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Alcohol-type Fuels for Mobility

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Abstract

Alcohols, promising fuels for mobility?

Currently, the world is dependent on hydrocarbon as its primary energy supply. In 2013, human consumed over 13 billion tons of oil equivalents globally (EIA, 2014). Over 30% of all the energy used is from oil and the transportation sector accounts for the largest share of total oil consumption. During the last decades, concerns regarding climate change, declining hydrocarbon reserves and energy security have resulted in a wide interest in renewable alternatives for transportation fuel. Production of biofuel is one way to reduce both consumption of hydrocarbon and greenhouse gas emission. The world annual biofuel production has exceeded 100 billion liters in 2013 and bioethanol is by far the most widely used biofuel for transportation. Global ethanol production increased by 6.1% in 2013 and the United States and Brazil are the largest ethanol producing countries (BP, 2014). In this paper, we will consider only alcohol fuel.

The alcohol-type fuels used presently in the market are methanol and ethanol. Other types of alcohol such as butanol and other higher alcohols are only used in industries and have limited share in the transportation sector. Ethanol and other alcohol fuels can be used as direct substitute for gasoline or in the form of blend additives. The advantages of alcohol fuels include increased energy diversification on the transportation sector and air pollution benefits from reduced emissions. According to the International Energy Agency, biofuels will account for over 25% of transportation fuel by 2050 and alcohol fuels could capture large part of the market.

Generally, crops grown for ethanol production absorb CO_2 for photosynthesis and release O_2 back into atmosphere. This subsequently reduces the lifecycle greenhouse gas emissions of ethanol fuel. Besides environmental benefits, government incentives and the development of oil price have contributed to increased use of ethanol fuel in the market. Although the 1st generation ethanol production from corn and sugarcane is a well-established process with low uncertainties, it is very dependent on the cost of raw materials and the market price of ethanol. Corn-based ethanol production has also shown some environmental issues.

2nd generation ethanol from lignocellulosic materials have abundant feedstock supplies. Therefore, in the long term, lignocellulosic ethanol is the most viable pathway from environmental point of view. However, it is limited by technical and economic challenges. Its production cost must be reduced and potential returns need to increase to allow its penetration into the transportation sector. Before expanding 2nd generation ethanol production, there are challenges that need to be addressed such as costly pretreatment processes, lack of efficient enzymes and low ethanol yield.

Butanol and higher alcohols demonstrated high potential as transportation fuel as they have very similar characteristics as gasoline and are almost perfect substitutes. The main drawback to butanol production is its low chemical yield. Until new process that produces higher butanol concentrations is found, butanol may not be adapted as an alternative fuel. Other higher alcohols are limited to research and have not shown any commercial viability.

The objective of this paper is to present a general review of different alcohols as transportation fuels, various technical aspects on production, economic and environmental assessments, and describing scenarios for 2030.

Contents

Alcohol-type Fuels for Vehicles

The changing prospect for liquid fuels, the increment of global demand, the evolution of transportation sector and the environmental situation have triggered an intense international search for alternative liquid fuels. Alcohol-type fuels technology is well established and widely available throughout the world. This creates the possibility of a major shift from food production to non-food purposes. Alcohol-type fuels are lower pollutants than petroleum-based fuels and can be used in blends or high purity concentration, but technical and economical limitations have hinder the presence of alternative fuels in the global market and suppress it's potential to replace hydrocarbon-type fuels. However, global efforts to search for new technologies to supply the energy sector's demand and to control global greenhouse gas emissions have put alcohols as potential power engines fuels. In addition, the depletion of hydrocarbon reserves and the highly fluctuating market prices provide alternative fuels the opportunity to develop.

I. Technical aspects

A. Alcohol-type fuels and their uses:

Currently, among the alcohol-type fuels we can find different types of products according the carbon number. The most common alcohols are[i]:

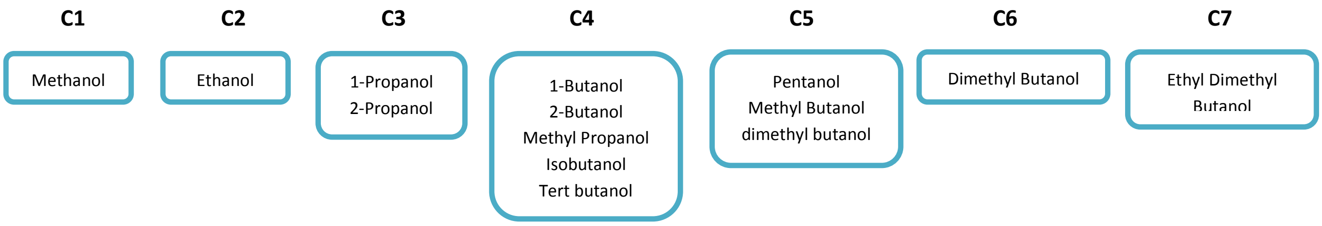

Figure 1. Example of classification of lower and higher alcohols according the carbon number

Alcohol is considered as a biofuel since it mostly made with biomass.

LOWER ALCOHOLS:

1. Methanol:

Methanol is the simplest form of alcohol since it has only one atom of carbon. Methanol can be derived from fossil fuels (methane), biomass or from the most simply process carbon and water. The emissions of CO_2 decrease due to the lower carbon-to-hydrogen ratio and the improved energy efficiency.

Methanol can be used directly as a fuel or blended with gasoline (M85). It can be also transformed into Dimethyl Ether to be mixed with diesel. In addition, different engines applications uses methanol as fuel due its high performance and energy efficiency.

It is possible also to mention other uses:

- Marine engine fuel because its lower sulfur concentration[ii]
- Currently, refineries uses methanol to increase the octane number of gasoline (up to 3% in Europe: a limit sets by law). In China, the methanol is blended with gasoline up to 15%.
- A high concentration mixture also can be used in vehicles engines: M85: 85% of methanol (requires modification of the engine, but it remains similar to gasoline engines).

It should be noted that Flex-fuel cars that deal with E85 (85% of ethanol + 15% of gasoline) cannot use M85.

Advantages of using methanol:

- Methanol has a higher octane value than gasoline, this allows higher compression rate and more power available than pure gasoline. That is why methanol is a common fuel used in racing.
- Moreover, as it can be used in gasoline cars (with a few modifications), it can also be stored in the main car's storage tank (no need to install another special tank)[iii].
- Finally, it could be a first step to a transition to fuel-cell for electric vehicles since these fuel-cells can be feed with methanol as well as with hydrogen.

2. Ethanol

Ethanol is mostly produced via alcoholic fermentation of sugars under anaerobic conditions. As methanol, ethanol also can be obtained from fossil fuels.

$$C_6H_{12}O_6 \rightarrow 2C_2H_6OH + 2CO_2$$

Microorganisms such *Saccharomyces cerevisiae* are used in fermentation processes. Usually, microorganisms presented in industry are selected to provide the best combination of characteristics for the process and equipment being used (Prasad et al, 2007). Three major classes of raw materials in ethanol production are **sugar plants** (cane, beet), **cereal plants** (corn, wheat, and barley), **lignocellulosic plants** (agricultural residues, wood residues) (Ballerini, 2012). In this case it is possible to mention the first and second generation of biofuels, precisely bio-ethanol.

Using agricultural crops for ethanol production will compete with the limited agricultural land needed for food and feed production. Potential source for low cost ethanol production is to utilize lignocellulosic materials.

HIGHER ALCOHOLS:

3. Propanol

Propanol has the potential to be used as liquid fuel engine in replace of gasoline due to its characteristics: low flash point and similar energy content.

There are two forms of propanol: *1-propanol* and *2-propanol*, both are derived from fossil fuels. *2-propanol* is produced from hydration of propene that is extracted during oil refining. Production of *1-propanol* is a more complicated process. Two steps are required: catalytic hydroformylation of ethylene to produce propanal and catalytic hydrogenation of the propanal.

1-propanol is primarily used as a solvent in the pharmaceutical, paint and cosmetic industries. It is used as a carrier and extraction solvent for natural products and as a chemical intermediate in the manufacture of other chemicals. *2-propanol* has received attention for use in direct Propanol fuel cells for laptops or cellular phones and perhaps, in time, for electric vehicles. Propanol has a reduced application as liquid motor fuel.

4. Butanol

Butanol as biofuel is obtained mainly from fermentation. It may be used as a fuel in an internal combustion engine as its longer hydrocarbon chain causes it to be fairly non-polar. Butanol is more similar to gasoline than it is to ethanol. Butanol has been demonstrated to work in vehicles designed for use with gasoline without modification. It has a four link hydrocarbon chain and can be produced from biomass (as "biobutanol"), as well as from fossil fuels (as "petrobutanol"). The RON in butanol is 113, higher than others lowers alcohols.

Biobutanol and petro-butanol have the same chemical properties.

Three are commercially important: n-butanol, isobutanol, tertbutanol.
n-butanol / isobutanol / tertbutanol : $C_4H_{10}O$

Advantages of using butanol:

- It can be blended to any ratio with gasoline as well as diesel directly in the refinery without the requirement for additional infrastructure.
- Easy transportation through pipelines because of low vapor pressure. Less corrosion in the pipelines compare to ethanol.
- Air: fuel ratio of butanol is close to gasoline's fuel ratio. This is within the limits of the variation permissible in existing engines. Although complete replacement of gasoline by butanol would requires an enhancement of air: fuel ratio, blends of up to 20% butanol can be easily used in existing engines.
- The heat of vaporization of butanol is slightly higher than that of gasoline. Therefore, vaporization of butanol is as easy as gasoline. An engine running on butanol-blended gasoline should not have a cold start problem. It should be mentioned that Ethanol or methanol blended gasoline is known to cold weather issues because of higher heat of vaporization.
- Low solubility of butanol in water reduces the potential for groundwater contamination.

