

**Alternative energy carriers for the transportation sector**  
Report prepared in framework of Øresund Ecomobility project

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# Alternative energy carriers for the transportation sector



Report prepared in framework  
of Øresund Ecomobility project

Edited by

*Irini Angelidaki and Dimitar Karakashev*  
Department of Environmental Engineering,  
Technical University of Denmark

January 2012



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## Preface

The transport sector constitutes a major energy consumption sector. Conventional fuels such as gasoline and diesel are currently the main fuels. The conventional fuels have very good properties as vehicle fuels, such as high energy density, good established distribution infrastructure, easily applied and transported in liquid form. However, these traditional fuels are not renewable and it is foreseen that in the future will not be available. Additionally, they contribute to increase of greenhouse gases, which is an urgent issue due to the climate change challenges. Therefore, need for discovery and implementation of new fuels for the transport sector is urgent. There is currently intensive research and development for finding new solutions in the area of fuels for the transport sector. The different energy carriers/fuels are currently used in transportation sector. Among them, synthetic gasoline, synthetic diesel, DME, biodiesel, ethanol, biogas, methanol and electricity are utilized in different vehicles produced commercially. Butanol and hydrogen are also promising alternative fuels. However they are mainly produced for demonstration purposes and no vehicles are available on the market so far. Fuel characteristics, production methods, and practical applications of the energy carriers in transportation sector are presented in this report. Distribution and storage of fuels is discussed with respect to infrastructure and facilities currently available. Future perspectives and challenges are presented in the light of technology development, economics, and environmental impacts.

In this report we collect information about relevant fuels for the transport sector, both in respect to production, application, and current status. Additionally, we have made an attempt to evaluate and compare them to each other.



# Ethanol

*Irini Angelidaki, Department of Environmental Engineering, Technical University of Denmark*

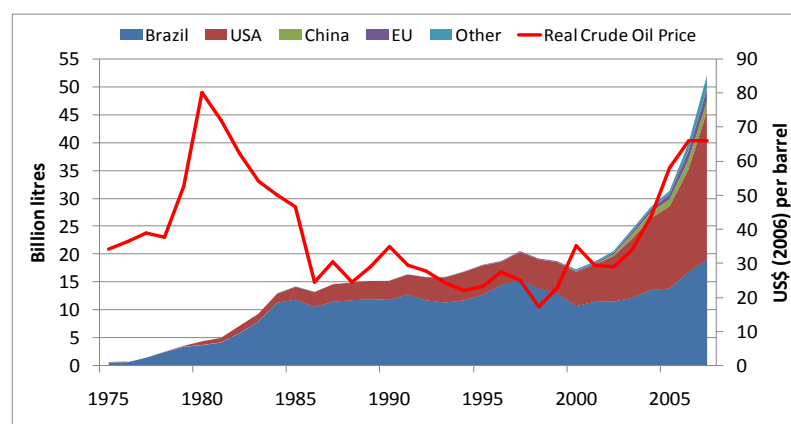
## Introduction

Ethanol is an alternative vehicle biofuel. Use of bioethanol as transport fuel is not new. Already in 1908 Henry Ford designed his motor to run on ethanol (Figure 1). He proclaimed bioethanol to be the fuel of the future. Henry Ford wrote in New York Times in 1925, that *"The fuel of the future is going to come from fruit, weeds, sawdust - almost anything. There's enough alcohol in an acre of potatoes to drive the machinery necessary to cultivate the field for a hundred years."*



**Figure 1 Henry Ford, New York Times 1925.**

However, the following years, the fossil fuels took over, and became the predominant transport fuels. Renewed interest in ethanol came during the first energy crisis in the 1970s. There is an apparent relationship with crude oil prices and the increase in production of bioethanol (Figure 2).



**Figure 2 Ethanol vs. Oil Prices (Licht's 2006)**

This crisis was followed by several initiatives around the world for finding alternative fuels for road vehicles. The most important are the National Alcohol program (ProAlcool) in Brasil and the Gasohol program in the USA. The NAP in Brasil was initiated in middle 1970s and resulted in

over 26,000 gas stations could provide anhydrous ethanol for cars. Several millions of cars could run only on ethanol. Like the NAP in Brasil, the Gasohol program was initiated in the USA. Production of ethanol in Brasil was based on sugar canes, while maize was used in USA as feedstock. Still today, the main ethanol producing countries are Brasil and USA. However, new ethanol producing countries have come, such as China and India. Nowadays ethanol is mainly added as supplement to gasoline, in shares ranging from 5% to 85%.

### ***Fuel characteristics***

Ethanol (C<sub>2</sub>H<sub>5</sub>OH) is liquid at room temperature and can be used either alone or in different blends with gasoline. Ethanol fuel characteristics are presented in Table 1.

**Table 1. Combustion properties of ethanol**

	Units	Gasoline	Pure Ethanol
Oxygen content	100%	Close to 0	36
Octane Number	100%	85 – 94	112,5 – 114
Vapor pressure	Bar	0,48 – 1,034	0,159
Lower heating value	MJ/Liter	31,2 – 32,4	21,1 – 21.3

Ethanol has a lower energy content compared to gasoline, and approx. 50% additional ethanol volume is required for the same energy compared to gasoline.

Pure ethanol has some limitation as fuel such as cold-start problems. These can be overcome by making different blends of ethanol and gasoline (Table 2). Additionally blends of ethanol in gasoline help in another inherent problem of ethanol which is its high volatility.

**Table 2. Different fuel formulations containing ethanol.**

Fuel	Ethanol content (% v/v)
E5 (North Europe incl. Øresund region)	5
E10 (Gasohol) (North America)	10
E85 (North America)	85
Hydrous ethanol (Alcool) (Brazil)	95.5
Gasoline (Brazil)	24
Oxygenated fuel (USA)	7.6
Reformulated gasoline (USA)	5.6

## ***Production methods***

### **Biological ethanol production**

Bioethanol is produced by fermentation of sugars. Sugars are stored as polymers in biomass. There are two main lines of bioethanol processes. The first generation (1G) technologies are based on primary biomasses, mainly food crops such as sugar cane, maize, or wheat (Figure 3). The sugars in these crops are easily hydrolysed to monomers and mature technologies for bioethanol production are existing.



**Sugar Streams**

- Sugar Cane – molasses/juice
- Beet – molasses/juice
- Sweet sorghum juice



**Starch Streams**

- Grains: Corn, wheat, rice, sorghum etc.
- Tubers: Cassava, potato



**Figure 3: Feedstocks that can be used in 1G-technologies for ethanol production**

Second generation technologies (2G-technologies) are based on agricultural residues and wastes. The biomass utilized in 2G technologies has mainly lignocellulosic structure, and therefore, intensive pretreatment and hydrolysis is needed to release sugars so they can be fermented by microorganisms to ethanol.

Biomasses that are used in 2G-technologies are shown in Figure 4



**Forest residue**



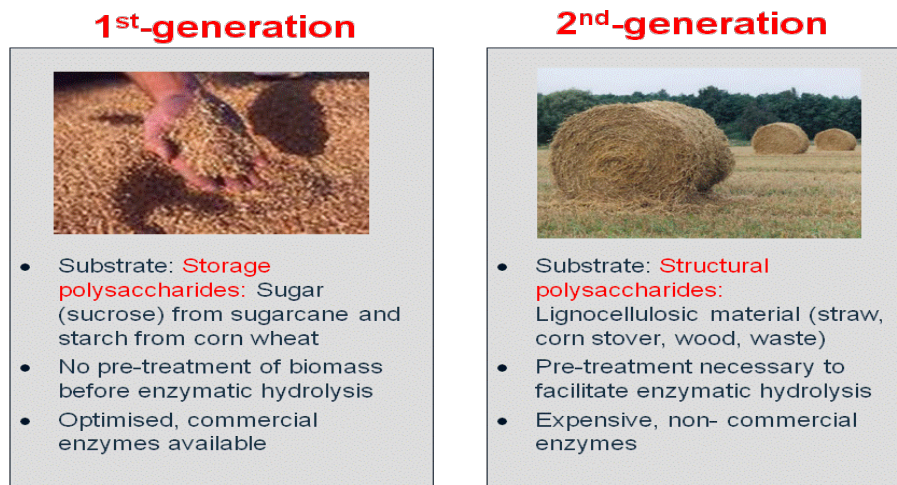
**Agricultural waste**



**Municipal waste**

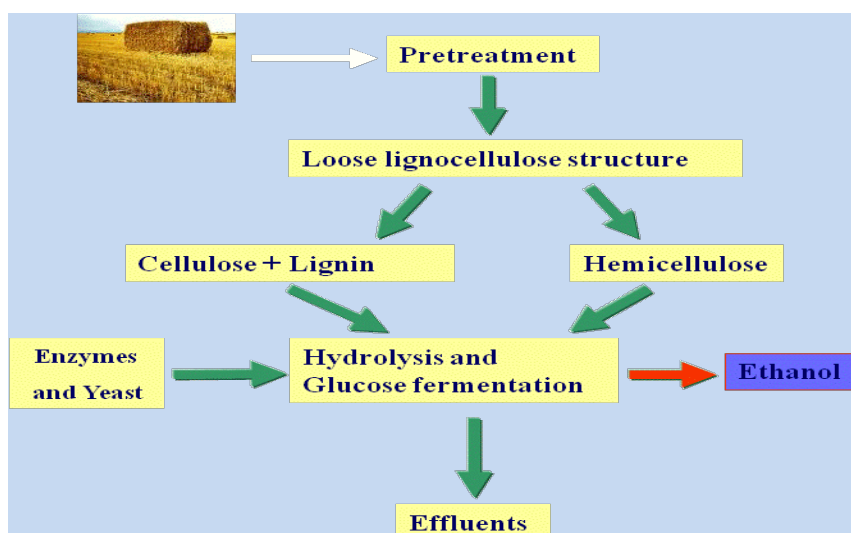
**Figure 4. Feedstocks that can be used in 2G-technologies for bioethanol production**

Differences between 1 and 2-G technologies are summarized in Figure 5



**Figure 5: Differences between 1-G and 2G-technologies for bioethanol production**

Depending on the biomass used as feedstock for ethanol production different steps are needed. For 2-G technologies the following steps are needed for production of ethanol. The first step is pretreatment for breaking down the rigid structure of lignocelluloses materials. Several pretreatment methods, mainly based on thermochemical treatment are found. Thereafter, hydrolysis of the sugar polymers is applied to hydrolyse the polymers to monomers, following by fermentation where sugars are fermented to ethanol. The fermentation broth then is distilled to separate the produced ethanol. Finally, the process wastewaters need to be treated/disposed. For 1-G technologies the pretreatment and often the enzymatic hydrolysis steps are not needed. In Figure 6, a schematic representation of the process steps is shown.



**Figure 6: Process steps for bioethanol production from lignocellulosic material.**

## Chemical ethanol production

Ethanol can be made from petrochemical feed stocks, primarily by the hydration (in presence of catalyst) of ethylene (ICIS.com. Ethanol production and manufacturing process), represented by the following chemical equation:



The process suffered from disadvantages such as corrosion from the large volumes of catalyst (sulphuric or phosphoric acid) handled and the energy required for up-concentration. For this reason alternative synthetic processes based on methanol or synthesis gas feedstocks have been developed. The synthesis gas is converted to methanol which is carbonylated to acetic acid. The acid formed is esterified with methanol to methyl acetate which is then hydrolysed to methanol and ethanol. Alternatively, the acetic acid can be hydrolysed directly to ethanol.

## *Use in transport today*

The largest single use of ethanol is as a motor fuel and fuel additive. Ethanol as a fuel reduces harmful tailpipe emissions of carbon monoxide, particulate matter, oxides of nitrogen, and other ozone-forming pollutants (American Coalition for Ethanol). Comparing ethanol blends with gasoline alone, it was shown reductions of 8% with the biodiesel/petrodiesel blend (B20). Following type of ethanol blends has recently become more widespread in Øresund region:

### E5

E5 ethanol blends are easily available on normal petrol filling stations in Øresund region (Denmark, Sweden)

### E85

E85 blends is widely used in flex fuel vehicles (FFVs) in Sweden.

### E95

E95 has been used with success by transport company Scania for buses and trucks in Sweden (Scania, 2008) (Figure 7).



**Figure 7. Public ethanol fueling station in Sweden (Euro Charity 2006-2011)**



## ***Challenges and future perspectives***

Currently, almost all bioethanol is produced from grain (maize) or sugarcane. However, as this feedstock is essentially food, biofuel production from these food crops, has been criticized due to rising food prices and the global food demands (Mussato et al., 2010). In addition, the ethanol production from grains like corn has several important environmental impacts such as soil erosion, and loss of biodiversity. This ethanol production technology has also an energetic balance disadvantageous, and requires a significant area for plantation and water (Solomon et al., 2007). For all these reasons, new technologies for the production of this biofuel need to be found. In this aspect, bioethanol from lignocellulosic materials is one promising alternative.

However, while 1G- bioethanol technologies are mature and well established, the 2G technologies are still under development. Full scale applications are found only for 1G-technologies, while 2G-technologies are applied only at pilot and demonstration scale. Despite recent substantial progress in cellulosic ethanol research, many challenges remain to be overcome, such as: 1) Development of economically viable hydrolysis process step. This stage requires the use of enzymes to convert the cellulose in sugars, and utilization of such enzymes resulted in elevated costs for a commercial process; 2) High energy consumption for lignocellulose pretreatment remains a big challenge; 4) Process scale-up is one of the key challenges for commercial production; 5) Capital equipment required for commercial demonstrations of some technologies, such as steam explosion, does not exist; 6) The recovery of chemicals (used in biomass pretreatment) and wastewater treatment are also important issues in selecting pretreatment technologies in commercial production.(Zhu and Pan, 2010).

