Comparison of Biogas and Bioethanol for Sweden Transportation Fleet

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Abstract:

Biofuels were recently seen as a solution for the predicaments of our age; the “energy crisis” and the” climate change”. Today biofuels derived from food crops are a subject of debate for food hunger of the world’s poor and one of the main reasons of increased food prices. Latest studies also show that biofuels have no significant reduction in energy consumption and emissions. Today many attentions have been focused on biofuels extracted from biomass of different residual material such as agriculture residuals. Sweden produces biogas from different sources and also is one of the main users of Brazil’s bioethanol.

In this report we aim to study two biofuel alternatives for Sweden transportation fleet; biogas from sugar beet residues in Sweden and imported bioethanol from sugarcanes from Brazil. The study is based on a life-cycle assessment (LCA) of the two mentioned biofuels. Three main units of agriculture, industrial production process and transportation is studied in the life cycle of the mentioned fuels.

Based on energy inputs and emissions biogas from sugar beets in Sweden is a better alternative for Sweden transportation fleet. Bioethanol from Brazil is a crop-based fuel and highly energy consuming in the agricultural operations and industrial production process. Biogas fuel production requires increase in production capacity and technological developments.

Keywords: Biofuel, biogas, ethanol
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Chapter 1: Introduction

1.1. Historical background

In ancient times, with the invention of fire, “wood” became the premier form of biofuel. With the exploration of fossil fuel resources such as oil and gas, low price and availability of such resources along with the acceleration of technological development, the production and utilization of biofuels suffered a severe impact (History of biofuels, 2010).

The first technical advances in the field of biofuels took place during the Second World War due to the shortage of imported fossil fuel and the high demand of biofuels as an alternative fuel. In this stage many crops such as potato and peanut were used for the production of alcohol and diesel fuel mainly in Germany and Britain. While major technological changes took place in periods of war, during the period of peace, cheap oil from the Middle East and the Gulf eased off the pressure (Bolling and Suarez, 2001).

Today, crops used for biofuels production vary from country to country for instance in the US, maize is the major crop for bioethanol production while in Brazil sugarcane is cultivated for the same purpose. Currently, Germany is the largest biodiesel producer mainly from rapeseeds (World Bank, 2006). Bioethanol from cereals such as maize and sugarcane, and biodiesel from rapeseed are the two major biofuels in Europe with rapid increase in production (Euroobserver, 2007). Today Sweden, France and Germany are the largest producers and users of biofuel in Europe. Figure 1 shows the share of renewable energy sources in the United States of America. Apart from energy shortages, today climate change and environmental
impacts of fuels along with concerns on global food supply has brought up the importance of optimal management of our consumption and production of fuel sources. Currently major biofuels, such as bioethanol and biodiesel, are derived from crop plants and engage major industries of agriculture, industrial production process and transportation. Therefore it is crucial to investigate the energy consumption and environmental impacts of the biofuels as alternatives to fossil fuel.

The current interest towards biofuel production and utilization is mainly due to various facts such as environmental benefits in regards to greenhouse gas emissions and more environmental friendly fuels. Biofuels combustion emits less polluted particles which are important for the human health. Biofuels are also an available fuel for all countries, while fossil fuel resources are limited in terms of region and time. Apart from the existence of commercial technologies which allow fermentation of cereals in order to produce biofuels, the necessary infrastructure for biofuel distribution exists. Another positive aspect of biofuels is the potential to blend with petrol and diesel. There are also various incentives for energy, climate and
agricultural policies which promote biofuels due to suitability issues for example many governments have arranged high profits for farmers which grow crops for energy purposes comparing for food production due to various economical incentives. Biofuels have the advantage to recover energy from a wide range of left over material such as agricultural by-products and residues. Above all governments are highly concerned about biofuel application mainly in order to comply with international commitments and their energy Security (Börjesson and Mattiasson, 2007)

1.2 Aim and objectives

This study aims to compare the two major biofuels, biogas and bioethanol, for Sweden transportation fleet. In order to reach this aim, energy inputs and emission outputs in the life cycle of the two corresponding fuels have been studied. The life cycle studied includes three main units of agriculture, industrial production process and transportation. Shipment of bioethanol from Brazil to Sweden has also been considered in the bioethanol life cycle.
Chapter 2: Theoretical Review

2.1. Energy crops

Energy crops are plants cultivated with low maintenance costs with the aim to exploit its energy content. Energy crops production is an emerging field in agricultural science and industry which is enforced by the Renewable Energy Sources Act in Europe. The new paradigm in the agriculture industry is the shift from crops for food production to the production of energy crops for fuel purposes. Regarding qualitative aspects, increase in protein content of food crops will be replaced by maximizing the dry matter content or yield per area unit in energy crops. In other words, plants high in glucose and sugars can be used as energy crops while lignin and cellulose contents are not suitable, since these two hydrocarbons cannot be digested in current biofuel production processes such as the bioethanol production. (Sticklen, 2008).

Energy crops consist of a "closed-loop process" which they grow particularly for their potential to generate energy. Crops such as switch grass, woody crops (e.g. Willow, Poplar and Cottonwoods, hybrid Willows) and sugarcane are being studied in order to investigate their potential to serve as an energy crop for fuel production (McKendry, 2002). The advantage of these crops is that they are short-rotation and multiple–harvesting crops, which grow after each harvest without the need of re-planting (Sims. 2001). Crops such as corn and sorghum serve as dual purpose with the ability to be grown for fuel and the leftover by-products could be used for other purposes, including animal food and fertilization.

Sugarcane is a tropical crop which is processed into raw sugar and molasses. Since alcohol is a result of fermentation of sugars, it could be easily gained by converting
sugar crops such as sugarcane and sugar beets into alcohol. Forage and sugar beets are known as energy crops due to high organic dry matter yield per hectare and are also easily ensiled and stored for the use through the whole year.

One the main factors influencing the development of energy crop production for biofuels is market developments in relation to politics in the field of agriculture and energy. Regress in the legal promotion of energy crops will result in the collapse of recent developments of energy crop production (Rode et al. 2005).

### 2.2. Main issues facing biofuels

Since the development of biofuels, many issues have raised from the use of biofuels as the replacement of fossil fuel. “Food crisis” is the main issue of biofuel development since apart from monoculture of energy crops for biofuel production, a large portion of food crops are being fed to vehicles while based on UNDP statistics more than 1.02 billion people of the world population are suffering from famine (FAO, 2009). The rapid increase of energy crop demands as a source of biofuel has lead to other important social-economical issues as follow (Global Forest Coalition, 2006):

- Increased land competition which results in further land concentrations, demotion of small-scale agriculture and the extensive conversion of forests and other ecosystems
- Drastic increase in food prices leading to hunger, malnutrition and poverty amongst the poorest sectors of society due to the conversion of arable land for growing fuel crops
- Extensive use of agrochemicals e.g. fertilizers and pesticides which deteriorate and decline human health and ecosystems
- Destruction and pollution of watersheds e.g. rivers, lakes and streams
- Local and regional climate extremes such as droughts
• Extensive use of genetically modified organisms (GMO) leading to extraordinary risks

• Destruction of the traditions, cultures, languages and spiritual values of indigenous peoples and rural communities

2.3. Biofuel life cycle

Fossil fuels are limited for use in vehicles due to high emissions and the high contribution to global warming. Biofuel alternative to vehicle fuel is also a major issue of debates today since the biofuel life cycle consists of major industries of agriculture, biofuel production processes and transportation which have considerable emissions and other related environmental issues. In the following sector the three main industries and the major operations in the life cycle of biofuels will be mentioned.

2.3.1. Agriculture industry

Agriculture is the process of exploitation of soil, water and air by humans in order to fulfill their principle need of hunger and shelter and is in close connection with the ecosystem which bears upon all living beings. By increase in the global population and evolution of techniques, agriculture is no longer a simple mean of earning livelihood, but has become an industry which deals with major amounts of matter and energy. Today, agriculture is a major industry affecting economic activities and employment in the society.

Agriculture is also one of the main targets for climate change effect studies since it is intimately affected by climate and on the other side it affects the climate as a major origin of emissions. As an example, the studies published by IPCC indicate that between 1970 and 1990 direct emissions of greenhouse gases (GHGs) from this
sector grew by 27% (IPCC, 2007). Apart from energy crisis the global water crisis is facing the world and the agriculture sector is the largest consumer of water, up to 75%, particularly due to inefficient management and non-sustainable practices (Cornish et al., 2004). Therefore mitigation measures and sustainability issues are of great importance in the subject of agriculture production and management.

Energy in agriculture is mainly used for irrigation and ground water pumping, farm machinery such as thresher and tractors and also transportation. While neglecting the direct emissions from fuel combustion, the major emissions from agricultural operations are due to fertilizer production, mismanagement of soil and water, tillage, and inappropriate cropping patterns (Giampietro, 2003). Fertilizers are one of the largest sources of emissions in the agriculture sector, for example agricultural soil naturally release nitrogen dioxide that is increased by fertilization and study’s of the United States Environmental Protection Agency (EPA) show that 38% of nitrogen dioxide is of fertilizer applications (EPA, 2006). The beginning of the green revolution in agriculture (1943-1970), caused a great increase in emissions from the agriculture sector, for example, “Intensification” which is the cultivation of bicrops has increased the emission from soil due to distribution of hybrid seeds, high consumption of fertilizers and pesticides, and irrigation.

