Implementing Biogas on Dairy farms in California

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Abstract

With an increasing interest for renewable energy and the focus on lowering the energy use around in the world, every energy source that isn’t used, which easily could be used should be used. Biogas is one of the unused energy sources that have a lot of energy potential using it the right way. Biogas production is a perfect example of having a waste product from one industry which can be used as a good fuel for another industry.

This project will analyse the opportunity to get as much energy as possible out of the collected biogas. Because of the big milk production in California there is a great opportunity to build some big biogas systems. Manure is collected in the cow barns and let to the digesters to produce biogas furthermore the air in the cow barns is ventilated through a membrane to capture the methane in the air in the cow barns. Producing biogas from manure is a well know technology, but collecting even more biogas from the air in the barn is a new way of thinking. The biogas is filtered and sent to a combined cycle with a organic rankine cycle implemented. The combined cycle has a higher efficiency than the traditional gas engines, by using the combined cycles the energy input/output ratio is the largest.

A combined cycle is more expensive than the gas engines and is normally not build as small as gas engines. It is suggested to build a gas grid to collect biogas from more than one farm to get a bigger plant and a lower investment for each farm. It is shown that it is feasible to build a biogas plant which collect biogas from both manure and air and that a combined cycle can be used as the power unit instead of a gas engine.

This is a solution which could be interesting in the future, when the energy prices is increasing and the natural gas sources is running out. In the future the energy systems have to be more efficient and not only cheap to invest in.

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The remaining is a group contribution
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1. Introduction

20 percent of all milk production in the US takes place in small areas in central California. In the top six counties live around 1.4 million cows. Cows produce energy in the forms of manure, methane and other gases. The methane gas pollutes 25 times more than CO₂ pr. molecule, which previously this year raised a discussion in the EU whether or not to tax gas emission from life stock. With the amount of life stock in California polluting methane is a big concern, but it is also a great renewable source. At the moment the US farms is emitting this gas without any legislation and no incentives to collect gas or the manure for use in a biogas facility.

We wish to explore the possibilities for building in EU well known biogas facilities on the Californian farms and adding new technology to make this an economical feasible product. We will describe to ways to collect biogas from the cows, and how to implement a combined cycle on a farm. One way is a chemical membrane combined with a ventilated cow house to collect methane from the air, the other way is a classic biogas facility where the gas is collected from the manure, and used in a gas engine. Gas engines are normally based on an even production of electricity and heat. This is not the best solution in California because of the low heat demand. To have a higher electric efficiency this report will explore the possibility to exchange the gas engine with a combined cycle based on a gas turbine and a steam cycle. Thus the questions to be answered are:

- How can the methane gas from livestock in California be captured?
- Can this methane gas and a simultaneous production of biogas from manure be processed effectively with a high electricity turnover?
- How will the biogas infrastructure look like in the counties?
- In what way can the initiative be feasible economically and apply with current legislation?

We expect to make a suggestion to the average Californian farmer which enables him to produce sustainable energy in collaboration with others, do something good for the environment and maybe save some money on the long run. We wish to explain the technical solution and estimate the solution as a package product to the counties.
2. Addressing climate problem and challenges in the feature

a. Kyoto Protocol

In 2005 the Kyoto Protocol took effect. Among other the following key elements of the Kyoto Protocol was decided:

**Key elements of the Kyoto Protocol [Kyoto]:**

**Gases:** Controls emissions of six heat-trapping gases: carbon dioxide (CO2), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

**Targets:** Assigns numerical targets for reducing or limiting emission, compared with a 1990 base, to 35 industrialized countries among 140 nations that ratified the pact.

**Trading:** Allows emissions trading among the 35 countries. Industrial plants that don’t use up allocations of gas output can sell the resulting “credits” to those who overshoot their allowances.

One of the important things in these elements was that it was decided to control emissions from six different gases, and among these gases methane is found. Methane is affecting the greenhouse gas emissions 25 times more than carbon dioxide. Furthermore it was decided to introduce targets and trading opportunity which gives a biogas power plant the change to sell credits by emitting less methane.

b. Reduction of greenhouse gas in California

Governor Arnold Schwarzenegger signed the AB 32 deal in 2006 with the promise of pursuing one of his main goals when he became governor, to make California nr.1 in the world in the global warming fight. By signing the AB 32 California is reaching for a 25% reduction in carbon emissions by 2020 which is the same level as in 1990. The goal is to reduce the carbon emissions as much as 80% of the emissions in 1990 by 2050[SLRGGG].

Some of these reductions could be reached by removing the methane emissions from the diaries farms and earn some money on the electricity production at the same time.

In 2013 California will determine if it should be mandatory for dairy farms to capture the methane in a manure digester to reduce the methane pollution [MMS].

![Figure 2.2: AB 32 goal for CO2 Equivalent Emissions [CGGR]](image)

c. Addressing methane from cows and manure as a global climate challenge

Denmark and Ireland have made a proposal on taxes on cows. In Denmark a price of 80€ pr. Cow is proposed and a price of 15€ in Ireland. This tax should pay the global warming penalty each country is facing. The Danish tax commission has estimated that a cow is emitting as much as 4 tons of methane each year; in comparison a car is emitting approximately 2.7 tons of carbon dioxide.
Due to this proposal using the methane in a biogas power plant is being considered. If such a proposal should hit US, the big dairy farms really would have to consider a method to remove the methane pollution [PTLDK].
3. Introduction to current biogas installations in California

a. Current installations

Biogas in California started back in the early seventies just after the first oil crisis in 1973 and then again after the second oil crisis in the start of 1979. The majority of those plants were terminated because of economic and technical reasons. In 2000-2001 California had an electricity crisis which resulted in several rolling blackouts because of electricity shortage [CALCRISIS]. The California government launched several incentives to make more decentralized power production [TWOAPP]. This brought back interest in biogas in California and the development was support by a California government. The programs were initiated by the California Energy Commission and the program was called the Dairy Power Production Program (DPPP). The key thing in this program was a $15 million in a grant for developing and installing a new generation of anaerobic digesters. Of the total $15 million, $10 million was assigned for dairies. This was given as a buy-down grant to reduce the initial cost. Up to 50% of the capital cost was the program allowed to found. There was also a possibility to apply for a production motivation. The majority of the biogas plant applied for the buy-down grant.