For cellulose use in ethanol production to be performed in large scale and in a competitive level, major research efforts are still needed in order to: 1) develop more efficient biomass pretreatment technologies; 2) Discover/develop new enzymes for cellulose hydrolysis resulting in high yield of fermentable sugars; 3) Discover/develop ethanologenic microorganisms able to convert all pentose and hexoses with high ethanol yield and production rate; able to withstand elevated concentrations of ethanol and process inhibitors; 4) integrate the optimal conditions in a economic system for ethanol production. The economical sustainability of ethanol production from cellulose is very important because it will allow an increase in the production of ethanol fuel, which will strengthen the international bioethanol market. Besides the development of an efficient and economically viable technology for ethanol production from lignocellulosic materials, other processes based on the use of aquatic biomass (algae) have also been strongly evaluated being considered as promissory strategies for a future development of this sector (Goh and Lee 2010). However currently bioethanol from algae is not evaluated as economical feasible.

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# Butanol

Per Jørgensen, *Department of Environmental Engineering, Technical University of Denmark*

## **Introduction**

Butanol as an alternative biofuel has recently become an interesting choice due to its favorable fuel characteristics compared to other fuels. Historically butanol has been produced by anaerobic fermentation since the beginning of the 20th century. The fermentation process known as the ABE, due to the simultaneous formation of acetone, butanol and ethanol, was mainly performed by using *Clostridium acetobutylicum*. The industrial production of butanol by fermentation was ongoing in many countries until the 1980's, but from the 1960's it was gradually outcompeted due to increased price of substrates, low solvent yield and a more competitive process based on fossil fuels.

Butanol has not yet been used in large scale as a fuel for transportation. The field is attracting a lot of interest inspired by entrepreneurs like Ramey who proved it was possible to drive his ordinary car all across USA only using butanol as fuel. (NABC Report 19. Agricultural Biofuels: Technology, Sustainability and Profitability).

## **Fuel characteristics**

Butanol exists as four isomers namely n-butanol, 2-butanol, i-butanol and t-butanol. The four isomers contain about the same amount of heat energy. They are essentially identical in blending with gasoline and in combustion. However, their methods of manufacture are very different.

t-butanol is a petrochemical product while n-butanol often referred to as bio-butanol is produced by fermentation.

Some features of butanol, important for the engine performance, are shown in Table 3. The energy content of butanol represented as the lower heating value is approx. 86 % the value of gasoline. (Szulezyk 2010).

**Table 3. Butanol fuel properties.**

Parameter	Value
Octane number	87
Vapor pressure (Bar)	0.023
Lower heating value (MJ/Liter)	27.8

Compared with ethanol, butanol has many advantages (Butamax advanced biofuels) that are attractive for application as a liquid biofuel as follows:

- butanol is non corrosive;
- it has lower vapour pressure;
- it has 50 % higher energy content per unit of weight;
- it can be blended with gasoline at any ratio without the necessity for modification of vehicle engines.

## Production routes

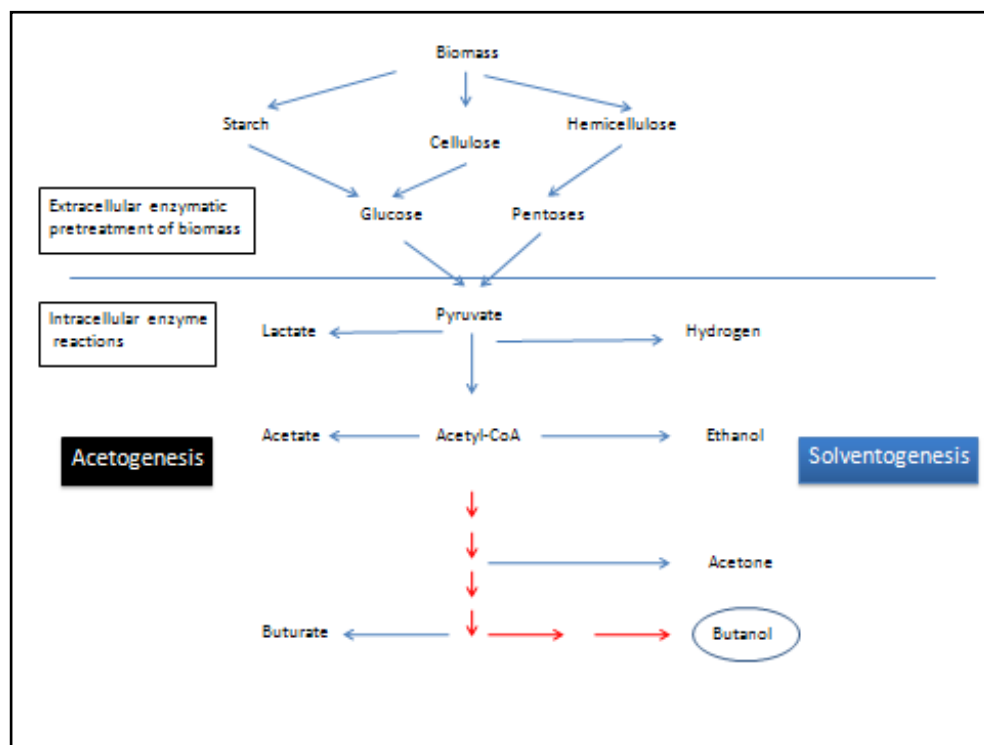
### Biological production by Acetone – Butanol – Ethanol (ABE) fermentation

The ABE fermentation is well known and in fact one of the oldest industrial fermentations. The fermentation converts sugar containing substrates into 3 main products: acetone, butanol and ethanol in ratio of 3:6:1.

The main microorganisms used in this type of fermentation are *C. acetobutylicum* and *C. beijerinckii*, but several other *Clostridium* spp. can also perform this fermentation.

Complex biomass substrates can be used without pretreatment due to the production of extracellular enzymes and variety of sugars including pentoses can be utilized in the fermentation.

A typical ABE fermentation can be divided into two phases (Figure 8), acidogenesis and solventogenesis, respectively (Huang et al, 2010). In the acidogenesis phase the bacteria are grown exponentially which results in formation of acids (acetic and butyric acid) and production of hydrogen. Due to the formation of acids, the pH in the medium drops and the fermentation enters the phase of solventogenesis with a steady state cell growth and decreased hydrogen formation. In this stage, acetone, butanol and ethanol are formed with partial uptake of the acids produced in the acidogenic growth phase.



**Figure 8. Simplified butanol biosynthesis pathway chart. Arrows are indicating specific enzyme reactions. The six red arrows represent enzyme reactions specific for the ability to produce butanol.**

The solvent yield from a classical batch ABE fermentation using *C. acetobutylicum* and *C. beijerinckii* are up to 20g/L of mixed solvents. The relatively low yields are generally thought to be caused by solvent toxicity at the end of the fermentation (Qureshi and Blashek, 2000). These yields

are relatively low as compared to a comparable bioethanol process and are the main obstacle on the way to making this process for production of biobutanol economically feasible.

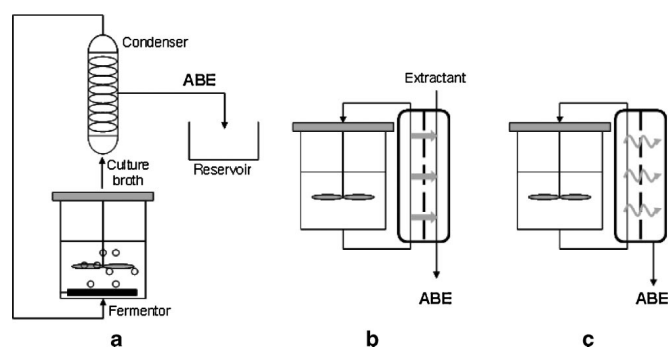
## Chemical route

Butanol can be produced chemically from compounds such as propylene, carbon monoxide and hydrogen (Product Safety Assessment (PSA): n-Butanol). The chemical company DoW produces 9% of the world's capacity of butanol by chemical synthesis.

## Future perspectives and challenges

Many attempts are being made to improve the efficiency of the ABE process. Annous and Blaschek (1991) selected a hyper producing mutant of *Clostridium beijerinckii* with a solvent productivity of 29g/L. In addition to being a good butanol producer, the strain is more stable due to fact that *C.beijerinckii* has the butanol biosynthesis genes in the chromosome and not on a plasmid as in *C. acetobutylicum*. Others have successfully produced butanol in microbial hosts more tolerant to butanol, by use of metabolic engineering. Steen et al. (2008) transferred 6 genes representing the butanol biosynthetic pathway to *Saccharomyces ceravisiae* and thereby enabled butanol production in this host. Atsumi et al. (2008) and Smith et al. (2010) reported the production of isobutanol in *E. coli* and *Corynebacterium glutamicum* respectively. So far only low yields as compared to the traditional clostridial ABE process have been reported. Another approach for increasing the productivity in the ABE fermentation is by designing a continuous fermentation. As compared to the batch fermentations the concentration of butanol in the reactor is lower and thereby not reaching the toxic and nonproductive levels for the production strain. Using a continuous reactor with immobilized *Clostridium beijerinckii* BA101 cells, Qureshi and Blashek (2001) were able to increase the overall productivity as compared to a batch fermentation by 40 fold.

Due to the relatively low concentration of butanol in fermentations higher distillation costs must be anticipated, but techniques like pervaporation are being developed which would remove butanol continuously and selectively from the broth (Guo et al., 2004) This technique is using a selective membrane and might in the future be a more economical purification process. The continuous removal of butanol would also keep the concentration of butanol in the fermentation under the toxic level for the organism and thereby increase the productivity of the production strain (Lee et al, 2008). Other promising techniques aiming for the same purpose are gas stripping and liquid-liquid extraction (perstraction) (Figure 9).



**Figure 9. Integrated systems for fermentation and in situ solvent recovery: fermentation coupled with (a) gas stripping, (b) liquid–liquid extraction (perstraction), (c) pervaporation ( Lee et al., 2008)**

## ***Current status and prospects***

Despite the better fuel characteristics of biobutanol, as compared to ethanol, it is not used as a biofuel today. The current ABE processes developed are still not efficient enough to compete with the bioethanol processes. Lots of promising research in fields like fermentation, strain improvement and solvent purification might deliver the necessary breakthrough for an efficient process. Possibility of developing more efficient process is represented by the many large companies investing in research and pilot scale production of butanol. Butamax (Butamax Advanced Biofuels), a joint venture between BP and DuPont are planning to commercialize biobutanol production in 2013. Gevo (Gevo. Renewable hydrocarbons for the chemical and fuel markets) has also plans for a full scale production of isobutanol possibly by the use of genetically modified yeast. Other companies with activities in butanol production are listed in Table 4.

**Table 4. Companies working on biobutanol production**

Company	Activities	Homepage/ref
Butamax	<ul style="list-style-type: none"> <li>- A joint venture made between DuPont and BP</li> <li>- Focus on ethanol plants retrofitted to biobutanol</li> <li>- Successful testing in real vehicles with a 16% blend of biobutanol and gasoline</li> </ul>	<a href="http://www.butamax.com">http://www.butamax.com</a>
Gevo	<ul style="list-style-type: none"> <li>- Plans to modify existing ethanol plant for isobutanol production</li> <li>- Planning to start isobutanol production in 2012</li> <li>- Use of genetically engineered yeast for isobutanol production.</li> </ul>	<a href="http://www.gevo.com/">http://www.gevo.com/</a>
Cobalt Technologies	<ul style="list-style-type: none"> <li>- Plan to build a 470000 gallons of butanol/year demonstration plant in 2012.</li> <li>- Use of cellulosic biomass as feedstock for the butanol production.</li> <li>- Develop bacterial strains able to ferment all sugars found in plant materials</li> <li>- Develop a continuous fermentation process which results in 11-fold increase of butanol production rate over traditional batch fermentation processes.</li> </ul>	<a href="http://www.cobaltech.com/">http://www.cobaltech.com/</a>
Butalco	<ul style="list-style-type: none"> <li>- Develops new technologies for production of biobutanol</li> <li>- Use of on genetically modified yeast strains</li> <li>- Special focus on development of yeast strains able to utilize C-5 sugars</li> </ul>	<a href="http://www.butalco.com/">http://www.butalco.com/</a>
TetraVitae Bioscience Inc.	Use of patented genetically engineered <i>Clostridium berinckii</i> strain.	<a href="http://www.tetravitae.com/">www.tetravitae.com/</a>

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# Methanol

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## **Introduction**

Alcohols have since long been regarded as potential fuels for vehicles. Methanol (CH<sub>3</sub>OH) is the simplest alcohol with unique characteristics that make it useful as an alternative fuel. Methanol was first discovered in 1823 by condensing gases from burning wood and is naturally found in the environment from metabolic processes of bacteria participating in the pectin biodegradation.

During the oil crisis in the seventies methanol gained interest as vehicle fuel and was then produced from natural gas or via gasification of coal and subsequent processing of that gas. Later on, methanol was produced from the gasification of biomass to synthetic gas. Still in 1997, 86% of all methanol in the world, was produced from natural gas (Ohlström et al., 2001). In 1976 methanol was introduced as a replacement for lead as octane booster in gasoline (Bromberg and Cheng, 2010). During the 80's and 90's, methanol was blended in gasoline fuels in both Europe and the US, and by the mid 90's a substantial number of vehicles, mainly in California and New York, had been converted into methanol vehicles that could use 85% methanol (M85) as fuel (Bromberg and Cheng, 2010). Methanol has also been used for its ability to enhance performance of race cars and drag racing cars (Bromberg and Cheng, 2010).