5. Pentanol and others higher alcohols

Pentanol and other higher alcohols can are obtained by fermentation in a restricted volume or considered as secondary products (primary product: Ethanol). Currently, the principal method of production is related to the reaction of two intermediates and an alcohol chain growth from CO and H_2. The reaction occurs by addition of one or two carbon to the alcohol chain with a Cu/ZnO catalyst.

All of the alcohols are soluble in water, but higher alcohols, mainly Pentanol and longer alcohols are relatively insoluble. Less engine power is produced as the water content of an alcohol increases. Furthermore, vapor lock, fuel mixing and starting problems increase with water.

Higher alcohols are considered attractive liquid fuels for motor engines due their lower vapor pressure and high octane number (RON). Currently, higher alcohols are used in fuels blends for increases motor and combustion efficiency. Research of pure combustion of higher alcohols is in progress.

Advantages of using higher alcohols:

- Lower vapor pressure compare with lower alcohols. This can be traduced in lower losses by evaporation.
- Easy transportation through pipelines because of low vapor pressure. Less corrosion in the pipelines due higher alcohols flows.
- Higher alcohols fuel ratio is close to gasoline's fuel ratio. This is within the limits of the variation permissible in existing engines.
- The heat of combustion is higher as the number of carbons increases.
- Low solubility in water of higher alcohols reduces the potential for groundwater contamination and increases motor efficiency.

6. ETBE

Ethyl tertiary butyl ether is considered as a biofuel derived from ethanol and isobutylene. ETBE is an oxygenated gasoline fuel component. ETBE is used as octane booster to replace toxic and carcinogenic compounds such as lead. ETBE's unique properties of high octane, low boiling point and low vapour pressure make it a very versatile gasoline blending component, allowing refiners to address both their octane and bio-component incorporation needs. ETBE also allows petroleum companies to adjust to changing gasoline markets by using it to upgrade naphtha to gasoline or to upgrade lower octane gasoline grades to higher ones while meeting increasingly stringent environmental specifications.[iv]

The octane number improvement with ETBE in general depends on the base gasoline. Clear octane numbers for ETBE are relatively high and therefore ETBE is used widely to improve the octane rating for gasoline.

The octane number of ETBE is 117, lower than ethanol's octane number 127. The blending Vapour Pressure (DVPE) of pure ETBE is 28kPa, well below that of finished gasoline, thus allowing the use of more light hydrocarbons, typically butane during gasoline blending. It is important to keep light contaminants such as ethanol to a reasonably low level in commercial ETBE in order to maximize its vapour pressure benefit to gasoline.

Resume

- The melting point of alcohols increases with increasing carbon count and several C7 and C8 isomers exhibit melting points in excess of -40 ^{o}C making their use as vehicle fuels questionable.
- Boiling points increase with increasing carbon count and n-structures generally have slightly higher boiling points than their respective iso-structures.
- Latent heat of vaporization decreases with carbon count, the mass-specific value for ethanol is triple that of gasoline, the energy specific ratio increases to a factor of 5.
- RVP decreases with increasing carbon count and alcohol fuels generally have a significantly lower RVP than gasoline.
- Stoichiometric air demand and fuel energy content increase with carbon count.
- Knock resistance expressed as Research Octane Number (RON) and Motor Octane Number (MON) decrease significantly with increasing carbon count, iso-structure show increased knock resistance compared to their respective n-structures.
- Overall, the Renewable Fuel Standard (RFS) requires a significant increase in production of advanced, cellulosic and non-cellulosic biofuels. Longer-chain alcohols might turn out to be an interesting alternative to ethanol due to their properties which more closely resemble gasoline[v].

B. Chemical processes: sources and products

1. Methanol synthesis

Methanol from catalytic synthesis via

In catalytic synthesis via, methanol production requires synthesis gas (CO, H_2) as reactive. The reactions that take place for methanol synthesis are:

$$CO + 2\,H_2 \leftrightarrow 2CH_3OH$$

$$CO_2 + 3\,H_2 \leftrightarrow 2CH_3OH + H_2O$$

The gaseous mixture must to have a hydrogen/carbon ratio between 2 and 3.

The syngas can be obtained from natural gas via the following equations:

$$CH_4 + H_2O \leftrightarrow CO + 3H_2$$

$$CO + H_2O \leftrightarrow CO_3 + H_2$$

$$CH_4 + 2H_2O \leftrightarrow CO_2 + 4H_2$$

Methanol from coal

Another via is using coal. For example, China has one of the largest coal reserves in the world. In fact, 75%[vi] of methanol in China is produced from coal (25% from gas). Currently, China is the world's largest market for methanol, representing more than 20% of the total production and consumption[3].

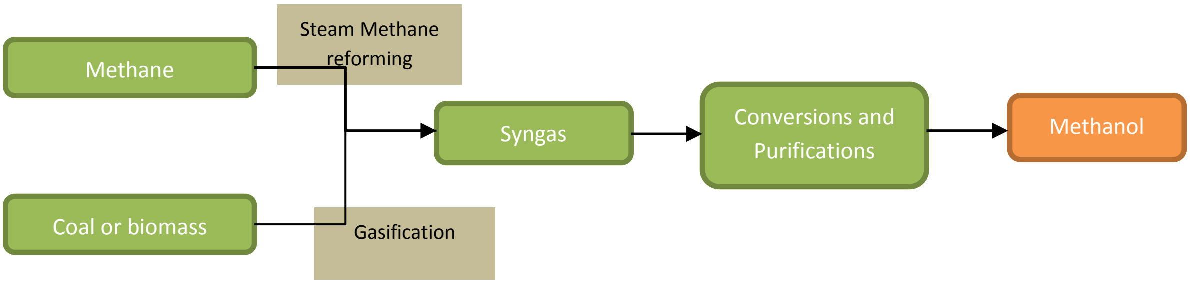

Figure 2. Simplified Schema of Methanol Production

Methanol from biomass

Methanol can be produced industrially from nearly any biomass, including animal waste, or from carbon dioxide and water or steam by first converting the biomass to synthesis gas in a gasifier. It can also be produced in a laboratory using electrolysis or enzymes[vii].

2. Ethanol

Ethanol from cane and other sugar plants

Sugarcane molasses, a byproduct of sugar industry, is a major raw material for ethanol production (Prasad et al., 2007). It contains up to 50% simple sugar that can be easily fermented into ethanol. Molasses' low cost and high availability have made this raw material ideal for ethanol production. Once raw materials are delivered to the ethanol plant, it is stored in the warehouse and conditioned to prevent from early fermentation and contamination (Gnansounou & Dauriat, 2005).

The following figure shows the various steps involved in the production of ethanol from sugar cane:

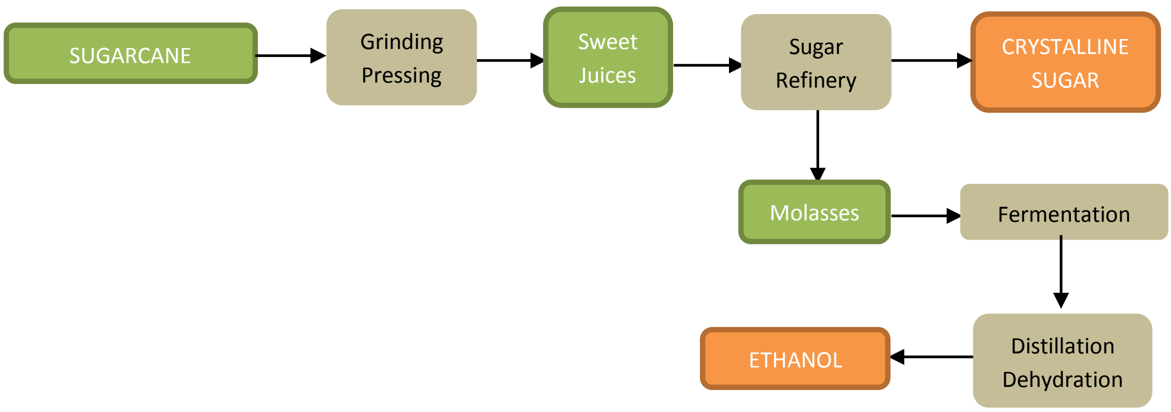

Figure 3. Simplified schema of Ethanol production (Ballerini, 2012) (Gnansounou & Dauriat, 2005)

Ethanol from starchy materials

In the ethanol fuel industry, grains such as corn, wheat and barley mainly provide starch. Starch is a complex sugar that composed of long chains of glucose. Starch must be first decomposed into simple sugar through hydrolysis reaction before fermentation to ethanol (Gnansounou & Dauriat, 2005). Ethanol production from starchy materials involves milling of grains, enzymatic hydrolysis of starch into simple sugars, followed by conversion of the sugar into ethanol by fermentation. By-products of these processes are oil, fiber and protein that can be converted into animal feed.