Today, biofuel extracted from agriculture and livestock waste is an alternative to fulfill the expanding need to fuel our automobiles. Energy crop plantation for fuel application is a major issue such as the need of intensification, nutrient depletion, soil erosion, followed by massive energy inputs and emission outputs solely from the agriculture industry.

2.3.1.1. Production process of arable crops

Energy crops, as any other crop, are produced in a process of operations which require energy and emit gases, and are of great concern for sustainable management
and development. The agricultural operation considered in this report for energy crops are the following stages (campus et al., 2004):

**Ploughing:** The initial stage of crop cultivation is ploughing, which includes soil preparation operations for sowing seeds and planting crops. In this group of operations the upper layer of soil is turned over in order to improve the soil structure for supporting the newly grown plant, efficient aerations and water penetration and also incorporating the residue from the previous crop into the soil. Ploughing reduces the frequency of weeds in the field and eases later planting processes. Most tractors and agricultural machinery used in this stage consume fossil fuels which have high contribution to energy consumption in the agricultural operations. Emissions in this step are direct emissions from fuel consumption in agricultural machinery and soil disturbance. In this report direct fuel consumption of machinery and the fuel consumption in the industrial production processes have been considered.

**Seeding:** This group of operations is done for preparing the soil bed for sowing and germination of plant seeds by machine or hand sowing. Machinery such as tractor driven seed drills combined with rollers is used. Since the soil disturbance in this stage is low in comparison with other stages, energy consumption and emissions are low too.

**Fertilization and chemical application:** Studies show that the major problem of fossil fuel use in industrial farming is not transportation of material and food or fueling machinery; but chemicals. More than 40% of energy consumption in agriculture and food system goes towards the production of artificial fertilizers and pesticides (Center for Sustainable Systems, 2009).
**Fertilizers:** Plant productivity is limited by the lack of nutrients therefore fertilizers are applied in order to improve crop growth which could be either organic or mineral substances (Gellings and Parmenter, 2004)

- Mineral fertilizers: This group of fertilizers are artificially produced from minerals and fossil resources. The most energy intensive mineral fertilizers are nitrogen while phosphate fertilizers are produced from resources of phosphate rock (Table 1, Figure 2).

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen</th>
<th>Phosphate</th>
<th>Potash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>69530</td>
<td>7700</td>
<td>6400</td>
</tr>
<tr>
<td>Packaging</td>
<td>2600</td>
<td>2600</td>
<td>1800</td>
</tr>
<tr>
<td>Transportation</td>
<td>4500</td>
<td>5700</td>
<td>4600</td>
</tr>
<tr>
<td>Application</td>
<td>1600</td>
<td>1500</td>
<td>1000</td>
</tr>
<tr>
<td>Total</td>
<td>78230</td>
<td>17500</td>
<td>13800</td>
</tr>
</tbody>
</table>

Table 1: World average energy requirements for inorganic fertilizer production (kJ/kg) (Helsel, 1992)

- Organic fertilizers: This group of fertilizers are composed from organic and mineral substances. Organic fertilizers are mainly wasted materials and processed residues
such as manure, compost and even the biogas digestate from the biogas plant (Gellings and Parmenter, 2004).

Fertilizers, chemical pesticides, hybrid seeds, and special feed supplements for livestock are characterized as an indirect energy consumer on the farm and a majority of this energy consumption is accomplished away from the farm. Tractors, irrigation pumps, and other types of agricultural equipment are considered as direct energy consumers (Gellings and Parmenter, 2004).

The main aim of fertilizer application is to maintain soil fertility and increase crop yield. Since 1900s, fertilizer applications have grown extensively and in many developing countries continue to grow at a steady rate. By increase in world population fertilizers have become an important element in worldwide food production since fertilizers enable higher yields on less crop area than it would be required without the use of fertilizers. In spite of their benefits, production of fertilizers has high energy consumption, particularly natural gas. Due to energy limitations and high fuel costs it is necessary to implement energy efficiency measures in the production and use of fertilizers (Table 2).

Table 2. Carbon emissions from the production of fertilizers (Lal, 2004)

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Equivalent Carbon Emissions (kg CE/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>0.9-1.8</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>Lime</td>
<td>0.03-0.23</td>
</tr>
</tbody>
</table>
**Chemical plant protection:** This stage consists of chemicals such as pesticides, herbicides, and fungicides, applied to protect plants against biological invaders which reduce the plant performance. These agents can cause problems to the environment and human health. They cause decrease in biodiversity on a large scale and human health problems by leaking into surface water and finally to drinking water. Since there is a small amount of material and energy flow related to pesticide production in relation to the total amount of all material flows in the overall life cycle, therefore in this report we will not analyze pesticides in detail (Hamilton and Crossley, 2004).

**Harvesting:** This stage includes operations of cutting, silage, cleaning, and storage in order to harvest the crop from land. Harvest is an energy intensive operation. After harvest energy crops are stored and stocked to be transported to the biofuel production plant. Raw materials for biofuel plants are first cleaned from dust and compressed in order to reduce the amount of oxygen and finally stored in special storage containers (Crofcheck et al., 2006)

**Ensilage:** Silage is the high–moistened forage that is fermented in the silo and stored, the process is called ensilage. Plant material suitable for ensiling are high in moisture, ranging from 55-75% which depend on the degree of compression, amount of water lost during storage and the storage construction. The reason for ensiling is that it influences the quality of silage. The silage must be compressed by tractors driven on the laid silage in the storage, in order to eliminate the oxygen as much as possible before covering the silage. After four to six weeks the silage is ready (Wegener et al., 2005).

**2.3.1.2. Ecological effects of energy crop cultivation**
Biofuels were firstly produced as fuel alternatives with the main aim of reducing emissions of greenhouse gases. Many prior studies found that the biofuel production will reduce greenhouse gases since the feedstock of biofuel industries, which were plants and crops, sequestered carbon during their growth on the field. Today results show that energy crop production on arable land has major ecological effects such as narrow crop rotations and intensive production systems which is a great issue between nature conservation and the agriculture industry. Energy crop production and its occupation have the following effects (Rode et al., 2005):

- Soil compaction which causes interference with other functions in soil such as the activity of vital micro-organisms. Soil compaction is the result of traffic of agricultural machines and mainly depends on factors such as soil quality, frequency, time and duration of machines used, and the weight and type of machine tires.

- Soil erosion largely depends on the kind of crop covering the soil, cultivation operations, topography, and crop rotation.

- Decrease in biodiversity as well as landscape features and their habitats. Cultivation of energy crops for biofuel production is a shift from biodiversity to monoculture in agriculture which increases the risk of crop failure followed by global food crisis.

- Soil depletion is one of the main results of energy crop cultivation. Monoculture of energy crops for biofuel purposes will extract nutrients and elements from soil leading to soil nutrient depletion.

- Food crisis for humans and animals

- Pests and aliens tend to survive in monoculture croplands
But with response to the high prices of energy crops farmers worldwide tend to convert food cropland, forest and grassland to croplands where grain or crops diverted to biofuel feedstock are cultivated. Studies on switch grass grown on U.S. corn lands for biofuel production, shows that emissions will increase by 50% which raises concerns about large biofuel mandates and emphasizes the importance and value of using waste products for biofuel production (Searchinger et al. 2008). Many opponents believe that biofuels increase greenhouse gas emitions since more land is being cleared. Biofuel production has also large impacts on ecosystems such as forests and rural livelihoods which are expected to accumulate rapidly. In countries such as Brazil which is a large scale exporter of biofuels, monocultures of crops such as sugarcane, corn, oil palm, soybean etc. is required. Monocultures of crops are not only a cause of ecological disasters but also the main cause of rural depopulation and deforestation worldwide.

2.3.2. Biofuel industrial plants

Biofuel plants vary in function and technology based on the kind of biofuel produced, for instance a biogas plant which its energy production is based on anaerobic digestion of biological material is a plant which constitutes of high resistant tanks, pipes and pumps and requires well maintenance of the whole system. Pretreatments of the raw material for the biogas plant depend on the kind of feedstock. While the bioethanol industrial plant performs fermentation on sugar crops in order to produce alcohol. In such an industry stages are more complex in order to pretreat the feedstock and there are by-products which should be cared (Anderson et al., 2003).

2.3.3. Transportation

Today transportation is a system standpoint in every industry and the global transportation emits 14% of the total CO₂ emissions (WRI, 2006). Transportation
consists of all modes of trucks, railroads, barges, and ocean vessels. The agricultural supply chain is a major user of the world’s transportation system therefore energy consumption and emissions of the transportation sector in agricultural studies should be taken into account in planning and assessing of the industry.