## **Properties and fuel characteristics**

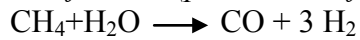
Methanol is a toxic, colorless, volatile and high energy flammable liquid with a boiling point of 65 °C. As it is partially oxygenated, it requires less oxygen for complete combustion than conventional gasoline fuel. Methanol is a high octane fuel which gives a vehicle more power and faster acceleration. It provides octane enhancement to gasoline fuel and it is often used as octane booster. It has a lower energy density than gasoline, which means that a higher flow rate of methanol is required to give the same energy output, leading to a decreased fuel range and larger fuel tanks. However, it has been shown to give a slightly better engine operation efficiency than gasoline. Since methanol lacks carbon-carbon bonds, it does not leave any particulate residue after combustion (Dave 2008). Methanol is seen to reduce hydrocarbon emissions by 30-40% with M85 (mixture of 85 % methanol and 15 % unleaded gasoline) compared to gasoline (Clean alternative fuels fact sheet) and even more when methanol is used in a fuel cell vehicle. Methanol also disperses easily into environment and is rapidly biodegradable. It has a corrosive nature, which puts demands on the engine systems to be modified.

## **Production methods**

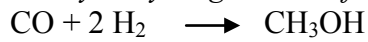
Methanol has traditionally been produced in large scale from natural gas and coal, but there is an increasing trend towards using renewable feedstock for production. The most commonly used method for producing methanol is based on a thermo-chemical process in two steps, the first one being gasification of a feedstock into synthesis gas with CO and H<sub>2</sub> as main components. The synthesis gas (syngas) is then further used for catalytic conversion to methanol over a copper or

platinum surface at high temperature. The industrial scale manufacturing of methanol from natural gas is made according to the following:

*Gasification (production of syngas CO+H<sub>2</sub> from methane):*



*Catalytic hydrogenation of carbon monoxide to methanol*



Besides using coal and natural gas as feedstock, renewables can be used including forest biomass, agricultural waste, solid municipal waste etc. Lately, methods for the production of methanol from biomass feedstock have gained an increasing interest. A direct oxidation of methane produced from biomass can be made as in the syngas process described above. By using biogas as starting material instead of natural gas, an obvious environmental benefit could be made. However, the syngas process is energy intense and requires high temperatures and pressure. A more obvious way from a conventional chemical engineering point of view is to directly oxidize methane into methanol (Gang et al., 2000).

Methane oxidation also takes place in the nature. Efforts to utilize microorganisms catalyzing the process are now being investigated (Kim et al., 2010, Antoni et al, 2007). One biotechnological strategy is to apply microorganisms containing methane monooxygenase, an enzyme that catalyzes the hydroxylation of methane to methanol. The drawback is that the organism also contains enzymes for further processing of the methanol by oxidizing it into formaldehyde by methanol dehydrogenase. Then it will be important to inhibit the activity of the methanol dehydrogenase thereby minimizing the formation of aldehydes in the reaction mixture (Kim et al., 2010). The inhibition may be obtained via addition of a chelating agent since the dehydrogenase is metal ion dependent, and by complex formation between the chelator and the metal ion, the enzyme turns inactive and thereby methanol enrichment takes place. This technology is still on the experimental stage in research laboratories (Kim et al, 2010). The concentrations of methanol produced are still low, and upgrading by distillation will hence be energy demanding. Another approach is to utilize the enzyme pectin esterase, contained in bacteria and fungi, to ferment a pectin-rich compound such as sugar beet pulp which contains about 60% (w/w) pectin. The enzyme acts by demethoxylating the pectin which results in release of methanol.

A completely different reaction route can be applied when producing methanol from methoxy-groups in wood lignin (Swedish Pulp Mill Biorefineries, 2008). When Kraft pulp is produced, the methoxylated polymers are treated such that methanol is released. This is done in relatively large scale, but the problem is that the methanol produced is contaminated by sulphur containing compounds (mercaptanes etc.) with very strong off-smell. This methanol is difficult to purify and it is often today used as a fuel in the pulp mill. If/when new process technology is applied in the pulping process avoiding the sulphur, then this may be a resource to consider for further upgrading.

## ***Practical applications***

### **Transportation fuel**

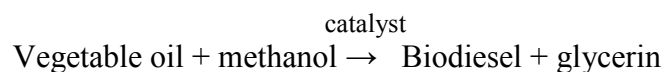
China is the world's largest user of methanol for transportation vehicles with their large abundance of coal, natural gas and biomass (Bromberg and Cheng, 2010). In Europe, methanol has mainly been used as a light blend in gasoline (Bromberg and Cheng, 2010). Low levels of methanol can be used in existing vehicles, with the use of proper co-solvents and corrosion inhibitors. The European Fuel Quality Directive allows up to 3 % methanol with an equal amount of co-solvent to be blended in gasoline sold in Europe. Pure methanol is required by rule to be used in Champ cars, Monster Trucks (Figure 10), USAC sprint cars and other dirt track series. Drag racers and mud racers, as well as heavily modified tractor pullers, also use methanol as their primary fuel source. Mud racers have mixed methanol with gasoline and nitrous oxide to produce more power than gasoline and nitrous oxide alone.



**Figure 10 Methanol-powered Monster truck (Monster trucks)**

### **Biodiesel production**

Methanol can also be used to produce biodiesel, an alkyl ester produced through a transesterification process:



Biodiesel is essentially non-toxic, biodegradable and can be blended in petroleum diesel at any level.

### **Chemical industry**

Methanol, or methyl alcohol,  $\text{CH}_3\text{OH}$ , is an important basic chemical for the chemical industry. It has been used for more than 100 years as a solvent and for the production of plastics, plywood, and paint. It is also used directly in windshield-washer fluid and gas-line antifreeze.

### **Fuel cells**

The direct use of methanol for fuel cells (DMFC) has since its invention in 1990 by researchers from University of Southern California's Loker Hydrocarbon Research institute ([www.machine-](http://www.machine-)

history.com), been demonstrated in automotive and other portable applications. In the fuel cell, chemical energy is transformed into electrical energy through an electrochemical process (Figure 11). The use of liquid methanol instead of gaseous H<sub>2</sub> has several advantages. One disadvantage is however that the electrodes in the fuel cell needs large quantities of platinum (McGrath et. al., 2004). The technology is still in its infancy, but is by some considered as the power source of the future.



**Figure 11 Methanol fuel cell (Methanol fuel cell)**

### ***Current status and future prospects***

Biomethanol has recently got large attention in Scandinavia, where access to forest biomass makes it attractive to produce methanol from forest-residue biomass. One example is VärmlandsMetanol AB in Sweden (Figure 12), who is building the world's first commercial gasification plant for production of methanol from forest biomass. It will have a capacity of gasifying 1000 tons of wood per day. The resulting synthetic gas will be converted to about 375.000 l methanol per day (Värmlandsmetanol AB).

Besides the conventional way for methanol production from methane through syngas generation, new and more efficient chemical technologies are under development: methane bromination followed by hydrolysis of the obtained bromomethane, and photochemical methane conversion.

Promising prospects for practical development offers also the biological methanol production. A very interesting approach is to use enzymes for a sequential conversion of CO<sub>2</sub> to methanol. As CO<sub>2</sub> is a greenhouse gas, its conversion offers gas recycling (environmental benefits) combined with production of an alternative fuel (energy benefits). In long terms, enzymatic biomethanol production presents entirely new bioenergy technology with huge potential for commercial utilization.

Further development of the biotechnological processes using microorganisms harboring either methane monooxygenase or pectin esterase also holds future promise for the production of sustainable methanol production from biomass.



**Figure 12. The prospected Forest biomass to methanol plant, Värmlands Methanol in Sweden (Värmlandsmetanol AB; In short about Värmlandsmetanol AB)**

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# Hydrogen

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## **Introduction**

Molecular hydrogen H<sub>2</sub> is a colourless, odourless and non-poisonous gas with very low specific gravity. It is the lightest of all gases (Lide et al., 2007), around 14 times lighter than air. The future energy economy will have an important role for hydrogen as a clean, CO<sub>2</sub>-neutral energy source. Unlike electricity, H<sub>2</sub> can be stored. Hydrogen is the most abundant element on the Earth (Schlapbach and Züttel 2001). The sources of hydrogen are versatile (fossil fuels, water, biomasses, organic wastes etc) and globally distributed. Hydrogen can be converted to electricity efficiently and without air emissions. The major advantage of energy from hydrogen is the lack of polluting emissions since the utilization of hydrogen either via combustion or via fuel cells, results in pure water.

## **Fuel characteristics**

Hydrogen has the highest per weight heating value of all fuels: 1 kg hydrogen contains as much energy as about 2.5 kg natural gas or about 2.8 kg gasoline (Das 1996). On the other hand, due to low specific gravity, the volumetric energy density of H<sub>2</sub> is low: 3.7 L of liquid H<sub>2</sub> has the same energy as 1 L of gasoline. Hydrogen gas must be handled with extreme care, since hydrogen has a wide ignition range in air, and low ignition energy (Busby 2005). Even though hydrogen has wide ignition range in air, hydrogen leaks are diluted rapidly due to high diffusion coefficient 812 times higher than gasoline's (Lovins 2005). The hydrogen flame in air is almost invisible making it difficult to spot (Busby 2005), but emits only 10 % of the radiant heat compared to hydrocarbon fuel fire (Lovins 2005). In air atmosphere, hydrogen does not explode easily and it rather burns. The theoretical explosion power is 22 times lower than that of gasoline (Lovins 2005).

## **Production methods**

Hydrogen can be produced from non-renewable resources (fossil fuels) and from renewable sources-different biomasses and organic residues. Approximately 96 % of the hydrogen produced is coming from fossil fuel-based processes and the rest 4 % - from water electrolysis. Among fossil fuel based technologies, main methods employed for hydrogen generation are being steam reformation of natural gas (48 % of hydrogen globally), partial oxidation of coal (18 %) or oil (30 %) (Balat and Balat 2009). Water electrolysis is considered feasible process for hydrogen production only when low-cost electricity is available or when high hydrogen purities are required (Busby 2005).

The methods available for hydrogen production from biomass can be divided into two main categories: thermochemical and biological routes (Balat and Balat 2009). Thermochemical biomass conversion processes includes: pyrolysis (Demirbas 2006), gasification (Demirbas 2002), steam reforming of bio-oils (Garcia et al., 2000), and supercritical water gasification of biomass (Guo et al., 2007). Biological production of hydrogen (biohydrogen) is one of the alternative methods where processes can be operated at ambient temperatures and pressures, and are less energy intensive and more environmental friendly (Mohan et al., 2007). Biological hydrogen production can be classified into the following groups (Balat and Balat 2009): direct biophotolysis, indirect



biophotolysis, biological water-gas shift reaction, photo-fermentation and dark fermentation. A promising method for biohydrogen production is the dark fermentation process performed by diverse group of bacteria.

### ***Hydrogen distribution***

Typically, hydrogen would be transported from the production site to the end users as a gas, via pipeline. Ideally, the current natural gas distribution system would be used for at least the initial stages of a transition to hydrogen. However, pure hydrogen reacts at the surface of certain pipeline steels, embrittling them and accelerating the growth of fatigue cracks (Lewis 1986). Hydrogen could not be shipped in pipelines made of susceptible steel unless the embrittling reactions were inhibited. Some compounds can be added to hydrogen to inhibit embrittlement. In gas-phase hydrogen atmosphere, even a small amount of oxygen present may eliminate (Dayal and Parvathavarthini 2003) subcritical crack growth rate. If an acceptable inhibitor is found, a transition to hydrogen fuels would be relatively unrestricted. Otherwise, dedicated hydrogen pipelines would have to be built. This would require a greater investment cost, which will delay a transition to hydrogen.

Hydrogen also could be shipped in liquid form, in 49000 L tank trucks, 132000 L rail cars, or for short distances, in vacuum-jacketed pipelines (De Luchi 1989). The last option would be feasible only for shipment to large potential end users, such as airports.

### ***Hydrogen storage***

Hydrogen storage is a key problem in implementation of hydrogen as fuel.

Current on-board hydrogen storage approaches (Hydrogen storage) involve compressed hydrogen gas tanks, liquid hydrogen tanks, cryogenic compressed hydrogen, metal hydrides, and chemical hydrogen storage materials. Storage as a gas or liquid or storage in metal hydrides or high-surface-area adsorbents constitutes "reversible" on-board hydrogen storage systems because hydrogen regeneration or refill can take place on-board the vehicle. For chemical hydrogen storage approaches (such as a chemical reaction on-board the vehicle to produce hydrogen), hydrogen regeneration is not possible on-board the vehicle; and thus, these spent materials must be removed from the vehicle and regenerated off-board.

Other forms of hydrogen storage, such as glass microspheres, cryoadsorbents and liquid hydrides, are discussed in the literature (Taube et al., 1985; Yan et al., 1985; Noh et al, 1987), but with exception of liquid hydrides, none are nearly as well developed for vehicular use.

### ***Safety issues***

Hydrogen is more hazardous than gasoline in several ways. It is invisible and odorless, and therefore an odorant must be added to enable detection. Hydrogen flames are very hot, yet radiate very little heat and are invisible (De Luchi 1989), which makes them harder to locate, and thus harder to distinguish or to avoid. A flame colorant addition would make detection easier. Hydrogen can ignite within a rather large range of hydrogen/air densities, from 4 to 74 % (by volume), and compared to methane or gasoline needs very little energy to ignite.

Hydrogen has a much higher normal burning velocity (De Luchi 1989) than has methane or propane. This mean that given a burning, detonable mixture of hydrogen, methane or propane, in a

confined space, the hydrogen configuration is most likely to detonate. However, if the mixture is not burning, is not capable of exploding or is not in a confined space, this is no longer true. Thus hydrogen is more explosive than the other fuels only in certain circumstances.