Out of this and other programs a total of fourteen biogas plants were approved and ten were built. Another four were added afterwards. According to The AgSTAR Program [AGSTAR], six are still in operation, but 4-6 have shut down due to economic or air emission problems. The size ranges from 40kW to 1500kW. It has not been possible to find the capacity factor for the operation but the statistics from AgSTAR shows that depending on the setup this is a difference in the population feeding the digester compare to the gas output. The gas output over the year will change because of change in feed consumption based on the temperature in barns/feedlots, the composition of the feed and etc. Those parameters influence the daily operations of the biogas plant, which makes a biogas plant a living organism and the power production will vary over different periods.

i. Technical information

The technical information for digesters in California is based information from Agstar [AGSTAR] and California Biomass Collaborative News letter [BIOMASSCA]. The technical information is brought overview over the current technology used in California and is not comparison of the technologies. The digesters are based on an anaerobic design, which is an air tight, oxygen-free container type which is fed with organic material. The organic material can have a brought range but in relation to farming it is animal manure, food scraps and organic material which are the most used. Biogas generation happens when this mixture produces methane gas and an odor reducing happens along.

ii. Digester

There are different digesters designs of the current biogas plants in California. Lagoon, plug flow and mix digesters. The most common one is the lagoon type. This is built by covering a large lagoon with a plastic cover and adds gas extraction pipes inside the lagoon. Covered lagoons are used with flush manure systems, which is a common system in California for cleaning and transporting manure in barns [FLUSHSYS]. The diluted manure will have a solid content in the 0.5 to 2 percent range. Often a solids separation system
is used before the liquid manure goes in to the 3 main digesters types in California. The separated fibrous solid is used for bedding. The solids separation keeps 80-90% of the fertilizer in the liquid manure.

Lagoon digester has a retention time in the interval 30-45 days depending on the lagoon size and layout. The biggest influents on the retention time are the temperature which speeds up the process and created a more stable gas production. The climate in California makes lagoon digesters an option and the daily operation is kept to a minimum.

Plug flow digesters is made with a horizontal vessel as the digester. There will be a ration in the area of 4-6:1 between the length and width. The advantage with this type of digesters is the possibility to operate with thick manure, which cow manure is. The typical retention time is 15-20 days. It does not need agitation but it is preferred with heating. This could be waste heat from the cooling circuit of the power generation engines.

Mixed digester is large containers with a mixer inside. It is often seen as a big tank with insulation, build of concrete or steel. It offers possibility to add feedstock for co digestion and increasing the yield of gas. The typical retention time is 10-20 days. It handles a lower content of solids compare to the plug flow digesters but slightly more than lagoon digesters.

iii. Combustion of biogas

In California the biogas program was created with the intention of electric production therefore boiler operation has not been used for biogas. It could be a possibility in feature plants. The most common combustion is gas engines and gas turbines. The majority of biogas combustion takes places in gas engines. Gas engines is typically heavy-duty industrial diesel engine’s which is rebuild into combusting biogas. Depending on the design there is requirement for scrubbing the biogas before entering the cylinders. Biogas is composed of methane (majority), carbon dioxide and a small quantity of gases like hydrogen sulfide. Some engines has problem’s running with hydrogen sulfide and this needs to be scrubbed before combustion.

Depending on the different type of energy use on the farm, cooling water from the engine’s can be used in a combined power and heating cycle. The heat put can be used for heating up the digesters, process and housing.

That process produces a biogas, which is composed mostly of methane and carbon dioxide and is generally contaminated with small quantities of other gases such as H2S.
b. Current legislations for biogas and parts products

i. Air Quality

California has the last many years had problems with smoke, dust and other pollutions which make the air quality in California to a massive problem. In the hot sunny summers there will be several days with bad air quality and this is particularly at the San Joaquin Valley. The valley covers most of the dairies in California.

The state’s air quality program is guide by California Air Resources Board [CARB] which is a division of the California Environmental Protection Agency. CARB makes suggestions to regulation. The state is divided into 35 local air districts which is responsible for administrating regulations and rules for stationary sources within the districts. As a side comment CARB is the agency which is going to implement AB 32 which is Global Warming Solutions Act of 2006. This is going to reduce the greenhouse gas (GHG) to the 1990 levels by 2020 and one of the reducing strategies is get more to use anaerobic digestions.

Until 2004 agriculture was exempt for permitting requirements but legislation SB 700 change that. Permits are now required if the emission is above 12.5tons per year. Also the biogas engines needs to meet the requirement of CARB which is based on Best Available Control Technology [BACT]. Currently few biogas engines can honor those demands and this created problems with expanding and building new plants.

ii. Water Quality

In California the State Water Resources Control Board [SWRCB] and nine regional boards has the responsibility for protection of water. The local boards regulated the waste discharges. If the discharge of waste, like degas biogas manure in to a open lagoon and irrigation with the liquid manure. The discharger (the farmer/cooperative) must submit a Report of Waste Discharge. This is reviewed in the local board and approved. If there is change in the character, location, or volume of the discharge it needs a new review.

The boards has expressed concerned with water quality with concerns to future expansion of in ground digesters [SWRCBOR] . The main concern is about leakage in the lagoons containing manure and digestion. The main way to take care of the leakage concern is installing a liner. This make is more expensive to rebuild a lagoon into a digester or build new lagoons.

iii. Solid Waste

Biogas plants produce different types of solid waste. Some of it can be composted into bedding or be used direct in the fields. Parts of the digestion create solid digestate which can be applied to the fields as soil amendment. The California Integrated Waste Management Board is one of the agencies which regulate composting. This is an issue if the dairy choose to compost the solids from the digester. There are also regulations if the composting is done on or offsite. The most common practice is to compost onsite in the moment but in the future there can be an objective in composting on larger sites.
iv. Nutrient management

The product which comes of the digester is methane and digested slurry. This slurry is spread the same way as liquid manure. The composition of digested slurry is different compared to liquid manure because of the mix of slurry and waste. There is also an organic matter because the slurry is partly degraded. This changes the fertilizing effect of the slurry. This is important to address when the fertilizing plans are made [LR]. This is particular the higher content of ammonia and the thin digested slurry which moves quickly though the soil.

v. NOx restrictions in California

As mention earlier CARB has divided California into 35 local air districts. Most of the dairies in California is located in the central valley and this area are under the San Joaquin Air Pollution Control District [SJVAPCD]. SJVAPCD has made a Best Available Control Technology Guideline [BACT]. SJVAPCD currently has a BACT NOx limit which is 9 parts per million by volume (ppmv). This emission level is hard to reach with a combustions engine without a NOx reduction system. Combustions engines are the most common way to combust biogas. It is possible to add equipment which reduces the NOx emission. There is different ways to lower the NOx content. Two of the technologies could be selective catalytic reduction [SCR] and exhaust gas recirculation [EGR]. SCR is done by injecting a catalyst into the exhaust gas. It has been shown to lower the NOx content 70-95%. Engines with internal combustion has the possibility to add exhaust gas recirculation which essentially takes 10% of the exhaust gas and recalculates back to combustion cylinder. EGR lowers the NOx content 40-50%.

Another possibility is combustion in a continuous combustion process, this is typical gas turbines with an advanced control strategy. Some gas turbines are already approved by CARB with a low emission of NOx. There have been some installations with micro turbines but not with the NOx controlled aspect. Our plant will use these NOx filters to lower the emission to less than 9 ppmv.
4. Suggested technology solutions

a. Capture of methane from the top of the barn

i. Why use the methane gas?

It is essential to optimize the economy and efficiency of installing a biogas plant on a Californian dairy/cattle farm or in a short distance of several farms in a community connected by a local gas micro-grid. To improve these factors, we suggest capturing the energy-rich methane from the cows and adding this gas to the conventional biogas plants volume of biogas.