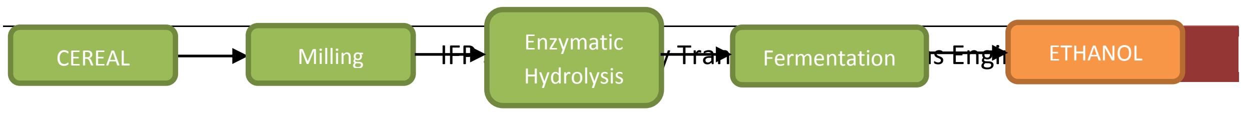

Figure 4. Simplified schema of Ethanol production from Cereals

Ethanol from lignocellulosic materials

Contrary to the conversion of sugar plants and starch to ethanol, production of ethanol from lignocellulosic raw materials is still faced with various technology and economic barriers. Lignocellulosic materials are mainly composed of cellulose, hemicellulose and lignin. Each category of lignocellulosic material contains variable proportion of each chemical compound. **Lignocellulosic materials are abundant in nature and do not affect food production**. Common sources of lignocellulosic materials are agricultural residues, forestry residues and industrial wastes. Processing of lignocellulosic materials to ethanol consists of four major processes: (1) pretreatment, (2) hydrolysis, (3) fermentation, and (4) distillation.

Cellulose exists as crystalline structure and requires pretreatment to soften the materials and change the structures. Pretreatment involves the removal of lignin components in the feedstock in order to make cellulose more accessible (Gnansounou & Dauriat, 2005). Hydrolysis of cellulose is carried out by cellulose enzymes, which are usually a mixture of several enzymes (Prasad et al., 2007). Similar to starchy materials, enzymatic hydrolysis is then followed by fermentation of the hydrolyzed materials into ethanol.

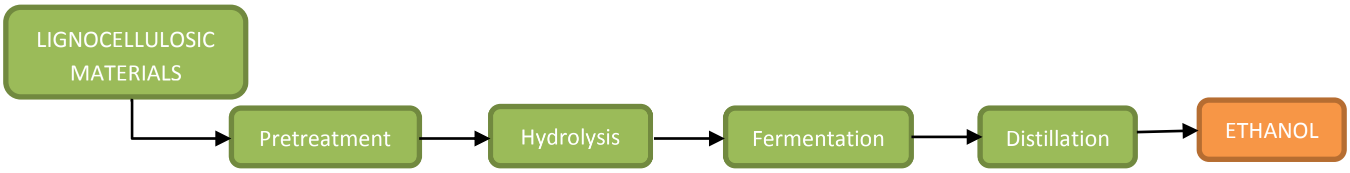

Figure 5. Simplified schema of Ethanol production from L.M.

3. Butanol

Biobutanol can be produced by fermentation of biomass by the A.B.E. process. (**Acetone–butanol–ethanol (ABE) fermentation**)

Biobutanol is made via fermentation of biomasses from substrates ranging from corn grain, corn Stover and other feedstocks. Microbes, specifically of the Clostridium acetobutylicum, are introduced to the sugars produced from the biomass. These sugars are broken down into various alcohols, which include ethanol and butanol.

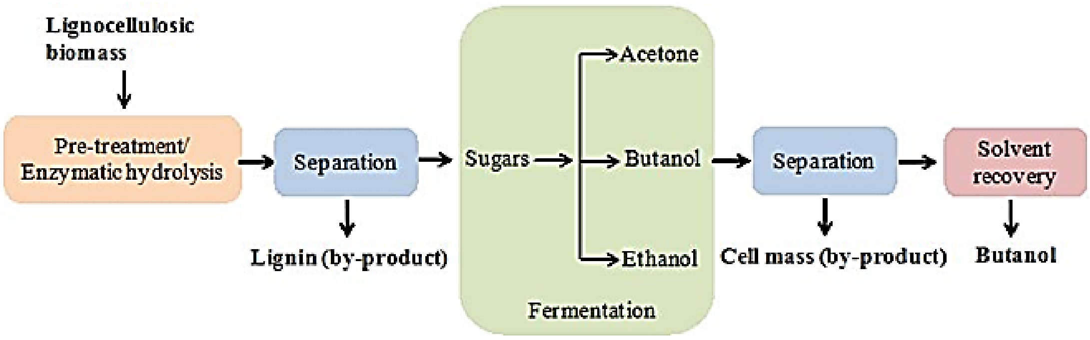

Figure 6. Phases of ABE fermentation for producing butanol

A promising trend is a slew of recent ethanol fermentation plants purchases by biobutanol companies. These ethanol plants are being retrofitted with advanced separation systems to allow them to produce biobutanol. Since biobutanol has inherently higher value vs. bioethanol, the trend of the plant conversions is likely to continue.

Butanol was traditionally produced by ABE fermentation, however, cost issues, the relatively low-yield and sluggish fermentations, as well as problems caused by end product inhibition and phage infections, meant that ABE butanol could not compete on a commercial scale with butanol produced synthetically and almost all ABE production ceased as the petrochemical industry evolved.

However, there is now increasing interest in use of biobutanol as a transport fuel. 85% Butanol/gasoline blends can be used in unmodified petrol engines. It can be transported in existing gasoline pipelines and produces more power per litre than ethanol. Biobutanol can be produced from cereal crops, sugar cane and sugar beet, etc., but can also be produced from cellulosic raw materials

Fuel	Energy density [MJ L^{-1}]	Air: fuel ratio	Heat of vaporization [MJ/kg]	Research octane number	Motor octane number	Cetane number
Gasoline	32	14.6	0.36	91-99	81-89	-
Butanol	29.2	11.2	0.43	96	78	-
Ethanol	19.6	9.0	0.92	129	102	54
Methanol	16	6.5	1.2	136	104	-
Biodiesel	31-33	12.5	-	-	-	48-65

Table 1:Characteristics of liquid fuel

4. Pentanol and other higher alcohols

Pentanol and other higher alcohols can are obtained by fermentation in a restricted volume or considered as secondary products (primary product: Ethanol). Currently, the principal method of production is related to the reaction of two intermediates and an alcohol chain growth from CO and H_2. The reaction occurs by one or two carbon addition only in the alcohol chain over a Cu/ZnO catalyst.

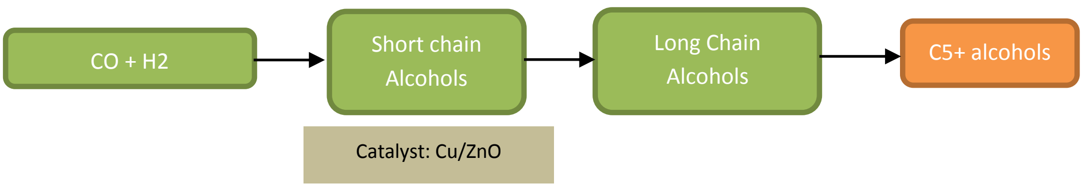

Figure 7. Simplified schema of C5+ alcohols production form CO and H2

C5+ alcohols can also be produced by selective fermentation and metabolically engineered microorganisms.[viii] However, technology for the development of engineering microbial host can be imply a huge investment only for the production phase and can be economically restricted.

5. ETBE (as additive for gasoline)

ETBE is produced by the reaction of ethanol with isobutene in an exothermic reaction of equilibrium. To increase the conversion of isobutene requires operating the reaction system at low temperatures (50-75^{o}C) and with excess ethanol in order to displace the equilibrium towards the products. ETBE and ethanol form an azeotropic mixture, which hinders the recycling of nonreacted ethanol in the process.

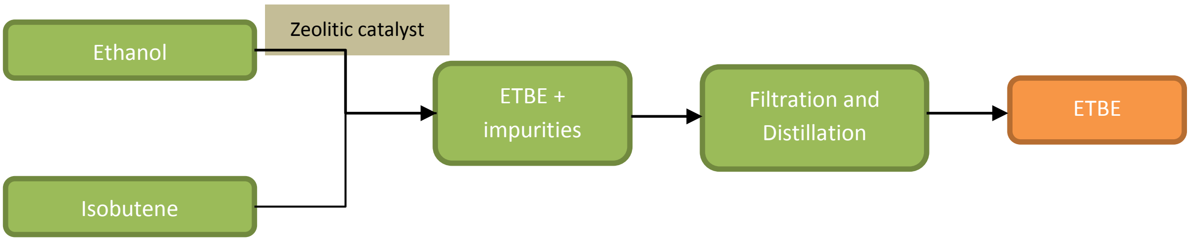

Figure 8. Simplified block diagram of ETBE production

Generally, ETBE is produced in to reactors, one principal reactor for main conversion and a second reactor for "complete" the reaction. After the reaction zone a debutanizer is used for separate C4 unconverted products in top of the column and ETBE in bottoms. All the system functions at medium pressions (20-21 bar).

C. Technical limitations

1. Methanol

- Methanol is highly corrosive: the tank and the equipment must be protected.
- It is a very toxic substance that needs to be handled carefully because it can be very harmful if swallowed or absorbed through the skin.
- It is usually presented as a clean fuel but in reality, its environmental impact depends on the feedstock used to produce it.

2. Ethanol

- Ethanol has lower energy content than gasoline. This means that it takes about one-third more ethanol than gasoline to travel the same distance.
- Ethanol's corrosive properties pose transportation and storage problems. Currently, ethanol fuel is not transported in existing pipelines but is transported by rail and truck.
- Ethanol tends to absorb water, which can leads to phase separation of ethanol-gasoline blend, and subsequently reducing engine performance.
- Production of 2nd generation ethanol fuel from lignocellulosic materials is still under development and is not yet commercially feasible.