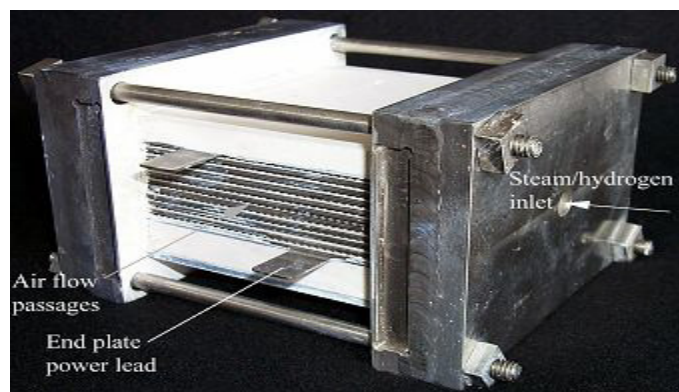
Contact with liquid hydrogen destroys human tissues. Wearing gloves reduces the risk of tissue damage.

## ***Practical applications***

### **In fuel cells**

Converting fuel to power on a kW scale with an efficiency reaching 50 to 60 % is a unique characteristic of the hydrogen fuel cell (Figure 13).

Many companies like Honda, General Motors, Daimler-Chrysler Mercedes, etc. are currently researching fuel cell technology ([Hydrogen Powered Fuel Cell Cars](#)). Many of them have also come up with models using fuel cells, for sale. Most of the [fuel cell](#) vehicles that are in operation today, use liquefied hydrogen tanks as a source of hydrogen, while the oxygen is used from the air. Some other models use a device known as the 'reformer'. A reformer is used to extract hydrogen from hydrocarbon fuels. Some cars also use a fuel cell that directly uses methanol. In this process, the hydrogen is directly removed from methanol within the fuel cell. In short, if you want to own a hydrogen powered fuel cell car, you have to have the facility of an hydrogen filling station or a methanol filling station.



**Figure 13. Hydrogen fuel cell (Hydrogen fuel cells)**

### **Hydrogen Powered Fuel Cell Cars**

Honda FCX Concept (Figure 14): The Honda FCX is one of the latest models of fuel cell concept cars that Honda has come up with. It uses a fuel cell stack that is placed in the mid-portion of the car for [energy](#) generation, and deploys two hydrogen tanks that are at the rear of the vehicle. It has a very low body and an over all length of 186 meters.

*GM Hy-wire Hydrogen Car:* The General Motors Hy-wire Hydrogen Car was an attempt by General Motors to make fuel cell driven cars more affordable. The designers of the Hy-wire have made it driver friendly and care has been taken that the driver experiences maximum comfort while maneuvering the car. The Hy-wire deploys 3 compressed hydrogen cylinders as a source of fuel.

*GM Equinox Hydrogen Car:* The GM Equinox Hydrogen Car was designed by General Motors to solve some problems and drawbacks of fuel cell driven cars. One of the major drawback that has been overcome by this model, is the working of fuel cells in sub-zero temperatures. The stack of fuel cells that powers the vehicle was an in-house research and development done by General Motors. The engineers claim that the car is designed to run exactly 50,000 miles.

*Ford Focus Hydrogen Car:* This car is a mixture of high fuel economy, excellent performance, and high comfort for the passengers. The car has undergone several modifications since its original designing. Many changes regarding the stack of fuel cells, vibration and noise reduction in the car has made it very comfortable to ride in. The fuel cell that is used by the car is known as the Ballard 902 and it uses one pressurized hydrogen tank.

Some of the other prominent manufacturers of the hydrogen powered fuel cell cars are [Toyota](#), Hyundai, [Mazda](#), Daimler-Chrysler Mercedes, Suzuki, [Nissan](#), Peugeot etc. In addition, many of the car manufacturers have come up with buses and trucks too. Some of the prominent cities in Europe have even deployed these fuel cell powered buses for public transport.

The use hydrogen powered fuel cell cars will not only facilitate resource conservation, but will also help us preserve the environment. The use of this technology will ensure that we have a greener and cleaner future.



**Figure 14. Honda FCX Clarity, a hydrogen fuel cell demonstration vehicle introduced in 2008 (Hydrogen Cars- an Illusion of Green 59)**

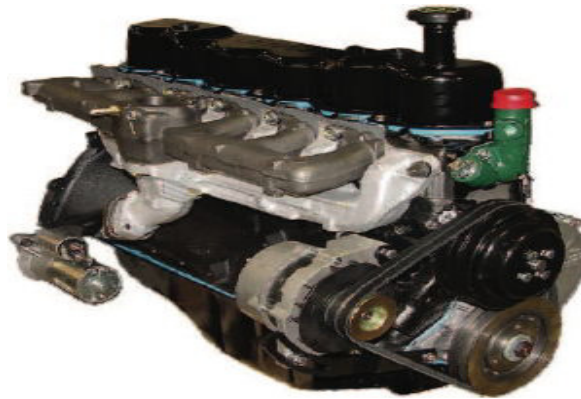
### **In internal combustion engines**

The use of hydrogen as a fuel for internal combustion engines potentially increases the efficiency of these engines (compared to gasoline) by an average of 20 % (Barbir 2001). The specific power of an internal combustion engine on gaseous hydrogen however decreases by up to 40 % due to lower heating value of the stoichiometric mixture of hydrogen and air compared to gasoline/air mixtures. Emissions of hydrogen fuelled internal combustion engines can be much lower than for gasoline. The emissions of NO<sub>x</sub> in hydrogen engines are typically one order of magnitude smaller than emissions from comparable gasoline engines (Barbir 2001).

Pre-ignition and back-firing are important engine design issues which need to be eliminated in the currently available spark-ignition engines to obtain an efficient and trouble-free engine running on

hydrogen (De Luchi 1989). The use of liquid hydrogen as a fuel alleviates the problems of engine design.

The efficiency of the hydrogen internal combustion engines (Figure 15) however will not come close to the efficiency expected for fuel cells on hydrogen. This is true even if substantial improvements can be obtained from the specific development of internal combustion engines for hydrogen. Using internal combustion engines for hydrogen only aggravate the real issues for transport on hydrogen: storage requirements and the efficiency of the full cycle (production of hydrogen to utilization in vehicle).



**Figure 15. Hydrogen internal combustion engine (Directory: Hydrogen Engine Center Inc)**

### ***Hydrogen economy***

The use of hydrogen as energy carrier is inextricably linked to efficient and clean final conversion. Hydrogen economy includes the production, storage, distribution and use of hydrogen as an energy carrier (Turner 2004). The main drivers and barriers of hydrogen economy are listed in Table 5. European commission has outlined that hydrogen economy would aid in sustaining high life standards and simultaneously providing a clean, safe, reliable and secure energy supply (European Commission 2003). The main barriers of hydrogen economy are related to the immaturity of technology, the lack of commercially competitive technology and infrastructure, and economical risks.

The potential climate impacts of hydrogen economy are unknown. The potential environmental concerns of hydrogen economy may be the increase in water vapour in the stratosphere due to unintended hydrogen emissions (Tromp et al., 2003). The increase in water vapour can cause stratospheric cooling, increase ozone degradation, and change tropospheric chemistry and atmosphere-biosphere interactions (Tromp et al., 2003)

**Table 5. Main drivers and barriers of hydrogen as energy carrier**

<b>Drivers of hydrogen utilization as energy carrier</b>		<b>Barriers of hydrogen utilization as energy carrier</b>	
Environmental and public health impacts related to the use of	Global climate change	Immaturity of technology, lack of commercially	Hydrogen production, fuel cells, storage and distribution
	Air and water		CO <sub>2</sub> sequestration

fossil fuels	pollution	competitive technologies	technologies
	Acid rain		Fuel cell vehicles
Increasing energy demand	Growth of population	Availability of lower cost energy alternatives (e.g. coal, natural gas, nuclear power)	Prices for fossil fuels not high enough
	Economic growth, growth in energy intensity and standard of living		Energy prices not yet affecting economic growth enough
Energy security	Depletion of fossil fuel resources	Difficulties in finding national, regional and global consensus for priorities of energy solutions	
	Decreasing the dependency of fossil fuels		
	Geographical distribution of fossil fuel resources and its political impacts		
Directives and regulations	E.g. the proportions of renewable in vehicle fuel	Hydrogen safety issues	

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# Biodiesel

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## ***Introduction***

The replacement of fossil fuels to secure future energy supplies continues to be a major concern. In this connection, biodiesel is an alternative to petroleum-based diesel fuel (petrodiesel). Biodiesel is defined as the mono alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, for use in compression-ignition (diesel) engines (Fukuda et al., 2001). The most common fatty esters contained in biodiesel are those of palmitic (hexadecanoic) acid, stearic (octadecanoic) acid, oleic (9(z)-octadecenoic ) acid, linoleic (9(z) 12 (z)-octadecanoic) acid and linolenic (9(z), 12(z), 15(z)-octadecatrienoic) acid ((Knothe 2008). Commercial biodiesel production started in 1991 with plants of up to 100000 tonnes per year having being constructed (Li et al., 2007). The process technology is well understood and established although there are some variants on the technologies used (Marchetti et al., 2007). Biodiesel have received considerable attention in recent years as a renewable, biodegradable, and non-toxic fuel. Estimations showed that a potential market of 20 EJ by 2050 which is around 10 %-20 % of total energy supply (IEA Energy Technology Essentials).

## ***Fuel characteristics***

Most important characteristics of biodiesel as fuel are cetane number, heat of combustion (heating value), kinematic viscosity, and oxidative stability (Knothe 2008).

The cetane (CN) number is a dimensionless parameter related to the ignition quality of a fuel in a diesel engine. Generally, higher CN values reflect better ignition quality of the fuel. The CN of given compound depends of the chemical structure of the compound. The CN increases with an increasing chain length and increasing saturation. Branched and aromatic compounds have low CNs. Thus, compounds found in biodiesel, such as methyl palmitate and methyl stearate, have high CNs, while methyl linolenate has a very low CN.

The heat of combustion increases with an increasing chain length and decreases with an increasing unsaturation. European standard for using biodiesel as heating oil, EN14213, specifies a minimum heating value of 35 MJ/kg. The heat of combustion is important for estimating fuel consumption: the greater the heat of combustion, the lower the fuel consumption.

The kinematic viscosity is the main reason why fats and oils are converted to biodiesel. The viscosity of biodiesel is approximately an order of magnitude lower than that of the parent oil draft, resulting in better atomization in the combustion chamber of the engine. Generally, viscosity increases with the number of CH<sub>2</sub> moieties in the fatty ester chain and decreases with an increasing unsaturation. Viscosity increases exponentially with a decreasing temperature, influencing flow properties.

Oxidative stability depends on the unsaturation level of the fatty acids. Saturated fatty acids are very oxidatively stable, while double bonds increase the fatty acids susceptibility to oxidation. The use of antioxidant additives is common to improve the oxidative stability of biodiesel.



## Feedstocks and production methods

Considerable research has been done on producing biodiesel from vegetable oils: palm oil, soybean oil, sunflower oil, coconut oil, and rapeseed oil. Animal fats, although mentioned frequently, have not been studied to the same extent as vegetable oils. Some methods applicable to vegetable oils are not applicable to animal fats because of natural property differences. Oil from bacteria, fungi and algae (single cell oil, SCO) also have been investigated (Li et al., 2007). Most promising seems SCO production from microalgae as some investigations showed extremely high production potential amounting to 46 ton of oil per hectare per year (Demirbas 2007)

Normally, triglycerides present in extracted crude oil, are converted into esters through transesterification (Figure 16) with alcohol (often ethanol or methanol) usually in the presence of a catalyst: acid, base or enzyme (Marchetti et al., 2007). Almost all biodiesel is produced using the base-catalyzed technique as it is the most economical process requiring only low temperatures and pressures and producing over 98 % conversion yield (Biofuel Production Data). Recently enzymatic transesterification methods for biodiesel production employing highly active lipase from psychrophilic bacteria were developed (Luo et al., 2006).

However toxicity and/or loss of catalysts and the relatively large amount of water necessary to clean both glycerol and biodiesel product, which represents a polluting burden to the environment, are considered as the main factors responsible for increasing the biodiesel production costs.

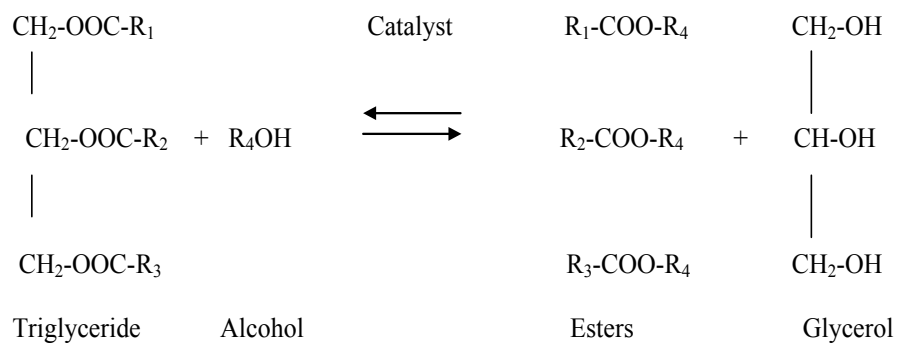


Figure 16. Transesterification process

### Distribution

Biodiesel is distributed from the point of production via truck, train, or barge. Pipeline distribution of biodiesel, which would be the most economical option, is still in the experimental phase. Biodiesel is distributed to retail fueling stations and directly to end users such as large vehicle fleets. Most biodiesel distributors deliver pure or pre-blended (with petroleum diesel) biodiesel depending on the customer's preference.