Biogas plants in northern Europe are usually placed on swine farms, as the manure from swines can produce a large amount of biogas, while the methane emission from the animal itself is only a fraction. The swine manure methane production is larger than from manure from cows [DLT]. A single cow can produce approximately 587 ± 61 liters of pure methane per 24 hours, from which only 6% comes from the animals manure. This percentage will increase if the manure is appropriately treated in a biogas reactor, but the numbers clearly show high potentials for collecting the methane gas as of now is just literally escaping into thin air [COWGAS].

The concern of methane being a serious greenhouse gas has grown rapidly in Europe the last years and resulted in a proposal earlier this year to tax the methane emission from livestock. The idea never became legislation anywhere, of course, as the affected farmers competition abilities at the free market would be destroyed, but the discussion continues [TAX]. The reasoning follows here. It is well documented and thus now-a-days well accepted that global warming and climate changes are made or partly made by the human pollution with e.g. greenhouse gases. The UN appointed Intergovernmental Panel on Climate Change (IPCC) has attention on methane gas and advises a worldwide reduction. The IPCC reports methane gas as a 25 (averaged over 100 years) times worse greenhouse gas than CO₂, thus counting one molecule of CH₄ equal to 25 CO₂ equivalents [IPCC]. Cows in the US emit 5.5 million tons of methane per year (2004) and another 1.6 million tons is produced directly from manure or from the manure in uncelled lagunes for later use as nutrient on crops fields. This adds up to 71% of all methane emission in American agriculture [AIRPOL]. 10% of all greenhouse gas emitted in the US comes from methane calculated into CO₂ equivalents (680 million tons in 2004). Thus the cow emission comprises the following fraction: 5.5 + 1.6 * 25 = 177.5 million tons CO₂ equivalents, which is 26% of US total [US EIA]. As 21% of all cows in the US live in California, the methane amount is enormous and the environmental savings of capturing some of the gas have huge potentials besides the obvious economical perspective.

ii. How to capture the methane gas:

Previous interviews with Danish farmers have given an estimate of the pricing for running a farm. From that we have learned that upgrading a cow barn from the conventional simple and cheap ones with natural ventilation to a full modern stable with ventilation system and climate control will cost approximately $1500 per cow. This price would be lower in the US and also decrease with many more cows in each CA stable compared to the Danish average of 110 animals, but the cost is still considerable. Especially, as a
large amount of cooling energy would be needed in California. Instead, we propose to keep the natural ventilated stables, but install a ventilation system at the top of the barn which will create a lower pressure sucking the air upwards so all gas in the barn will go out through the ventilators at the top. Additionally, the roof of the barn will be extended outwards to ensure full capture of the gas emissions inside the barn (Figure 4.1):

- Figure 4.1: The cow barn before and after our installation. The arrows indicate air flow, the “V.” is the ventilation system.

The ventilation system will have to be exposed to huge amounts of air/gas/others and will need several inexpensive filters to separate the air from hay, grass, dust, particles etc. before sending the load on. The ventilation now leads the air flow through a key point. We will introduce a chemical membrane designed to purify methane from biogas to capture the energy rich methane gas from the barn air. This purified methane gas will then be send to a combustion chamber for further processing. See next chapter.

The purification of methane from biogas can be done in many ways and it has been when aiming at selling the methane as natural gas or fuel. The methods are primarily chemical and cryogenic separation combined with the use of highly elevated pressure. These methods are expensive and complicated, but new simpler methods are being investigated into and a such could be integrated in our solution. Experiments have been conducted using polyimide membranes and variations of this will be our suggestion for a methane purifier solution. These membranes part the gas into a permeate and a retentate portion and with biogas of high methane concentration, the result gas in the retentate could be up to 94% methane [IMIDE]. The membrane should consist of rigid polyimides. Non-rigid polymers such as polyether sulfones, polyphenylene oxides and polyimides have been reported as good gas separators, but with non-perfect preferences for various gasses that we wish to handle here. Non-rigid polyimides with specific aromatic sidechains are on the other hand more suited. Polyimides are chains of imides (see figure 4.2). We propose to use a chain of imides that originates from already patented gas separation membranes. The required membrane will demand further work but builds on the following configuration polyimide [PAT3]:

- Figure 4.2: Imide monomer
Figure 4.3: A proposal for a polyimide membrane structure [PAT3].

In figure 4.3; $X$, $X_1$, $X_2$ and $X_3$ are independent alkyl groups, preferably $\text{CH}_3$ or $\text{C}_2\text{H}_5$. $Z$ is one of them or a hydrogen atom. This structure delivers a highly permeable gas membrane that is rigid due to the large aromatic side chains being rotationally hindered. The composition depicted has gas permeabilities in the following preferable order: $\text{CO}_2 > \text{He} > \text{H}_2 > \text{O}_2 > \text{N}_2 > \text{CH}_4$ [PAT3].

This order results in the sorting of $\text{CO}_2$ and $\text{O}_2$ in the barn air from the methane and reaches the impressive 94% purity with a simple inexpensive membrane. This type of membrane will also remove some of the $\text{H}_2\text{S}$ that is unwanted in the gas processing. The pressure needed can be as low as 0.6 MPa, which should be possible to deliver through the ventilation system with the help of a compressor. A few consecutive membranes would ensure a high purification, but would require a larger pressure and would increase cost [IMIDE]. The membrane will be produced with a well-known method of glass transition. The liquid solution of polyimide mixture will be exposed for high temperatures of 300-400°C and rapidly cooled to form a thin layer while coagulating to a semi-permeable membrane. Many of these methods are patented and will have a production cost, however, still making the solution inexpensive [PAT1].

Alternatively, a polyester membrane with heavy aromatic side chains has proven highly permeable to methane leaving most other gasses behind. This could be introduced along with the polyimide membrane to ensure high efficiency with an unusual combination that sends the methane gas behind the polyimide membrane rapidly through the polyester membrane leaving the small rests of other gasses behind [PAT2].

It is difficult to estimate the capture percentage of this system without extensive testing, but as the barns are still subject to natural ventilation the capture is expected to lie around 70-80% of all methane from animals constantly living inside the barns.
b. The conventional biogas method

Figure 4.4: A conventional local biogas plant. 1: Manure, 2: Process storage tank, 3: process tank, 4: Storage tank, 5: Biogas, 6: Heat, 7: Gas processing, 8: Electricity. [DEVE]

Figure 4.4 above depicts what a biogas plant could look like. The storage tank and process storage tank can be exchanged with a covered lagoon like on the Gallo farm, California. This will however lose the temperature control and agitation in the tank and will most likely decrease methane production efficiency [DEVE]. A previous study has estimated the potential methane production out of the manure produce per cow. Each cow produces 24 kg of wet feces on average per day and that contains 2.8 kg of organic matter that if treated right can produce a lot of methane. Results for dairy cows show that the 2.8 kg organic matter can by anaerobic digestion produce 672 liters of methane (0.24 m³ CH₄ / kg organic matter) plus CO₂. This is the optimal potential for an average biogas system [MANURE].