2.4. Bioethanol in Brazil

2.4.1. Ethanol

Awareness of current energy supplies, commitments to national and international climate change protocols and strong evidence of the large contribution of the transportation sector to global warming has focused the world’s attention on renewable and environmental friendly fuels. One of the various biofuel alternatives is ethanol from sugarcane crop which is the first production source of ethanol. Today the major suppliers of bioethanol production are Brazil and the US, holding 89% of the world’s bioethanol production (Wiessner, 2008). Bioethanol in Brazil is extracted from the sugarcane while maize is the main energy crop in the United States for bioethanol production. In 2008, Brazil produced 37.3% of the world’s total bioethanol used as fuel (Licht, 2001; The World Bank 2008). The use of bioethanol from biomass as a fuel was innovated in Brazil as a result of high fossil fuel prices and limitation of fossil fuel resources. Therefore the bioethanol production has great correlation with fuel prices. Bioethanol production was peaked in the 1980s and reduced as fossil fuel prices declined. Later on higher oil prices, reduced cost of bioethanol production, design of dual-fuel vehicles and environmental aspects such as the climate change lead to increase in bioethanol production. Today many countries are commencing the infrastructure and facilities for bioethanol fuel installation mainly due to environmental pollution by the transportation sector.
2.4.1.1. Bioethanol production (reaction)

The reaction below is common for the production of bioethanol in beverages and more than half of the industrial bioethanol. Simple sugar is the raw material for the reaction, and by a biological agent sugar is fermented to bioethanol and CO$_2$ (Donal O'Leary. 2000)

$$C_6H_{12}O_6 \rightarrow CH_3CH_2OH + 2 CO_2$$

The main biological agent in the reaction of bioethanol is yeast such as $Zymomonas mobilis$. (Gunasekaran and Chandra, 1999). The Feedstock for bioethanol production is biomass high in sugar, such as follow:

- Crops: sugarcane, corn, sugar beet, sorghum, switch grass, barley, kenaf, potatoes, sweet potatoes, cassava, sunflower, grain, wheat, straw, cotton
- Waste residues: bagasse, molasses

2.4.1.2. Bioethanol composition

Bioethanol is a straight-chain alcohol, with the chemical formula of C$_2$H$_5$OH. It is known as pure alcohol, which is volatile, flammable. Bioethanol used as fuel could have different compositions which differ in application (Donal O'Leary. 2000):

- Anhydrous ethanol: 100% pure ethanol suitable for blending with gasoline
- Hydrous ethanol: mixture of 95% ethanol and 5% water

2.4.1.3. Application of ethanol

**Fuel:** The major use of ethanol is as fuel and fuel additive for vehicle engines and motors. Ethanol as fuel could be hydrous or anhydrous differing in purity in the distillation stage. Many countries have replaced gasoline consumption with a mixture
of a certain percentage of bioethanol and gasoline which is called gasohol. Brazil has the largest bioethanol fuel industry.

**Industry:** Bioethanol is used as a chemical in industrial processes, also in industries of paint, perfumes and cosmetics and medicine and as an antiseptic. Bioethanol is an effective agent against bacteria and fungi and some viruses while not effective against bacterial spores.

**Beverages (portable alcohol):** The smallest share of bioethanol is among the beverages since beverages have other sources such as fruits and malt. Main bioethanol beverage markets are China, Russia, USA, Brazil and Japan. Bioethanol in beverages is expressed by volume fraction of bioethanol, percentage or alcoholic proof unit (Licht, 2001).

### 2.4.1.4. Ethanol industry

Ethanol (C$_2$H$_5$OH) is a clear and colorless liquid. All industrial ethanol is a mixture of 95% ethanol and 5% water and known as, 95% alcohol. Industrial ethanol is produced through five main stages as follow (Donal O'Leary. 2000):

1. Conversion of biomass to fermented sugars: In this stage a solution of sucrose from biomass is prepared and yeast is added, the mixture is then heated up to 250°C and 300°C. The enzyme, invertase, which is present in yeast, acts as a catalyst to convert the sucrose into glucose (C$_6$H$_{12}$O$_6$) and fructose (C$_6$H$_{12}$O$_6$) which are fermented in the next stage. In case of sugarcane based ethanol, this step is not performed.

\[
\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \xrightarrow{\text{(invertase)}} \text{C}_6\text{H}_{12}\text{O}_6 + \text{C}_6\text{H}_{12}\text{O}_6
\]

<table>
<thead>
<tr>
<th>Sucrose</th>
<th>Glucose</th>
<th>Fructose</th>
</tr>
</thead>
</table>

19
2. Fermentation of sugars to ethanol: Fermentation is the process where the glucose (C$_6$H$_{12}$O$_6$) and fructose (C$_6$H$_{12}$O$_6$) are converted into ethanol and carbon dioxide by another enzyme, Zymase, which is also present in yeast.

\[
\text{C}_6\text{H}_{12}\text{O}_6 \xrightarrow{\text{zymase}} 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2
\]

Glucose Ethanol

Plant components such as sugars, starch and cellulose can be fermented to bioethanol by microbes, since they are high in sugar content. Currently only sugar and starch from plants can be economically fermented and studies in order to ferment cellulosic compounds are to continue.

3. Distillation: In this stage separation and purification of ethanol is done. Ethanol is purified by distillation of the solution from the fermentation stage. This stage is performed in the production of ethanol fuel while the purity is limited to 95-96% due to the formation of water-ethanol azeotrops.

4. Dehydration: Five dehydration processes are used in order to remove water from ethanol. Due to energy savings many new method propose to omit distillation for dehydration and use physical methods to remove water from fuel.

2.4.1.5. Ethanol as fuel

Ethanol or ethyl alcohol is an alcohol which can be used as vehicle fuel, mainly as a biofuel additive for gasoline due to good combustion properties. Ethanol is efficient as fuel due to its high octane number and the high heat of vaporization and is an excellent fuel for spark ignition internal combustion engines. Ethanol is known to be more efficient in terms of environmental effects since it is less volatile than gasoline and has low photochemical reactivity in the atmosphere, reducing the risk of smog formation from evaporative emissions of pure ethanol (Rasskazchikova et al., 2004).
Ethanol is usually blended with a fossil fuel and two major ethanol blended fuels are E10 (10% ethanol and 90% gasoline) and E85 (85% ethanol and 15% gasoline). Vehicles which can run on higher blends require engine modification. Flexible-fuel vehicles which can safely run either on 100% bioethanol or on any combination of bioethanol and gasoline are recently designed in Brazil. In Brazil, bioethanol is either used as hydrous ethanol known as ethanol in 100% alcohol-fuelled passenger cars or is blended with gasoline known as anhydrous ethanol which the proportions is usually about 24% to operate in gasoline engines. Hydrous ethanol can be used in any proportion in flexible-fuel vehicles (FFV) (Macedo et al. 2008).

2.4.2. Sugarcane

Sugarcane is one the major agricultural activities in Brazil with 8 million hectares under cultivation in 2008. Brazil has the total annual production of 22.2 million cubic meter of alcohol (Ometto et al., 2009). Brazil is the largest producer of ethanol from sugarcane having the most successful biofuel programs and is the world's first sustainable biofuel economy. The US ethanol production is based on corn crops which have many drawbacks such as high dependency on subsidies for fuel blenders and ethanol refineries, use of food crops as a fuel source, driving more farmers to cultivate more corn and the conversion of considerable land for corn production. Generally corn is a high consumer of fertilizers and pesticides (National Geography, 2007). All reasons mentioned has raised corn prices and endangered food sources since corn and sorghum are the main source of food for the poor and undeveloped countries and the main exporter of this crop is the US which due to fuel requirements has changed its priorities from fuel to food. As mentioned Brazil's sugarcane based ethanol industry is far more efficient than the US corn-based industry. According to The Economist (The Economist, 2007), Brazilian distillers are able to produce ethanol for 22 cents per liter, compared with the 30 cents per liter for corn-based ethanol of the US. Apart
from industrial advantages, the sugarcane crop is one of the most efficient crops in the plant kingdom in terms of resource consumption due to efficient photosynthesis system.

2.4.2.1. Plant physiological
Sugarcane is known as a "harvester of sun" since this plant is highly efficient in converting solar energy into sugar and fiber. Anciently sugarcane was known as a great source of energy and today known as a source of fuel (Netafim's Agriculture Department, 2010).

Sugarcane is scientifically known as *Saccharum Officinarum* L., a perennial grass of the genus *Saccharum* -sacchar= sugar (Greek). This plant is native to warm temperate to tropical regions of Asia and currently its cultivation has extended to all tropical and sub-tropical regions, 36.7° N and 31.0° S latitude. Sugarcane has solid and fibrous, jointed stalks which are rich in sugar, two to six meters high and rich in sugar. Major commercial cultivars of sugarcane are complex hybrids (Naik, 2010). In the maturity stage of sugarcane, vegetative growth is reduced and sugar content of the cane increases. At the harvest stage the sugar content is usually 10 - 12 percent of the cane fresh weight. Increase in cane yield can reduce the sugar content (Netafim's Agriculture Department, 2010).