### Storage

In general, the standard storage and handling procedures used for petroleum diesel can be used for biodiesel. The fuel should be stored in a clean, dry, dark environment. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene and teflon. Copper, brass, lead, tin, and zinc should be avoided.

### Practical applications

Biodiesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration in most injection pump diesel engines. New extreme high pressure (29,000 psi) common rail engines have strict factory limits of B5 or B20 depending on manufacturer. Biodiesel

has different solvent properties than petrodiesel, and can degrade natural rubber gaskets and hoses in vehicles (mostly vehicles manufactured before 1992). Biodiesel has been known to break down deposits of residue in the fuel lines where petrodiesel has been used (Biodiesel Handling and Use Guide). As a result, fuel filters may become clogged with particulates if a quick transition to pure biodiesel is made. Therefore, it is recommended to change the fuel filters on engines and heaters shortly after first switching to a biodiesel blend.

### ***Use as transportation fuel***

#### **In car and buses**

DaimlerChrysler has recently launched a project involving tests of Mercedes-Benz C-class cars running exclusively on biodiesel (DaimlerChrysler's biodiesel agenda is go) (Figure 17). Few changes were made in the rubber and plastic parts in the fuel lines. The engine itself was not modified.

Starting in 2004, the city of Halifax (Nova Scotia, Canada) decided to update its bus system to allow the fleet of city buses (Figure 18) to run entirely on a fish-oil based biodiesel (Biodiesel and Ethanol Investing). This caused the city some initial mechanical issues but after several years of refining, the entire fleet had successfully been converted.

In 2007, McDonald's of UK announced that it would start producing biodiesel from the waste oil byproduct of its restaurants. This fuel would be used to run its fleet (McDonald's bolsters green credentials with recycled biodiesel).



**Figure 17. Biodiesel-fuelled car (Mercedes-Benz C-Class)**



**Figure 18. Bus run on biodiesel (Biodiesel in Transit and Municipal Fleets)**

#### **In trains**

British Train Operating Company Virgin Trains claimed to have run the world's first "biodiesel train", (Figure 19) which was converted to run on 80% petrodiesel and only 20% biodiesel, and it is

claimed it will save 14% on direct emissions (First UK biodiesel train launched). Environmental impact was equivalent to taking 23000 cars off the road.



**Figure 19. Biodiesel driven train (First UK biodiesel train launched)**

### **In aircrafts**

A test flight has been performed by a Czech jet aircraft (Figure 20) completely powered on biodiesel (Worlds first Jet flight powered entirely on renewable biodiesel fuel). Other recent jet flights using biofuel, however, have been using other types of renewable fuels.



**Figure 20. Biodiesel driven aircraft (Worlds first Jet flight powered entirely on renewable biodiesel fuel)**

### **Use as a heating oil**

Biodiesel can also be used as a heating fuel (Biodiesel: the New American Heating Oil) in domestic and commercial boilers. When Biodiesel is used for heating, it is mixed with regular heating oil to produce a new energy source with even lower emissions. It is sometimes known as "bioheat". Heating biodiesel is available in various blends; up to 20% biofuel is considered acceptable for use in existing furnaces without modification. Older furnaces may contain rubber parts that would be affected by biodiesel's solvent properties, but can otherwise burn biodiesel without any conversion required. Care must be taken, however, given that varnishes left behind by petrodiesel will be released and can clog pipes- fuel filtering and prompt filter replacement is required. Another approach is to start using biodiesel as blend, and decreasing the petroleum proportion over time can allow the varnishes to come off more gradually and be less likely to clog. Thanks to its strong solvent properties, however, the furnace is cleaned out and generally becomes more efficient.

### ***Biodiesel economy***

Biodiesel is commercially available in most oilseed-producing countries (Demirbas 2007). Currently biodiesel is more expensive than petrodiesel (cost is 1.5–3 times higher than the fossil diesel cost in developed countries), though it is still commonly produced in relatively small quantities (in comparison to petroleum products and ethanol). The competitiveness of biodiesel to petrodiesel depends on the fuel taxation approaches and levels. Generally, the production costs of biodiesel remain much higher compared to the petrodiesel ones. Therefore, biodiesel is not

competitive to petrodiesel under current economic conditions. The competitiveness of biodiesel relies on the prices of biomass feedstock and costs, associated with conversion technology.

Development of new, clean and more effective transesterification process is a key issue for economically feasible biodiesel production. Currently, in most EU Member States, diesel consumption has gradually become the most preferred fuel compared to petrol due to number of advantages over gasoline-power and fuel economy (it burns considerably less fuel than a gasoline engine performing the same work), no ignition system, reduction of air pollution and greenhouse gas emissions. Biodiesel can be used most effectively as a supplement to other energy forms, not as primary source. It is particularly useful in mining and marine situations where lower pollution levels are important.

Despite numerous environmental benefits, a broader use of biodiesel is hampered by the extensive agricultural area required for sufficient production of oilseed crops. The main challenge is with respect to limited availability of fat and oil resources and relatively high cost of vegetable oil prices. Therefore, processes are urgently needed to enable biodiesel production from more readily available bulk plant materials like cellulose. Towards this goal, a recent efforts for sugar-based biodiesel production due to enzymatic activities of genetic engineered microorganisms was made (Kalscheuer et al., 2006). Aquatic biomass was also shown to be a promising source for biodiesel production due to high lipid accumulation rates and lipid yields in microalgal cells (Chisti 2007; Demirbas 2011). Those novel approaches can pave the way towards commercial production of biodiesel.

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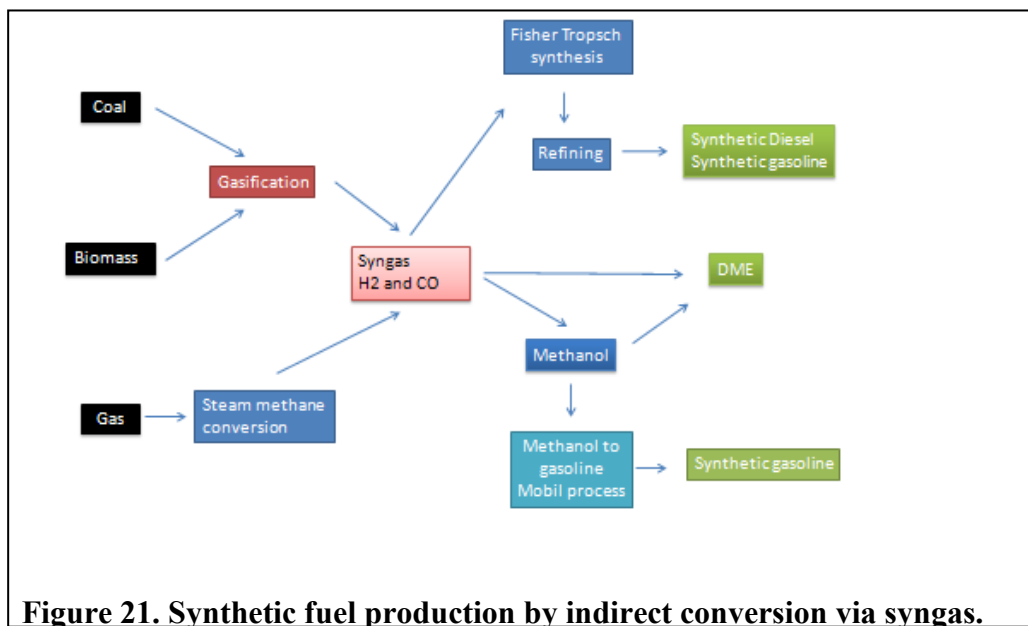
# Synthetic diesel, synthetic gasoline and DME

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## Introduction

The term synthetic fuel is usually defined as a liquid fuel obtained from coal, natural gas, or biomass. The technical process of converting the feedstock into liquid fuels can be divided in two: direct conversion and indirect conversion. In this chapter we will describe these fuels as produced by indirect conversion via synthesis gas ( $H_2+CO$ ) by gasification of various feedstocks. Many types of fuels can be produced by these processes, but among the most promising are synthetic diesel, synthetic gasoline and DME (di-methyl ether) (Figure 21).

Historically synthetic fuels have been produced commercially in periods of oil shortage or high oil prices. Most pronounced being the invention of the Fisher Tropsch (FT) process in Germany in the 1920's, where the following industrial application of this process resulted in a production capacity equal to 9,1 % of the total German oil supply during world war II (Leikel,2009). The fuels obtained by these processes have excellent properties especially in terms of exhaust emissions, but they are expensive to produce and the profitability depends highly on the competing oil prices and the feedstock used. Only if biomass is applied as feedstock the resultant fuel can deliver significant  $CO_2$  reductions as an alternative transportation fuel.



## Fuel characteristics

### Synthetic diesel

Synthetic diesel as represented by FT diesel is mainly composed of linear alkanes and has a low content of aromatic hydrocarbons as well as being virtually free of sulphur. This fact results in a fuel with a high cetane number (CN), almost double the CN of ordinary diesel fuel (Table 7). While the engine performance of the synthetic diesel is similar to the performance of the

petrochemical derived diesel, the synthetic diesel offers advantageous exhaust emissions. All major pollutants such as SO<sub>x</sub>, NO<sub>x</sub>, PM (particulate matter) and HC (hydrocarbons) are reduced as compared to standard petroleum derived diesel (Huang et al, 2008).

Synthetic diesel can be used in diesel engines without significant changes and can be blended into petro diesel in any ratio. Some properties of FT diesel are shown in Table 7.

**Table 7. Properties of synthetic diesel (F-T) and standard Diesel no. 2. (Demirbas, 2008)**

	F-T	No. 2
Density, g/cm <sup>3</sup>	0.7836	0.8320
Higher heating value, MJ/kg	47.1	46.2
Aromatics, %	0–0.1	8–16
Cetane number	76–80	40–44
Sulfur content, ppm	0–0.1	25–125

### **Synthetic gasoline**

Normal gasoline derived from oil is a complex mixture of hydrocarbons (alkanes, alkenes and aromatic hydrocarbons) having between 5 to 12 carbon atoms. Synthetic gasoline produced either by FT or by methanol to gasoline (MTG) process, is likewise a complex mixture of hydrocarbons. Advanced refining can make these products very similar to standard gasoline as measured by standard parameters like the octane number. (Kamara and Coetzee, 2009)

### **DME**

DME (Di-methyl ether) is the simplest ether with the chemical formula (CH<sub>3</sub>OCH<sub>3</sub>). DME is a promising fuel for diesel engines. It has a high cetane number (55-60), high oxygen content (Table 8) and absence of C-C bonds which gives a clean combustion with low exhaust emissions as compared to standard diesel fuels. DME is a gas at room temperature and vehicles need a pressurised fuel tank (5 Bars) to keep the DME in a liquid form. Only minor modifications of the diesel engine are needed to make it run on DME.

**Table 8. Comparison of selected fuel properties of DME and diesel**

Property	DME	Diesel
Cetane number	55	40-50
Lower heating value (LHV), MJ/kg	27,6	42,5
Oxygen content, Mass %	34,8	0

## ***Production routes***

### **Synthetic Diesel and Gasoline**

#### *FT synthesis*

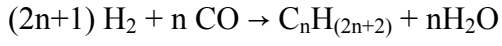
Production of synthetic diesel and gasoline by indirect conversion involves two steps. In the first step the carbonaceous feedstock is converted into syngas in a process called gasification (Figure 22). The feedstock is grinded and fed into the gasifier. In the gasifier the feed stock reacts with steam at high temperature (>700°C) and pressure in a low oxygen atmosphere to create syngas.



**Figure 22. Chemistry of gasification**

Main components of the syngas are CO and H<sub>2</sub>. The gas obtained is thereafter purified and unwanted gases like CO<sub>2</sub> are removed.

In the next step the gas mixture can be converted into a liquid transportation fuel (synthetic diesel or gasoline) by different methods. Here we will describe a well known and widely used process namely the Fischer Tropsch (FT) process. The process was invented in Germany early last century and many variations exist. In this process CO and H<sub>2</sub> reacts at high pressure and temperature (150 – 350<sup>0</sup> C) in the presence of a catalyst. The catalyst used can be based on Co, Fe, Ni and Ru. At these conditions many chemical reactions take place, but the main reactions create linear alkanes. The wanted overall reactions can be described in the following reaction scheme.



The alkanes produced range from C<sub>2</sub> (Ethane) to waxes > C<sub>35</sub>. The concentration of the different alkanes in the final product depends on the variation of the FT process being used.

High temperature FT process (HTFT) using Fe based catalysts will be optimal for producing alkanes in the gasoline range (C<sub>5</sub> – C<sub>12</sub>).

Low temperature FT process (LTFT) using either Fe or Co based catalysts will be optimal for producing alkanes of higher molecular mass like alkanes in the diesel range C<sub>12</sub>– C<sub>18</sub> and waxes (>C<sub>32</sub>). The high yield of waxes from this process can additionally be turned into diesel by mild hydro cracking (Dry, 2002).

*Methanol to Gasoline process (MTG, Mobil process)*

Alternatively the syngas produced from various feedstocks can be converted to synthetic gasoline by a method invented by the company Mobil. The syngas (CO+H<sub>2</sub>) is converted to methanol (CH<sub>3</sub>OH), which is turned into a mixture of hydrocarbons over a zeolite catalyst. 80% of this mixture can be used as high octane gasoline containing highly branched alkanes, highly branched alkenes, cycloalkanes and aromatic hydrocarbons (Coal to clean gasoline). The process has been commercialized in New Zealand in 1985 where the plant, in a period of 10 years, was producing 0,6 Mtons of gasoline per year from natural gas (Zhang, 2010). A new MTG plant using coal as feedstock is under construction in China with an expected capacity of 1Mtons of gasoline per year (He et al, 2009).