Along with the capture of methane from the barn air, we suggest that large farms could benefit from installing a modern biogas plant. The plant could be as seen in figure 4.4, but could also be a covered lagoon with the up-scaled capacity. Either way, the process from manure to biogas by anaerobic digestion comprises the following steps (see figure 4.5). The first step is the breakdown of biomass into smaller units via hydrolysis. This step may be rate limiting. The second step is fermentation where the fermentative bacteria break down the compounds to small molecules like acetate, propionate, fatty acids, and alcohol. Third step is acetogenic bacteria oxidizing the products to acetate and reducing protons to hydrogen. Then the interspecies hydrogen transfer occurs where energy is produced and bacteria cultures grow. Now, in the fifth stage, the methane is produced by methanogenic archaea. 70% from acetate and 30% from hydrogen and CO₂. The resulting biogas ordinarily consists of 50-65% methane, 35-50% CO₂, 0-2% H₂S and traces of O₂, H₂, NH₄ and moist [DEVE].
Several methods can be applied to this system to improve the rate and efficiency of methane production, but that is beyond the scope of this report. However, it is important to point out that there will be a difference in the production when moving the digestion to a non-agitated, non-temperature controlled lagoon which most likely will be the solution in California. Large farms with many cows require large storage for the manure and the climate invites to save the money of a heating system. The temperature in the digester determines the species of bacteria for the process. The thermophilic is more efficient and faster, but require temperatures of 50-60°C, while the slower mesophilic delivers the job at 30-40°C [SLIDE].

Collectively, the full proposed system delivers a large amount of methane per cow that can generate energy. We suspect to capture a large fraction of the 587 liters (between 70-80%) of methane from the barn air and all of the 672 liters from the biogas, which combined gives 1.11 m³ methane per cow per day and some CO2 along with it (if the 672 liters are 57.5%, the CO2 is approx. 41.5% = 485 liters. This gives a 70% methane concentration that can be sent to processing. That can produce a lot of energy depending of the size of the farms livestock, as we will see in the next chapter.

The last issue to address before sending the gas through the pipeline to processing is the H2S problem. H2S will estimated be approx. 1% of the gas volume and is poison to a gas turbine. The solution will be to purify the gas from H2S with a scrubbing mechanism, which is an expense and will also have to be replaced every six months. The product will be pure sulfur.

c. Biogas installation with a small combined cycle

i. Combined cycle

A traditional biogas power plant is using a gas engine to generate power. The gas engines normally has an electrical efficiency (LHV) around 30-40%, the rest is lost to heat production. In California the heat demand is limited; this is why it would make sense to implement a power cycle with a better electrical efficiency. A
combined cycle has efficiency around 50-60% depending on the turbines; the concept of a combined cycle is modelled below:

\[ \eta_{CC} = 46\% \text{ (LHV)} \]
\[ \eta_{CC(\text{optimised})} = 51\% \text{ (LHV)} \]
\[ \eta_{CC+ORC} = 57\% \text{ (LHV)} \]

**Figure 4.6:** Sketch of combined cycle model with ORC

**TABLE 4.1:** Conditions of model

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<td>465.37</td>
<td>21</td>
<td>459.8</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>burner</td>
<td>biogas</td>
<td>0.13</td>
<td>58</td>
<td>15</td>
<td>-6927.1</td>
<td>2.99E+03</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>burner</td>
<td>FLUE_GAS</td>
<td>-2.67</td>
<td>1330</td>
<td>21</td>
<td>99.6</td>
<td>-</td>
</tr>
<tr>
<td>302</td>
<td>302</td>
<td>burner</td>
<td>HEAT</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00E+00</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>turbine</td>
<td>FLUE_GAS</td>
<td>2.67</td>
<td>1330</td>
<td>21</td>
<td>99.6</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>turbine</td>
<td>FLUE_GAS</td>
<td>-2.67</td>
<td>600.71</td>
<td>1</td>
<td>-820.9</td>
<td>-</td>
</tr>
<tr>
<td>102</td>
<td>102</td>
<td>turbine</td>
<td>MECH_POWER</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.45E+03</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>---</td>
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<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>heatex</td>
<td>FLUE_GAS</td>
<td>2.67</td>
<td>600.71</td>
<td>1</td>
<td>-820.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>heatex</td>
<td>FLUE_GAS</td>
<td>-2.67</td>
<td>120</td>
<td>1</td>
<td>-1360.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>heatex</td>
<td>STEAM</td>
<td>0.46</td>
<td>81.34</td>
<td>3.603</td>
<td>340.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>heatex</td>
<td>STEAM</td>
<td>-0.46</td>
<td>500</td>
<td>3.603</td>
<td>3485.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>heatex</td>
<td>HEAT</td>
<td></td>
<td></td>
<td></td>
<td>0.00E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Pump</td>
<td>STEAM</td>
<td>0.46</td>
<td>81.32</td>
<td>0.5</td>
<td>340.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Pump</td>
<td>STEAM</td>
<td>-0.46</td>
<td>81.34</td>
<td>3.603</td>
<td>340.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>205</td>
<td>Pump</td>
<td>ELECT_POWER</td>
<td></td>
<td></td>
<td></td>
<td>1.63E-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Turbine</td>
<td>STEAM</td>
<td>0.46</td>
<td>500</td>
<td>3.603</td>
<td>3485.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Turbine</td>
<td>STEAM</td>
<td>-0.46</td>
<td>249.17</td>
<td>0.5</td>
<td>2974.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>Turbine</td>
<td>MECH_POWER</td>
<td></td>
<td></td>
<td></td>
<td>-2.34E+02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Condenser</td>
<td>STEAM</td>
<td>0.46</td>
<td>249.17</td>
<td>0.5</td>
<td>2974.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Condenser</td>
<td>STEAM</td>
<td>-0.46</td>
<td>81.32</td>
<td>0.5</td>
<td>340.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>323</td>
<td>Condenser</td>
<td>HEAT</td>
<td></td>
<td></td>
<td></td>
<td>-1.21E+03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.7: Conditions of ORC plant**

The traditional combined cycle consists of a gas turbine and a steam turbine. The water in the Rankine cycle is heated through a heat exchanger from the exhaust gasses from the gas turbine. This causes a lower heat loss and higher electricity production. To get an even higher efficiency than a normal combined cycle, an organic Rankine cycle (ORC) is implemented to produce power from the waste heat from the steam cycle. An ORC is basically the same as a steam cycle (Rankine cycle), the media in the cycle is just a refrigerant instead of steam. In this case the ORC is using R113 as media, which due to its properties evaporates at a different temperature and has higher energy content. The ORC has the advantage that it can use the waste heat from any cycle to produce some electricity, the disadvantage is that it is pretty expensive which will be talked upon later in this report.
ii. Model

A model of a combined cycle has been made in DNA\(^1\) and a model of the ORC has been made in EES\(^2\). The fuel used in the model is a mixture of methane and carbon dioxide (75% CH4 and 25% CO2). The fuel input used in the model is 1100L of methane + 485L of carbon dioxide (found earlier in chapter 3), which is the amount that one cow can produce in one day. It is expected that the amount of cows producing biogas for the power plant is around 10.000 cows.

\[
\text{Density CO}_2 = 1.98 \frac{kg}{m^3} \\
\text{Density CH}_4 = 0.7 \frac{kg}{m^3}
\]

Using the two densities the flow into the combustion chamber was found to be 0.13 kg/s. The ambient temperature in California is set to be 25C in average.

