).

Substrate Feed-in Typology	**Shredded Maize, triticale, sorghum, beet compressed, stalks, animal manure**
Head of cattle quantity	n.a.
CHP Power [kW$_{el}$]	2 x 499 kW
Self-consumption [%]	8-9 %
Thermal Power [kW$_{th}$]	550 kW$_{th}$
Thermal Power Usage	Digester temperature, dryer, facilities
Digester Number	2 (23 m of diameter)
Post Digester Number	1 (26 m of diameter)
$FeCl_2$/$FeCl_3$ supply	no
Chiller	yes
Activated Carbon	no
Total Investment cost	5 M€ (leasing formula)
Incentives	0,28 €/kWh
Operating Cost [€/year]	30.000 €/year
Insurance Cost [€/year]	n.a.
Estimated Payback Time	5-6 years
Respected Payback Time	Yes (but engine management cost not)
Ordinary Maintenance Cost [€/year]	n.a.
CH_4 Biogas Yield [%]	60%
Annual operating hours [h /year]	8570 hrs
Total Energy Produced [TWh / year]	8,5 TWh
Substrate supply [Kg / day]	n.a.
Biogas production [m^3/h]	n.a.

5.5 The first European Biogas plant powered by livestock biomass[1]

The installation has been set up in a farm company named "F.lli Pedrotti of Reggio Emilia", a site where a cattle farming for the production of Parmigiano Reggiano cheese are situated (Figure 5-18). The cattle are raised in two business sites located only 2 km one from the other. The plant was built in 2010 and it was the first one in Europe to be fed with manure and animal sewage and during its first months of operation lot of people coming from all over the Europe and Italy saw it to take cue from it.

It consists essentially of a pre-treatment system of the effluents to the load, two anaerobic continuously stirred tank reactors and heated under mesophilic regime sheltered with gasometric coverings with double membrane; at the end of the process of fermentation, the digestate converges in a solid-liquid separation system with helical compression and a storage tank of the clarified fraction, sheltered with a covering for the containment of residual gaseous emissions into the atmosphere. The produced biogas is collected in gasometers placed above the tanks and, after desulfurization, dehumidification and cooling, it fuels the co-generator of 330 kW_e.

Figure 5-18: Geographical position of "F.lli Pedrotti" farm. (Source: Google Maps).

At the moment of the visit the company housed in their breeding 1.850 heads, in detail about 850 lactating cows, 200 heads in dry and 800 more heads including heifers, young heifers and calves. Depending on the season, the consumption of bedding straw varies from 3.2 kg/head/day for the confinement in crates to 6-8 kg/head/day for the usage of beddings. There are two milking rooms but only the washing waters of one of them are mixed with the effluents and this determines a difference in the chemical characteristics of the effluents coming from the two sites. Another part of sewage comes from the other farm far away 2 Km, delivered by tanker truck; the sewage is used to

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[1] Collected data is partly achieved from direct interview in the farm. In this study case more technical and economical figures are extracted by [35].

make more liquid the manure in order to obtain a sort of "yogurt" as defined by Pedrotti. The company owns also a PV system of 500 kW (100 kW on the roof of one farm and 400 kW on the other) and part of electrical energy is self consumed in home and part is injected into the grid sold to GSE. The electrical energy produced by biogas plant in entirely put into the distribution network except the energy needed by the plant as represented in Table 5-5.

In accordance with what has need declared by the owner and with what is stated in [35], the plant has been designed with the following purposes:

- allow the maximum supply flexibility to grant its future adaptation to the different matrices that may be available from time to time;
- minimize sand and solid bodies sedimentation inside the digester;
- optimize the conversion of organic substances into biogas by providing a digester with a processing temperature up to 44° C;
- to be dimensionally compatible with the production of biogas, in terms of quantities and characteristics, as indicated in Table 5-5.

Figure 5-19: A view from satellite of "Pedrotti" Biogas Plant (Source: Google Earth)

The process temperature of tank reactors (max 44°C) is kept stable with a system of insulated ring coaxialtubes internal to the digesters and fixed with brackets, the hot water distribution instead takes place thanks to manifolds. Inside each tank there are 2 immersion Mixer Mod. GTWSI-Ex 204 (stainless steel Ø 820 mm Propeller) with stainless fixing system and vertical positioning system with a guide tube.

The installation was developed following the scheme shown in Figure 5-20: it is possible to individuate a homogenisation tank called "kitchen", a system for pre-treatment of the effluents to the load, two circular anaerobic tank reactors continuously blended, heated under mesophilic regime and sheltered by gasometric coverings with double membrane, a helical compression solid-liquid separator for the treatment of the digestate and a storage tank of the clarified fraction sheltered by a covering for the containment of residual gaseous emissions into the atmosphere. The sewage produced by the two operation centers of the farm are conveyed in a mixing tank designed to be heated and inoculated with a part of the recirculation digestate. The load of the effluents in the "kitchen" is made through one automatic dispenser wagon, equipped with load cells to monitor the quantity; the shredding of the straw fractions, instead, is obtained thanks to a grinding pump equipped with a separator of solid elements such as stones, iron, wood, etc; after the mixing, the pump is programmed for dosing the load at regular intervals in the two fermenters. The biogas produced in the two fermenters is stored in the gasometers overlying the tanks and, after having been undergone to a predominantly organic desulfurization with controlled insufflation of air into the gasometric dome, it is dehumidified and cooled by a refrigeration system; later, it is sent to the cogeneration group (AB ENERGY - ECOMAX 3BIO 330 kW_e, JENBACHER endothermic engine) and installed in a container that acts as a soundproofed utility room; the power of the plant has been identified in relation of the potential increase in cattle breeding.

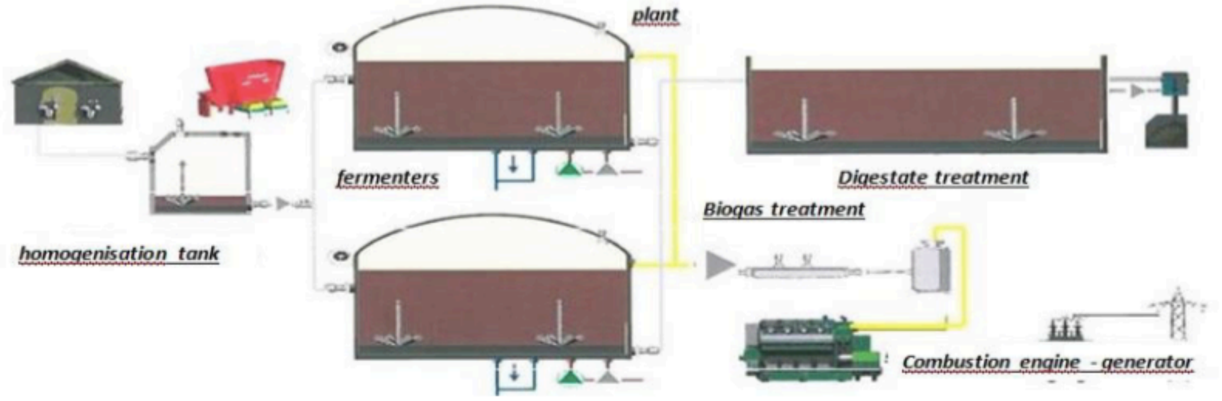

Figure 5-20: Scheme of plant layout of "Pedrotti farm". (Source: [35]).

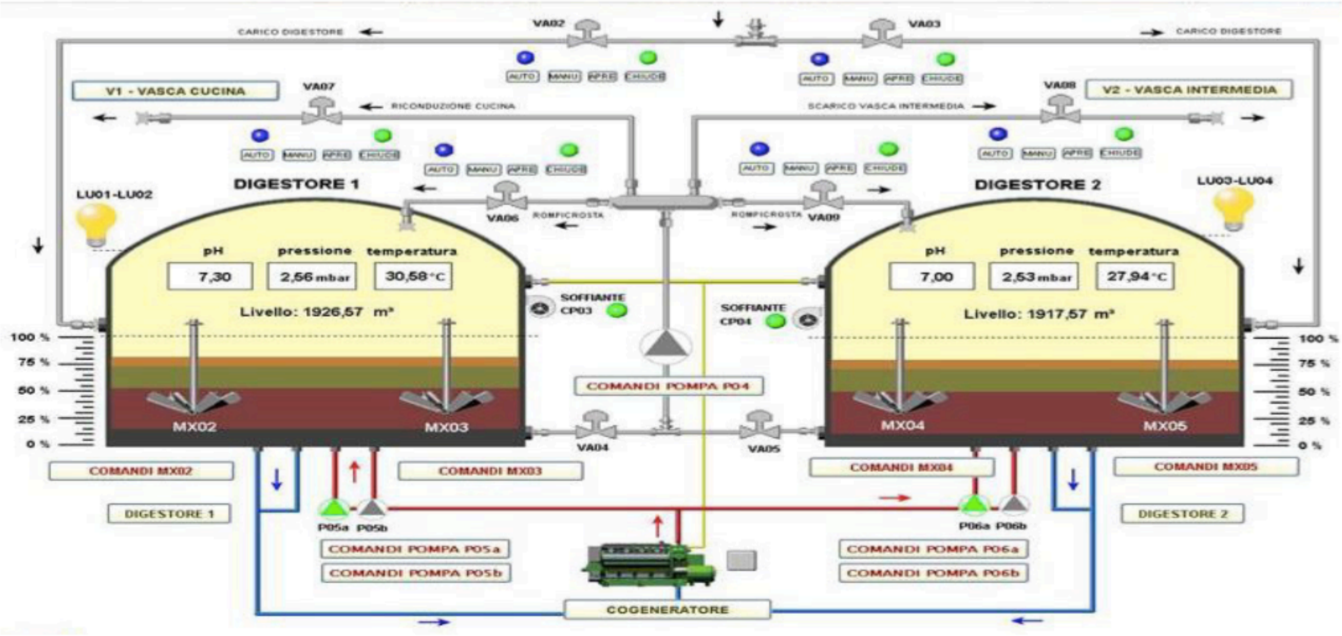

Figure 5-21: Graphical user interface of management software. (Source: [35]).