Sugarcane is one of the most efficient photosynthesizers in the plant kingdom. It is a perennial grass with C4- photosynthesis path with a maximum conversion efficiency of solar energy to biomass at 30°C and 380 ppm atmospheric CO₂, is 6% (Zhu *et al.*, 2008). C4 photosynthesis is an adaption method of plants to arid conditions; they have faster photosynthesis rates under high light intensity and high temperatures and result in better water use efficiency. These plants are seen to have higher sugar and
carbohydrate storages. Important characteristics about these plants are as follow (Hatch, 2002):

- A particular leaf anatomy termed “kranz anatomy”
- High water use efficiency
- High growth rates at higher light and temperature degrees
- Dimorphic and bi-functional chloroplasts
- A very low CO$_2$ compensation point
- High leaf photosynthesis rates connected to high light and temperature optima for photosynthesis.
- Increase of biomass and yield by increase in CO$_2$ and temperature

2.4.2.2. Sugarcane cultivation

Sugarcane crop cycle varies depending on local climate, agricultural practices and plant verities. The sugarcane crop cycle is 6 years in which five cuts and four ratoon cultivations are performed during the crop cycle and one field reforming is done (Macedo et al., 2008). Harvesting is done 12 to 18 months after cultivation and ratoon harvesting is done once a year, during four consecutive years. Cane productivity gradually decreases during years, leading to reduced sugar contents in canes. Sugarcane has the potential to re-grow five times after each annual cut therefore partial sugarcanes must be removed for planting new sugarcanes. Each year 20% of the sugarcanes are replanted. Removal of old canes are done by machines (35.8%) and chemicals (64.2%) (Ometto et al, 2009). Pesticides are also applied in this step before new planting. Plantation is only performed in the area necessary to re-grow new sugarcanes. Main fertilizers applied to sugarcane crop are the N-P-K which is spread by tractors, liming is performed in case of low pH soil. The harvesting operations are high in both energy input and emission outputs. Harvesting of sugarcane is performed from May to August in Brazil. In the studied region of Sao Palou harvesting is carried
out manually (63.8%) and by machinery (36.2%). Burning before harvest is to facilitate harvest operations such as burning of dried cane leaves and killing of poisonous snakes and spiders. Chemicals could also be an alternative to burning the canes. The average cane productivity in Sao Paulo region in Brazil ranges from 80 - 85 tone cane per hectare (Macedo, et al., 2008).

2.4.2.3. Sugarcane for Ethanol Production

Commercial ethanol can be produced from either corn or sugarcane, while ethanol from sugarcane is much simpler and only requires a yeast fermentation process. There are other factors that determine the feasibility of ethanol production such as energy and technical costs. Relative production costs, conversion rates, processing facilities and costs, governmental policies and facility construction are lower for sugarcane originated ethanol. Feasibility studies have shown that ethanol production from sugarcane is much feasible than corn which has raised the interests in the US for this feedstock (Jacobs, 2006). Figure 3 shows ethanol yield from different agriculture feedstock.

![Fig. 3: Ethanol yield from different feedstock (Biofuels2b2, 2010)](image-url)
Sugarcane is a renewable and agricultural source since apart from providing sugar as the main product, biofuel, fertilizers and fiber are gained. Fertilizers and several co-products have ecological sustainability. Molasses is another main product from sugarcane with culinary applications and is the main raw material for alcohol and alcohol-based industries. Bagasse is the fibrous residue remaining after the extraction of juice from the sugarcane and is currently being used as raw material in the paper industry and as fuel for the eco-generation of power and electricity in most sugar mills. Bagasse as fuel is 20.2Mt of oil equivalent (Macedo, et al., 2008).

2.4.3. Ethanol in Brazil

Brazil is the second largest ethanol producer in the world after the US and the largest exporter of ethanol. In 2006, the United States and Brazil were the major ethanol producers with the share of 46% and 42% respectively (The World Bank, 2008). US ethanol industry is based on corn while Brazil is based on sugarcane and currently half of the Brazilian cane is cultivated for ethanol production. Ethanol production in Brazil directly affects international prices of sugar. Sugarcane for fuel production in Brazil is mostly based on vast agricultural land and intensive application of chemicals such as fertilizers, herbicides, CaCO₃ for liming the soil, high water consumptions and etc. (figure 4).

![Scheme of bioethanol production in Brazil](image)
2.4.3.1. Sugarcane Industry in Brazil

Brazil is the world’s largest sugarcane producer, producing both sugar and ethanol with the potential to adjust sugar production rapidly to potential world sugar shortfalls and high international demands (Bolling and Suarez, 2001; The World Bank 2008). Sugarcane cultivation occupies an area of 20.42 million hectare worldwide with a total production of 1333 million metric tons. Brazil has the major area under sugarcane cultivation which is 5.343 million hectare (Figure 6), while the highest productivity stands for Australia with 85.1 tons/ha (Netafin's Agriculture Department, 2010). Figure 5, indicates the share of ethanol and biodiesel global production in 2006.

![Fig. 5: Percentage of global production of fuel ethanol and biodiesel in 2006 (Licht, 2007)](image)

![Fig. 6: Sugarcane harvested area in Brazil (Bolling and Suarez, 2001)](image)
In Brazil the Center-South and the North–Northeast are the main two regions of sugarcane production which differ in governmental and agricultural policies. The center–south region is governed by the Sao Paulo state which holds 60% of the sugarcane production, supplying more than 70% of the sugar output and 90% of the ethanol. The North-Northeast region, governed by Pernambuco and Alagoas states, holds less than 20% of the sugarcane production which covers 25-30% of sugar output and 10% of the countries ethanol production. Currently most of the ethanol is produced in the Center-South region (Bolling and Suarez, 2001) (Figure 7).

Fig.7: Sugarcane regional statistics in Brazil (Bolling and Suarez, 2001)

In the early 1970s petroleum shortage forced Brazil to start ethanol production by innovating methods to turn biomass of sugarcane to ethanol as an alternative source of fuel (Bolling and Suarez, 2001). Figure 8 indicates the proportion of alcohol and sugar production of Brazil from 1975 till 2002.
2.4.3.2. Industrial operations

There are great advantages of producing ethanol and sugar simultaneously, therefore the most adopted mill structure in Brazil is an ethanol distillery combined to a sugar mill. The ethanol industrial production process is named an autonomous distillery (Macedo et al., 2008).

Traditional process of hydrated ethanol production is considered for this report. The first stage is the “washing” stage where the canes are washed and ready to enter the mills by conveyor belts. In the mills the sugarcane juice is extracted. In the milling stage there are three products; sugarcane juice, bagasse and filter cake. The juice is converted to alcohol for ethanol production, bagasse is used as fuel for the production of steam and electricity for the cogeneration plants in the industrial unit. Filter cake is also used as a fertilizer mass for crop production (Figure 9).
Solid materials are separated from the juice in special settling tankers. Afterwards *Saccharomyces* a yeast species is injected into the juice as an agent for a fermentation reaction which converts saccharose $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ into ethanol $\text{C}_2\text{H}_5\text{OH}$, other by-products of this fermentation process is $\text{CO}_2$. Ethanol from the fermentation stage is distilled to elevate the alcohol concentration. Output of the distillation step is hydrated alcohol and vinasses. Vinasses the co-product of ethanol distillation and other decomposed solid residues are transported and used as fertilizers in the sugarcane crop fields (Table 3) (Madson and Monceaux, 2003).

**Table 3: By products of ethanol production process**

<table>
<thead>
<tr>
<th>by-products</th>
<th>Quantity</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinasse</td>
<td>15 lit/lit ethanol</td>
<td>Fertilizer for sugarcane fields</td>
</tr>
<tr>
<td>Bagasse</td>
<td>4.085 kg/ kg ethanol</td>
<td>Fuel source - production of steam and electricity in the cogeneration plants</td>
</tr>
</tbody>
</table>
2.5. Biogas in Sweden

2.5.1. Biogas

Biogas is produced as a product of the biological breakdown of organic matter in the absence of oxygen and it is used as biofuel due to its biogenic origin. Typically there are two types of biogas which differ in the production process and composition, as follow (Duret, et al., 2005).

1. Biogas produced by an anaerobic digestion or fermentation of biodegradable materials such as manure, waste, sewage, energy crops and biomass. The composition of such biogas is primarily methane and carbon dioxide.

2. Wood gas produced from gasification of wood or other biomass and primarily comprised from carbon monoxide, nitrogen, hydrogen, along with trace amounts of methane.

Biogas production or in other words anaerobic digestion is the process of degradation of organic material by microorganism in the absence of oxygen. The feedstock for this process can be any material high in organic fraction from household waste to dedicated energy crops such as maize and sugar beet. Biogas production can be implemented in large, centralized plants, with a wide range of different feed stocks, and also at small farm-based units which utilize mainly local and agricultural feed stock for digestion.

2.5.1.1 Biogas Production

Biogas is produced either as landfill gas (LFG) or digester gas. Biogas plants are anaerobic digesters which treat farm waste or other energy crops. The feedstock for these plants can be energy crops such as maize silage, beet sorghum or biodegradable wastes including sewage sludge and domestic food waste which are stored in an air-
tight tank and finally transformed into methane. The methane produced is a renewable energy source for heating, electricity, and many other operations purposes. In the biogas plant there are two main processes for digestion, mesophilic and thermophilic digestion. Landfill gas is produced in anaerobic conditions where wet organic wastes are decomposed in a landfill. The waste must be compressed mechanically by the weight of the above decomposed material which prevents oxygen exposure and allowing anaerobic digestion by anaerobic microbes. There must be a cover on the waste which captures the released gas from the digestion. Landfill gas is hazardous for three main reasons:

1. The risk of explosion if the gas escapes from the landfill and mixes with oxygen. The lower explosive limit is 5% methane and the upper explosive limit is 15% methane (Hazardous Atmospheres, 2002; Safety Pages, 2010).