If the Combined cycle is optimised the efficiency is around 51%, this is done by lowering the pressure after the steam turbine to 0.2 bars. This is due to the change in work produced by the turbine according to the following equation:

\[
W_{\text{turbine}} = \dot{m} * (h_{\text{in}} - h_{\text{out}})
\]

When the pressure after the turbine is lowered, the enthalpy is lowered \((h_{\text{out}})\), and thereby the turbine can produce more work \((W_{\text{turbine}})\). The mass flow in the steam cycle is constant \((\dot{m})\). On the same time the temperature after the turbine is lowered to around 90C before the condenser which gives the smallest heat loss and best electrical efficiency \((\eta_{CC})\) for the combined cycle. In this case the temperature would be too low for the ORC to work probably so in addition to add the ORC cycle the efficiency of the combined cycle is lowered and the pressure and temperature raised. If the pressure is raised to 0.5 bars, the efficiency on the combined cycle drops to 46%, and the temperature after the turbine is 254C which should be enough for the ORC to work probably.

The temperature in the chimney has to be around 120C to make sure that the flue-gas gets into the sky and not just dumps to the ground around the power plant. By setting this temperature the \(\Delta T\) in the heat exchanger is known and the amount of heat transferred to the steam cycle can then be calculated \((Q_{\text{heatexchanger}})\):

\[
Q_{\text{heatexchanger}} = \dot{m} * C_p * \Delta T
\]

Adding the ORC which has an efficiency of 20% gives a total efficiency of 57%. The following equation is used to calculate the total efficiency of the power plant:

\[
\eta_{\text{Total}} = \eta_{GT} + \eta_{ST} * (1 - \eta_{GT}) + \eta_{ORC} * (1 - \eta_{GT}) * (1 - \eta_{ST})
\]

Where \(\eta_{GT}\) is the electrical efficiency of the brayton cycle, \(\eta_{ST}\) is the electrical efficiency of the rankine cycle and \(\eta_{ORC}\) is the electrical efficiency of the ORC.

---

\(^1\) DNA – Dynamic Network Analysis – Developed on DTU at department of mechanical engineering

\(^2\) EES – Engineering equation solver – Academic Professional V8.200-3D (08/31/08)
The power production of the combined cycle + ORC is estimated to approximately 1.65 MW which is 165 W pr. Cow, compared to existing plants [JDFD] which is producing around 100 W pr. Cow ours is a little higher due to the extra biogas from the membrane, the heat needed to be removed is around 1 MW which as described earlier could be through a cooling tower or used for district heating of the digesters. More details can be found in the appendices in the models.

d. Biogas micro-grid

i. The microgrid between farms

A suggestion to collecting the biogas needed for the combined cycle would be to build a biogas micro-grid between the farms.

Figure 4.8: Sketch of gas micro grid system

In this way the farms could share the investment costs for the power plant, and still receive electricity to the farm. It is estimated that it would be possible to collect biogas from at least 10,000 cows on an area of 100km². The biogas grid would be like a natural gas collecting grid, with either fans or compressors to raise the pressure depending on the distance from the farm to the power plant. Furthermore a district heating grid should be implemented to heat up the digesters on the farms; which in this case is using the accelerated thermophilic process [JGFD]. This process needs waste heat to raise the temperature to 50-70C in the digester.

It would also be possible as described earlier to use a lagoon with the mesophilic process at a lower temperature which is the same method as used on the Gallo Biogas [JGFD]. In this case the heat from the power plant should be removed by a bigger cooling tower.
ii. Storage

It would make sense to have biogas storage close to the biogas power plant in case of low demand or breakdown. If one of the farms can’t deliver the amount of biogas that the power plant needs, it would be possible to transfer some biogas from the storage to the power plant.
5. Dairies in California

California is the United States largest milk-producing state [CHANGESI]. It is followed by Wisconsin, Minnesota, New York state and Pennsylvania. This five states producers more than half of the total U.S. milk production. The success in dairy production in California comes from environmental factors which is unique for California. Some the major factors has the reduce cost to house dairy cattle in wintertime, compare to Wisconsin and other cooler climates. It is possible to harvest corn two times a year and over a longer period of time. This reduces cost of feed storage and makes it possible to adjust the composition rapid during operations. Most of the milk production in California is produced in Central valley which has some limitations geographically, with Sierra Nevada and Rocky Mountains as obstacles for transport of raw milk. This has created large processing capacities in-state and large dairy organizations. The state’s population growth (figure 5.1) since the start of the sixties and still growing has created the steady demand for milk products and the motivated technology development of the complete operation, from cows to packing and delivery systems.

![Figure 5.1: California’s population growth](image)

i. Development in size

Milk production has been shifting towards California and other western states for the last decade. The older dairy’s with 0-500 cows goes into larger farms. Statics shows that the large farms which is getting build, has a size of +2000 cows. This size improved the economics in operations and reduction of the milk price for costumers. In California dairy’s with <500 cows account for 88 percent of the production in 2006 and in some county the average size is above 3000 cows [ECONDAIRY]. Even in the currently bad economic projects with 7500 milking dairy’s is getting built. This is to reduce cost of operations.

ii. Concentration of dairy’s

California produces 20% of the total milk production in the US according to US Department of Agriculture [CHANGESI]. Of the 34 milk producing counties in CA, six of them produce 89% of the milk production in the state [DASTATS].
TABLE 5.1: Dairies overview

<table>
<thead>
<tr>
<th>County</th>
<th>Number dairies</th>
<th>Average cows</th>
<th>% of total CA Cows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tulare</td>
<td>332</td>
<td>1450</td>
<td>28%</td>
</tr>
<tr>
<td>Merced</td>
<td>312</td>
<td>843</td>
<td>15%</td>
</tr>
<tr>
<td>Stanislaus</td>
<td>301</td>
<td>621</td>
<td>11%</td>
</tr>
<tr>
<td>Kings</td>
<td>166</td>
<td>1076</td>
<td>11%</td>
</tr>
<tr>
<td>Kern</td>
<td>55</td>
<td>3137</td>
<td>10%</td>
</tr>
<tr>
<td>Fresno</td>
<td>115</td>
<td>1050</td>
<td>7%</td>
</tr>
</tbody>
</table>

Those dairies have opportunity to implement either a small biogas plant with electricity production, injected biogas into the natural gas grid or go together in a cooperative with 2-10 farms and make a small-medium size power plant. Depending on the distances between the farms the last option can be an idea for future implanting of bio gas. An example is Tulare County. It covers 12,494 km² and with the assumption the farms is even distributed the average distance is 6km between farms [WIKITU]. This gives an indication of the distance which the gas needs to be transported to a central power plant. If a project was build the distances is properly shorter because the dairies is located outside towns and etc.
6. Economic analysis

a. Economical assumptions

There are numerous estimations connected to this analysis. The aim is to calculate whether or not it is economical possible to establish the facility and produce electricity on that facility. The top six dairy counties hold an average of 2,800 cows per farm. As it would be impossible for just one farmer to invest in such a biogas plant alone, a few or several farmers of nearby geographical distance must unite and invest as a group and share the plant. In this way, the large cost of the machinery would be divided between the farmers and the plant could be placed a close enough distance from each farm. Each farmer would still have to install a lagoon, a better ventilated barn or barns and the chemical membrane to capture the methane. The combined biogas will then be sent by piping to the central plant and processed into electricity. 3-4 farmers per plant seem most likely to share a plant given the infrastructure and capacity that can be achieved. Thus, the following calculations are done using 10,000 cows as the contributors to the methane volume. In this way the calculations can also relate to the many very large farms also present in California.