Table 5-5: Techcnical and economical details of "Pedrotti Farm located in the fraction of Cella (RE).

Substrate Feed-in Typology	Cow Sewage and Manure
Head of cattle quantity	1850
CHP Power [kW_{el}]	1 x 330 kW_{e} (294 kW_{e} net)
Self-consumption [%]	14% (energy need for biogas plant)
Thermal Power [kW_{th}]	205 kW_{th}
Thermal Power Usage	Mesophilic digester temperature (171 $kW_{e)}$
Residual Thermal Power [kW_{th}]	122 kW_{th}
Digester Number	2
Post Digester Number	1
$FeCl_2$/$FeCl_3$ supply	yes
Chiller	yes
Activated Carbon	no
Total Investment cost	2 M€
Incentives	0,28 €/kWh
Operating Cost [€/year]	n.a.
Insurance Cost [€/year]	n.a.
Estimated Payback Time	4 ½
Respected Payback Time	yes
Ordinary Maintenance Cost [€/year]	n.a.
CH_4 Biogas Yield [%]	55 %
Annual operating hours [h /year]	8000

Total Energy Produced [TWh / year]	2,372 TWh/year
Energy need by the plant [kWh/ year]	343.100 kWh/year
Salable Electricity generation [kWh/year]	2.029.400 kWh/year
Incomes by Energy selling	568.230 €/year
HRT [days]	30 days
Substrate supply [Kg / day]	95.000 Kg/day (sewage + manure)
Biogas production [m^3/h]	150 m^3/h

5.6 Committee vs Biogas

“Società Agricola San Prospero” is located in Massenzatico, a small town close to Reggio Emilia in the area of Parmiggiano Reggiano cheese production (Figure 5-22). The company was born for milk production but in the last decade the cattle increased (now around 400 head of cattle are present, 240 are cow in lactation) and the owner decided to build 1 MW biogas plant entrusting the construction and maintenance to AB ENERGY company. Progressively they achieved experience and autonomy and decided to build (autonomously) another 1 MW biogas plant. Therefore the entire facility includes two separate biogas plants: one made of 2 primary in-line digesters and one made of 2 primary digesters plus a post-digster where digestion is completed but a little bit of biogas is still produced. The layout and the number of tanks is appreciable in Figure 5-23.

The digesters are fed with, animal sewage and manure, litter residuals, potatoes peel,molasses and glycerine and shredded maize. The first two are produced within the farm, the rest is bought from external sources. This mix is necessary to produce 13500 m^3/day of biogas, the heat is used for digesters temperature (42°C), cattle hot water usage and for fodder drying. Theoretically there is the possibility to cover heat for district heating and for facilities (offices) heating but now it is not working.

Figure 5-22: Geographical position of "Azienda Agricola San Prospero", located in Massenzatico (RE). (Source: Google Maps).

Figure 5-23: A view from satellite of "Azienda Agricola San prospero". Four fermenters and one post digester are noticeable. (Source: Google Earth).

The biogas plant is equipped with a screw low efficiency separator which output is liquid and solid part (see Figure 5-24). The post digestate is entirely used as fertilizers and chemical analysis proved to be an optimal fertilizers with good absorption properties and with very low olfactory impact. Microfiltration device usage to obtain very low solid matter percentage liquid is now under evaluation – the solid fraction in the liquid part is 4% and not so liquid now.

The biogas which enters the engine (12 cylinders JANBACKER) does not go trough specific pre treatment units as activated carbon, washing column by caustic soda or other chemical additives (FeCl) because the owner thinks they are too expansive and useless. Just insufflation of air inside the digesters is carried out and H_2S concentration is monitored by portable device and not by the control system managed by external construction company due to the very high cost (2500-3000 €/year). The engine stop is programmed every 1500 hours and lasts around 4 hours; in one year the maintenance stops are estimated in more or less 15 days so the plants works around 8400 hours/year and the total electrical energy produced is injected into the network except the standard self-consumption for pumps, auxiliaries and so on (8-10 %).

Inside the farm there is a laboratory where biochemical biomethane potential (BMP_{exp}) test take place and operator computed the correct HRT is 25 days on average. Obviously the retention time continuously fluctuates and strongly depends on the input matrixes therefore if we add more glycerines or more fibres and lipids, the digestion time is extended even up to 40 days and in this case the post digester became fundamental because it works as supplementary digester where methanogenesis ends.

The total investment cost was 10 M€ and the estimated payback time around 9 years even if one important consideration was not taken into account: the fluctuation of maize silage market price. When business plan was done the price was fixed about 0,01 €/kg but it doubled quickly and production cost increased as well (cost of fuel) and the payback time estimated were wrong and the correct time are more extended than previous ones.

Finally, at the beginning the project found the opposition of neighbourhood and a committee was created to face the construction biogas plant. The company is defined as an “open landfill”. A lot of complaints were caused by increased traffic of heavy-duty vehicles along the provincial road due to the substrate transportation (potatoes peel, shredded maize, molasses etc) to be fed into fermenters. This brought to erosion and road wear and pollution issue all around the campaign close to the plant. Due to these problems the plant experienced frequent visit of ARPA and unexpected controls by security force.

Figure 5-24: Solid Fraction of post digestate storage area in “Azienda Agricola San Prospero”.

Table 5-6: Techcnical and economical details of "Azienda Agricola San Prospero" located in Massenzatico (RE).

Substrate Feed-in Typology	Animal sewage and manure, shredded maize, potatoes peel, molasses, glycerine, fruit and vegetables residuals
Head of cattle quantity	400
CHP Power [kW_{el}]	2 x 999 kW_{el}
Self-consumption [%]	10%
Thermal Power [kW_{th}]	n.a.
Thermal Power Usage	Digester, barn, fodder dryer
Digester Number	2 + 2
Post Digester Number	1
$FeCl_2/FeCl_3$ supply	no
Chiller	no
Activated Carbon	no
Total Investment cost	10 M€
Incentives	0,28 €/kWh
Operating Cost [€/year]	n.a.
Insurance Cost [€/year]	n.a.
Estimated Payback Time	10 years
Respected Payback Time	not
Ordinary Maintenance Cost [€/year]	n.a.
CH_4 Biogas Yield [%]	49-52%
Annual operating hours [h /year]	8400 hours/year
Total Energy Produced [TWh / year]	15,12 TWh/year
Substrate supply [Kg / day]	n.a.
Biogas production [m^3/h]	560 m^3/h

5.7 Flue gas recovery: a turbine in biogas plant

"Azienda Agricola Ceradello" is located in Carpaneto Piacentino (PC) and before biogas plant construction it produced milk for Grana Padana cheese formation. In 2011 the owner decided to build a 845 kW biogas plant in order to coproduce both milk and electrical energy to be sold in the energy market optimizing the farm's by-product usage. Actually in this way the farm produces maize (enough to feed cattle and to feed part of digester diet) and the post digestate is used as good fertilizer for maize fields therefore the supply chain turns out to be closed and company's income increases since energy is sold to GSE (well paid by 0,28 €/kWh incentives), self consumption permits avoided costs (no taxes on electrical energy bill component), no chemical fertilizers are used and theoretically heat recovery by

DH could be added but they computed too many expenses for the district heating system so the heat recovered by engines is used only for digester temperature.

Up to now no difference with other visited plants, actually this study case present lot of peculiarities. First of all it is noticeable the presence of a 75 kW turbine that recovers energy by engine outlet flue gases so the plant is able to produce more than 900 kW (mechanical losses and other losses are to be considered). Turbine is manufactured by Bosch and this kind of application is very rare all around the world since the German Company implemented this component in Austria (3 biogas plants) and in Italy "Azienda Agricola Ceradello" is pioneer among all the biogas systems. According operators depositions they experienced just one turbine stop for impeller substitution and H_2S has to be more monitored to avoid component wear and erosion. The turbine produces on average 60 kW_e and a bypass valve is used in case turbine is not used.