3. Butanol

Butanol overcomes most of the ethanol's constraint such as low energy content, which influences the economy of the blended fuel. As mentioned earlier, ethanol also is likely to separate from gasoline in the presence of water leading to operational problems.

- To match the combustion characteristics of gasoline, the utilization of butanol fuel as a substitute for gasoline requires fuel-flow increases (though butanol has only slightly less energy than gasoline, so the fuel-flow increase required is only minimal, maybe 10%, compared to 40% for ethanol.)
- Alcohol-based fuels are not compatible with some fuel system components.
- Alcohol fuels may cause erroneous gas gauge readings in vehicles with capacitance fuel level gauging.
- While ethanol and methanol have lower energy densities than butanol, their higher octane number allows for greater compression ratio and efficiency. Higher combustion engine efficiency allows for lesser greenhouse gas emissions per unit motive energy extracted.
- Butanol is one of many side products produced from current fermentation technologies; therefore, current fermentation technologies allow for very low yields of pure extracted butanol. When compared to ethanol, butanol is more fuel efficient as a fuel alternative, but ethanol can be produced at a much lower cost and with much greater yields.

- Butanol is toxic at a rate of 20g per liter and may need to undergo Tier 1 and Tier 2 health effects testing before being permitted as a primary fuel by the EPA.

4. C_5+ alcohols

- Difficult to obtain and highly costly in development and production phases.
- Purification of specific higher alcohols is difficult due to the number of isomers that one carbon number has. Generally, the number of isomers increases with the carbon number.
- Raw materials for ethanol production are the same for synthesis of higher alcohols. The limitations and the problems (food competition, disponibility) are applied for both cases.

5. ETBE

- Used as additive for increase octane number, ETBE has a limit in gasoline blends.
- ETBE is usually presented as a clean fuel additive but in reality, the environmental impact depends on the feedstock used to produce it. ETBE is considered as Hybrid Product. (Semi-biofuel).

D. Current situation: BRIC, Europe, United States

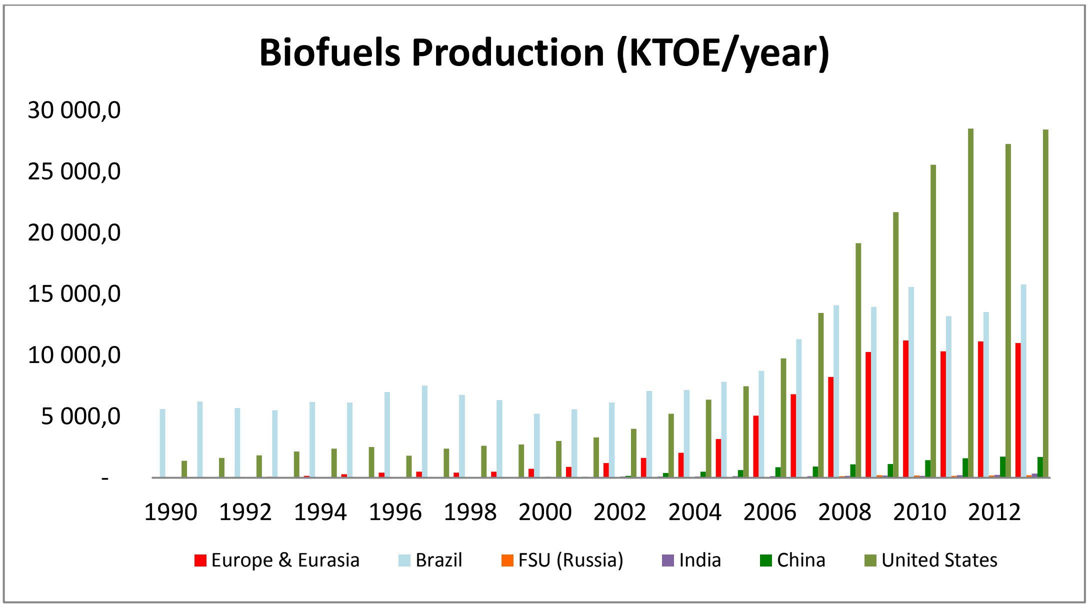

Figure 9 -Biofuels production by year[ix]

Respectful biofuels producer in the world are the United States, Brazil, and Europe. Emerging countries, namely China, India, and Russia, are important due to fossil fuels and biomass production. Biofuels production consists of bioethanol and biodiesel (Figure 10), yet this study will focus on bioethanol (Figure 11). Until 2008, Brazil was the largest producer of biofuels, but since then the United States surpassed Brazil's production. Europe has become one important player thanks to an ambitious program launched in 2006: the EU Energy and Climate Change Package (CCP). Meanwhile, China is expected to become a key player for the years to come because of ethanol production and methanol production (mainly coal based).

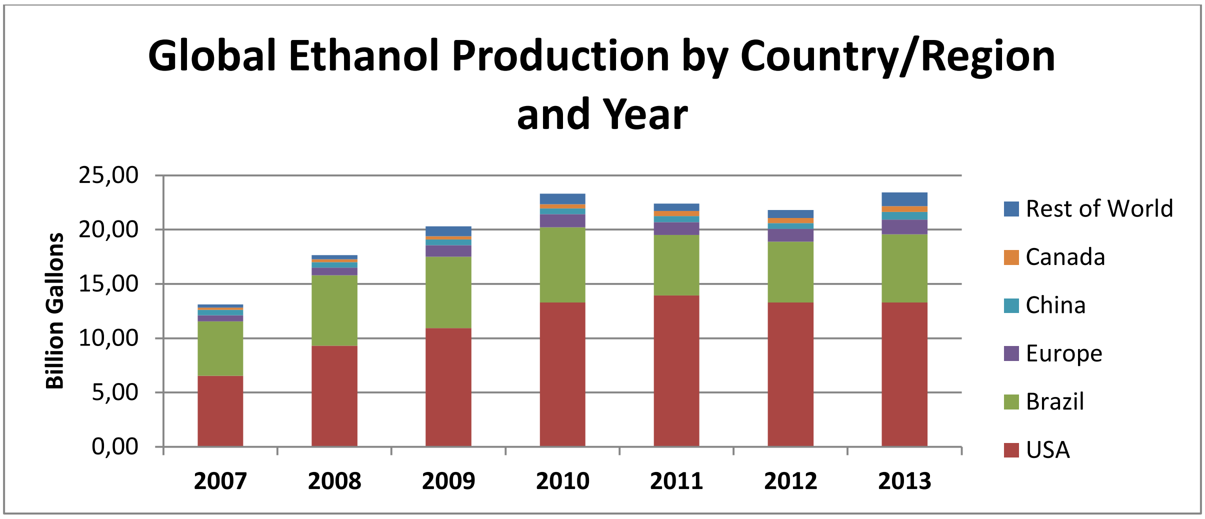

Figure 11 –Global ethanol production by country per year[x]

1. Brazil (Ethanol)

Brazil is the world's second largest producer of ethanol fuel and using mainly sugar cane as the feedstock. In 2013, Brazilian ethanol production reached 23.2 billion liters (6.2 billion gallons). Most of this production is absorbed by the domestic market where it is sold as either pure ethanol fuel or **blended with gasoline at levels between 18 to 25 percent ethanol.**

Since 1976 the government made it mandatory to blend ethanol with gasoline. Moreover, in 2007 all fuel sold in Brazil must be a blend of 25% ethanol and 75% gasoline. High production of sugarcane ethanol begun in 2003 when Brazil introduced the flexible fuel vehicle that runs on ethanol or gasoline. More than 90 percent of new cars sold today in Brazil are flex fuel due to consumer demand, and these vehicles now make up about sixty percent of the country’s entire light vehicle fleet. There are no longer any light vehicles in Brazil running on pure gasoline.

In terms of energy equivalent, **sugarcane ethanol represented 18% of the country's total energy consumption** by the transport sector in 2008.

Licensing of Ethanol Powered Vehicles (pure ethanol & flex fuel units)						
2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013 1/**
2,032,361	2,356,942	2,711,267	2,876,173	2,848,071	3,162,824	1,803,298
Source: National Association of Vehicle Manufacturers (ANFAVEA) 1/ January-July						

Tableau 2-Number of ethanol powered vehicles sold

2. Russia (Ethanol)[xi]

The majority of biofuel ventures in Russia are supported by regional governments or financed by foreign investors. These projects are in the pilot phase and produce just enough biofuel to generate heat/electricity for their own facility, or for the production of organic fertilizer from agricultural waste. **Biofuel is not considered as national priority in Russia.**

Limited presence of bioethanol in Russia is due to high wheat and grain prices worldwide, which makes biofuel production less profitable than gas & oil sector.

→ Production of ethanol will be driven primarily by the demand of the chemical industry rather than for fuel consumption.

3. India (Ethanol)[xii]

In 2009, Government of India (GOI) approved its National Policy on Biofuels, encouraging the use of renewable energy resources as fuel for motor vehicles. The policy encourages use of renewable fuel as an alternative to petroleum and proposes to supplement India's fuel supply with a 20% biofuel (bioethanol and biodiesel) mandate by end of 2017. India would require more than 6.3 billion liters of ethanol to meet this ambitious target.