As stated in section 4c., the energy produced from these 10,000 cows is 1.65 MW of electricity. To find out if that amount of energy can be produced at a reasonable cost, we must estimate the costs of installing the whole plant and infrastructure and calculate a production price, which can be compared to our selling price. That is done using the biogas model calculator at [http://biomass.ucdavis.edu/calculator.html](http://biomass.ucdavis.edu/calculator.html). Table 6.1 below describes which parameter we have changed in the model. Others are left untouched/standard.

**TABLE 6.1: Important values for biogas model calculations [CALC]**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Reason for estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digester and Feedstock Handling System Capital Cost ($)</td>
<td>2,800,000</td>
<td>The larger part of the price goes to building covered lagoons. Other expenses are piping, H₂S scrubbing filter and the chemical membrane</td>
</tr>
<tr>
<td>Power Generation System Capital Cost ($)</td>
<td>7,000,000</td>
<td>A combined cycle is large and complicated compared to a traditional gas engine</td>
</tr>
<tr>
<td>Heat Recovery System Capital Cost ($)</td>
<td>0</td>
<td>We do not recover any heat</td>
</tr>
<tr>
<td>Gross Electrical Capacity (kWe)</td>
<td>3,000</td>
<td>Electricity produced before reduction of compressor, pumping and other usage by biogas from 10,000 cows</td>
</tr>
<tr>
<td>Net Electrical Capacity (kWe)</td>
<td>1650</td>
<td>After the above reduction. See Ch. 4</td>
</tr>
<tr>
<td>Capacity Factor (%)</td>
<td>85</td>
<td>We project a steady continuous methane production</td>
</tr>
<tr>
<td>Net Efficiency—Biogas to Electricity (%)</td>
<td>57</td>
<td>The percent of electricity of the energy produced. See Ch. 4</td>
</tr>
<tr>
<td>Methane Concentration in Biogas (% by volume)</td>
<td>70</td>
<td>The percentage of methane in the biogas is unusually high due to the net methane influx from cow emission. See Ch. 4</td>
</tr>
<tr>
<td>Methane Production (m³/kg VS destroyed)</td>
<td>0.24</td>
<td>The amount of methane that is produces on average from 1 kg of organic matter in the manure. See Ch. 4</td>
</tr>
<tr>
<td>Fuel Cost ($/t)</td>
<td>1</td>
<td>Covers only the transport of manure to the digester</td>
</tr>
</tbody>
</table>
Debt ratio (%) | 90 | Very speculative. Could be 100, could be 80, but has heavy impact on equity (here 10%), which the project is very sensitive to.
Economic Life (y) | 20 | A normal value and also the time the whole system is at least expected to last

The results from the calculations are as follows in table 6.2:

<table>
<thead>
<tr>
<th>Constant $ Level Annual Cost (LAC)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Real Cost of Money (inflation adjusted)</td>
<td>0.1263</td>
</tr>
<tr>
<td>Capital Recovery Factor (constant)</td>
<td>0.1392</td>
</tr>
<tr>
<td>Constant $ Level Annual Revenue Requirements ($/y)</td>
<td>921.209</td>
</tr>
<tr>
<td>Constant $ LAC of Electrical Energy ($/kWh)</td>
<td>0.0750</td>
</tr>
</tbody>
</table>

In words, the production of 1 kWh with our system will cost $0.075 through the investment period. Beyond the 20 years of investment the system will begin to produce very cheap energy to the farmer(s). To estimate if the investment is sound we can compare to the Net Energy Metering rates provided by the Californian utilities (see table 6.3). It shows that it could be possible to break even if making a deal with SCE. That depends on the duration of the various peak periods.

<table>
<thead>
<tr>
<th>NEM Bio Net Metering Rate, $/kWh</th>
<th>PG&amp;E</th>
<th>SCE</th>
<th>SDG&amp;E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-Peak</td>
<td>2.2 – 2.3 $</td>
<td>3.1 $</td>
<td>6.5 $</td>
</tr>
<tr>
<td>Mid-Peak</td>
<td>3.1 – 3.2 $</td>
<td>6.9 – 8.4 $</td>
<td>6.5 $</td>
</tr>
<tr>
<td>On-Peak</td>
<td>3.6 $</td>
<td>11.6 $</td>
<td>8.9 $</td>
</tr>
</tbody>
</table>

b. Sensitivity analysis

This analysis can generate an understanding of the different assumptions made via a graph that show the consequence of one of them being wrong. In a complicated calculation as above there are many parameters to take into account and several are pure guesstimates. To analyze a parameter among many, it is crucial to only change one thing at a time and then see the consequence. In this way, the sensitivity analysis will disclose which parameters are subject to the greatest sensitivity and thus where the model can be attempted manipulated to achieve better results.

The graph (Figure 6.1) show seven important parameter’s sensitivity to an increase or a decrease. The y-axis depicts the cost per kWh, while the x-axis shows the change in percent. The graph shows that the cost per kWh is very sensitive to dept ratio and capacity factor. It will not change much to further increase the capacity factor, but on the other hand would it be quickly be bad if it dropped some percents. The dept ratio is not dept itself, but reflects the danger of investing money with equity. It is possible that the farmer
can invest with bank dept alone or contribute with private money so equity can be deleted. If the latter is an option, the dept interest rate poses less danger to the calculations. The last very important factor is of course the capital cost. We have little chance of estimating this correctly, but it seems that this parameter is only moderately influencing on the result. Even with a 50% increase, the kWh cost will not raise above $0.08.

![Graph](image)

Figure 6.1: Sensitivity analysis of the cost of producing 1 kWh via our biogas plant [CALC]

If different payback periods are considered, the impact on the graph is solid and very interesting depending on how long the plant can run efficiently (not shown on graph). Another factor is the input of methane. It is clear that more methane influx to the system will create more value. Hence installing this system between even more farms with more cows could really benefit the KWh price even though lagoon, piping and membrane cost would increase, as the capital cost of the combined cycle constitutes the majority of the plant expense.
7. Discussion

In these days, energy is so cheap that no one really cares about using a little energy compared to having a low investment. In the future the price on energy must be changed and when this happens this technology is going to be very interesting. The theory of using the biogas from cows and to use it in one of the most efficient power cycles is really good, the only uncertainties is how the energy prices will change in the future, and how much profit this solution could give a farmer. Because of the blend of all the different technologies it is hard to give an exact payback time of the system which of cause is an important issue for investors. If the Californian government have any thoughts about implementing the methane taxes on cows and pigs, it would really boost the interest for ideas and projects like this Biogas system to save money.