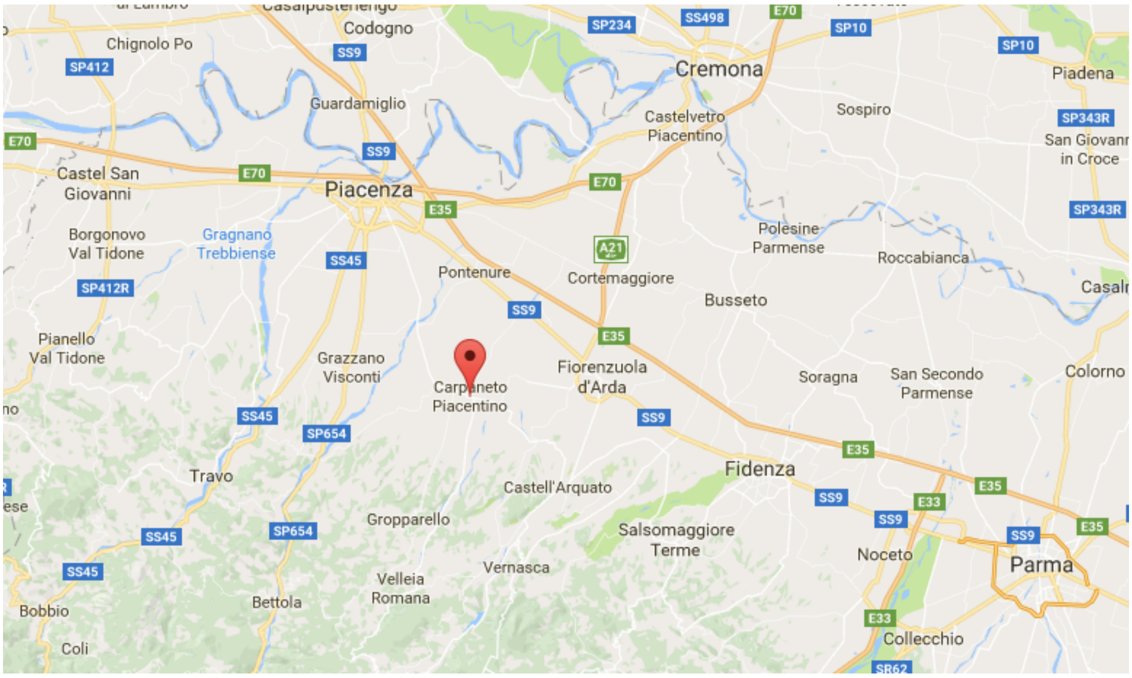

Figure 5-25: Position of "Azienda Agricola Cerdallo" located in Carpaneto Piacentino (PC). (Source: Google Maps).

The engine is a 12 cylinder JANBACHER and it works around 8600 hours per year and this year (2016) the longer engine stop is required (after 40.000 operating hours) and they expect a maintenance period stop of at least two weeks. There is an operator inside the plant that manages all the ordinary problems as oil change or spark substitution (every 2000 hours) but for more serious problems a full-service pack was subscribed with construction company.

The biogas plant is made of 3 double membrane in-line digesters with digestate recirculation from the last fermenter to the fisrt one: when feeding system works the recirculation pump work as well and about 150 m^3/day of digestate enters the first tank every 5 m^3/day of animal sewage fed. This excessive recirculation is due to temperature fermenter fall because heating system inside the first tank is only around the central agitator so to maintain constant temperature. The digester work at 48 °C and it is another different feature respect with other plants. Literature confirms optimal temperature is lower but the operator experienced less biogas yield if the temperature decreases.

"Digester diet" is very complex and includes:

- 13 tons/day of triticale
- 10 tons/day of maize (self-produced)
- 2 tons/day of poultry manure
- 2 tons/day of manure
- 12 tons/day of sweet maize
- 11 tons/day of old maize
- 20 m^3/day of liquid sewage

If they had only a good maize the would feed the digester by "only" 30 tons/day rather than 50 tons/day of above described mix because triticale is old and methane yield is low. Biogas yield of good maize is about 230 m^3/ton whereas triticale produces 170 m^3/ton. For further details see Table 5-7.

Table 5-7: Technical and economical details of "Azienda Agricola Ceradello", Carpaneto Piacentino (PC).

Substrate Feed-in Typology	Diet very complex (see 5.7)
Head of cattle quantity	130
CHP Power [kW_{el}]	845 $kW_{e\ CHP}$+ 75 $kW_{e\ turbine}$
Self-consumption [%]	8%
Thermal Power [kW_{th}]	550 kW_{th}
Thermal Power Usage	Digesters temperature (no DH)
Digester Number	3
Digester Temperature	48 °C
Post Digester Number	1
$FeCl_2$/$FeCl_3$ supply	yes
Chiller	yes
Activated Carbon	no
Total Investment cost	5 M€
Incentives	0,28 €/kWh
Operating Cost [€/year]	n.a.
Insurance Cost [€/year]	n.a.
Estimated Payback Time	10
Respected Payback Time	n.a.
Ordinary Maintenance Cost [€/year]	30000 €/year
CH_4 Biogas Yield [%]	55 %
Annual operating hours [h /year]	8600 hours/year

Total Energy Produced [TWh / year]	6,9 TWh/year
Substrate supply [Kg / day]	60000-63000 Kg/day
Biogas production [m^3/h]	330 m^3/h

5.8 Biogas Plant for experimental research

No profit experimental body “Azienda Sperimentale Vittorio Tadini” was founded in 1933 in Podenzano (PC) (Figure 5-26) where part of terrain is used for normal production and part for experimental tests in order to define biogas yields for some energy crops. In last years “the productive part “ that is the farm with around 110 cows in lactation was given to another company. The biogas plant is made of just one double membrane fermenter of 1300 m^3 fed with animal sewage,manure and some maize silage and a 110 kW_{el} 6 cylinder MAN. The plant was built in 2009 with 0,28 €/kWh incentives but year by year it was improved and mechanical scraper was installed. Inside the digester the insufflation of O_2 in order to decrease H_2S formation is present. The O_2 percentage inside the tank oscillates between 1-1.5% but they also add FeCl to further decrease H_2S. The engine can work continually with 200 ppm value but in any case after 70.000 hours partial or total substitution is needed due to crusts formation inside cylinders. The plant experienced lot of stops due to lightning then problem with maintenance company therefore in last years many stop hours occurred. The heat is not recovered for district heating due to many estimated expenses. They have could recover thermal power from engines to heat the formation centre or laboratory. Self- consumption is around 18-20% that is proportional to 1 MW big plant but this will be investigated in next chapter. The plant was fed by just animal sewage and manure for a bit but the energy produced was 50-60% of the maximum potential so decided to use also other substrates and experiment a lot of kind of energy crops such as triticale, maize silage, maize bran and by-products with integrators. In laboratory facilities a group of micro fermenters (self built) were used and 6 years of proves took place [36].

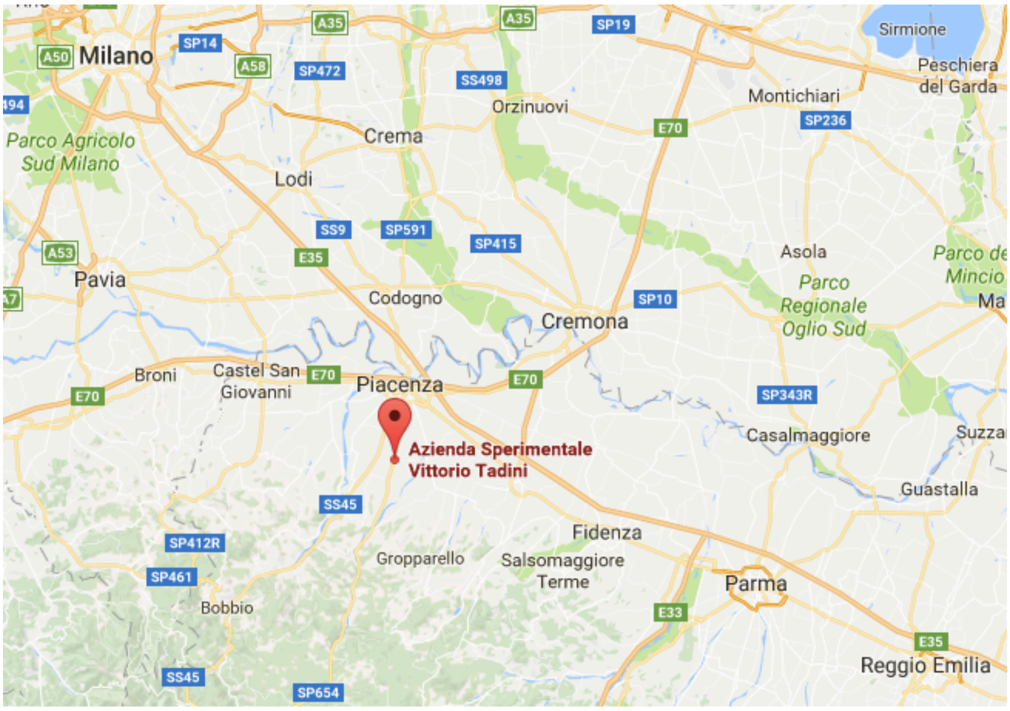

Figure 5-26: Position of "Azienda Sperimentale Tadini", Podenzano (PC). (Source: Google Maps)

Figure 5-27: A view from the satellite of the only one fermenter of "Azienda Sperimentale Tadini", surrounded by laboratory facilities. (Source: Google Earth).

5.9 Working in progress

Before concluding the chapter, it is useful to have also the point of view of a future biogas plant owner. Now the biogas plant is under construction but a deposition was recorded as well to delight entrepreneur's thoughts and worries in order to have an overall view of the biogas plant impact and perspectives.

Now a biogas plant is being built close to previously descripted "Azienda Agricola F.lli Pedrotti" and the size of plant will be 100 kW. Now the farm owns 550 head of cattle and produces milk for Parmiggiano Reggiano Cheese but property owner decided to raise own incomes by selling of electricity and providing heat to all the surrounding area by recovering heat of Biogas plant CHP. Actually the area is heated by old diesel fuel boilers (since no methane pipeline is present) and the actual investment cost of 950.000 € will be paid back in 4 – 5 years accordingly business plan and considering diesel saving around 40.000 €/year . The 100 kW biogas plant costs so much due to district heating components and equipment expenses. They computed a recovered thermal power of 150 kW_{th} and a cost of DH system around 200.000 €. Cheese factory will not be connected to DH because steam boiler requires too thermal power in too little time.

Basically the plants will have an effective power of 89 kW because 11% of self-consumption is to be considered. Given such size plant the 0,253 €/kWh incentives are to be taken into account for energy selling to GSE for 20 years (visit date: march 2016). The plant will include one digester fed by a "kitchen" (open tank where mixture of manure and sewage is done like "Azienda Agricola Pedrotti") , one post digester and 6 cylinder CHP unit. Finally a chiller and activated carbon as pre-treatment for biogas before entering engines were designed.