Domestic ethanol production in 2015 will be closer to 2.1 billion liters compared to 2 billion liters in 2014. An increase of ethanol blending is mandated to 10 percent. However, a target of 7.5% blend of ethanol-gasoline is theoretically feasible in 2015.

Market penetration for fuel ethanol in 2013 was limited and the blending rate amounted to less than one percent of the fuel consumed in India. In 2014, 13 states will establish blending rates of 2.1 percent and may increase to 2.5 percent by end of 2015.

Most Indian ethanol is produced from sugarcane molasses for blending with gasoline.

4. China

Ethanol[xiii]

In 2012, 64% of fuel ethanol production was derived from corn, 30% from wheat, and 6% percent from cassava. Within this year, ethanol production was 40% for beverages and hard liquor and 60% for fuel and industrial chemical use. China's 2013 fuel ethanol production reach 2.6 billion liters (2.08 million metric tons). Blending rate for ethanol (in gasoline) is between 8 and 12 percent.

In 2012, China's total number of passenger vehicles was up to 89.4 million units. Passenger vehicles categories: 10% of large size vehicles (e.g. buses) and 90% of small sized vehicles (sedans, sport utility vehicles (SUV), or taxi).

Methanol[xiv]

China is the world's largest methanol consumer and producer, accounting for >20% of global methanol output. In 2009, >75% of methanol in China was made from coal, with the rest are coming from natural gas (Peng, 2011).

In 2009, an estimation of 3-5 million metric tons of methanol were blended in gasoline, **approximately 3.5-5.8% of China's gasoline consumption that year**.

→ By the year 2015, China's government aims to cap methanol production capacity at 50 million metric tons per year.

Implications:

- Energy security for fuel
- But the lifecycle CO2 emission of coal-based methanol is 84% higher than the gasoline.

5. United States

The United States is the largest producer and consumer of ethanol fuel in the world. Over 13 billion gallons were produced in 2011 and it accounts for 62% of the global production. Most ethanol production in the U.S. is produced from corn.

In 2007, the U.S. Environmental Protection Agency (EPA) implemented the Renewable Fuels Standard (RFS2) policy which helped spur the production of biofuels. This policy requires that gasoline sold in the United States to contain a minimum amount of renewable fuels. Currently, More than 95% of U.S. gasoline contains ethanol, typically E10 (10% ethanol), to increase the oxygen content of the fuel and reduce air pollution. Biofuel production is expected to increase and could replace 30% or more of U.S. gasoline demand by 2030.

Ethanol produced from lignocellulosic materials is expected to gain momentum in the coming year with advancing technology and higher demand. Lignocellulosic ethanol is estimated to have life cycle GHG emissions at least 60% lower than gasoline fuel (AFDC, 2014).

6. European Union (ethanol)[xv]

Regulations influencing the EU biofuels and biomass market are the EU Energy and Climate Change Package (CCP) and the Fuel Quality Directive (FQD). One of the goals for 2020 is a 20% share for renewable energy in the EU total energy mix. Part of this share is a **10 % minimum target for renewable energy consumed by the transport sector** to be achieved by all Member States.

As a consequence, EU bioethanol production capacity quadrupled from about 2.1 billion liters in 2006 to about 8.5 billion liters in 2012. EU bioethanol production in 2013 is 1.3 billion gallons.

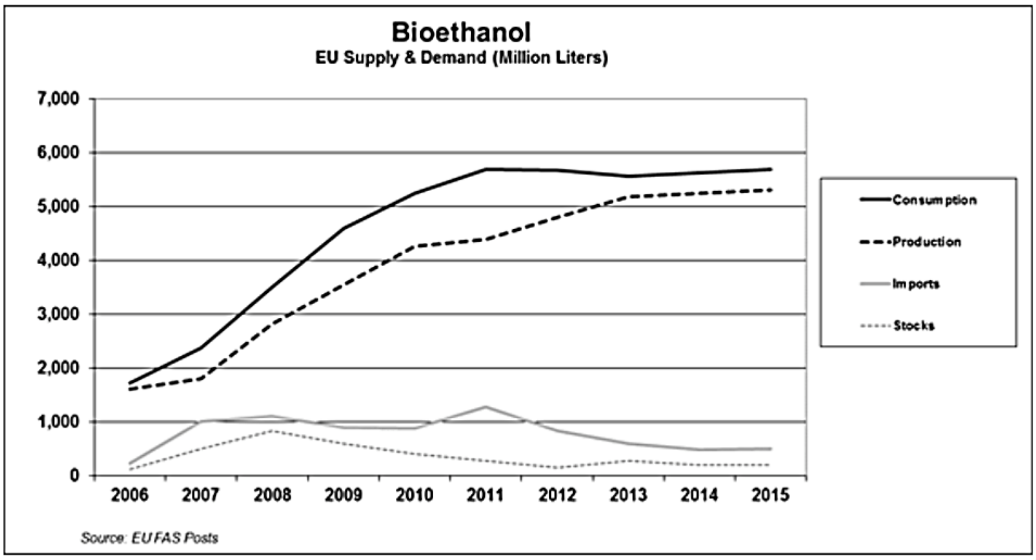

Figure 10- EU bioethanol supply and demand

In the EU, **bioethanol is mainly produced from wheat, corn, and sugar beet derivatives**; Wheat is mainly used in northwestern Europe, while corn is predominantly used in Central Europe and Spain. Barley & rye are used for bioethanol production in Germany, Poland, the Baltic Region, and Sweden. In Italy, 30% of ethanol is produced form wine byproducts and about 10% from wine. In northwestern Europe and Czech Republic, sugar beets are used for bioethanol production. In France and Germany respectively about 45% to 40% of bioethanol is produced from sugar beet derivatives.

Fuel Ethanol Consumption – Main Consumer (million liters)								
Calendar Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Germany	791	1,142	1,475	1,568	1,581	1,527	1,520	1,650
UK	152	354	582	696	785	810	820	850
France	814	805	782	777	810	796	800	800
Italy	176	232	306	480	463	358	360	360
Benelux	234	357	363	390	341	354	360	360
Other	1,342	1,713	1,745	1,792	1,696	1,725	1,775	1,680
Total	**3,509**	**4,603**	**5,253**	**5,703**	**5,676**	**5,570**	**5,635**	**5,700**

Table 3- EU ethanol consumption by year

II. Economic and environmental issues

A. Methanol

1. Environmental issues

Methanol is a naturally occurring, biodegradable alcohol that is present in our environment. It is produced naturally through biological processes in vegetation and microorganisms. However, a large release of methanol to the surface water, soil, or groundwater can potentially affect the surrounding environment.

As mentioned earlier, methanol can be produced from three different sources: biomass, natural gas and coal. Depending on the raw material selected, the energy efficiency varies across each process. Therefore, the emissions depend on the types of production.

Efficiencies of methanol production processes			
Feedstock	Coal	Methane	Biomass
Energy efficiency	43 to 50%[xvi]	60-70%[xvii]	54 to 60%[xviii]

Coal-based methanol production is currently the dominant process in China. Expanding coal-based methanol could significantly **affect water resources** and increase greenhouse gas emissions. Producing 1 ton of methanol from coal requires about 20m^3 of freshwater and discharges huge amount of wastewater (Yang & Jackson, 2008). Besides, coal mining also consumes significant amount of water. Consequently, increasing methanol production from coal may consider as an unsustainable practice as it could lead to water shortages.

Another environmental concern is replacing gasoline with coal-based methanol as transportation fuel **increases CO_2 emissions**. The lifecycle CO_2 emissions for a coal-based methanol fuel are approximately 5.3 t CO_2 per ton of methanol burned, while the lifecycle CO_2 emissions are approximately 4.03 t CO_2 per ton of gasoline (Yang & Jackson, 2008). Therefore, unless a more sustainable methanol production such as biomass-based process is used, using methanol as transportation fuel contribute more to climate change compare to gasoline.

Generally, methanol-gasoline blends have lower vehicular emissions than pure gasoline. The carbon monoxide (CO) emissions are significantly smaller. However, concentrations of methanol and formaldehyde are found to be higher with methanol fuel (Yang & Jackson, 2008). More studies on methanol and formaldehyde pollution are required to assess the environmental impact of large scale use of methanol fuel.

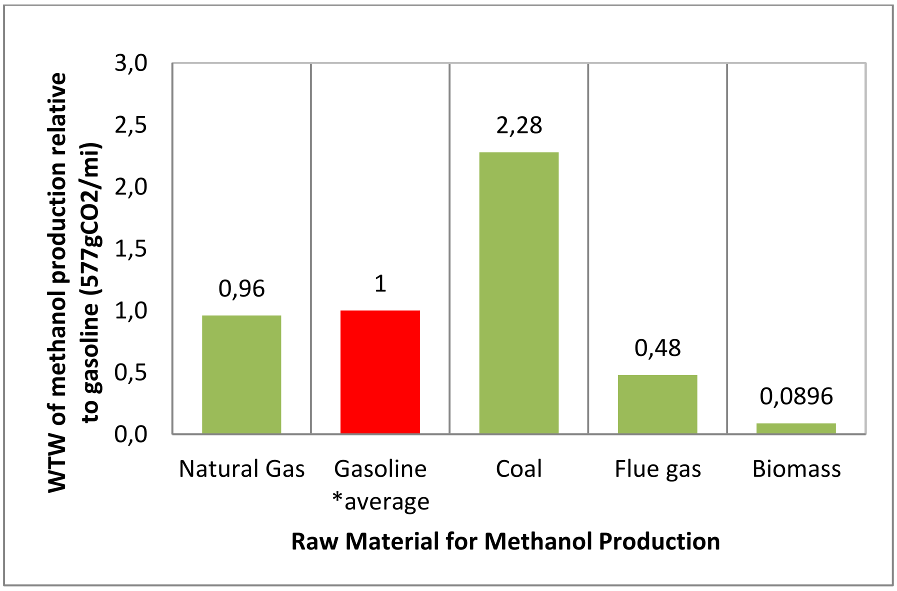

Figure 11- Well to Wheel of methanol production relative to gasoline (Bromberg &Cheng, 2010)

Methanol is naturally produced by the human body at a very low quantity. Effects of methanol on human health depend on the amount of methanol present and the duration of exposure. Human exposure to methanol can occur through inhalation, ingestion, or dermal contact. Ingestion of methanol can have adverse health effects, ranging from **headaches to loss of vision**. There are known cases of death related to consuming large amounts of methanol.