2. Global warming effects due to the presence of methane in biogas which is 20 times more potent as a greenhouse gas than carbon dioxide. Therefore in case gas escapes into the atmosphere it may significantly contribute to the effects of global warming.

3. Volatile organic compounds (VOCs) within landfill gas highly contribute to photochemical smog formation.

2.5.1.2. Biogas Composition

Biogas mainly consists of methane (50–80%), carbon dioxide (20–50%), small fractions of hydrogen sulphide (0–0.4%) and water vapor. Depending on the anaerobic digestion process the composition of biogas differs, for example landfill gas generally has around 50% methane while advanced waste treatment technologies produces biogas with methane ranging from 55–75%. Siloxanes in biogas combustion transform to silicon and (SiO$_2$) or silicates (SixOy) along with calcium, sulfur, zinc, phosphorus (SGC, 2005).
2.5.1.3. Applications of biogas

Biogas has many applications such as electricity production, combined heat and power engines which in biogas plants the heat from the CHP unit is used to heat the digester. Other applications are water heating in industrial processes, space heating and heating. Biogas can be compressed and be used as vehicle fuel for either internal combustion engines or fuel cells. For application of biogas as vehicle fuel, carbon dioxide, water, hydrogen sulfide and particulates must be removed, concentrated and compressed. Today compressed biogas is widely being used in Sweden, Switzerland, and Germany (Biomethane emerging as a car fuel option, 2009).

Biomethane is another product of biogas. Methane in biogas can be concentrated by a biogas upgrader to the same standards of a fossil natural gas called biomethane which if high in quality and composition, it can be used by local gas distribution networks.

Anaerobic digestion for biogass production also transforms the added feedstock into a digestate, containing all the non-degradable substances present in the original feedstock and all plant nutrients, which can be used as a fertilizer for crop production. Digestate applications as crop fertilizers will increase plant available nitrogen by the degradation process thus enriches the efficiency of fertilization of the treated feedstock, reduces the application of mineral-based fertilizers and the risk of nitrogen leaching from arable land (Borjesson and Berglund, 2003, 2005; Nielsen et al., 2002). Biogas production and the use of digestate as a fertilizer present a sustainable mean to control and direct nutrients in the society (Galloway, 1998).

2.5.1.4. Biogas as fuel

Since biogas comprises of methane and hydrogen it has the potential to be oxidized or combusted with oxygen and releases energy such as fuel. Since biogas is a low cost fuel it can be used in any country as heating purposes, from cooking till running heat engines for mechanical and electrical power generation. Biogas has the potential to be
used as vehicles fuel by being compressed, much like natural gas, and to power motor vehicles. Biogas is concerned as a renewable fuel and qualifies for subsidies in many countries.

The overall environmental benefits of the use of biogas are highest when the biogas is used as a vehicle fuel replacing petrol or diesel due to the reduction in emissions of hydrocarbons, nitrogen oxides and particles. Biogas replaces fuel oil or natural gas for heat and electrical power production and in the large scale has significant reduction effects on air pollutions (Lantza et al, 2007). Utilization of biogas as vehicle fuel requires upgrading, which most of the carbon dioxide and the hydrogen sulphide are removed. Other additional treatments are performed in order to make the biogas injection into the natural gas grid possible (IEA, 2005). Although the price of upgraded biogas differs locally but current market price is approximately 20–30% lower than petrol on energy basis (Lantza et al, 2007).

2.5.1.5. Biogas industrial plant

Various biological, procedural, and energy conversion steps occur in biogas plants. The biogas vessel is the main part in the biogas plant where anaerobic bacteria degrade hydrocarbons into methane, carbon dioxide, trace gases, and biogas slurry. The content in the vessel is mixed and heated. Generally, combined heat and power plants (CHP) are attached to this vessel where biogas is converted into electrical and thermal energy. Other subsidiary installations that are required for the plant operations are pipes, pumps, gas, conditioning facilities, hygiene installations etc.

Biogas plants are either farm-scale or large-scale, approximately 5% of biogas plants are large centralized plants which are based on animal manure and non-agricultural co-substrates as feedstock. The typical treatment capacities of these plants are between 30,000 and 90,000 m$^3$/yr (Weiland, 2003). Anaerobic digestion is the main reaction for
energy production in the biogas plants. Since the biogas yield obtained per cubic meter of the reactor volume depends on the energy density and biologic degradability of the applied feedstock, therefore the kind of feedstock used in the anaerobic digestion is important. Manure as the only feedstock for biogas production is not economically a suitable since the energy rich substances is degraded by the animal and the organic dry matter is relatively low. Waste and byproducts from food and agricultural industries such as fruits and vegetables residues, pulps or overlaid foodstuffs are ideal co-substrates since such materials are normally free of pollutants, pathogens, and heavy metals. Fat containing material have the highest biogas yield but the disadvantage related to this kind of feedstock is the pretreatment stage for reducing particle size, separation of contaminants and pasteurization (Weiland, 2003).

2.5.1.6. Biogas upgrading

Raw biogas from the digestion is roughly composed from 60% methane and 29% carbon dioxide and traces of H$_2$S, which is not high in quality for selling or using as fuel gas for vehicles (Belcher, 2010). Biogas upgrading or purification process is performed in order to remove contaminants in the raw biogas stream resulting in 98% methane per unit volume of gas. Other corrosive elements such as H$_2$S are removed. Based on studies of Börjesson and Berglund (2003) the primary energy used in upgrading the biogas is assumed to correspond to 11% of the energy content in the biogas produced (Börjesson and Berglund, 2003).

There are four main biogas upgrading methods including water washing, pressure swing adsorption, selexol adsorption and chemical treatment (Person, 2003). Water washing is the most popular method which uses high pressure gas flows into a column and scrubs the carbon dioxide and other trace elements by cascading water running counter-flow to the gas. The resulting biogas has 98% methane and 2% of the methane is lost during the washing process.
2.5.2. Sugar beet

2.5.2.1. Plant physiology
Sugar beet (Beta vulgaris L.), is from the Chenopodiaceae subfamily and the Amaranthaceae family. Root’s of sugar beet contains a high concentration of sucrose and is cultivated commercially for sugar production and accounts for 30% of the world’s sugar production. The three largest sugar beet producers are the European Union, the United States, and Russia (FAO Statistics, 2005).

2.5.2.2. Sugar beet cultivation
Sugar beet has been grown commercially worldwide in a variety of different climate temperatures due to its hard texture. Sugar beet is a biennial vegetable which during its first growing season it produces large root storage of up to 1–2 kg with 15–20% sucrose by weight. In the second year nutrients in the root are consumed to produce the plant’s flower and seeds. In the second year the plant is harvested. For commercial beet production, the root is harvested in the first growing season when the root has its maximum size. Sugar beets are produced from small seeds which a 1 kg of beet seed comprises approximately of 100,000 seeds which can plant over a hectare of ground.

2.5.2.3. Sugar beet for biogas production
The sub terrestrial roots and leafs of the sugar beet plant are used for biogas production. Beets demand high supply of nutrients and good soil properties therefore great effort must be performed in the soil cultivation step. Since beets are vulnerable to nematodes, no crops such as carrots, spinach and onions should be cultivated before therefore beets are normally cultivated in a quadrennial crop rotation. Fertilizer requirements for beets are 100 kg up to 160 kg nitrogen, 300 kg potassium and 90 kg phosphate fertilizers (Steffen, 2006).

Use of forage beets (chenopodiaceae) for biogas production was first analyzed by Hassan (2003). According to his studies forage beets could become an important energy crop for biogas production due to the following reasons (Hassan 2003):
1. High organic matter yield per hectare

2. High percentage of light degradable components and hardly any lignin and cellulose

3. Sugar beets similar to forages have optimal conditions for ensiling with the potential to be stored and used for the whole year. Forage beets are grinded and ensiled. The beet pulp consistency in this stage is slurry and can be easily discharged by conventional displacement pumps. Automatic controlled feed inlet to the digester and exact adjustment of substrate mixtures are possible (Weiland, 2003).

4. Forage beets are low in dry matter content which allows pumping, which can be used for fully automated biogas plants.

Table 4 indicates LCI of forage beets for the production of one functional unit.