The plant was supposed to have been built 6 years ago at the sime time of Pedrotti Biogas plant construction but some wrong decisions were taken and everything was postponed. Given huge economical gain of close farm (for further details read 5.5) , finally owner decided to start plant erection. Just manure and animal sewage will be fed to digesters but buttermilk usage will be evaluated as well.

The interview has pointed out the real nowadays-agricultural need: farmer is no longer able to earn by traditional activities as cheese production, corn sales etc. We are witness of an evolution and a reorganizational model of agricultural system but more detailed discussion will be argued in next chapter.

6 DATA ANALISYS AND CONSIDERATIONS

In this chapter the most important consideration recognized by informants deposition are resumed. Particular attention is pointed to fragile environmental and social equilibrium in a region emblem of food excellence and agricultural products. Finally energetic analysis of more salient biogas production chain stages will prove impact of such technology has not to be neglected.

6.1 Feedstock digestion scenarios and issues related to Food Valley

Among the raw materials available are organic wastes from the food industry, municipal organic waste, agricultural harvesting residues, manure, sewages and crops. Only a few of them are currently being used for energy production. The use of substrate for energy production is strongly affected from the geographical position and in Emilia Romagna there is a restriction about silages use in the Parmiggiano Reggiano Cheese Production Zone [37]. This is due to the presence of Clostridium bacteria that affects Parmiggiano Reggiano production chain and may cause explosion of cheese wheels. Clostridium are anaerobic and spore-forming bacteria able to withstand at mesophilic condition inside digester and they may survive in post digestate and “pollute” the food for animal compromising all the closed chain. Almost all investigated plants do not use silages for the previous reason even if a lot of farm owner or cooperative members complained about impossibility to use such substrate and they state that such controversy is absurd. Someone declared to have a good digestate with lower clostridium bacteria respect with other sewage spread over field of Parmiggiano Reggiano Production chain.

In 6.3 paragraph calculations and results will be showed to prove the energy consumption entity to produce corn to be injected into the fermenters. all the different co-digestion scenarios of biogas plants under investigation are resumed. Only three biogas plants co-digest energy crops for production of electrical energy and this is considered illogical even by most of operators work into. Shredded Corn and triticale are the most diffuse energy crops even used in co-digestion with manure and animal sewages in all almost all biogas plants.

Single feedstock digestion is only applicable to small-scale biogas plants and base case is usually cattle manure. Considering the possible variations in feedstock availability, coupled with the importance of energy efficient transportation, and AD process considerations, single feedstock digestion is considered unsustainable for large-scale plants [38]. For example, sub-optimal composition of trace elements in single feedstock can impede the AD process. Similarly, rapid acidification of easily degradable feedstock e.g. food residues, may result in unsuitable conditions capable of stalling the AD process. As in Germany and research papers as [38] it is immediate to notice in Table 6-1 that almost all investigated biogas plants co-digest between three and five kind of different substrates. This is due to rotation of crops and availability of farms and in most of plants the correct daily supply is derived gradually with experience and tests in order to maximize CH_4 yields.

In Table 6-1 appears evident as corn (shredded or silage or flour form) is always present in “digester diet”. Indeed among the various employable crops for agro fuel production it is the one with highest productive potential and the highest value Transformation bio-combustible. The corn is considered one of the most interesting crops for feeding the digesters, even if the high yields of biomass and natural gas must be determined in relation to the use of the water and of the number of nutrients, in order to maximize electric production. The problem of sustainability of maize cultivation for the production of biogas is definitely involved in Italy due to low water availability, compared to the environments of Central Europe where the biogas production with the use of corn is a established practice [39].

Table 6-1:Different co-digestion scenarios for investigated Biogas plants.[2]

AD Feedstock	Az.Agr. Codeluppi	CAT	Valtrebbia Energia	Az.Agr. Ceradello	Az.Agr. Pedrotti	Az.Agr. Agrienergia	Tadini	S.Prospero	Kinexia
Animal Manure	X			X	X	X	X	X	
Animal Sewage	X			X	X	X	X	X	
Shredded Corn		X	X	X				X	X
Corn Silage		X				X	X		
Triticale		X	X	X					X
Food Residues								X	
Sorghum		X							X
Slaughterhouse waste									

There are many reasons that have made the corn the most used crop as a substrate for anaerobic digestion. The cultivation technique of corn silage is well known and well established in all area of Pianura Padana and its very high productivity respect with other energy crops and its high biogas yield determined the strong expansion as dedicated energy cultivation. Although it is considered an optimal substrate for biogas production rotation of cultivations is highly recommended to avoid terrain deterioration and increase field yield. Therefore it is suggested to resort to substrates mix by diversifying the cultivations and informants motivated that just experience can justify the correct digester feed and a correct biomass mix may increase biogas yield and CH_4 percentage biogas composition. In any case corn covers and will cover more and more main role among co-digestion products and accordingly [39] make more competitive energetic corn –based production chain by incentives, technology improvement and increase efficiency transformation results to be essential. It is worth adding that also extend favoured price for diesel fuel for corn cultivation process could be useful for such purpose.

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[2] It was considered co-digestion of predominant feeding substrates. Small quantities as flour maize, poultry manure etc. were neglected

At the same time almost all informants are sceptic regarding corn (and other crops) usage to produce electric energy due to social and environmental issue. It is true that corn has a high biogas yields and therefore we need less substrate to generate the same quantity of biogas that means electricity/heat production but corn cultivation phases require diesel fuel that means energy primary consumption that means CO_2 emissions released in atmosphere. To state that electrical energy produced by biogas is “green energy” is not totally corrected.

U.M.A. (Utenti motori agricoli) located in Reggio Emilia provided a list of processes included into corn cultivation/recovery activity by specifying diesel fuel consumption for each supply chain phase. The measure unit is:

$$\frac{l_{DF}}{ha \cdot y} \qquad \text{Equation 6-1}$$

In 6.3 paragraph calculations and results will be showed to prove the energy consumption entity to produce corn to be injected into the fermenters.

Table 6-2: CH_4 percentage of biogas composition of investigated plants.

Biogas CH_4 % ranges	Az.Agr. Codeluppi	CAT	Valtrebbia Energia	Az.Agr. Ceradello	Az.Agr. Pedrotti	Az.Agr. Agrienergia	Tadini	S.Prospero	Kinexia
49 - 52								X	X
53 - 56	X	X		X	X	X	X		
57 - 60									
> 61			X						

In Table 6-2 appears evident as the most diffuse range of methane composition in biogas mixture is around 55%. It is worthwhile noting that more complex layout plant (Valtrebbia energia, see 5.2 for more details) present a higher CH_4 percentage value whereas the basic plant of Gazzata present the lowest value.

6.1.1 Local problems

Additionally, people throughout the region have organized themselves in committees against biogas and perceive this new rural activity as extremely harmful for their health, the rural economy and the environment. Information gathered through semi-structured interviews proved and confirmed different studies and research like [40] about obstacles to sustainable bioenergy development since social opposition (committee, investigative reports) was formed and collected information are grouped in Table 6-3. By seeing the table it is possible to notice that almost biogas plants have or had problems with local committee and owners or operators associate such opposition to ignorance and unknown-fear. Depositions and consideration regarding weak role of local governments or wrong policy schemes creation (incentives, government-business-research sector link) were given as well.

Table 6-3: Local opposition problem and complains of investigated biogas plants.

	Az.Agr. Codeluppi	CAT	Valtrebbia Energia	Az.Agr. Ceradello	Az.Agr. Pedrotti	Az.Agr. Agrienergia	Tadini	S.Prospero	Kinexia
Committee problems		X	X	X	X	X		X	X
CRPA inspections		X			X			X	
Investigative report		X							X [41]
Research Funds Cut							X		
Wrong policies schemes complain	X								X
Neighbourhood complain	X		X	X		X	X	X	X

Heavy-duty traffic increase due to biomass transportation seems to be the major complain among residents and locals but odour and feedstock accumulation are to be contemplated as well. Increase of biomass transportation may contribute to PM and GHG emissions increase. Informants confirm studies in [40] and even if biogas development present environmental positive effects as transmission of electricity in the grid, consumption of "bioheat" in-house and in surrounding dwellings by DH and the use of digestate as fertilizer, only negative effects result to be observed by local communities living around plant. However biogas producers claim that the plants are located too far from other rural buildings to provide heat by district heating service and the absence of an incentive makes it unaffordable (see. Table 6-4) Each biogas plant owner or operator seem to be conscious of the huge potential of upgrading biogas into biomethane to inject into grid. Since between 2014 and 2015, the national authorities gave dispositions (i.e. quality and technical criteria, incentive schemes) for the production and transmission of biomethane from biogas in the natural gas grid, it looks like to be more efficient produce biomethane rather than produce electric energy and too few heat.

Table 6-4: District heating exploited by investigated biogas plants.

	Az.Agr. Codeluppi	CAT	Valtrebbia Energia	Az.Agr. Ceradello	Az.Agr. Pedrotti	Az.Agr. Agrienergia	Tadini	S.Prospero	Kinexia
DH	X								X
DH transmission distance	<0.5 Km								<2 Km

CEMBRE 2012 IL FATTO DEL GIORNO | 5

LA PROTESTA Ombretta Daccari abita a 19 metri dall'impianto

«Ci hanno sempre negato che fosse in costruzione l'impianto»

di LUCA GEMMI

Gli abitanti della frazione di Gazzata il biogas non lo vogliono. Più volte hanno incontrato l'amministrazione comunale di San Martino in Rio per esprimere la propria contrarietà alla costruzione dell'impianto, contrarietà espressa anche dal Comune, che però dichiara di non poter fermare l'impianto. Ma fra i residenti della zona c'è chi il biogas lo subirà più di altri. E' il caso della signora Ombretta Daccari, la cui abitazione è situata a una vicinanza impressionante rispetto a una delle quattro vasche-silos dell'impianto: appena 19 metri.