This biogas facility is build with the thought that energy is the most valuable thing, but if the payback time is double of a conventional biogas plant, the farmers would probably choose the conventional system and not get as much energy out of the fuel as possible. From the calculations done in this report, it shows that it is possible to sell the electricity for 0.065-0.08$/kWh[EPIC] but it will cost 0.075$/kWh to produce the electricity. Without any initiative from the government with tax regulations or feed in tariffs for bio energy these systems is too expensive right now economical wise. This is if you only look at the income from electricity production, but actually there is a significant drop in use of fertilizer by using the digested manure. Existing farms with normal biogas facilities is reporting savings from 30-60.000$ just by using the digested manure [EXPBIO].

Another issue could be the special membranes used in this system to filtrate the air in the cow barns. The membranes have only been tested in small scale laboratories, in large scale there could be some problems that have not been dealt with. Maintenance of the filters after the membrane is another issue how often do they need to be changed, is it possible for the farmers to change them or is it professional work to change filters. From our point of view the membranes is believed to work in large environments as well as small.

Combined cycles is a well known technology which normally has a low maintenance cost compared to the produced energy, different filters needs to be changed and this cannot be done by the farmers, the plant needs to be controlled by a personal that has some power plant knowledge which is an ongoing cost compared to the traditional biogas plant. It might be possible to control the power plant from another power plant so the need for people on the plant is minimal. The combined cycle in this project is a simple cycle which can be optimized with reheat and dual pressure turbines which would improve the efficiency of the plant, a state of the art combined cycle has the possibility to run with an electrical efficiency as high as 60% (LHV), and in combination with the ORC the cycle would have an even higher efficiency. It has to be taking into consideration how much an ORC cost compared to the amount of electricity the power plant gains by installing it, would it make more sense to use the extra money on a better digester instead of a lagoon, or maybe using the costs on implemented ground heat under the lagoon.

One thing is for sure, Biogas is an unused source that has a lot of potential to produce some green energy and by using the system shown in this report, the maximum amount of methane is taken from the barns (as mentioned in chapter 4, a closed barn would be the optimal solution), and the maximum electricity is produced from the gas compared to other up to date solutions.
8. Conclusion

Biogas is a mature technology in California, it has a proven track record for burning/combusting methane and create energy with supply’s the grid with electric and some places heat. Unfortunately a low percentage of the dairies in CA have a biogas plant installed and few of the installed is in operation. There is different ways to address see these issuers. The main thing is the incentive to build biogas and regulatory to operated them. Currently the installation cost and business case is too expensive to installed biogas without grants, buy down or feed-in tariff. Regulations in the area of air quality and NOx controlled, creates multiple barriers for operation and building new biogas plants.

To create a new generation of biogas plant technology can to some extend address see some of the current regulations and maybe created attractive business case. This report has tried to look out to the general power industry and see which solutions there can be possible to address see some of the regulations. Biogas is more than just the manure; biogas is also the gas which comes of the cow under daily digestion. This gas can be clean and used for combustion. Being a greenhouse gas, this can be a way to reduce the GHG and the improved the biogas electric production.

Combine with a manure digester, chemical filter and a modern power plant with gas turbines this can improved power generation and applied to the current regulations. This can be done with a minor trade off in NOx. This can be seen as a minor trade compare to the possible reduction of greenhouse gas, odors and more. But in California there many different regulatory which takes care of individual needs. Some of those boards needs to get together and flexibility to implement more biogas into California.
9. Recommendations for future work

The next step in this project would be to look closer into the different prices on the different components in the system. Get a real proposition from a company on the price of the combined cycle and the biogas collector system.

A big step in the future would be to build a pilot plant in corporation with one of the Californian Diary farms. This would give the best experience with the different technologies, and at the same time give some numbers to show the government.

Eventually it would be good to make an even more detailed modelling of the total plant and not only the power plant but including the biogas facility as well.

The uncertainties in building the gas grid as well as the chemical membrane and a combined cycle in this scale should be investigated in the future to see if this idea is feasible or not.
10. List of references

[AGSTAR]:
http://www.epa.gov/agstar/accomplish.html#ca The AgSTAR Program

[AIRPOL]:
Steinfeld et al., Livestock’s Long Shadow – Environmental issues and Options, Food and Agriculture Organization at The United Nation, Rome 2006, Chapter 3: Livestock’s Role in Climate Change and Air Pollution.

[BACT]:
http://www.valleyair.org/busind/pto/bact/chapter1.pdf Best Available Control Technology (BACT) Guideline 1.1.1

[BIMASSCA]:
California Biomass Collaborative – Quarterly Newsletter Vol. 1 No. 1

[CALC]:
Biogas model calculator from http://biomass.ucdavis.edu/calculator.html

[CALCRISIS]:

[CARB]:
www.arb.ca.gov California Air Resources Board

[CGGR]:
California Greenhouse Gas Reduction –AB 32 & SB 375 -An Overview of Recent Legislation - Alexander Clayton - California State Polytechnic University, Pomona - February 6, 2009 -
http://leonard.csusb.edu/outreach/documents/FINAL_GHGReductionOverview-AB32_SB375_ARC.pdf

[CHANGESI]:

[COVERLAG]:
http://www.biogas.psu.edu/coveredlagoon.html Covered Lagoon

[COWGAS]:

[DASTATS]:
2008 Dairy Statistics Annual

[DEVE]:
Sannaa, Department of Environment, Technology and Social Studies, Roskilde University, Denmark: “The Development of Biogas Technology in Denmark: Achievements & Obstacles”.

[DLT08]:
Danish Agriculture in Numbers 2008, Yearly Report, Agricultural Council Denmark, Axelborg. (Danish)

[ECONDAIRY]:
Profits, Costs, and the Changing Structure of Dairy Farming. James M. MacDonald, Erik J. O’Donoghue
[EGR]:

[EPIC]:
Anders, University of San Diego, EPIC, “Biogas Production and Use on California’s Dairy farms”

[EXPBIO]:

[FLUSHSYS]:
http://www.bae.ncsu.edu/programs/extension/publicat/wqwm/ebae040_77.html  Dairy Manure Flush / Lagoon Treatment System Randleigh Dairy Farm

[IMIDE]:

[IPCC]:

[JGFD]:
Gallo Biogas System, California

[Kyoto]:
Key elements of the Kyoto protocol - http://public.sd38.bc.ca/sdweb/envstew/linksinfo/I01C6C4AD


[MANURE]:

[MMS]:

[PAT1]:

[PAT2]:

[PAT3]:

[PTLDK]:
Proposals to tax the flatulence of cows and other livestock have been denounced by farming groups in the Irish Republic and Denmark. - http://www.timesonline.co.uk/tol/news/environment/article5877416.ece

[SCR]:

[SJVAPCD]:
http://www.valleyair.org/  San Joaquin Air Pollution Control District
Jenkins, Bio Energy Lecture Slide Show, 08/27/09.
http://www.local-re.org/~locale/index.php/downloads/presentations


http://www.swrcb.ca.gov/ State Water Resources Control Board

From The Times, UK, March 10, 2009: “What do cars and cows have in common? No, not horns”, Carl Mortished.