Table 4. LCI of forage beets for the production of one functional unit (Von, 2006)

<table>
<thead>
<tr>
<th>substance</th>
<th>compartment</th>
<th>unit</th>
<th>amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide, in air</td>
<td>Raw</td>
<td>Mg</td>
<td>586</td>
</tr>
<tr>
<td>Gas, natural, in ground</td>
<td>Raw</td>
<td>m³</td>
<td>944</td>
</tr>
<tr>
<td>Occupation, arable, non-irrigated</td>
<td>Raw</td>
<td>m³/a</td>
<td>58,700</td>
</tr>
<tr>
<td>Oil, crude, in ground</td>
<td>Raw</td>
<td>Mg</td>
<td>4.28</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Air</td>
<td>kg</td>
<td>278</td>
</tr>
<tr>
<td>Carbon dioxide, fossil</td>
<td>Air</td>
<td>kg</td>
<td>15.86</td>
</tr>
<tr>
<td>Dinitrigen monoxide</td>
<td>Air</td>
<td>kg</td>
<td>83.8</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>Air</td>
<td>kg</td>
<td>167</td>
</tr>
<tr>
<td>Particulates, &lt; 2.5 um</td>
<td>Air</td>
<td>kg</td>
<td>19.3</td>
</tr>
<tr>
<td>Particulates, &gt; 2.5 um, and &lt; 10 um</td>
<td>Air</td>
<td>kg</td>
<td>8.41</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>Air</td>
<td>g</td>
<td>29.5</td>
</tr>
<tr>
<td>Arsenic, ion</td>
<td>Water</td>
<td>g</td>
<td>29.2</td>
</tr>
<tr>
<td>Cadmium, ion</td>
<td>Water</td>
<td>g</td>
<td>37.1</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Soil</td>
<td>g</td>
<td>-60</td>
</tr>
<tr>
<td>Copper</td>
<td>Soil</td>
<td>kg</td>
<td>-1.27</td>
</tr>
<tr>
<td>Metamitron</td>
<td>Soil</td>
<td>kg</td>
<td>21.4</td>
</tr>
<tr>
<td>Zinc</td>
<td>Soil</td>
<td>kg</td>
<td>-1.03</td>
</tr>
</tbody>
</table>

2.5.3. Biogas in Sweden

The current quantity of the Swedish biogas production is approximately 5 PJ which is equivalent to 0.3% of the total energy consumption (SCB, 2005) Biogas energy resource has many services which are mainly heat and power and approximately 10% of this biogas is used in order to fuel passenger cars, busses and distribution trucks.
Estimates show a potential of approximately 50 PJ/year of biogas in Sweden and suggesting the possibility of a 10-fold increase of the present production (Linné et al., 2005; Nordberg et al., 1998). The ambitions of a society towards sustainability issues such as sustainable energy consumption patterns and the benefit of the environment has great effects on the implementation of a biogas system. There are many acts being done regarding greenhouse gases, renewable sources of energy and alternative fuels for transportation which Kyoto Protocol and negotiations within the European Union has issued a number of policy documents (EC, 2001).

Biogas implementation has significant advantages and improvements such as resource efficiency and many well environmental impacts and is a great method for waste handling and agricultural production practices (Börjesson and Berglund, 2003, 3005; SGC, 2005; Sundberg et al., 1997) such as the emissions of greenhouse gases, indirect reduction of air pollution and water pollutions e.g. eutrophication and the advantage of improved utilization of crop nutrients. Therefore putting into biogas infrastructure is affected by different policies such as energy, waste treatment and agricultural policies.

Biogas systems are the most complex system than any other bioenergy system since they involve many actors such as governments and municipalities, farmers and energy companies, therefore there are many factors acting as either incentives or barriers. Under the current Swedish conditions, the economical feasibility of biogas production is limited (Lantz, 2004; Svensson, 2005). Increased prices of fossil fuels along with political incentives may be effective in the near future (Lantza et al., 2007).

2.5.3.1. Potential of the agriculture sector

The potential of agricultural crops as biogas production feedstock is large and almost not well developed. In addition to centralized plants there are a few farm-based biogas plants and various pilot plants, which treat mostly agricultural crops as feedstock. Sugar beet and straw residues are one of the main feedstock for biogass
production. The biogas potential of sugar beet tops and straw are estimated to be approximately 3.5 PJ/year and 25 PJ/year, respectively (Berglund and Börjesson, 2006). However, recent studies and calculation do not consider straw in the biogas potential due to the difficult digestion. Straw is better suited to combust for energy recovery.

Sweden has the potential to dedicate 600,000 hectare to energy crops (Herland, 2005). Estimation by Nordberg (1998) shows that ley crops grown on 170,000 hectares could be used for biogas production with the yield of 12 PJ/year (Nordberg et al, 1998). A result of Linné (2005) presents 26 PJ/year, by assuming 260,000 hectares under cultivation of various crops (Linné et al., 2005). The total biogas potential of the agricultural sector, including manure, crop residues and energy crops amounts to almost 40 PJ/year (Lantz, 2006).

Figure 10 indicates the scheme of biogas production from a range of different material.

Fig.10: Scheme of biogas production
Chapter 3: Methodology

Life cycle assessment (LCA) method is a powerful mean of investigating the interactions between human activities and the environment and is performed for having a sound judgment of our product for future developments. LCA for the bioethanol and biogas fuel for Sweden evaluates the efficiency of these two fuel alternatives for Sweden fuel requirements based on input energy and output emissions. The complete life cycle of the two products includes three main units of agricultural operation, industrial production processes and transportation. This quantified research is based on bibliographic revision, documented researches, documented data acquisition, corresponding with specialists and analysis based on data manipulation. Spatial and temporal borders of bioethanol production in Brazil are respectively confined to the Sao Paulo region for the period of 2001 and 2008. Shipment is considered between Brazilian and Swedish port which is also included in the bioethanol LCA. Spatial and temporal borders of biogas production in Sweden are confined respectively to southern regions of Sweden in 2009. Neither the domestic distribution of bioethanol and biogas in Sweden nor the consumption phases of the corresponding fuels are considered in this study. Figure 11 shows the borders of the current study which is a comparison of the life cycle of bioethanol from sugarcanes in Brazil with the life cycle of bigas from sugar beet in Sweden as two alternative fuels for Sweden transportation fleet.

Fig. 11: Borders of study
Chapter 4: Results

4.1 Biogas
In the life cycle study of biogas production, the energy input to the three considered units of; agriculture, biogas industrial plant and transportation have been calculated. Figures are based on sugar beet cultivation in the southern region of Sweden with an average of 80 ton/hac yield and gas yield of 98000 liter/ton sugar beet.

4.1.1 Energy input
In figure 12 the energy input to the three different units of biogas production in Sweden is indicated. Results show that the energy input in the industrial unit is far beyond the other units and contributes to 74% (Figure 12, 13) of the total energy input to the whole system. Figure 13 show the total energy input to the three units of the biogas life cycle. Considerable time and cost are required for the collection and preparation of the efficient biomass resources, for example the biomass resource in the case of this report is sugar beet which must be treated (e.g. shredded) in order to facilitate its flow into the digester reactor, and in order to increase the efficiency of bacterial reactions, the influent solids content should be treated in a way that the influent solids are not too diluted or too concentrated. Heat for the digester is provided from the heat produced from the process in the combined heat and power (CHP) engine. Storage of raw material is also a time consuming operation in the industrial unit, which is done in a moist and confined space for an average of over ten days. The storage conditions initiates anaerobic bacteria action and reduces the time for the digester to function. Capital costs of the biogas industrial plant are gas holder, frames, piping, stove and civil engineering construction (e.g. tank, inlet and outlet, etc.).
Approximately a fifth (21%) (Figure 12) of the energy input consumption is in the agriculture unit. The agricultural operations for sugar beet in Sweden comprises of operations such as ploughing and stubble cultivator in the soil preparation step, harrowing and sowing in the cultivation step and finally harvest of tops and leaves of sugar beets. Harvest and fertilization are the most energy consuming steps.
contributing to 50% and 44% of the energy input in the agriculture unit, respectively (Figure 14). Figure 15 and 16 show the amount of energy input to the agricultural operations. It is important to mention that although the aim of sugar beet cultivation is sugar production, and for biogas production the tops and leaves of sugar beets are recovered and transported to the biogas plant, the full agricultural operations are considered in order to compromise the borders of study for both biogas production from sugar beet and ethanol production from sugarcane.

Fig. 14: Energy input to the agriculture unit

Fig. 15: Energy input to the agriculture unit

Fig. 16: Energy input to the agriculture unit
The energy input to the transportation sector is 5% (Figure 12), which includes the transport of raw material such as fertilizers, chemicals and seeds to the field, transport of raw material to the biofuel plant and the transport of digestate to field for spreading. Trucks such as compacting trucks and suitable trucks for carrying specific raw material have been considered and the average transport distance is assumed to be 10 km (Börjesson and Berglund, 2006). In this report transportation calculations include the transport of inputs e.g. chemicals and workers to the field and industry which is mainly done by lorries and railway for long distances and the transport of raw material from field to the biofuel plant. Apart from vehicles there are other means of transport used for inputs to the industrial plant such as pipelines carrying liquid substrates which is only applied for high volumes. Resource consumption in the transportation consists of fossil resources for fuels of vehicles and mineral resources for the production of vehicles, sheds, and roads which the later is not considered in this report. In the report solely fuel consumption which is conventional diesel for transport of inputs and products are considered.