Daccari, lei è stata avvertita della costruzione dell'impianto dall'amministrazione comunale?

No. Ed è per questo che siamo molto arrabbiati: quando ho telefonato in Comune, nel novembre 2011, mi hanno assolutamente negato che ci fosse un progetto del genere. E invece era già stato approvato in luglio, quattro mesi prima.

Quali sono i disagi che l'impianto provoca ai residenti?

Sento vibrazioni continue in tutta la casa. Non solo: non rispettano gli orari dei cantieri, che sarebbero dalle 8 alle 12 e dalle 15 alle 19. Alle 5 di mattina sono già sul cantiere a fare rumore.

Per arrivare qui si passa per una strada molto stretta e dissestata. I camion arrivano da lì?

Esatto. La via è stata rovinata dal passaggio quotidiano di camion, per tutto il giorno tutti i giorni, creando delle crepe nell'asfalto tali che sta diventando impraticabile percorrerla in bici. Oltretutto all'inizio della strada c'è il divieto d'accesso per i camion!

Non molto lontano da casa sua passa anche il treno ad alta velocità.

Quando sono venuta a vivere qui era tutta campagna. Negli ultimi anni hanno costruito Tav, tangenziale e ora il Biogas. E nessuno ci ha detto nulla. Neppure il Comune di San Martino in Rio, guidato dal mio sindaco.

Ora cosa pensa di fare?

Io chiedo di bloccare i lavori, non lo voglio il biogas. Oppure che mi paghino la casa, perché voglio andarmene da qua. L'ho messa in vendita da più di un anno, ma ora non la venderò più. Sono anche venute delle persone a vederla, ma quando hanno saputo che c'era questo progetto non erano più interessate. Chi è che vuole abitare vicino a un biogas?

ll'utilizzo di vegetali per produrre il biogas

limenti, non energia»

ais e non si userebbero liquami

realtà dell'im-
ogas di Gazzata
ione opposta.
cipale materia
averso la quale
produrrà bio-
nais. Una scelta
a la più impor-
teristica di que-
energia alterna-
basarsi sull'uti-
iuti organici o
ti provenienti
ltura, come i liquami.

Coltivare alimenti solo per farli fermentare in una cisterna per alcuni è un controsenso, ma un controsenso estremamente redditizio sia per i produttori di biogas che per gli agricoltori: il mais produce molta più energia dei liquami e viene venduto a un prezzo più alto rispetto ai mercati alimentari.

(Luca Gemmi)

Figure 6-1: Article of local daily newsapaper [42] about "Kinexia" biogas plant in Gazzata (RE) complain

Many biogas firms lack of proper storage arrangements (i.e. facilities, exact amount of time), thus for instance, the liquid that results from biomass decomposition (leachate) does on many cases flow into irrigation ditches. Leachate affects soil and air quality (including bad smell), thus eventually resulting in more GHG emissions. Second, since the amount of electricity fed in the grid is conditional to the feed-in-tariff (FIT), it may happen that the exceeding part of biogas is burnt in the flare thus contributing to GHG emissions increase. Informants motivated that over-production of biogas and flare utilization is exclusively due to maintenance operations and a correlation between biogas plant yearly operating hours and flare utilization is found and showed in Figure 6-2.

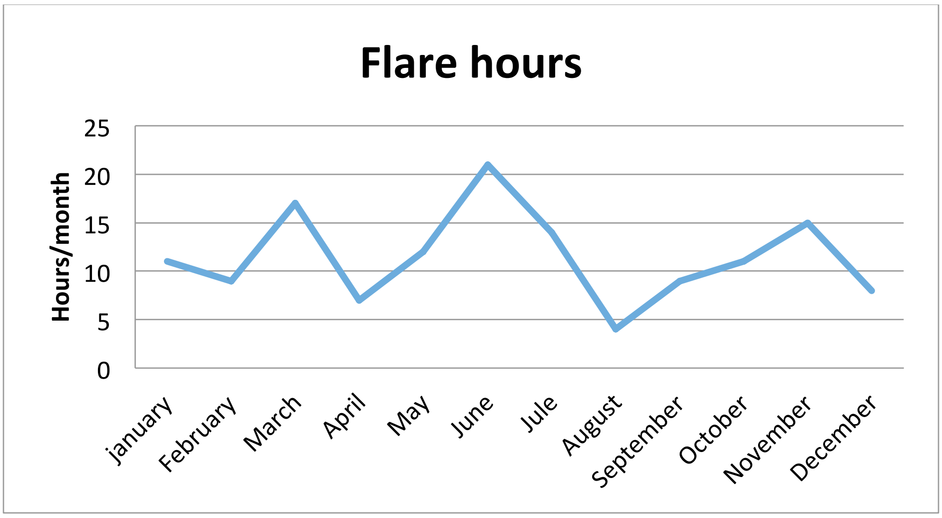

Figure 6-2: Yearly trend of flare usage in Kinexia Plant

Table 6-5: Annual operating hours rages of under investigation plants.

Annual operating hours [hours/year]	Az.Agr. Codeluppi	CAT	Valtrebbia Energia	Az.Agr. Ceradello	Az.Agr. Pedrotti	Az.Agr. Agrienergia	Tadini	S.Prospero	Kinexia
< 8000					X				X
8001 - 8200			X						
8201 - 8400	X							X	
8401 - 8600		X		X		X	X		
> 8600									

6.2 Mass balance

The first analysis conducted on the systems involved in the study was the definition of the mass balance of incoming and outgoing substances from the manufacturing process and biogas valorization. The second will be relevant for energetic computations inherently digestate post-treatment energy consumption evaluation (see 6.3.2 for more details). As for the balance of the digestion phase, it was reconstructed on the basis of data provided by operators. The input substances to the process are represented by the base substrates and estimated to be constant (but in reality it varies accordingly resources and availability). The different mass flows are expressed in terms of tonnes per year and tons per day accordingly analysis tipology. Including for biomass input, therefore, it has been reported the data "raw" supplied by operators and reported to the fresh biomass "as is."

The biogas flow produced, generally expressed in terms of volume (m^3/y), it has been converted into a mass flow assuming a density of 1.1 kg / m^3. The data of production considered is that measured at output from the gasometer; have not been considered in the budget any losses in the gasometer and the connecting pipe to the CHP. Even the air quantities used in the biogas desulphurisation process (If any) they have been neglected, since it amounted to smaller percentages of 2% from the biogas produced.

The biogas is then sent in cogeneration units, where, it is mixed with the combustion air, is oxidized within the thermodynamic cycle that leads to the transformation of the thermal energy contained in the biogas into mechanical energy, with subsequent production of electricity through the alternator. Residue of the biogas valorisation process are exhaust gas of high temperature discharge, the mass flow rate which corresponds to the sum of the biogas flow and combustion air.

Since the stoichiometric combustion of 1 m^3 of methane requires 9.52 m^3 of air, the ratio of the stoichiometric combustion of the biogas (for which it is assumed a variable methane content from 50 to 60%) was roughly equal to 1: 5.5. To limit as much as possible the formation of NO_x , the combustion usually takes place in excess of oxygen, with a lambda value of 1.45. for each m^3 of biogas are used to burn about 8 m^3 of air, or, considering the respective density under normal conditions, each kg of burned biogas requires approximately 9.5 kg of air (biogas density 1.1 kg / Nm³, air density 1.29 kg / Nm³). Final results for each investigated plant are resumed in Table 6-6.

Table 6-6: Mass Balance flow analysis for investigated biogas plants.

	Codeluppi	*Valtrebbia*	*Pedrotti*	*Melli*	*Ceradello*	*Agrienergia*	*CAT*	*Kinexia*	*Tadini*
Tipology	Manure	Crop	Manure	Manure	Mix	Crop	Crop	Crop	Mix
Rated Power [kW]	250 kW	999 kW	330 kW	1998 kW	845 kW	999 kW	999kW	999 kW	110 kW
Substrate mass flow [ton /day]	93	52	95	n.a.	60	70	n.a.	50	10
Biogas flow rate [m^3/h]	125	160	145	660	330	560	n.a.	500	n.a.
Biogas mass flow rate [Kg/h]	138	176	160	726	363	616	n.a.	550	n.a.
CH_4 composition %	53%	61%	55%	49%	55%	55%	54%	51%	54%

6.3 Energy balance

The analysis of the energy balance of the plant was carried out with the aim of quantifying the actual energy benefits produced by the anaerobic digestion of biomass, net of consumption associated with the various phases of transport, treatment, and disposal of the digestion process residues. The boundaries of the system taken as a reference for the energy balance are then presented, upstream from the stage of collection and transport of the fresh biomass to the system, downstream from the transport phase of the process waste from the biogas to disposal sites. Energy balance analysis will be conducted to compare:

- Biogas production by using energy crops (corn)
- Biogas production by using cattle manure

The general system boundaries is schematically depicted in Figure 6-3 and the only difference between manure and corn case is the energy consumption dedicated for cultivation and harvesting process (the first green box). More detailed description is given in the following sub paragraphs.