It is important to note that these health effects are not likely to occur at concentrations of methanol that are normally found in the environment.

2. Economical assessment

Given that China has abundant coal resources, production of coal-based methanol is thus economically feasible. Referring to Figure 13, price of methanol in China is about one-third to one-quarter of the price of gasoline (Yang & Jackson, 2008). This allowed the coal-based methanol production to expand rapidly in China.

One economical aspect to consider in large scale use of methanol fuel is engine conversion requirement. M15 gasoline (15% methanol) does not require any modification to the current internal combustion engine. However, M85 gasoline (85% methanol) requires an engine conversion (Yang & Jackson, 2008). Due to the incurred cost, high levels methanol blends unable to reach mass market.

	Gasoline prices (Chinese Yuan/metric ton)	Methanol prices (Chinese Yuan/metric ton)
2009	6220–7900	1600–2800
2010	7900–8530	2200–3200

Figure 12 Gasoline and methanol prices in China (Yang & Jackson, 2008)

Concerning the production of bio-methanol from biomass, the technology is still evolving and has high production costs. Besides, the transportation cost of feedstock and high energy consumption in the chemical plant also limit the bio-methanol's commercial viability. Referring to Figure 14, production cost of bio-methanol is still significantly higher than coal-based methanol, partly due to high capital investment.

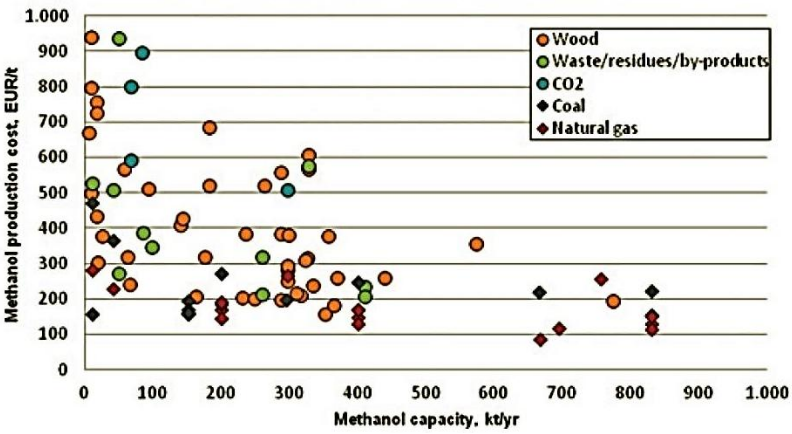

Figure 13 Production costs and production capacity of methanol for various feedstocks (IRENA, 2013)

B. Ethanol

1. Environmental issues

Currently, there are many controversies surrounding the environmental benefits of using ethanol as a transportation fuel. 1st generation ethanol fuel produced using starchy plants like corn could create significant environmental issues. In the United States, corn production causes more soil erosion than any other crops (Pimentel, 2003). Large scale use of insecticides, herbicides and nitrogen fertilizers in cultivation of corn poses significant environmental threats to groundwater and surface waters. Large volume of water required for crop irrigation to support corn farming raises serious questions on the sustainability of corn-based ethanol fuel.

Other than corn farming, various air and water pollution problems are also associated with the production of ethanol in the chemical plants (Pimentel, 2003). Air pollution is an issue when the carbon dioxide and other odor causing emissions produced during the fermentation process are not recaptured or cleaned before being exhausted. Water discharged from the fermentation and distillation processes create wastewater management problems. Water consumption in chemical plants is another effect of ethanol production. These issues suggest that 1st generation ethanol production from corn may not be environmentally sustainable for the future.

There is a wide debate on air pollution benefits associated with burning ethanol fuel in a vehicle's engine. Generally, ethanol blended fuel has measurable greenhouse gas emissions benefits compared with gasoline. Referring to Figure 15, ethanol fuel may provide significant greenhouse gas benefit, but its magnitude strongly depends on the raw materials used. However, there are also concerns on the tailpipe emissions of other harmful gases. Ethanol blended fuel causes significant increase in emissions of acetaldehyde (Niven, 2005). Acetaldehyde is an irritant and probable carcinogenic substance. Formaldehyde emission from burning ethanol fuel is also similar to gasoline. Other gas emissions that should be noted are nitrogen oxides (NO_x) and volatile organic compounds (VOC). Ethanol blended fuel is more efficient than gasoline due to higher oxygen content. However, ethanol has approximately 33% less energy content than gasoline. Depending on ratio of ethanol-gasoline blends, using ethanol in vehicles may lead to a slight increase in fuel consumption, thus producing a modest increase in CO_2 emission (Niven, 2005).

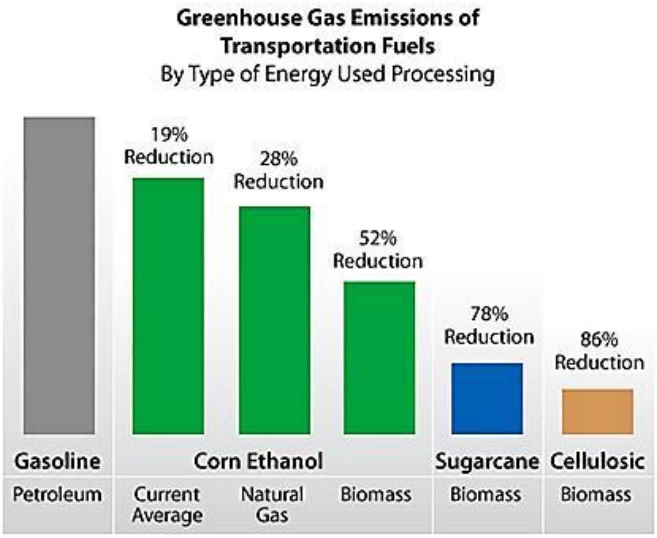

Figure 14 Greenhouse gas emissions of gasoline and ethanol of different feedstocks (AFDC, 2014)

According to Niven (2005), a study on ambient air pollutions concentration in Sao Paolo, Brazil, reported that ethanol levels are many times higher than in other major cities. Concentration of acetaldehyde and formaldehyde in major Brazilian cities are also higher than elsewhere in the world. These emissions can be attributed to high evaporative emissions of ethanol fuel. Low ethanol blends usually have higher vapor pressure than gasoline, and thereby increasing evaporative losses.

More detailed studies incorporating data about crop production rates, land use, consumption and waste management are required to assess the environmental impacts of ethanol fuel.

2. Economical assessment

The economic competitiveness of ethanol fuel varies across the world. Production costs of ethanol fuel depend of various factors: conversion processes, size of chemical plants, types of raw material and byproducts. These factors appear to be quite variable from one country to the other. Currently, ethanol produced from sugar plants is cheaper than the other raw materials, as in the case of Brazil (Figure 16).

Production costs in United States and Brazil are less than in Europe due to learning curve and other differences in expenditures (Gnansounou & Dauriat, 2005). Economy of scale and byproducts from production also contribute to differences in production costs.

	Feedstock	Country	Production Cost US$ / l
1st generation	Sugarcane	Brazil	0,249
	Corn	USA	0,323
	Sugar beets	EU	0,890
2nd generation	Corn Stover	USA	0,528**

(USDA)

*excludes capital costs & transportation costs

*cost varies with prices of feedstocks

**Dupont

Figure 15 Typical ethanol fuel production cost

Considering that the production cost of gasoline is US$ 0.20 – 0.28 /l (EIA, 2014), it is noted that apart from Brazil, ethanol fuel is currently not commercially competitive (Figure 16). To date, the cost of ethanol is still considerably higher than the cost of gasoline, particularly in the European markets (Figure 17). Therefore, in many countries, special government policies are required to encourage production and use of ethanol fuel in transportation sector. Without subsidies and tax incentives, ethanol price may not be competitive for consumer.