4.1.2 Emissions
In figure 17, emissions from different units of the biogas life cycle are shown. Biogas industrial operations emit the largest amounts of carbon dioxide mainly due to the production and upgrading of the biogas. Nitrogen oxide (NOₓ) and carbon monoxide (CO) are the next major emissions in the biogas life cycle. Methane is an important and destructive greenhouse gas emitted from the industrial unit, although amounts of emissions of methane are low comparing to other emissions but it has massive effects. Based on the U.S. environmental protection agency methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide (CO₂) over a 100-year period (EPA, 2010).
Agricultural operations emit high amounts of nitrogen oxide (NO\textsubscript{x}) and sulfur oxide (SO\textsubscript{2}) comparing to the other two units. In agricultural operations, NO\textsubscript{x} is the result of biogenic sources in soils, but in following report calculated agricultural emissions of NOx only implies to agricultural machinery. There are great variations in emission levels among various tractors in agricultural operations therefore modifications can be considered for fewer emissions from machinery. SO\textsubscript{2} is mainly the result of fertilizer production especially phosphorous fertilizers (World Bank Group, 1998) which by applying the digestate instead of chemical fertilizers, emissions will decrease.

Since the considered transportation distances are short, approximately 10km, there is limited impact from the emissions of the transportation unit in Sweden biogas life cycle.

![Graph showing emissions from biogas production](image.png)

Fig. 17: Emissions from biogas production
4.2 Ethanol

4.2.1 Energy inputs
Ethanol calculations were based on (Ometto et al., 2009). It was assumed that the total sugarcane yield in the south-west region of Brazil is 80 ton/hac and ethanol yield is 85 liter/per ton cane. Since the produced ethanol was to be exported to Sweden, shipment is considered as one of the main units in ethanol life cycle. In figure 18, energy inputs in the four units of the bioethanol life cycle are shown. The industrial operations for ethanol production have the major energy consumption with a share of 65% of the total energy consumption (Figure 19), mainly due to high electricity consumption and the production of steam. The main renewable resource inputs in the industrial processes for ethanol production is water and steam which are very high in quantity comparing to biomass as the other renewable resource input. In the total life cycle of bioethanol, energy consumption is less than energy production due to the electrical energy cogeneration unit (CHP). In the current study the CHP unit is not considered, since in this unit bagasse is used as the main fuel to heat the water for steam production, while previously this bagasse was used in other industries as fuel. Currently the bagasse produced in the ethanol industry is used for ethanol production and from the industry’s economical view it may be a profit while globally bagasse fuel of other industries is now used in the ethanol industry itself with the similar emissions.

Fig.18: Energy input to bioethanol production for Sweden
In this report bioethanol is considered as a biofuel imported to Sweden from Brazil, therefore shipment is considered as a transport mean of bioethanol through the ports of the two countries and the energy and emissions will be assessed in the bioethanol life cycle. As results show shipment has the second major share of 17% in the total energy consumption of ethanol life cycle (Figure 19). It was assumed that the shipment is done by chemical tankers-cargo fueled with fuel oil. Other assumptions are given in table 5.

Table 5. Assumption of chemical tankers-cargo characteristics for fuel export to Sweden

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption of a container ship</td>
<td>lbs/hp/hr</td>
<td>0.25</td>
</tr>
<tr>
<td>average container ship’s horsepower</td>
<td>hp</td>
<td>100,000</td>
</tr>
<tr>
<td>Average cruise speed</td>
<td>knot(mph)</td>
<td>25 (28.75)</td>
</tr>
<tr>
<td>Average distance between brazil Sweden (Sau Paulo-Stockholm)</td>
<td>nautical miles (miles)</td>
<td>5890 (6778)</td>
</tr>
<tr>
<td>Density (ρ)</td>
<td>Kg/m$^3$</td>
<td>890</td>
</tr>
<tr>
<td>Tanker capacity</td>
<td>Ton</td>
<td>30,000</td>
</tr>
</tbody>
</table>
In the agricultural operations, harvesting is a high energy consuming stage which utilizes intensive machinery in order to cut the thick and fibrous sugarcanes (Figure 20). This stage accounts for more energy comparing to the total transportation unit in the ethanol life cycle. In the sugarcane harvesting stage, a burning step is performed in order to ease harvesting operations and to shorten the harvest season by as much as 10%, it also reduces the number of loaded units on the motorways towards the industrial unit, reduces the volume of material to be processed by the factory, increases yield and quality in sugar production industries and finally reduces energy expenditures in the field and by the factory (LSUAgCenter, 2006).

Fig. 20: Energy consumption by Agricultural operation

4.2.2 Emissions
The agricultural operations have the major emissions of greenhouse gases of the whole life cycle of ethanol. Harvesting of sugarcanes has the largest contribution to emissions in the unit, and comparing to other operations has the most potential impact of photochemical ozone formation. Shipment is the second major emitter of CO₂ and NOₓ. The industrial operations of ethanol production are high in CO₂ emissions (Figure 21).
4.3 Comparison of Biogas and Bioethanol

The energy inputs of the two systems were compared based on the heat value of the two considered fuel. A kilo watt hour of heat value provides a sensible benchmarking of the energy inputs to the two considered fuel cycles since the two fuels differ in the state of matter and more important is that the two fuels must be compared based on the energy content (combustion energy output).

As figure 22 indicates all units of operation in the bioethanol life cycle consume more energy comparing to biogas. The energy input in the industrial units of the two fuels have drastic differences. Biogas industrial processes is much simpler requiring a certain space, time and concentrate of biomass in order to yield biogas, while bioethanol is a result of processes with certain steps of fermentation, distillation and purification.

Shipment is a major energy consuming unit which does not occur in the life cycle of biogas for domestic utilization. Transport is not a major concern of energy
consumption since many fields and industrial plants are not built far from each other and the average distance in the report has been considered to be 10 km.

Fig. 22: Comparison of energy input to biogas and bioethanol life production units

In almost all agricultural operations, sugarcane is much more energy intensive than sugar beet. Figure 23 indicates that the fertilizer requirement of sugar beets is more energy consuming than sugarcane.

Fig. 23: Comparison of energy input in agriculture operations of biogas and bioethanol
Chapter 5: Discussion

The aim of this report is to compare the efficiency of the two most common biofuels, biogas and bioethanol, for Sweden transportation fleet. Biogas is produced from sugar beets of Sweden while bioethanol is an imported fuel from Brazil. The Study is based on energy inputs and emission outputs and according to the results, bioethanol production and import to Sweden is more energy intensive in comparison to biogas in almost all units considered in the life cycle. In order to make a more precise conclusion it is necessary to take in consideration many other aspects of the two mentioned fuels as follow:

- **Energy and emissions from bioethanol plant:** Although bioethanol which is extracted from biomass of the sugarcane crop, is known as a renewable fuel but its production involves a high quantity and diversity of non-renewable and renewable sources in different production stages. Sugarcane is one of the major energy and material intensive crops with high consumptions of chemicals and water. There are also considerable emissions from agro-chemicals production and agricultural machinery production and combustion. In sugarcane harvest stage, burning emits NOx and CH₄ gases due to diesel combustion, also Brazilian soils under sugarcane cultivation emit NO₂ due to pedogenic properties. Assessments indicate that ethanol releases less greenhouse gases than other fuels such as gasoline during combustion (Wang 2002).

Fortunately, the life cycle activities of the ethanol fuel has not been changed for a long period, potential improvements are considerable such as electricity cogeneration from solid waste, recycling of waste and implementation of a water recycling system.
- **Energy and emissions from biogas plant:** Varying plant operations differ in processes which can cause differences in energy consumption patterns and emissions. Emissions from a biogas plant are directly related to the plant size and amount of processed material. In a typical biogas plant the combined electricity and heat generator unit, CHP unit, has the most emissions and causes great ecological effects. Various CHP plants are different in conversion efficiency and gaseous emissions therefore they have different ecological effects. CHP plant are attached to a vessel for mixing and heating the contents where the hydrocarbons are degraded into methane, carbon dioxide, trace gases, and biogas slurry by anaerobic bacteria. In the CHP unit biogas is converted into electric and thermal energy. Pipes, pumps, hygiene installations, storages, gas conditioning facilities etc. are other subsidiary instruments for the units operation (Fachagentur, 2004).

- **Shipment:** Emissions from aviation and air travel have received great attentions mainly because most of the related emissions are at high altitude, but recently the shipping industry has increasingly become the focus of attention. The share of shipment has globally increased significantly both in scale and volume. Different legislations have been enforced in the industry due to massive emissions of SOx and NOx, and financial and operational measures have been set in order to regulate greenhouse gas emissions particularly CO$_2$ from the shipping industry.

Studies show that CO$_2$ emissions from shipment are equal or higher than aircraft. The graph below (Figure 6) indicates emissions and fuel consumption of road traffic, shipping and aviation in a logarithmic scale. Road traffic ranks first in CO$_2$ emissions while aviation and shipping are at a similar order of magnitude. Nitrogen oxide (NO$_x$) emissions from shipping are at the same level of road traffic which are both 10 to 13 times higher than aviation, respectively. Sulfur oxide (SO$_x$) emissions from shipping are far higher than road traffic and aviation, mainly due to the low quality of fuel used
in shipping which is mainly fuel oil. According to the same source, constant increase in container ships by 2050 will double the emissions of CO$_2$, and SO$_x$ while NO$_x$ emissions will exceed road traffic (Abuelsamid, 2007; SEAT, 2010).