6.3.1 Energy Crops supply and transportation

As we can see from Table 6-1 some biogas plants use only energy crops (corn, triticale, maize silage, sorghum etc.) and it is true that biogas yield is greater and therefore less feedstock respect with manure or sewage is required as stated in [38] but at the same time fuel consumption -that means primary energy consumption- has to be taken into account. Cultivation process of energy crops includes a lot of ordinary processes and phases as we can see in Table 6-7, provided by U.M.A. offices in Reggio Emilia (Utenti Motori Agricoli). Diesel fuel consumption strictly depends on culture typology, field extension and kind of soil. A medium mixture soil and waxy corn was considered for calculation.

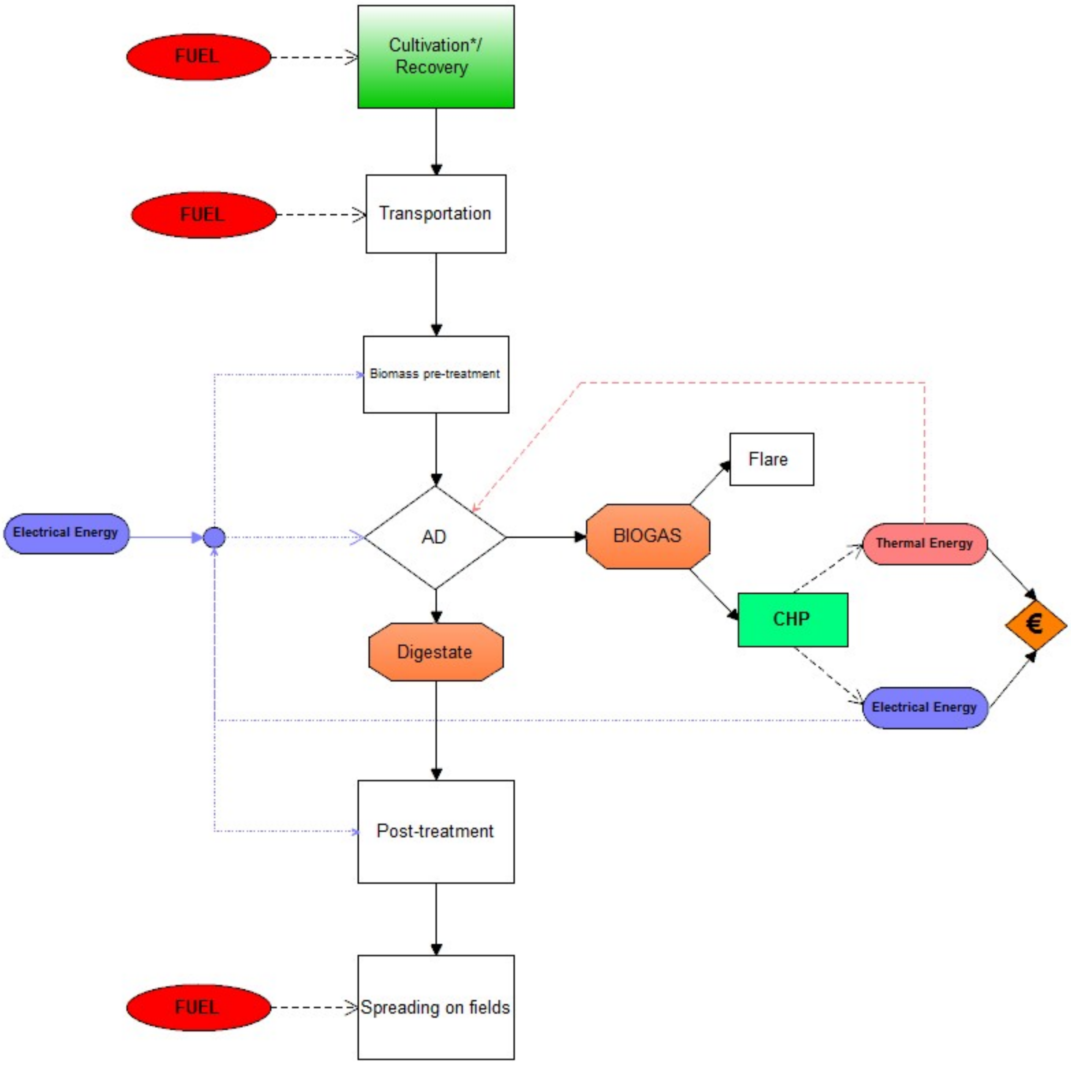

Figure 6-3: Flow chart of energy vector used in biogas production chain.

Ordinary production phases	Diesel fuel consumption [l / ha y]
Ploughing/ hoeing	44
manuring	13
Weeding/treatments	9
Harrowing	15
Irrigation	97
Harvesting	88
Rolling	3
Weeding	9
Sowing	8
Transportation (into fields)	10
SUM	**296**

Table 6-7: Diesel fuel consumption for various stages of corn cultivation process.

A we can see from above listed values the amount of diesel consumption for all the corn production chain is almost 300 l/ha y. From datas of diesel fuel [43] we consider 0,832 Kg/l as density value and 43,13 MJ/Kg as LHV and we can compute:

$$E_{DF} = 300\ \frac{l}{ha \cdot y}\ \times 0{,}832\ \frac{Kg}{l} \times 43{,}13\ \frac{MJ_{DF}}{Kg} = 10765\ \frac{MJ_{DF}}{ha \cdot\ y}$$

Where E_{DF} is diesel fuel energy consumption.

Then from [43] we can compute Energy Primary consumption to use such quantity of diesel fuel:

$$E_{PRM} = 10765\ \frac{MJ_{DF}}{ha\ \cdot y} \times 1{,}157921\ \frac{MJ_{PRM}}{MJ_{DF}} = 12465 \frac{MJ_{PRM}}{ha \cdot y}$$

Then by using conversion factor is possible obtain Primary energy consumption in kWh:

$$E_{PRM} =\ 300\ \frac{l}{ha \cdot y} \times 9{,}85\ \frac{kWh}{l} = 2955\ \frac{kWh}{ha \cdot y}$$

By considering for example a plant of 999 kW, like Kinexia Plant, 350 ha of field necessary for cultivation are to be taken into account and it results:

$$E_{PRM} =\ 12465 \frac{MJ_{PRM}}{ha \cdot y}\ \times 350\ ha = 4362\ \frac{GJ_{PRM}}{y}$$

$$E_{PRM} = 2955 \frac{kWh}{ha \cdot y} \times 350\ ha = 1034 \frac{MWh}{y}$$

Then, if we consider 0,655 €/l as diesel fuel (favoured for cultivation) we can estimate the total expense for diesel fuel in order to supply energy crop biomass for biogas plant:

$$C_{DF} = 300 \frac{l}{ha \cdot y} \times 0{,}655 \frac{€}{l} \times 350\ ha = 68775\ €$$

Where:

- $1{,}157921 \frac{MJ_{PRM}}{MJ_{DF}}$ was used since for each MJ of diesel fuel we are going to burn in our car, we need 15% more primary energy to produce it. Basically is the primary energy which needs to be extracted to produce 1 MJ of diesel fuel.

- E_{PRM} is the energy primary we need to achieve a defined process. It refers to energy that has not undergone any conversion or transformation process.

- C_{DF} is the total amount of euros for purchasing diesel fuel.

Above consideration are valid for each plant that is fed by energy crops but up to now just cultivation process was considered and fuel consumption due to transportation has to be added. Actually it was noticed from the interviews and visited biogas plants that transportation is an important part of the entire biogas production chain because it strongly affects relationship with neighbourhood due to emissions and traffic increase. In Table 6-8 are listed the range distances of energy crops/feedstock producing area and biogas plants and [38] provides an estimation of Energy inputs for transportation feedstock.

Table 6-8: Distance ranges of feedstock origin for investigated biogas plants.

	Codeluppi	*Valtrebbia*	*Pedrotti*	*Melli*	*Ceradello*	*Agrienergia*	*CAT*	*Kinexia*	*Tadini*
Short distance ≤2 Km	X	X	X		X				X
Mid-range distance 2 Km ≤ 20 Km				X		X	X	X	
Long distance > 20 Km									

All biogas plants fed by manure or animal sewage is featured by feedstock production site almost next to digesters therefore diesel consumption was neglected. Only Valtrebbia biogas plant (energy crops as input substrate) present very short distance due to close cooperative fields availability. Kinexia biogas plant operator provided important figures to estimate fuel consumption and therefore energy primary consumption due to transportation process. Around 3 trips/ ha y (6 trips if we consider roundtrip) and a distance of 3 Km were considered with diesel consumption of 30 l/100 Km.

$$N_{trip} = 6\ \frac{trip}{ha\ y} \times 350\ ha = 2100\ \frac{trip}{y}$$

$$D_{Km} = 3\ \frac{Km}{trip} \times 2100\ \frac{trip}{y} = 6300\ \frac{Km}{y}$$

$$F_{cons} = 6300\ \frac{Km}{y} \times 0{,}3\ \frac{l}{Km} = 1890\ \frac{l}{y}$$

Where:

- N_{trip} is the number of trips of the trucks in one year from cultivation site to biogas plant
- D_{Km} is the total distance covered in one year by the trucks transporting biomass to the plant
- F_{cons} is the diesel fuel consumption in one year considering 30 l/100 Km as average value of heavy duty vehicle fuel consumption

Primary energy consumption is computed as follows:

$$E_{DF} = 1890\ \frac{l}{y} \times 0{,}832\ \frac{Kg}{l} \times 43{,}13\ \frac{MJ_{DF}}{Kg} = 67821\ \frac{MJ_{DF}}{y}$$

$$E_{PRM} = 67821\ \frac{MJ_{DF}}{y} \times 1{,}157921\ \frac{MJ_{PRM}}{MJ_{DF}} = 78.531\ \frac{GJ_{PRM}}{y}$$

$$E_{PRM} = 1890\ \frac{l}{y} \times 9{,}85\ \frac{kWh}{l} = 18.616\ \frac{MWh}{y}$$

Then if we consider average price of 1.3 €/l , the total expense for the transportation is computed as follows (maintenance and truck wear was neglected):

$$C_{DF} = 1890\ \frac{l}{y} \times 1.3\ \frac{€}{l} = 2457\ \frac{€}{y}$$

6.3.2 Digestate and residues transportation

For calculation of fuel and primary energy required for the last phase of biogas chain production, calculation of digestate mass flow rate is needed. It can be obtained by knowing:

- Annual flow rate to load (ton/year)
- Production of biogas (Nm^3/year)

By Mass balance of anaerobic digester is possible estimate output digestate mass flow rate (ton/year). Accordingly data provided by informants and operators a table with input/output mass flow can be done for each plant and by using a simple Excel spreadsheet is possible extract the following values as shown as example for Pedrotti biogas plant, since [35] provides correct values. Density of biogas is hypothesized as 1.1 Kg/m^3. Pedrotti plants is fed only with Cow Sewage and manure and Maximum production of biogas is around 3505 Nm^3/day, converted in ton/y it is 1407.