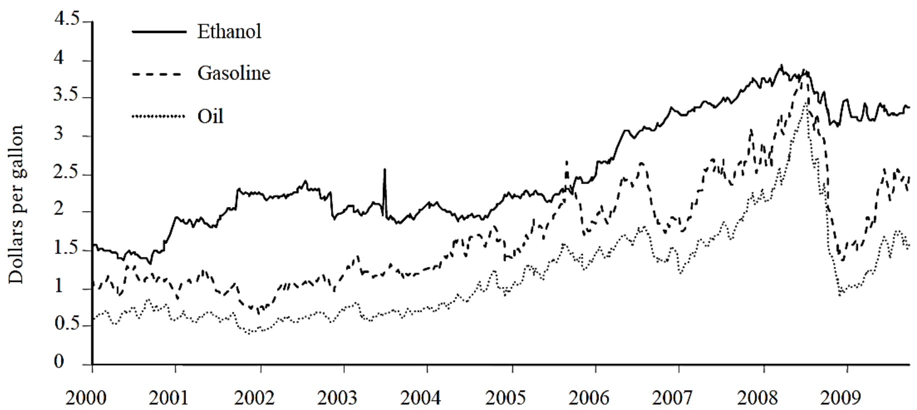

Figure 16 Development of the ethanol, gasoline and oil prices in Europe (Bloomberg, EIA)

Production costs of 1st generation ethanol fuel are highly dependable on the price of raw materials, which are volatile. The availability of raw materials for ethanol production can vary considerably from season to season and depends on geographical locations. Drought and poor harvests can substantially drive up the price of raw materials. Ethanol production generally utilizes food crops such as corn and sugarcane. Shortages of these crops can lead to competition between their use in food supply and ethanol production. Besides, expanding ethanol fuel production can be expected to increase corn prices further for beef production and ultimately increase costs for the consumer (Pimentel, 2003).

Increasing ethanol production may divert valuable land resources from cultivating corn needed for food supply to cultivating corn for ethanol fuel. This could affect food production and as well as create serious practical problems. Ethical issues arise when corn is used for ethanol production rather than feeding malnourished people. Large areas of land are required to grow sufficient corn or sugarcane to supply fuel for entire transportation sector. This can adversely affect the yield and production of other valuable crops like rice and wheat.

It is also important to note that if air pollution problems were controlled and included in the production costs, then ethanol production costs in terms of energy and economics would be significantly increased (Pimentel, 2003). Taking into account the amount of electricity used in ethanol production plant, corn-based ethanol may be an uneconomical transportation fuel.

Currently, producing ethanol from lignocellulosic materials has obstacles in terms investment costs and technological uncertainties. Costs of enzyme and plant investments are the major components of expenditures in 2nd generation ethanol fuel. Credible information regarding the selection of feedstock and various costs associated with production such as transportation and labor are required to assess the economic competitiveness of 2nd generation ethanol.

C. Butanol

1. Environmental issues

Currently, butanol is not used as transportation fuel in the market; it is generally used as industrial solvent. Due to butanol's lack of usage, its environmental assessment is limited and potential problems are unknown. Some health effects of exposure to butanol are irritation of the eyes and of the respiratory systems. Inhalation of large concentrations of butanol could affect the nervous system.

The ABE fermentation should not emit more CO_2 as it is the similar process as ethanol fermentation.

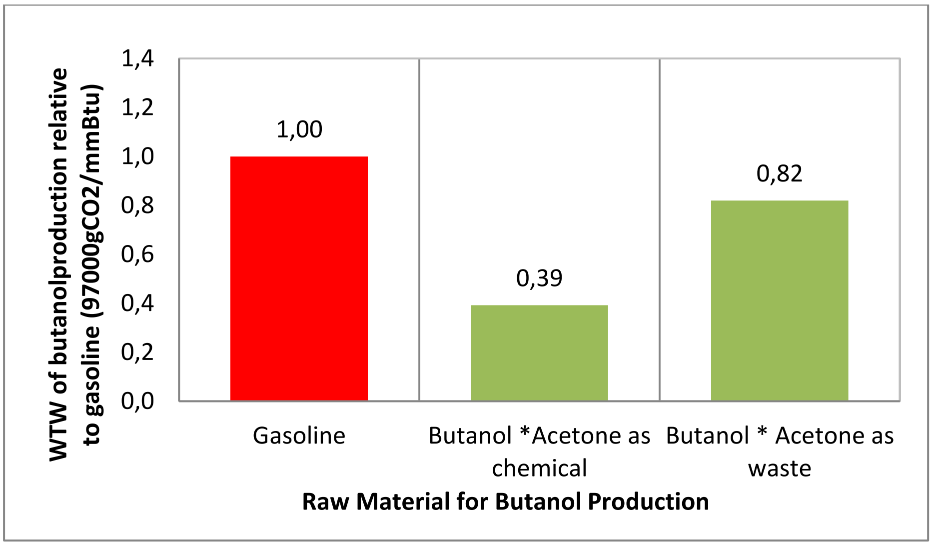

Figure 17 - Well to Wheel of butanol production relative to gasoline[xix]

2. Economical assessment

Currently, the ABE fermentation has low butanol yields, which casts doubt on its potential economy of scale. Besides, for butanol to be a viable diesel or gasoline substitute, the economics of the ABE fermentation need to be assessed in comparison to the market prices of petroleum fuels.

The ABE fermentation produces acetone as a byproduct. Acetone is used as a solvent and degreaser. Although acetone is highly flammable, it is not used as fuel or blended with fuel. Unfortunately, one important economic concern is that large-scale production of butanol through ABE fermentation could affects the acetone market and lowers its price. Consequently, acetone may not help offset the production costs for butanol and could become a waste byproduct (Szulczyk, 2010).

Similar to ethanol production, butanol production competes for the same feedstocks that are used for food supply. Increasing butanol production could increase food prices and puts consumers at a disadvantage.

III. Scenarios

Based on the previous parts, and thanks to some assumptions, rollout scenarios are considered hereafter. The first part is about microeconomics, looking at the price of ethanol compared to gasoline prices (only ethanol was considered because this is the only alcohol for which data exist). The second part deals with macroeconomics, assessing the investments needed by 2030 to meet the demand.

A. Assessing the price of ethanol

As discuss before, when it comes to ethanol it is necessary specify which generation is considered. Actually, ethanol produced via starchy material and sugar cane (first generation) is way cheaper than the generation ethanol. But what about the competitiveness with gasoline?

Currently, first generation of ethanol can compete with gasoline only in Brazil because the price of gasoline is quite cheap and the price of ethanol remains high in most countries. Yet, in 2030, the situation could be different.

To assess the potential competitiveness of **first generation ethanol** we have considered an ethanol plant built in 2015 (in the USA), which starts producing in 2016 and up to 2030.

Assumptions for the plant			
	1-Small	2-medium	3-large
Capacity (mgal/y)	18,7	40	100
$/gal			
Plant investment	1,95	1,39	1,22
operating costs (excluding corn)			
chemical inputs	0,13	0,13	0,11
Energy and utilities	0,27	0,31	0,29
Labor and other	0,17	0,12	0,17
Depreciation	0,17	0,12	0,12
Total operating cost	0,74	0,68	0,69
Coproduct value	0,35	0,34	0,34
Net operating cost	0,39	0,34	0,35
feedstock cost	1,5	1,5	1,5
Maintenance cost	0,049	0,035	0,031

Tableau 4 - Ethanol Plant Estimated Costs 1st Generation [xx]

The discount rate is 8% and it has been assumed an annual inflation rate of 2%. The load factor of the plant is 50% in 2016 and increases until 2020 where it reaches 100% (10% per year). The price of the raw material (corn = 8 $2015/bus[xxi] including taxes) is assumed to increase every year only because of the inflation rate (this is a strong hypothesis).

The aim here is calculate a minimum price of ethanol **to ensure an internal rate of return of 10%** for this project. The price is assumed to remain exactly the same at all time: no effect of inflation on it. Then, this price will be compared to a target price for ethanol: a price that would make it interesting to use (economically speaking).

Using Excel and with basic economic calculations, the following minimum prices have been obtained:

Minimum ethanol price ($2015 / l)	
Small plant	0,34
Medium plant	0,28
Large plant	0,27

First, these prices are in accordance with the ones that can be found in literature (for example, the ones that are given in page 15)[xxii]. The second important thing is the effect of economies of scale: large plants are more likely to emerge.

The first generation of ethanol could compete with gasoline since the production cost of gasoline range from 0.50-0.58/l (EIA 2014 production cost + crude oil at 47$/barrel). However, a massive emergence of this fuel could drive the price of corn up. As the feedstock accounts for a large part of the ethanol cost, the production cost could be significantly higher. Moreover, using corn to produce fuel rather than to feed people is an ethical issue. Finally, the first generation of ethanol might not expand as much as one could think.

The second generation of ethanol could overcome the problems that the first generation has to deal with. However, the price is a key point. In 2011, the NREL released a very comprehensive case study whose results are used here.

The plant is designed to produce 61 million gallon of ethanol per year. It is built in 2012, and is expected to produce ethanol for 30 years. Ethanol is produced thanks to a dilute-acid pretreatment and an enzymatic hydrolysis of corn stover. The technology is assumed to be mature so that the plant built is not a pioneer one but describes what would be the situation if the second generation of ethanol emerged.