## DME

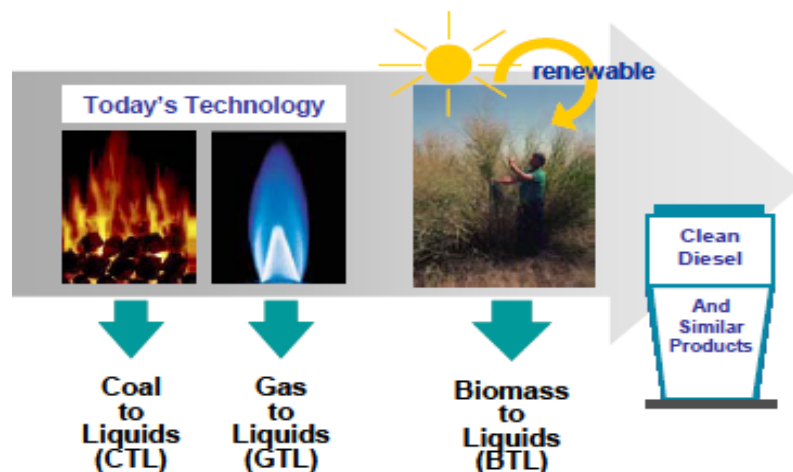
DME can also be produced from syngas in two different ways (Arcomanis et al., 2008)

- 1) Syngas is first converted to methanol by a copper based catalyst. In the second step the methanol is dehydrated to form DME using alumina or zeolite catalysts.
- 2) Syngas is converted directly to DME in a reactor where both of the above reactions take place simultaneously.

Most DME is produced using natural gas, but lots of efforts are being made to create a process using renewable biomass in the process. The term Bio-DME is being used when biomass is used as feedstock for the syngas production.

## *Current status and prospects*

The profitability and the modification of the general processes outlined above depend highly on the feedstock used. Depending on the feedstock utilized, following processes were developed: CTL (Coal to liquid), GTL (Gas to liquid) and BTL (Biomass to liquid) (Figure 23).



**Figure 23. Synthetic fuel nomenclature.**

### CTL (Coal to liquid)

In South Africa the company Sasol has pioneered this process since 1955. They are operating two plants converting coal to synthetic diesel and gasoline. These plants currently produce about 37% of the transportation fuel needs of South Africa (Lekel, 2009). As the known coal reserves are 25 times higher than the known oil reserves, many other countries are considering to use this process type for production of transportation fuels.

### GTL (Gas to liquid)

In this process methane, typically natural gas is converted to synthetic fuels. Methane is converted to syngas by steam reforming. Plants can in many cases take advantage of cheap natural gas feedstock from areas where the gas cannot easily be brought to market. Examples of commercial use of these technologies for production of GTL fuels are the plants operated by Shell in Bintulu, Malaysia and the Perl plant in Qatar. Both plants are using the FT process to produce GTL products. The Bintulu plant has been operating since 1993. It is producing 14700 barrels of GTL products per day where a substantial part is transportation fuel. The Perl plant in Qatar is almost

operational and will have a capacity ten times higher with an estimated production of 50 000 barrels of GTL gasoil per day (The Shell global homepage)

#### BTL (Biomass to liquid)

Although the basic technology is known from GTL and CTL, there is still no commercial production using these processes. According to Zhang (2010) the more complex and costly gasification and gas purification is the biggest challenge to commercialisation of BTL fuels. Many BTL demonstration plants are either running today or will be constructed in the near future. Some examples are described below.

- Piteå, Sweden: Bio-DME production from black liquor (waste from paper mills). The demonstration plant is part of an EU supported project where all aspects from production of DME, construction of filling stations and trucks (Figure 24) are tested. The production is based on gasification followed by synthesis of DME from syngas as described above. If all black liquor produced from paper mills in Sweden is converted to DME, it can substitute 50 % of all diesel used for road transport in the country (Volvo Bio-DME).
- Vaenamo, Sweden : Demonstration plant for gasification of biomass to produce transportation fuels like FT diesel and DME (Zhang, 2010)
- Gussing, Austria : A BTL demonstration plant (Oxford catalyst and SCG Energia) has been constructed for small scale production of fuels via the FT reaction. The plant is using syngas from the existing gasifier which successfully has demonstrated production of syngas for electricity production.(Oxford Catalyst homepage)
- Freiburg, Germany: The company CHOREN has built a BTL plant capable of producing 18 million liters of FT products per year from 60000 tons of biomass.

#### ***Use in transport today***

In a worldwide perspective the current use of DME and synthetic gasoline and Diesel (CTL, GTL and BTL fuels) are still limited. Locally the production and use of these fuels can be very high due to low feedstock cost or political incitements like in South Africa. CTL and GTL liquid fuels are currently being produced commercially in large scale and used either as a blend with standard diesel to improve specifications or directly as transportation fuel. BTL fuels which can offer CO<sub>2</sub> neutral energy still needs further optimisation to be a major contributor to the transportation fuel market.



**Figure 24. Volvo truck especially designed to run on Bio-DME (Volvo Bio-DME).**

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Volvo Bio-DME

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# Biogas

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## **Introduction**

When biomass decomposes under conditions without air access, so called anaerobic digestion (AD), then biogas is often produced (Angelidaki et al., 2011). Such events take place in e.g. wetlands. When you walk in such areas, bubbles will raise to the surface, and provided you have a match, it is possible to see that the gas is combustible. Such gas can, if collected and purified, be used as vehicle fuel.

Today, biomass is put into reactors and the biogas formed is collected, purified, dried and compressed before it can be used as a vehicle fuel.

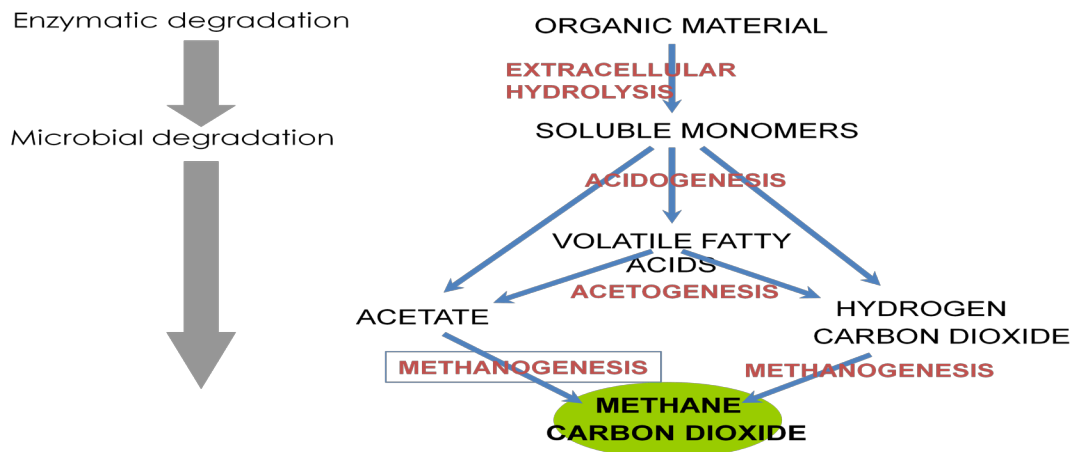
A beauty with the biogas production is that almost any biomass can be converted into biogas. This is a big difference as compared to the situation for production of alcohols or biodiesel when in essence only carbohydrates or fat, respectively, can be used.

## **Fuel characteristics**

Biogas is essentially methane (50-75% CH<sub>4</sub>), the rest-CO<sub>2</sub> (25-50 %), and minor components such as H<sub>2</sub>, H<sub>2</sub>S etc (The Biogas). The energy content is slightly lower than that of natural gas (natural gas contains some larger hydrocarbons with higher energy content). In Sweden the gas is purified (carbon dioxide and water vapor are removed) and pressurized. If the gas is to be added to the natural gas grid, then one has to add a small amount propane thereby improving the energy content to the same level as that of natural gas.

## **Production methods**

Traditional production methods involve stirred tank reactors with a dry mass of approx 8 – 10 % suspended in water (Angelidaki et al., 2011). The process is complicated since organic polymers (carbohydrates, proteins and lipids) are degraded, first to monomeric building blocks such as monosugars, amino acids, fatty acids and glycerol. These components are then further converted into organic acids and in a the acids are converted subsequently into acetate, hydrogen and carbon dioxide (CO<sub>2</sub>), Finally, methane is produced from acetate and from H<sub>2</sub> + CO<sub>2</sub> (Figure 25)

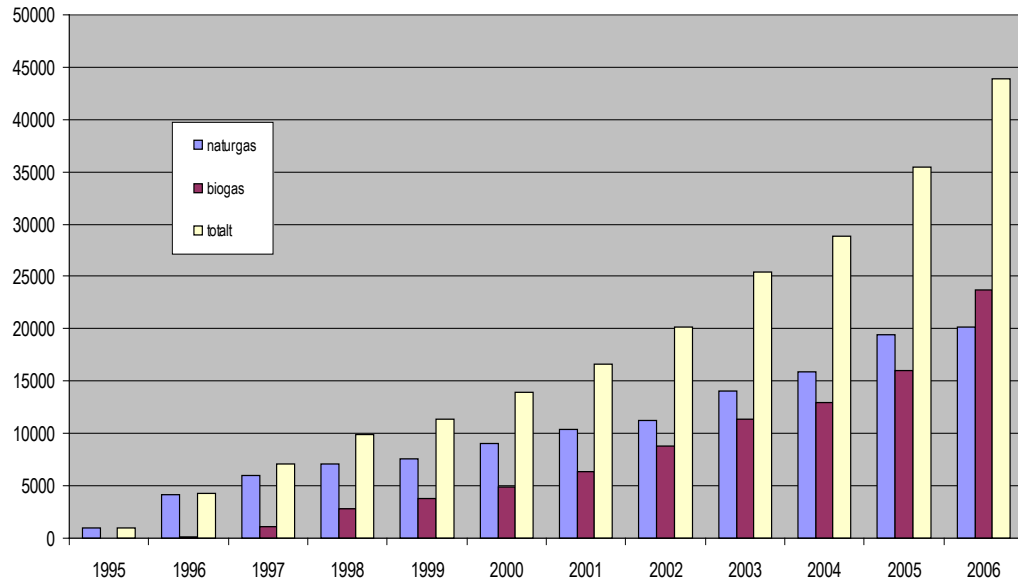


**Figure 25. Flow chart of AD process**

If the earlier steps in the process are much more efficient than the latter ones, then there will be a build up of intermediates such as organic acids. This will cause the pH to drop and eventually to such a low level that the methane forming archae are initially inhibited and later on dying. It is thus important to keep control over the feeding rate such that there is always a balance between amount of added organic material and the production of biogas. This is often a problem, and if the process is poorly managed, then there will be process failure and the whole concept of biogas production gets a negative publicity. Provided proper control is used, then it is an efficient process. In many cases, operators are afraid of process failure, and therefore only load a fraction of what the reactor could take theoretically.

After an initial peak when all easily degraded material is converted into biogas, a slower phase starts involving depolymerization of the biopolymers. This means enzymatic hydrolysis. This is often the rate limiting step.

In 2006 for the first time more biogas than natural gas was used as vehicle fuel in Sweden (Figure 26). During that year 24 million cubic metres of biogas was utilized as vehicle fuel, which is equivalent to 26 million litres of petrol (BIOGAS, basic data on biogas, 2007).

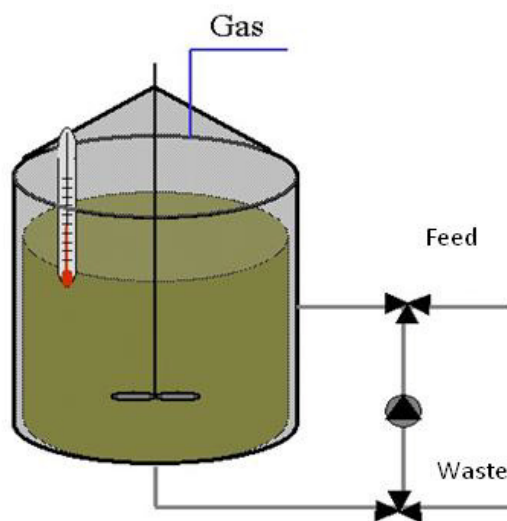


**Figure 26. Delivered volumes of methane gas as vehicle fuel in Sweden (source: Swedish gas association).**

### **Reactors**

The most common type of reactor used for anaerobic digestion is the continuously stirred tank reactor (CSTR) (Figure 27). Approx 8-10 % dry weight biomass is kept suspended in an aqueous phase, and more biomass is added when needed. This type of reactor is used at many wastewater treatment plants. The reactors are fed intermittently when, by experience, it is regarded suitable to feed. Control at many places is limited to monitoring gas volume produced and maybe pH.

The retention time in the reactor is dependent upon the composition of the fed biomass. Easily degraded material is converted relatively quickly, while lignocellulosic material will need extended periods of time to be degraded. For processing sludge from wastewater treatment plants, a retention time of approx 30 days is often used.



**Figure 27. Schematic presentation of a CSTR**

The volume of biogas produced per kg of biomass that is processed varies with the composition of the biomass. Carbohydrates give approx. 350 m<sup>3</sup> gas per kg of biomass, while fat gives higher values.

Large (industrial) scale biogas production is common practice in many European countries (State of biogas plants in European agriculture) -especially Germany and Denmark (Figure 28). Often the reactor volume is big, in range 2.000 – 4.000 m<sup>3</sup>. There are examples of reactors up to 100.000 m<sup>3</sup>.