Table 6-9: Example of Excel spread sheet for input-output mass flow calculation.

	Input [ton/y]	**Output [ton/y]**
Substrate fed into AD	34500	
Co-substrate		
Biogas		1407
Digestate		33092
TOTAL	34500	34500

This was done for all the investigated biogas plant (where data were available) and Table 6-10 shows all the results.

Table 6-10: Digestate yearly mass flow rate analysis for visited biogas plants.

[tons / year]	*Codeluppi*	*Valtrebbia*	*Pedrotti*	*Melli*	*Ceradello*	*Agrienergia*	*CAT*	*Kinexia*	*Tadini*
Substrate fed into AD	33900	18900	34500	N.A.	21900	26600	N.A.	18250	2190
Co-substrate	50	80	-	N.A.		1140	N.A.	-	-
Biogas	1200	1542	1407	5396	3180	5396	N.A.	4818	N.A:
Digestate	32750	17438	33092	N.A.	18720	22343	N.A.	13432	N.A:
TOTAL MASS FLOW RATE	33950	18980	34500	N.A.	21900	27740	N.A.	18250	N.A.

Sustainable biogas utilization requires closed cycle of matter encompassing the complete recycling of digestate. For large-scale biogas plant, limitation on the amount of nutrients that may be spread on agricultural land dictates the amount of digestate that can be safely recycled. Efficiency of digestate transportation may be enhanced by on site processing into chemical fertilizer substitutes (decanter or screw-press is used for separation). For example, separation of solid and liquid phases can reduce transportation requirement by up to 60% and another 25% after drying. Digestate separation, loading, transport and spreading on arable land account for the primary energy input in processing and handling. Solid fraction can also be composted for approximately 60 days or alternatively dried with hot air supplied from the system, then used as substitutes for chemical fertilizer. Almost all investigated plants have Screw-press for separation digestate and by considering energy inputs in processing and handling of digestate obtained from [38] is possible compute yearly Primary Energy consumption for screw-press separation in Pedrotti plant:

$$E_{PRM} = 4.3\,\frac{MJ_{PRM}}{ton_{DIG}} \times 33092\,\frac{ton_{DIG}}{y} = 142.295\,\frac{GJ_{PRM}}{y}$$

In such calculation residual digestate in tank, losses or recirculation of digestate into fermenters was not considered. Table 6-11 resumes all the calculations for all the plants under investigation.

Table 6-11: Primary Energy consumption values for each digestate post-treatment process for investigated plants.

[GJ_{PRM}/ year]]	*Codeluppi*	*Valtrebbia*	*Pedrotti*	*Melli*	*Ceradello*	*Agrienergia*	*CAT*	*Kinexia*	*Tadini*
Screw-press Digestate separation	140.825	75	142.295	N.A.	80.5	96.074	N.A.	57.757	N.A.
Solid fraction loading	12.379	6.59	12.508	N.A.	7.076	8.445	N.A.	5.077	N.A.
Solid fraction Transport	103.16	54.929	104.24	N.A.	58.968	70.380	N.A	42.310	N.A.
Solid fraction Spreading	84.6	45.042	85.476	N.A.	48.353	57.711	N.A.	34.694	N.A.
Liquid fraction loading	18.569	9.887	18.763	N.A.	10.614	12.668	N.A.	7.616	N.A.
Liquid fraction Transport	837.09	445.71	845.83	N.A.	478.48	571.08	N.A.	343.32	N.A.
Liquid fraction Spreading	594.216	405.38	600.42	N.A.	339.65	405.39	N.A.	243.71	N.A.
$E_{PRM,tot}$	**=**			**N.A.**			**N.A**	**734.5**	**N.A.**

Solid fraction is generally not more than 10-15% of the weight of the digestate and is characterized by a dry matter content relatively high, usually above about 20%. In it are concentrated the residual organic substance, the organic nitrogen and phosphorus. In our calculation 10% of digestate and 10 Km of transportation lenght were assumed and primary energy input are provided by [38]. For simplicity computations for Pedrotti plant are shown in following equations and final results resumed in Table 6-11.

$$M_{SF} = 0.1 \times 33902 \ \frac{ton_{DIG}}{y} = 3309.2 \ \frac{ton_{SF}}{y} \qquad \text{Equation 6-2}$$

$$E_{PRM,sf,loading} = 3309.2 \ \frac{ton_{SF}}{y} \times 3.78 \ \frac{MJ_{PRM}}{ton_{SF}} = 12.508 \ \frac{GJ_{PRM}}{y} \qquad \text{Equation 6-3}$$

$$E_{PRM,sf,transport} = \ 3309.2 \ \frac{ton_{SF}}{y} \times 3.15 \ \frac{MJ_{PRM}}{ton_{SF} \cdot Km} \times 10 \ Km = 104.24 \ \frac{GJ_{PRM}}{y} \qquad \text{Equation 6-4}$$

$$E_{PRM,sf,spreading} = \ 3309.2 \ \frac{ton_{SF}}{y} \times 25.83 \ \frac{MJ_{PRM}}{ton_{SF}} = 85.476 \ \frac{GJ_{PRM}}{y} \qquad \text{Equation 6-5}$$

Instead liquid fraction represents 85-90% of total volume of digestate accordingly [43] and for simplicity 90% of total weight of digestate was assumed and final results are listed in Table 6-11.

6.3.3 Saving due to digestate usage as fertilizer

Solid and liquid fraction may be used as fertilizers to spread on fields. We have just computed primary energy consumption to obtain such fractions but another consideration and computation has to be done to complete the investigation. Let us consider the following products required for cultivation given from [44]:

- fertilizers N: 109.3 kg/ha-y
- fertilizers K_2O: 16.4 kg/ha-y
- fertilizers P_2O_5: 21.6 kg/ha-y
- pesticides: 2.34 kg/ha-y

Primary energy consumption and GHG emissions emitted during production process of such products are listed in Table 6-12 and calculations for a 999 kW plant like Kinexia featured by around 350 ha of field size are showed.

Table 6-12: Primary energy consumption and CO_2 emissions produced during production of fertilizers used in fields [44].

Product	Primary energy consumption, MJ_{PRM}/kg	GHG emissions for production, $g_{CO2,eq}$/Kg
fertilizer N	49.17	6065.3
fertilizers K_2O	9.73	583.2
fertilizers P_2O_5	15.47	1017.8
pesticides	272.6	17257.6

$$E_{PRM,prod,N} = 49.17\,\frac{MJ_{PRM}}{Kg_N}\times 109.3\,\frac{Kg_N}{ha\cdot y}\times 350\,ha = 1881\,\frac{GJ_{PRM}}{y} \quad \text{Equation 6-6}$$

$$E_{PRM,prod,K_2O} = 9.73\,\frac{MJ_{PRM}}{Kg_{K_2O}}\times 16.4\,\frac{Kg_{K_2O}}{ha\cdot y}\times 350\,ha = 55.85\,\frac{GJ_{PRM}}{y} \quad \text{Equation 6-7}$$

$$E_{PRM,prod,P_2O_5} = 15.47\,\frac{MJ_{PRM}}{Kg_{P_2O_5}}\times 21.6\,\frac{Kg_{P_2O_5}}{ha\cdot y}\times 350\,ha = 117\,\frac{GJ_{PRM}}{y} \quad \text{Equation 6-8}$$

$$E_{PRM,prod,pest} = 272.6\,\frac{MJ_{PRM}}{Kg_{pest}}\times 2.34\,\frac{Kg_{pest}}{ha\cdot y}\times 350\,ha = 223.26\,\frac{GJ_{PRM}}{y} \quad \text{Equation 6-9}$$

Therefore total primary energy saved every year results around 2277 GJ_{PRM} due to the usage of digestate as fertilizer for the total amount of 257 tons of $CO_{2,eq}$ not emitted in one year.

Conclusions

The great interest directed towards biomass and, more generally, of renewable energy sources, is justified by a number of positive effects that accompany their use, both from a strictly energy point of view and from the point of view of social and environmental. The advantages may be summarized as follows:
- Sustainability (renewability);
- Protection of the environment (no environmental impact or almost zero);
- Dispersion on the territory (employment in inland marginal areas);
- Ease of use and efficiency in power conversion.