Two Different Approaches to Funding Farm-Based Biogas Projects in Wisconsin and California Kevin Porter, Exeter Associates, Ryan Wiser and Mark Bolinger, Berkeley Lab

US Energy information Administration
Emissions of Greenhouse Gases Report
Released date: December 3, 2008
http://www.eia.doe.gov/oiaf/1605/ggrpt/

http://en.wikipedia.org/wiki/Tulare_County,_California
Tulare County, California
11. Appendixes

Appendix A – System model

Sketch of the full biogas system
Appendix B – EES model of Organic Cycle

\[ P^* = 'R113' \]

\[ T_7 = 249 \]

\[ T_8 = 81 \]

\[ P_7 = 0.5 \]

\[ x_8 = 0 \]

\[ h_7 = \text{h ('Steam', } T = T_7, P = P_7) \]

\[ h_8 = \text{h ('Steam', } T = T_8, x = x_8) \]

\[ m_{\text{steam}} = 0.46 \]

\[ Q_{78} = m_{\text{steam}} \cdot (h_7 - h_8) \]

\[ Q_{1011} = Q_{78} \]

\[ Q_{1011} = m_{\text{steam}_2} \cdot (h_{11} - h_{10}) \]

\[ h_{11} = \text{h (P}, P = P_{11}) \]

\[ P_{11} = 15 \]

\[ T_{11} = 200 \]

\[ s_{11} = s (P^*, T = T_{11}, P = P_{11}) \]

\[ s_{11} = s_{12s} \]

\[ h_{12s} = \text{h (P^*, } P = P_{12}, s = s_{12s}) \]

\[ \eta_t = 0.9 \]

\[ \eta_t = \frac{h_{11} - h_{12}}{h_{11} - h_{12s}} \]

\[ P_{12} = 0.5 \]

\[ T_{12} = T (P^*, P = P_{12}, h = h_{12}) \]

\[ x_{13} = 0 \]

\[ P_{13} = P_{12} \]

\[ h_{13} = \text{h (P}, P = P_{13}, x = x_{13}) \]
\[ s_{13} = s(P$, \ x=x_{13}, P=P_{13}) \]
\[ s_{13} = s_{10} \]
\[ T_{13} = T(P$, \ P=P_{13}, h=h_{13}) \]
\[ h_{10s} = h(P$, \ s=s_{10}, P=P_{10}) \]
\[ P_{10} = P_{11} \]
\[ \eta_p = 0.9 \]
\[ \eta_p = \frac{h_{10s} - h_{13}}{h_{10} - h_{13}} \]
\[ T_{10} = T(P$, \ P=P_{10}, h=h_{10}) \]
\[ W_{113} = \dot{m}_{\text{steam}2} \cdot (h_{11} - h_{12}) \]
\[ W_{\text{pump}} = \dot{m}_{\text{steam}2} \cdot (h_{10} - h_{13}) \]
\[ W_{\text{total}} = W_{113} - W_{\text{pump}} \]
\[ Q_{\text{out}} = \dot{m}_{\text{steam}2} \cdot (h_{12} - h_{13}) \]
\[ \eta_{\text{total}} = \frac{W_{\text{total}}}{Q_{1011}} \]
\[ c_{p_{\text{and}}} = C_p('H2O', T=20) \]
\[ Q_{\text{out}} = \dot{m}_{\text{ORC}} \cdot c_{p_{\text{and}}} \cdot (70 - 35) \]
\[ \eta_{\text{cc}} = 0.3846 + 0.1225 \cdot (1 - 0.3846) + \eta_{\text{total}} \cdot (1 - 0.3846) \cdot (1 - 0.1225) \]
### Unit Settings: (kJ)/(C)/(bmr)/(kg)/(degrees)

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12 potential unit problems were detected.

Calculation time = 0 sec.
Appendix C – DNA Model

Title Gas Turbine

FLUID biogas CH4 0.70 CO2 0.30

media 1 SIMPLE_AIR 15 biogas 3 FLUE_GAS

struct compressor compre_1 1 2 301 101 0.9 0.9
addco p 1 1 t compressor 1.25
start m compressor 1.4 61
addco p 2 21
start t compressor 2.465 q compressor 301 0

struct burner gasbur_2 2 15 3 302 1330 1
addco q burner 302 0 t burner 15 58 p 15 15
addco m burner 15 0.13

start y_j FLUE_GAS O2 0.1 y_j FLUE_GAS N2 0.9

struct turbine turbin_1 3 4 102 0.9
media 3 FLUE_GAS
addco p 4 1
start t turbine 4 595

struct heatex heatex_2 4 5 6 7 304 20 0 0
media 4 FLUE_GAS
media 7 STEAM
addco T heatex 7 500
start m heatex 7 -0.80
addco t heatex 5 120
addco q heatex 304 0

STRUC Pump LIQPUM_1 9 6 205 0.9
start P 6 3.4
START T Pump 6 81
START E Pump 205 0.2693

STRUC Turbine TURBIN_1 7 8 112 0.9
start II Turbine 6 2984

STRUC Condenser STECON_0 8 9 323 0
ADDCCO p 9 0.5
START X Condenser 9 0
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**MECH. POWER PRODUCTION** = 2625.0377 kW
**TOTAL POWER CONSUMPTION** = 1295.6876 kW
**NET POWER PRODUCTION** = 1329.3501 kW
**FUEL CONSUMPTION (LHV)** = 2988.1339 kg/s
**FUEL CONSUMPTION (HHV)** = 3487.3100 kg/s
**THERMAL EFFICIENCY (LHV)** = 0.4660
**THERMAL EFFICIENCY (HHV)** = 0.5953

**MAXIMUM RELATIVE ERROR** = 7.3019E-15
**COMPUTER ACCURACY** = 2.210E-16

**IDEAL GAS COMPOSITION (MOLAR BASE):**

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**MEAN MOLE MASS** = 0.2500E+02 | 0.2438E+02 | 0.2560E+02
**NET CALORI VALUE** = 0.0000E+00 | 0.2239E+05 | 0.0000E+00
**GAS CALORI VALUE** = 0.0000E+00 | 0.2698E+05 | 0.0000E+00

**MEDIUM 39 : WATER**
**MEDIUM 300 : HEAT**
**MEDIUM 301 : PRODUCT HEAT**

**NUMBER OF CLOSED INTERNAL LOOPS IN THE SYSTEM:** 1
SOLUTION FOR THE INDEPENDENT ALGEBRAIC VARIABLES:

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