**Figure 28. Lemvig biogas plant (17,500 m<sup>3</sup> reactor volume)**

### ***Process control***

Since the anaerobic digestion is such a complex process with a large number of different microorganisms involved, there will appear problems in finding conditions that are suitable to all of these essential organisms, and at the same time conditions allowing production of biogas. A range of different strategies have been applied.

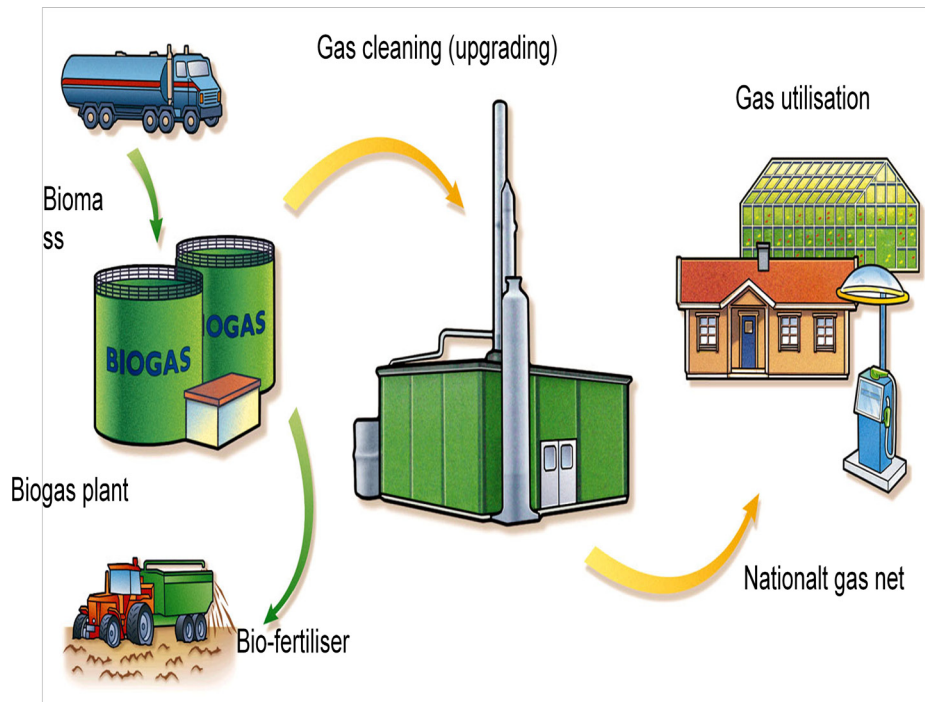
The most conservative has been to just use a low loading of the reactors, thereby not challenging the system. This gives a low productivity but a high stability.

Alternatively, one may add more substrate and then get a higher productivity but most often less control over the process. Risk for process failure is obvious, unless proper control is applied.

With modern process control it is possible to use high loads and still maintain good stability of the process while a high productivity is achieved (Liu et al 2006).

### ***Biogas upgrading***

Produced biogas need to undergo upgrading before distribution and utilization (Figure 29). This includes removal of the CO<sub>2</sub> content as well as H<sub>2</sub>S and other impurities.



**Figure 29. Flow chart: biomass production to biogas utilization**

### ***Biogas distribution***

There are several alternative ways to distribute biogas to the customer (Johansson 2010). In places where there is a natural gas grid (Figure 30), then injection of biogas into that net would be a very easy way for distribution. A large number of biogas filling stations are already installed in Sweden (Figure 31).

However, biogas contains slightly less energy than the natural gas since the latter also holds small fractions of higher alkanes which represent higher energy content. One way to solve the dilemma is to mix in small amounts of propane, and that is done in Sweden today.

Alternative modes of distribution is in pressurized form, often above 200 atm pressure. This is an expensive way of handling the gas since the pressurized vessels are heavy and expensive. Where there is no gas grid, this is the alternative to use.

Liquified biogas is an alternative that has come up recently. By freezing the gas to a temperature where it becomes liquid, it is possible to increase the energy density and thereby reduce the volumes substantially. Liquified biogas is a very interesting alternative for heavy vehicles, esp. trucks. The development is in its infancy, but the prognosis is that it will grow in importance.





**Figure 30. Natural gas grid in Southern Sweden**

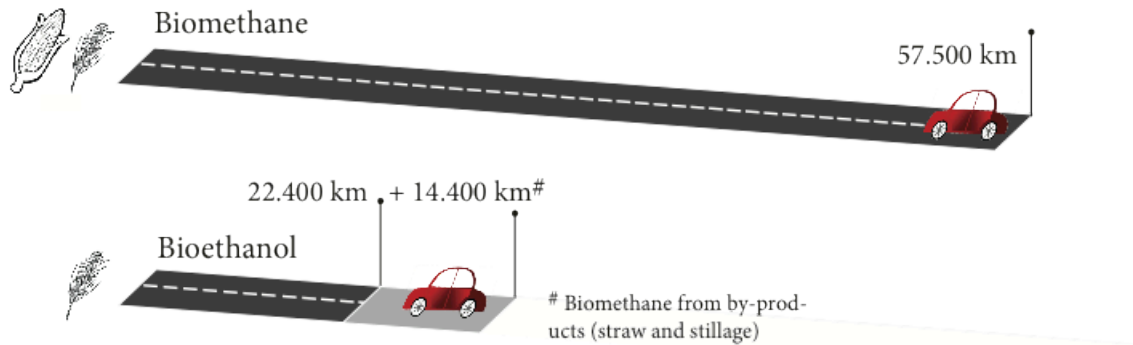


**Figure 31. Public filling station for natural gas and biogas in Sweden**

### ***Why biogas and not other biofuels?***

There have been calculations done concerning how far one can drive on the amount of crops that can be harvested from 10.000 m<sup>2</sup> under conditions of northern Germany, southern Sweden or Denmark (Figure 32). It then turns out that you can drive almost double the distance when biogas is produced, as compared to when ethanol is produced. This is partly due to the fact that biogas can be produced from all biomass polymers (carbohydrates, proteins, lipids), while the ethanol is produced from carbohydrates fraction only (Börjesson and Mattiasson 2007).

How far can one drive on the bioenergy produced from one hectare (10.000 m<sup>2</sup>) of land?



**Figure 32. Car driving distances with two scenaria -biomass to biogas and biomass to ethanol**

### ***Use in transport today***

Biogas is widely used in the public bus transportation system (Figure 33) in Sweden.



**Figure 33. Biogas fueled buses in Sweden**

### ***Future perspectives***

Logically, biogas would become an important fuel since it can be produced from almost any biomass. Furthermore, the fuel yield is higher when converting biomass as compared to any of the other fuels. A drawback is that it is gaseous and therefore does not fit in with the infrastructure built for handling of liquid fuels. There are however large number of vehicles that have been converted for use of natural gas in many countries, and such vehicles can directly by operated on biogas.

How big will be the share of biogas in the future renewable energy production? Answer to this question is very much a political issue. When used properly, anaerobic digestion will not only supply a fuel, it will also assist in handling a waste problem. If even larger volumes of biogas will

be needed in the future, energy crops might be used. The technology to utilize lignocellulose will be similar to that being developed for ethanol production.

Although biogas production is already commercially applied, there are still technological bottlenecks that can be improved. Emerging reactor technologies, development of advanced monitoring and control systems, as well as methods for increasing biodegradability of relatively recalcitrant feedstocks are making the biogas production more economically feasible. Although, biogas still needs subsidizing, it is foreseen that the biogas sector will increase in the coming years and biogas will be a significant biofuel.

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# Electricity

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## **Introduction**

An electric vehicle (EV), which is also known as an electric drive vehicle, uses one or more electric motors for propulsion rather than being powered by a gasoline-powered motor. Electric vehicles include electric cars, electric trains, electric lorries, electric airplanes, electric boats, electric motorcycles and scooters, electric bicycle and electric spacecraft [1, 2].

Electric vehicles (Figure 34, Figure 35) first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion [1]. In 1828, Hungarian, Ányos Jedlik invented a small-scale model car powered by an electric motor that he designed. Between 1832 and 1839 (the exact year is uncertain), Robert Anderson of Scotland invented a crude electric-powered carriage. In 1835, another small-scale electric car was designed by Professor Stratingh of Groningen, Holland, and built by his assistant Christopher Becker. In 1835, Thomas Davenport, a blacksmith from Brandon, Vermont, built a small-scale electric car. Davenport was also the inventor of the first American-built DC electric motor [3].

Due to major progress in battery technology, electric drive vehicle are expected to enter the market within the next few years. Electric vehicles are characterized by the highest engine efficiency of existing propulsion systems and zero tailpipe emissions. The use of electricity as an energy carrier for these vehicles offers the opportunity to broaden the range of primary energy sources in road transport [4].



**Figure 34. Edison and a 1914 Detroit Electric, model 47 (courtesy of the National Museum of American History) [1]**



**Figure 35. An electric vehicle and an antique car on display at a 1912 auto show [1]**

### ***Electricity sources***

***Full Electric Vehicles (FEV):*** It is also called on-board rechargeable electricity storage system (RESS), which is a system that stores energy for delivery of power and which is rechargeable. Power storage methods include: (1) chemical energy stored on the vehicle in on-board batteries: Battery electric vehicle (BEV) [5] (2) static energy stored on the vehicle in on-board: Electric double-layer capacitors. [6]

***Direct connection to generation plants.*** As what is common among electric trains, trolley buses, and trolley trucks.

***Renewable sources such as solar power and wind power.*** Solar vehicle is an electric vehicle powered by solar panels on the vehicle. Photovoltaic (PV) cells convert the sun's energy directly into electricity. Solar power may be used to provide all or part of a vehicle's propulsion, or can provide power for communications, or controls, or other auxiliary functions. [7]

***Diesel engine.*** Diesel-electric transmission or diesel-electric power train is used by a number of vehicle and ship types for providing locomotion. [8]

***Fuel cell.*** A Fuel cell vehicle or Fuel Cell Electric Vehicle (FCEV) is a type of hydrogen vehicle which uses a fuel cell to produce electricity for powering its on-board electric motor. The hydrogen and oxygen from the air are used in vehicles to create electricity for powering an electric motor [9]

***Nuclear energy.*** Nuclear energy is the potential energy of the particles inside an atomic nucleus, which are bound together by the strong nuclear force. Weak nuclear forces provide the potential energy for certain kinds of radioactive decay, such as beta decay. [10]

***On-board rechargeable electricity storage system and a fueled propulsion power source.*** It is also called plug-in hybrid. This system utilizes rechargeable batteries, or another energy storage device, that can be restored to full charge by connecting a plug to an external electric power source. [11]

### ***Challenges and possible solution***

The challenges facing by EV are mainly concerned from following aspects [12]:

#### ***(1) Energy and power density***

The total amount of energy that a battery pack contains determines the vehicle range. How quickly the energy can be removed translates to vehicle acceleration. For these two attributes there are constraints within the car of weight and volume. In the vehicle application small batteries increase range, and light batteries increase the power to weight ratio for better acceleration. The entire vehicle is constrained by cost. More batteries are more expensive which is why EVs are typically smaller. As the price of batteries fall along with volume and weight per unit energy, then larger

electric vehicles are economically viable. New battery chemistry such as nano-phosphate cathodes is now allowing for these high discharge rates. While this opens the door for great vehicle performance, the range of the vehicle will continue to be an issue.

### ***(2) Battery charging***

Charging frequency is one of the key limiting factors for electric vehicles. In most applications drivers cover fewer than 40 miles however the option to go further without waiting to recharge is one that drivers may be reluctant to relinquish. The plug-in hybrid (PHEV) and extended range electric vehicle (EREV) can fall back on the existing liquid fuel infrastructure at the sacrifice of some efficiency and fuel costs. This strategy will likely dominate in the near term.

### ***(3) Lifetime performance***

Every cycle of charging and discharging is a day in the life of a battery. Each chemistry battery has its own properties of how different usage parameters affect its usable life. Advanced lithium ion chemistry exhibits small cycle degradation rates up to 1000 cycles with deep discharge capability. Current battery technology in automotive applications is likely to last up to 5 years. This is a step down from the current expectation for new cars. The driving performance of electric vehicles diminishes over the vehicle lifetime. As with charging performance the battery technology will be the key determining factor for its application. The battery management system can control the charge and discharge rates to help extend life. Careful thermal management can also reduce capacity degradation over time. High temperature in particular is more damaging for the lifetime of batteries.

### ***(4) System Costs***

Batter costs are high, and the lifetime is relatively shorter than traditional power sources. There must be some efficient ways to address the cost of the vehicle. Electric sports cars are a good early market, but to make dent in gasoline consumption there need to be many more electric vehicles on the road.

## ***Current status and prospects***

The two elements of the landscape for the developing EV industry comprise battery developers and manufacturers of hybrids EVs (HEV), plug-in hybrids and battery EVs. The latter element is considered here as three sectors: major auto industry original equipment manufacturer (OEMs), EV companies that have vehicles in the market, EV start-ups that may have a concept vehicle but where market launch is still uncertain.

The past year has seen some major advances in all of the three EV categories. The forecast in early 2007 that there will be over 50 hybrid models in the market by 2010 now needs to be refined into a projection of how these will be divided among regular HEVs, PHEVs, and BEVs. The EV market estimated at \$30 billion market in 2006 has the potential to rise to over \$200 billion by 2015 [13].