Characteristic of all alternative sources of energy, sustainability and renewability of biomass is linked to a large regeneration of these resources speeds, which makes them virtually inexhaustible, provided you manage them properly and correctly in a sustainable way.

Concerning the second point we have to state that energy production by biogas has no impact null because we have to takes into account pollution due to transportation of feedstock but considerations are not over because a distinction between manure and energy crops as substrate has to be done. If we consider diesel fuel consumption to cultivate corn (or other energy culture) to feed fermenter it was resulted that for a 999 kW_e plant around 105.000 liters of diesel are consumed in one year and this corresponds to a huge cost for direct farmer and without incentives biogas energy production by energy crops becomes not sustainable both from economical and environmental aspects. Results show that energy crop cultivation stages counts for 70000 € per year and in terms of energy it is equivalent to electric energy supply for around 300 dwellings for the total amount of 1.034 GWh in one year.

Depositions and interviews underlined incapability for biogas to survive without incentives and the only perspective future looks like to be biomethane upgrading and injection into gas networks. Italian policies should be oriented towards such perception but an important factor has to be contemplated: NIMBY syndrome.

Some interviews within neighborhood next to some biogas plants showed lack od education towards such technology. A form of repulsion towards biogas plants, (Not In My Back Yard syndrome: not in my backyard). It is a psychological condition that is established in the population (usually in the embryonic stage of the project) that, even if it is proved by scientific data the safety of the project, can not accept the construction of the plant in its territory. Therefore, it is not a rejection to the construction principles for wanting to protect the environment, but only because you chose to erect a site near or next to your town.

7 Bibliography

[1] Labartino, Manfredi, Piccinini Fabbri, "Biogas, il settore è strutturato e continua a crescere," *L'informatore agrario S.r.l.*, pp. 11-18, 2013.

[2] Ettore Livini. (2016) Economia e Finanza. [Online]. http://www.repubblica.it/economia/affari-e-finanza/2016/05/09/news/lamara_fine_dello_zucchero_italiano_produzione_crollata_dell80_per_cento-139471537/

[3] GSE, "Energia da fonti rinnovabili -Anno 2014-," Rapporto statistico 2015.

[4] Giovanni Carrosio, "Energy production from biogas in the Italian countryside: Policies and organizational models ," *Energy Policy*, vol. 63, pp. 3-9, 2013.

[5] C., Lombardi Tricase, "State of the art and prospects of Italian biogas production from animal sewage: technical-economic considerations. ," *Renewable Energy* , vol. 34, no. 3, pp. 477-485.

[6] Christian Panzera, Gustav Rescha, Mario Ragwitzb, Gemma Reecec, Anne Held Reinhard Haas, "A historical review of promotion strategies for electricity from renewable energy sources in EU countries ," *Renewable and Sustainable Energy Reviews* , vol. 15, pp. 1003-1034, 2011.

[8] Pierluigi Navarotto, "Criticità dei piccoli impianti alimentati a reflui zootecnici," *L'informatore agrario*, pp. 16-19, November 2014.

[7] Donato Rotundo, "I nuovi incentivi agli impianti a biogas e a biomassa," *L'informatore agrario*, pp. 6-15, 2012.

[9] Marco Pezzaglia Elisa Codazzi, "I CONTENUTI DEL D.M. 23 GIUGNO 2016 FER NON FOTOVOLTAICHE ," *Biogas Informa*, vol. 17, pp. 32-37, 2016.

[10] NATHALIE BACHMANN, "Design and engineering of biogas plants ," in *The biogas Handbook: Science, production and applicaions*, IEA Bioenergy, Ed.: Woodhead Publishing, 2013, pp. 191-210.

[11] M. Caine, "Biogas Flares State of the Art and Market Review ," IEA Bioenergy, Topic report 2000.

[12] Angelika Steinhauser Dieter Deublein, "Measurement, control, and automation technology ," in *Biogas from Waste and Renewable Resources* , WILEY-VCH, Ed., 2008, p. 219.

[13] Nobuyuki Kawahara, Kazuya Tsuboi, Eiji Tomita Yungjin Kim, "Combustion characteristics and NOX emissions of biogas fuels with various CO2 contents in a micro co-generation spark-ignition engine ," *Applied Energy*, p. 9, August 2016.

[14] R.J. Crookes, "Comparative bio-fuel performance in internal combustion engines ," *Biomass & Bioenergy*, p. 7, 2005.

[15] EurObserv'ER, "Biogas Barometer," *Le. J. Des. Energies Renouvelables*, vol. 200, no. 2010, pp. 104-119, 2003.

[16] I. D'Adamo, M. Gastaldi F. Cucchiella, "Profitability analysis for biomethane: a strategic role in the Italian transport sector," *Int. J. Energy Econ. Policy* , no. 5, pp. 440-449, 2015.

[18] Technische Universitat Wein , "Biogas to Biomethane Technology Review," 2012.

[17] A. Hammar, and S. Ivarsson O. Jönsson, "Biogas Feeding To The Natural Gas Grid And Digestate Use In The Swedish Biogas Plant Of Laholm," Laholm Biogas AB, Report.

[19] Yehia A. Eldrainy *, Abdelhamid Attia Sameh Tawfik Abd Elfattah, "Upgrade Egyptian biogas to meet the natural gas network quality standard ," *Alexandria Engineering Journal* , vol. 55, pp. 2279-2283, 2016.

[20] S.T.A., Eldrainy, Y.A., Attia Elfattah, "Numerical simulation to optimize Di-Ethanol-Amine (DEA) strength for achieving the highest methane purity from biogas," *Int. J. Adv. Sci. Tech. Res.*, vol. 4, no. 5, pp. 742-751.

[21] SIemens, "Microgrids ," White paper 2011.

[22] Navigant Consulting for US Department of Energy and Energy Commission of the State of California , "Microgrids Research Assessment ," Final Report 2006.

[23] LIANG Huishi, SU Jian CHENG Lin, "Cost Benefit Analysis for Microgrid," *Proceedings of the CSEE*, vol. 31, pp. 38-44.

[24] Islanded Power Grids and Distributed Generation for Community, Commercial, and Institutional Applications, "Microgrids," Pike Research Report 2009.

[25] Power Systems Engineering Research Center (PSERC) , "Control and Design of Microgrid Components ," University of Wisconsin-Madison , Final Project Report 2006.

[26] GTM Research David J. Leeds, "The Smart Grid in 2010: Market Segments, Applications and Industry Players ," 2009.

[28] LI Heping, YUN Xiaoyin, LIU Xianming, "Biogas power generation technology and waste heat utilization technology ," *Huadian Technology* , vol. 31, pp. 74-78, 2009.

[27] LIU Jinpeng, WANG Guanqing. ZHAIHuijuan, "Benefits Evaluation of Large-Scale Biogas Power Generation Comprehensive Utilization Projects ," *East China Electric Power* , vol. 40, pp. 1241-1244, 2012.

[29] QI Hongbo, "Study of Wind Power and Biomass Power Generation ," *Application of energy technology* , vol. 4, pp. 39-42, 2015.

[30] Lei Yan, Lijie Yu, Jiayu Han Haifeng Liang, "Design of Micro-grid with Biogas Power Generation," State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources (North China Electric Power

University) , Hebei (China),.

[31] EEE Standard for Distributed Resources Interconnected with Electric Power Systems and all other new and revised parts of this standard, "IEEE Standard 1547TM".

[32] U.G Knight,.: John Wiley & Sons, 2001.

[33] Paul Fletcher Philip P. Walsh,.: John Wiley and Sons, 2004, p. 486.

[34] Ghazi TIM, Omar R, Idris A. Nasir IM, "Anaerobic digestion of cattle manure: influence of inoculums concentration ," *Int J Engin Technol*, vol. 10, pp. 22-26, 2013.

[35] Cesare Cremonesi, Giulio de Notaristefani di Vastogirardi, Massimo Dentice d'Accadia Francesco Calise, "Technical and economic analysis of a cogeneration plant fueled by biogas produced from livestock biomass ," *Energy Procedia*, vol. 82, pp. 666-673, 2015.

[36] Azienda Sperimentale Vittorio Tadini. (2011) [Online]. http://www.gasoff.eu/index.asp

[38] Shane Ward, Philip Owende Martina Poschl, "Evaluation of energy efficiency of various biogas production and utilization pathways," *Apllied Energy*, vol. 87, pp. 3305-3321, 2010.

[37] Sergio Piccinini Paola Vecchia, "Biogas e Parmigiano-Reggiano: una coesistenza possibile?," *I Supplementi di AGRICOLTURA*, vol. 48, pp. 22-26, 2011.

[39] Stefano Amaducci, Carlo Lorenzoni Mario Motto, "Mais, coltura ideale per produrre energia ," *L'informatore Agrario*, pp. 59-64, April 2008.

[40] Bianca Cavicchi, "Sustainability that backfires: the case of biogas in Emilia Romagna," *Environmental Innovation and Societal Transitions*, 2016.

[41] Corto Circuito -giornalino studentesco di R.E.-. (2012) [Online]. https://www.youtube.com/watch?v=jTAXCdSlk80

[42] Luca Gemmi, *PRIMA PAGINA* , pp. 5-6, Dicembre 2012.

[43] Paolo Mantovi Lorella Rossi, "Digestato: un utile sottoprodotto del biogas," CRPA Spa, 2012.

[44] Tommaso Lucchini, "Well to wheels analysis ," Energy Department , Politecnico di Milano, University Lecture 2015.

[45] P. Patrizio, G. Nardin D. Chinese, "Effects of changes in Italian bioenergy promotion schemes for agricultural biogas projects: Insights from a regional optimization model ," *Energy Policy*, vol. 75, pp. 189-205, 2014.