![Annual emissions from road traffic, aviation and shipping (Abuelsamid, 2007)](image)

Fig. 6: Annual emissions from road traffic, aviation and shipping (Abuelsamid, 2007)

Emissions from ships have not been included in the Kyoto agreement or other proposed European legislation. Few studies have been conducted on the air pollution of the shipping industry although they are increasing. For instance carbon dioxide emissions from aircraft and aviation has been estimated approximately 2% of the global emissions and are of great importance in climate change while emissions from shipping has risen with the same pace in the last 20 years but have been ignored and disregarded by governments and environmental groups. Approximately, 90% of the world’s trade is done by shipping which has also doubled in the last 25 years (The Guardian, 2007).

Based on results, shipment of bioethanol to Sweden had a high share in total energy consumption during the life cycle. It may be realized that Sweden consumes clean and environmental friendly fuel in the country, while many energy consumptions and emissions are attached to the fuel production before entering the borders of Sweden. Globally thinking, imported bioethanol emissions have destructive effects no matter
the terrestrial sources, therefore it’s important to think globally and act locally in order to achieve the millennium ecosystem goals (World Bank, 2010).

- **Energy value**: A suitable comparison between biogas and bioethanol must be done by heat value since the two fuels differ in the state of matter and more important is that the two fuels must be compared based on the energy content (combustion energy output). Heat value is a suitable indicator for fuels known as the amount of heat produced by combustion of a unit quantity of a fuel.

- **Distribution**: Due to the physical status of the two fuels the practices for infrastructure designs and implementation differs. Bioethanol and water are soluble in any ratio, therefore distribution of bioethanol for long distances via pipeline is practically impossible and thus different from pipe transportation of fuels such as gasoline, oil or diesel which separate off to the top of water and thus can be trapped. This can increase distribution costs since transportation to destination is done by trucks, ships, or railways. A major advantage of biogas is that it can be distributed in the same pipes such as other gases and there is no need for road transportation. A pipe–based distribution system transfers the biogas from the production plant to the end user. Biogas has the potential to mix with natural gas and both these gases can co-exist in the gas grid.

- **Feedstock**: Biogas production requires material with high organic content therefore a wide range of different feedstock could be used for biogas production such as manure, domestic waste and agricultural residue. Bioethanol production is based on fermentation of sugars such as sugarcane and maize which are crops mainly cultivated on lands for food production. High bioethanol prices have motivated many farmers especially in Brazil to change from food crop production to energy crops, such as sugarcane. Today many debates are on food source deficiency caused by energy crop
cultivations for bioethanol fuel production (Bioenergy and food security, 2002). Biogas production uses many agricultural residues and is known as an extra income for farmers with no threats of future food resources.

- **Fuel applications**: Biogas as fuel has many application in warming farms, homes and industries comparing to bioethanol. While handling of bioethanol due to the high absorption of water and explosive potential is hard.

- **Bioethanol in Sweden**: Main differences in bioethanol life cycle inputs and outputs were shipment to Sweden and agricultural practices of the sugarcane crop in Brazil, therefore the question arises that what would be the results if bioethanol was produced in Sweden? Results of studies (Auer et al., 2006) show that bioethanol production from wheat and wood is less efficient than biogas production from agricultural residues in Sweden. In other words we can conclude that bioethanol is a product of a more industrial process, while biogas is a product of natural conversion occurring during storage of organic material in anaerobic condition.

- **Maintenance**: Biogas- similar to Compressed Natural Gas (CNG) - should be extremely compressed in order to be usable as a vehicle fuel. Therefore it needs relatively expensive equipments such as high pressure resistant tankers, high pressure hoses, connections etc. which demand regular based maintenance and replacements. For example, studies show that with only 5% methane emissions from biogas storage tanks, will completely cancel the positive climate effect of biogas use, since the global warming effect of methane is at least a factor of 20 higher than CO₂. Tankers are either expensive or very heavy since they are normally made from stainless steel or enamels for example in the ensiling stage of forage beets, beet pulp is converted to liquid slurry which has low pH and high lactic acid concentration and protection against corrosion is necessary which in both cases is considered as a disadvantage (Weiland, 2003).
- **Millage**: Biogas mileage is identical to CNG mileage and is generally much less than bioethanol. Therefore biogas application is confined to local service vehicles unless a grand and expensive distribution infrastructure is provided.

- **Production capacity**: Biogas has limitations in production such as a time and space consuming processes. Therefore there is low potential for high volume production or covering a great share of energy provision in Sweden.

- **Water footprint of bioethanol**: Water footprint is known as the total volume of freshwater that is used to produce the goods and services of the individual or industry. In the bioethanol life cycle there is high water consumption during agricultural production, cane washing and steam generation for the CHP unit and from an environmental and economical point of view it is important for industries to reduce their water footprint.

- **Agriculture mechanization**: For sugarcane it is expected that mechanical planting will substitute separated agricultural operations of furrowing, fertilization and seed distribution. Most modification will happen for cane harvesting such as mechanical harvesting of unburned canes. In this case large amounts of trash will be available which could an attractive option for fuel purposes (Macedo, 2008).

- **Disadvantages of Biogas Fuel**: Development of biogas production for vehicle fuel is hindered due to factors such as;

  1. Not a well developed commercial market for biogas technology and the need to improve the quality of biogas
  2. Limited distribution infrastructures and number of biogas filling stations
3. Higher prices of dual-fuel vehicles comparing to vehicles using either bioethanol or biodiesel (Lantz, 2007).

From the view of vehicle fuel price, bi-fuel vehicles are more expensive than other conventional vehicles which due to extra cost of approximately 10% for private passenger cars it is a great barrier for implementation (Bilia, 2005). Therefore local initiatives can promote the use of biogas as a vehicle fuel for example providing subsidize in order to reduce the extra cost for bi-fuel cars by municipalities or cities offering free parking for bi-fuel passenger cars, as well as cars adapted for alcohol or electricity.

- **Disadvantages of ethanol fuel:** One of the main disadvantages of ethanol fuel is its high dependency to field crops. Ethanol requires large amounts of land to grow the crops such as sugarcane and corn, which also require large amounts of water and nutrients and could lead to food deficiency, especially in developing countries. If ethanol is produce by gasification method it can convert any kind of waste to ethanol with less threat to food sources. High cost associated with modifying vehicles for ethanol fuel is another barrier although the costs could vary if the number of vehicles produced increases. Ethanol still has a lower energy density comparing to gasoline therefore more ethanol is required to store in a vehicle comparing to gasoline for the same mileage (Budny and Sotero, 2007).

In the table 6 the advantages versus disadvantages of the discussed fuels are compared in semi-quantitative manner. Number of stars in the table represents the degree of advantage for each fuel.
Table 6. Summary of comparison of bioethanol and biogas

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<td>Bioethanol</td>
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<td>***</td>
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<td>Biogas</td>
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Chapter 6: Conclusions and Recommendations

Results from the different sectors in the biofuel life cycle show that the industrial production unit is highly energy consuming and along with major environmental effects. For example, bioethanol was considered as a procedural process where modifications in the bioethanol process can be done by installing a water recycling system in order to reduce water consumption in the cane washing step, technologies to reduce the volume of steam required or to reduce leakage of steam by increasing the efficiency of different sections and etc.

The agricultural operation is another main unit within the life cycle of both discussed fuels since in this report the main feedstock was agricultural products. Harvesting and fertilization are intense in energy consumption and emissions. Agricultural operations in the bioethanol life cycle in Brazil could be modified in ways such as burning prior to the harvesting stage which could be eliminated by bio-chemical applications. Fertilizer and chemical applications of different crops can be reduced by the use of crop residue and by-products. Traffic of agricultural machinery is a considerable issue which could be reduced by more accurate agricultural operations such as soil management and the use of renewable fuel for machinery. Many studies indicate that the biofuel industry is currently a business run by agro-industrial lobby and less attention is paid on the scientific aspects. Different scientific results on the emission impacts of biofuels indicate that there are still no certain assumptions in studies, therefore emission issues of biofuel production and conversion of cropland for biofuel production has no easy answer (Ballon, 2008). We all agree that biofuels are not the silver bullets for the world’s energy and environmental problems, but it is a path towards solving the problem. In order to reach reduction in fuel consumption
and emissions of the transportation unit, trucks with lower specific fuel consumption and higher load capacities could be used.

Biofuel production is an emerging subject with growing importance due to the high transportation share towards global warming phenomena. New technological modifications such as bioethanol production from cellulosic material are being developed. Woody crops such as Willow, Poplar and Cottonwoods, hybrid willows are being studied in order to investigate their potential to serve as an energy crops for fuel. These crops have the advantage of short rotations which grow after each harvest, and advantage of multiple harvests without the need to re-plant. Bioethanol from woody crops and cellulosic material could be a good option for Sweden which poses high acres of woodland.

In the first view bioethanol application in Sweden might appear environmental friendly, but as the review of our results and studies by other author’s show globally bioethanol production is energy consuming and emissions are high. Apart from environmental issues food is a resource in great danger by bioethanol production. Shipment accounts for high share in emissions and total energy consumption of bioethanol life cycle and therefore endeavors should towards less dependency on foreign imports.

Many studies have questioned bioethanol as a counter partner of total transportation energy basket of Sweden, therefore it is a necessity to revise energy scenario of transportation in Sweden.
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