The following Table 9 summarized the market-ready EV start-ups. At the end of 2007, there were more than 30 EV start-up companies that provided hybrids, plug-in HEV conversions, light electric vehicles (LEVs) or full power battery EVs (FPBEV) products. In the first rank are listed groups that have EVs in the marketplace or firm launch plans, as well as substantial financial and resource support. This group includes Azure Dynamics, Bolloré-Pininfarina, Commuter Cars, Dynasty Electric Vehicles, Electrovaya, Chrysler-GEM, Pininfarina-Bolloré, Myers Motors, Smith Electric Vehicles, Tesla, Zenn, and Zap Motors.

As with other key manufacturing sectors, the economic growth of Asia, especially the three billion populations and rapidly growing middle classes in China and India will have a major impact

on the EV market. India has only a few companies actively involved in EV production. These including the Reva (also known as the G-wiz), which is sold too in London, UK, and several groups developing in electric auto-rickshaws, known as tuk-tuks. Tara International also has a concept EV, the Tara Tiny that aims to compete with the Tata Nano ICEV. It is priced at just under 100,000 rupees (about \$2,450). Tara is partnered with Aucma, a leading Chinese electrical equipment supplier [14].

**Table 9. Established and Start-up EV Companies [14]**

Company	Vehicle/Type	Website	Status
AC Propulsion	Leading EV designer control/battery systems eBox conversion	<a href="http://www.acpropulsion.com">www.acpropulsion.com</a>	Equpt suppliers Tesla, X-Box, Venturi
Azure Dynamics	Canadian manufacturer of custom HEV vehicles including taxis and buses – partnered with Ford and Fedex	<a href="http://www.azuredynamics.com">www.azuredynamics.com</a>	Several custom commercial HEVs` in market
Bollore-Pininfarina.	Bollore Blue car – produced by Pininfarina	<a href="http://www.pininfarina.com">www.pininfarina.com</a>	Launched 2010
Commuter Cars	Tango model is concept car \$39K up – to order	<a href="http://www.commutercars.com">www.commutercars.com</a>	2 years to launch
Dynasty Electric Vehicles	Range of BEV models –price \$19,000	<a href="http://www.itselectric.com">www.itselectric.com</a>	Available
Think	Global Think City; original design by Ford; Li battery; LSV with predicted 175km range	<a href="http://www.think.no">www.think.no</a>	Launched in Norway, UK, and N. America during 2008.
Chrysler GEM	Earliest commercially available LSV	<a href="http://www.gem.com">www.gem.com</a>	Over 60K units sold
Cree Ltd	SAM EV - BEV 3-wheeler	<a href="http://www.cree.ch">www.cree.ch</a>	Launched 2008
Electrovaya Corp	Maya 100 Concept crossover SUV – plans to launch Maya 300 LSV late 2008	<a href="http://www.electrovaya.com">www.electrovaya.com</a>	Launched 2008
Hybrid Technologies	Offering custom conversion BMW	<a href="http://www.hybridtechnologies.com">www.hybridtechnologies.com</a>	Custom orders now

Inc	Mini and Mercedes Smart Car		
Hymotion	Custom conversion of PHEVs	<a href="http://www.hymotion.com">www.hymotion.com</a>	Recently acquired by A123
Magna Corp	PHEV produced by Austrian Steyr Group	<a href="http://www.magna.com">www.magna.com</a>	Launched 2006
Miles Electric Vehicles	2 LSV models plus XS500 FPBEV	<a href="http://www.milesev.com">www.milesev.com</a>	Available – XS500 in 2009
Myers Motors	Single seat BEV model NmG	<a href="http://www.myersmotors.com">www.myersmotors.com</a>	Available
Modec	UK based all-electric van	<a href="http://www.modec.co.uk">www.modec.co.uk</a>	Available in UK
Smith Electric Vehicles	BEV 2 models, Edison All battery delivery vehicle – priced at \$40K	<a href="http://www.smithelectricvehicles.com">www.smithelectricvehicles.com</a>	Available UK, US launched in 2009
Phoenix Cars	BEV Sport Utility Truck – partnered with Electrovaya	<a href="http://www.phoenixcars.com">www.phoenixcars.com</a>	SUT launched early 2008
Reva	LSV, Pb acid battery – price \$7K to \$9K	<a href="http://www.revaindia.com">www.revaindia.com</a>	Available India and UK
Tesla Motor	Custom sports car priced at \$100K	<a href="http://www.teslamotor.com">www.teslamotor.com</a>	Launched 2008
ZAP Motors	Plans to import EVs from China – Xebra Company big on hype – short on delivery	<a href="http://www.zapcar.com">www.zapcar.com</a>	Xebra model problems of range and performance
Zenn Car Company	LSV sold in US market	<a href="http://www.zenncar.com">www.zenncar.com</a>	Available in US and some Canadian provinces

### ***Project Better Place***

Project Better Place (PBP) is an ambitious plan created by Silicon Valley entrepreneur Shai Agassi to create EV recharging grid networks. The PBP business model is designed to reduce oil dependence by creating a market for EVs through equipping metropolitan areas and eventually entire countries with networks of charging stations. PBP would drive demand for renewable energy sources such as solar and wind, it would also create a new model for selling cars and fuel. Nissan and its alliance partner Renault are PBP partners with plans to produce EVs on a commercial scale by 2011-12. The vehicle will be a battery version of the Renault Megane with an advanced lithium ion battery developed by Nissan and NEC of Japan. Apart from the CO<sub>2</sub> generated at the power plant—and in Israel (solar) and Denmark (wind) they would be substantially renewable, emission-free sources—the electric Megane generates zero CO<sub>2</sub> emissions compared to the 180 g/km for the conventional model.



The Danish project would involve around ½ million charging stations and 150 battery swap stations. Under the Agassi business model, EV owners would rent the battery and pay a fee based on distance driven; thus the age of the battery will not be an issue. Battery replacement should be at least as fast as filling a tank with petrol.

Norway is also strongly pushing EV technology. The Think Global company is a major actor in the EV scene, as is Miljøbil Grenland, a subsidiary of Norsk Hydro (and also a partner of Canada’s Electrovaya) [14].

***Use in transport today***

**Hybrid electric vehicle**

A hybrid electric vehicle combines a conventional (usually fossil fuel)-powered vehicle with some form of electric propulsion. Common examples include hybrid electric cars such as the Toyota Prius (as shown in Figure 36) [15].



**Figure 36. Toyota Prius**

**Railborne electric vehicles**

The fixed nature of a rail line makes it relatively easy to power electric vehicles through permanent overhead lines or electrified third rails, thereby eliminating the need for heavy onboard batteries. Since electric vehicles do not need to carry a heavy internal combustion engine or large batteries, they can have very good power-to-weight ratios. The following Figure 37 shows an electric locomotive [16].



**Figure 37. Electric locomotives under the wires in Sweden [16]**

### **Airborne electric vehicles**

Along with the beginning of the era of aviation, electric power for aircraft has received a great deal of experimentation [1], one example is as shown in the following Figure 38.



**Figure 38. Helios electric-powered UAV [17]**

### **Seaborne electric vehicles**

Electric boats were popular around the turn of the 20th century. The following Figure 39 shows a solar powered boat [18].



**Figure 39. Passenger solar boat Solifleur, Switzerland 1995**

## Spaceborne electric vehicles

Electric power used in spacecraft has a long history. The power sources used for spacecraft could be batteries, solar panels and nuclear power [1]. The following Figure 40 shows a spacecraft power by electricity.



**Figure 40. Soyuz 19 spacecraft for the Apollo Soyuz Test Project**

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## Comparisons of fuels for light vehicles

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Among ten energy carriers mentioned in this chapter, only seven—synthetic gasoline, synthetic diesel, DME, biodiesel, ethanol, biogas and electricity (Table 10), can be utilized in light vehicles (Alternative Fuels Comparison Chart; Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues). The rest of the fuels are either produced for demonstration purposes and no vehicles are available for commercial sale yet (in case of butanol and hydrogen) or they are used mostly in medium and heavy-duty trucks and buses (in case of methanol).

Based on the fuel characteristics (particularly the octane number) and the environmental impacts (Table 10), biogas, bioethanol and electricity seems very promising alternative energy carriers for driving of light vehicles.

Biogas had very high octane number and recently becoming widely used in some European countries (Sweden followed by Switzerland and Germany) as a transportation fuel for cars (Biogas as Vehicle Fuel: A European Overview; Biogas and captive fleets).

Ethanol, from safety issues point of view, is less favourable compared to the other alternatives. This is due to the explosive properties of the ethanol blended fuels.

Electricity is the only energy form without any emissions to the environment. However, availability of cheap sources for electrical energy generation (to charge batteries in electrical cars) is a major pre-requisite for commercialization of battery-powered light electrical vehicles. A possible solution would be the fuel cell electrical vehicle using chemical reaction to produce electricity to power an electric motor. Major advantage of those fuel cell vehicles is that they have a fuel tank, eliminating long-recharging time of the battery-powered electric vehicles.

Taking into consideration energy security impacts, production of electricity, synthetic gasoline, synthetic diesel and DME is not always renewable - as production of those energy forms depends on both biomass and fossil fuels (coals) availability for each country. Nations that are rich in biomass and coal can produce and use synthetic fuels to off-set their use of petroleum derived fuels and foreign oil.

With respect to their ability to form flammable/explosive mixtures, biogas, ethanol and DME need special consideration as those fuels are more flammable than the others discussed in this chapter.

**Table 10. Comparison between fuels for light vehicles.** Sources: (Anaerobic digestion-gas production; Abramova et al., 2006; Biogas as a road transport fuel; Kamara and Coetzee 2009; What is cetane)

Parameter	Fuel									
	Synthetic gasoline	Synthetic diesel	DME	Biogas	Biodiesel	Electricity	Ethanol blend (E85)			
Cetane number	NA	55	55 to 60	NA	46 to 60	NR	NA			
Octane number	83-93	NA	NA	120	25	NR	100			
Energy ratio compared to gasoline	NA	NA	NA	NA	90 %	-	70 %			
Environmental impacts	Reduces PM (particulate matter) and CO <sub>2</sub> emissions compared to conventional oil-derived gasoline	Reduces PM (particulate matter) and CO <sub>2</sub> emissions compared to conventional diesel	NA	Reduction of 65% of the carbon oxides and 30% of the nitrogen oxide.	Reduces global warming gas emissions compared to conventional diesel; however NO <sub>x</sub> emissions may be increased	Zero emissions	25 % reduction in ozone-forming emissions compared to gasoline			
Energy security impacts	Renewable fuel when derived from biomass feedstock	Renewable fuel when derived from biomass feedstock	Renewable fuel when derived from biomass feedstock	Renewable fuel	Renewable fuel	Depends on coal or other sources for electricity generation	Renewable fuel			

Safety	Biodegradable, non-toxic	Biodegradable, non-toxic	Biodegradable, relatively non-toxic, highly flammable	Mixtures of air and biogas-highly explosive	Less toxic and more biodegradable than conventional fuel	No special safety precautions	Ethanol can form an explosive vapour in fuel tanks. However, ethanol is less dangerous than gasoline because its low evaporation speed keeps alcohol levels in the air low and non explosive
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NA-data not available; NR-not relevant



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## Comparisons of fuels for heavy vehicles (trucks)

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There is currently intensive research on alternative fuels for heavy vehicles. Swedish companies such as Scania and Volvo investigated possibilities for utilization of alternative fuels in their engines. Many factors were considered in this evaluation: energy efficiency, capital and maintenance costs, fuel costs, net CO<sub>2</sub> emissions.

Cost-benefit analyses of Scania had shown that biodiesel appeared as most promising alternative fuel for utilization in heavy trucks. The enterprise has designed vehicles running on 100 % biodiesel and special engines have been developed for ethanol blend E95 in local/regional transport. The Scania ethanol engine running on ED95 is unique, since it is based on diesel-concept without spark plugs. Since the energy content of ethanol is less than diesel, more fuel needs to be injected so the entire fuel system is adapted

On the other hand Volvo has evaluated that DME is the most promising fuel for heavy vehicles with respect to energy efficiency. DME was suggested as strong candidate for a more long term future fuel due to best well- to- wheel energy efficiency and also to the fact that this fuel is close to be CO<sub>2</sub> neutral if produced from biomass.

Both companies evaluate biogas (Figure 41) as other promising fuel for utilization in heavy vehicles. The biogas engine works with spark plugs and has special tanks in composite material in order to optimize payload while they need to withstand 200 bar pressure.



**Figure 41. Scania gas-driven garbage truck.**



## Conclusion

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Among ten alternative transportation energy carriers described in this chapter, only biogas, bioethanol, DME, hydrogen and biodiesel are used in transportation sector in Øresund region.

Biogas is widely used in public bus transportation system in Sweden. Plans for implementation of biogas in Danish transportation system are already established and public discussions initiated.

Bioethanol is used in different blends with normal gasoline in Øresund region: E85 (85 % ethanol, 15 % gasoline) and E95 (95 % ethanol, 5 % gasoline) are used only in Sweden; E5 (5 % ethanol, 95 % gasoline) is used in both Sweden and Denmark.

DME is being tested in Sweden as vehicle fuel on some heavy trucks. The activities are part of an EU project (2008-2012) with participation of Volvo and Swedish Energy Agency.

Hydrogen refueling stations were opened in Copenhagen (Denmark) by Shell in 2009. The infrastructure established can refuel 15-20 cars per day. So far only limited amount of hydrogen-driven vehicles are currently in use in Øresund region (8 cars in Denmark, 1 car and some busses in Sweden) (Allan Schrøder Pedersen, Risø DTU, personal communication).

Regarding biodiesel, Danish Transport Authorities recently announced that from 2012 all diesel blends sold in Denmark should contain 5.75 % biodiesel. This legislation is entirely in line with EU directive 2003/30/EF.



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