Assumptions for the plant	
lifetime of the plant (year	30
Capacity (mgal/y)	61
Plant investment (M$)	422,5
Equity pecent of total investment	40%
loan rate	8%
feedstock cost ($/gal)	0,74

Table 5 -Ethanol Plant Estimated Costs 2nd Generation[xxiii]

The discount rate is 10% and the calculations are made to ensure **an internal rate of return of 10%. Finally,** the minimum selling price of 2.15 $2007/ gallon has been computed. Using the inflation rate, the minimum selling price **becomes 0, 65 $2015 / l.** It has to be noticed that the minimum selling price is still high, and could compete with gasoline only if the oil prices were high. This is not the current situation, but in 2030, the crude oil import price will probably be high enough (ranging from 104 to 136 $/bbl according to EIA) so **that the second generation of ethanol will be able to compete with gasoline (production cost = 0.85 to 1.05$ /l)**

B. Meeting the demand – investments needed

It has been pointed out that the second generation of ethanol could compete with gasoline by 2030. That is why further investigation should be conducted to assess the potential market. Hereafter, the need for alcohol is evaluated according to the data from IEA. The International energy agency only considered ethanol and biodiesel, but we are going to include methanol and butanol in this insight. To do so, some assumptions will be made according to literature (the references will be given any time it is necessary). The timeframe is 2030, but we will also consider 2050 to see what markets are the most promising.

Biofuel consumption by regional market	Biofuel Consumption 2030 (EJ)	Biofuel Consumption 2050 (EJ)	market share - 2030	market share - 2050
Latin America	1,1	3,3	11%	11%
China	1,3	6,0	13%	19%
OECD - Europe	1,1	3,3	11%	11%
India	0,5	3,2	5%	10%
OECD - North America	1,9	4,7	19%	15%
Eastern Europe + FSU	0,3	1,4	3%	5%
SUM	6,2	22,0	62%	70%
World	10	31,5	100%	100%

Table 6 - Biofuels - Regional markets in 2030 and 2050 – (IEA, 2011, Technology Roadmap – Biofuels for transport)

NB: In 2030, Biofuels accounts for about 9.5% of the total fuel consumption (27.2% in 2050)

First, it is noticeable, that the **biofuel market is very promising** because the meet is expected to triple between 2030 and 2050. The market shares will remain the same, except in **India and China** where **the demand will increase more rapidly** and in North America where the growth will be lower than the world average. Further investigation is now necessary to identify the types of alcohol that will be used in the countries that has been identified as promising markets: China, India and the European Union (the EU is promising since it could be at the leading edge of butanol).

The quantity of each type of alcohol was calculated by using the data from IEA and by making assumptions based on the previous parts of this report (for example, the emergence of methanol in China). Two scenarios were built:

- Emergence of ethanol and methanol
- Emergence of ethanol, methanol and butanol

Hypothesis	Biofuel Consumption 2030 (EJ)				Biofuel Consumption 2050 (EJ)			
	Bio-Ethanol	Bio-Butanol	Methanol	Total	Bio-Ethanol	Bio-Butanol	Methanol	Total
Latin America	1,1	-	-	1,1	3,3	-	-	3,3
China	0,5	-	0,8	1,3	2	-	4	6,0
OECD - Europe	1,1	-	-	1,1	3,3	-	-	3,3
India	0,5	-	-	0,5	3,2	-	-	3,2
OECD - North America	1,9	-	-	1,9	4,7	-	-	4,7
Eastern Europe + FSU	0,3	-	-	0,3	1,4	-	-	1,4
TOTAL (EJ)	**5,4**	**0,0**	**0,8**	**6,2**	**17,9**	**0,0**	**4,0**	**21,9**

Figure 18:First Scenario

The figures were calculated using the data presented in the first part of this report (current situation).

Hypothesis	Biofuel Consumption 2030 (EJ)				Biofuel Consumption 2050 (EJ)			
	Bio-Ethanol	Bio-Butanol	Methanol	Total	Bio-Ethanol	Bio-Butanol	Methanol	Total
Latin America	1,1	-	-	1,1	3,3	-	-	3,3
China	-	-	1,3	1,3	-	2	4	6,0
OECD - Europe	-	1,1	-	1,1	-	3,3	-	3,3
India	-	0,5	-	0,5	-	3,2	-	3,2
OECD - North America	-	1,9	-	1,9	-	4,7	-	4,7
Eastern Europe + FSU	-	0,3	-	0,3	-	1,4	-	1,4
TOTAL (EJ)	**1,1**	**3,8**	**1,3**	**6,2**	**3,3**	**14,6**	**4,0**	**21,9**

Figure 19 - Second scenario: emergence of butanol

Today, many studies are carried by companies and supported by states in order to promote biobutanol. As its production is still in research phase, the following reasoning was assumed:

1. Butanol replace ALL Ethanol after considering it has a Higher Energy Content(Except Latin America due to Brazil influence)
2. Methanol still being used in China due to its large coal reserves

Knowing the demand it is possible to calculate the investments needed for the adoption of biofuels according to the type of fuel considered. For the ethanol production, the two generations of ethanol are combined in the previous figures [figure 16 and 17]. However, it is necessary to evaluate for how much each generation accounts in the total demand [figure 18]. This was done using IEA data.

Ethanol market share	2030		2050	
	market share in biofuel market	market share in ethanol market	market share in biofuel market	market share in ethanol market
first generation	39%	64%	13%	27%
second generation	22%	36%	36%	73%

Figure 20 : ethanol market share (IEA)[xxiv]

Then, the number of each plant in each region was evaluated thanks to the investment costs and capacities listed in Appendix.

Scenario 1										
Number of plants	Number of plant - Biofuel - 2030					Number of plant - Biofuel - 2050				
	Ethanol 1 G	Ethanol 2 G	Butanol	Methanol	Total	Ethanol 1 G	Ethanol 2 G	Butanol	Methanol	Total
Latin America	87	82	-	-	169	109	495	-	-	605
China	62	0	-	133	196	66	300	0	666	1033
OECD - Europe	88	81	0	-	169	109	495	0	-	605
India	40	37	0	-	77	106	480	0	-	586
OECD - North America	151	140	0	-	291	155	706	0	-	861
Eastern Europe + FSU	24	22	0	-	46	46	210	0	-	256
TOTAL (EJ)	**452**	**362**	**0**	**133**	**947**	**592**	**2687**	**0**	**666**	**3946**

Figure 21: Number of plant - scenario 1

Scenario 2										
Number of plants	Number of plant - Biofuel - 2030					Number of plant - Biofuel - 2050				
	Ethanol 1 G	Ethanol 2 G	Butanol	Methanol	Total	Ethanol 1 G	Ethanol 2 G	Butanol	Methanol	Total
Latin America	87	82	-	-	169	109	495	-	-	605
China	-	-	-	217	217	-	-	173	666	839
OECD - Europe	-	-	95	-	95	-	-	285	-	285
India	-	-	43	-	43	-	-	276	-	276
OECD - North America	-	-	164	-	164	-	-	405	-	405
Eastern Europe + FSU	-	-	26	-	26	-	-	121	-	121
TOTAL (EJ)	**87**	**82**	**328**	**217**	**713**	**109**		**1259**	**666**	**2035**

Figure 22: Number of plants - scenario 2

Using the capital needed for each type of plant, the total investment required for the construction of the alcohol fuel plants from 2015 up to 2030 and 2050 has been evaluated.

Total world investments (B$)	scenario 1		scenario 2	
	2030	2050	2030	2050
Ethanol 1 G	65	84	12	16
Ethanol 2 G	174	1294	39	238
Butanol	0	0	170	651
Methanol	39	197	64	197

Figure 23: plant construction - investment needed

Based on our forecasts, we have estimated that China, India and the European Union will be the largest markets for alcohol fuels by 2030. However, large investment is required in order to build the plants because there is a lack of infrastructure at the present moment. Government incentives and policies are necessary to make those kinds of fuels competitive with gasoline.

IV. Conclusion

The use of alcohols as transportation fuels gained considerable interest in the 1970s as substitutes for gasoline. Since then, alcohol fuel production has gradually increases and become an important industry in countries such as Brazil, China and United States. Currently, methanol is mainly produced from coal and natural gas while ethanol is mainly produced from food crops. These practices are considered to be unsustainable for long term from economic and environmental points of view. Coal based methanol production poses environmental hazards and ethanol produced from food crops risks food production. Therefore, 2nd generation ethanol and higher alcohols are possible replacement for transportation fuel in the future.

The increasing use of alcohol fuels will have both positive and negative impacts. First, it would reduce GHG emissions and help mitigate climate change. Then, it will reduce world's energy dependencies on hydrocarbon and help boost the incomes of agricultural sector and chemical industry. However, it also contributes negatively to the environment through soil degradation, water pollution and water consumption. Environmental problems of alcohol production and consumption must be addressed before large scale adoption of alcohol fuel.

With the increasing demand for alcohol fuel as well as the fluctuating oil market, it emerged the opportunities for a large scale 2nd generation ethanol production in the United States. Various companies such as DuPont, Abengoa and Poet & DSM have recently invested in large scale lignocellulosic ethanol production in United States. This situation also occurred in other regions such as Europe with Futorol project, giving 2nd generation ethanol production a bright outlook. However, more studies are required and uncertainties associated with 2nd generation ethanol must be assessed. Recently, BP decided to close down its U.S. cellulosic operation and will now focus on the profitability and scale of its sugarcane biofuels business in Brazil.

Through the scenario suggested for 2030, 1st and 2nd generation ethanol fuel, butanol and methanol have been discussed as a competitive biofuel for the automotive industry. The alcohol fuel will account for 9.5% of energy consumed by transportation sector. The capital investment required to meet the demand would range from 278B$ to 285B$ depending on the development of butanol. The promising markets are China, India and European Union because of expected high increase in biofuels consumption.

Despite showing great potential to replace gasoline as transportation fuel, alcohol fuel is still years away from wide adoption. More researches and improvements are necessary if we are to use alcohol as a fuel in the future.

V. Appendix

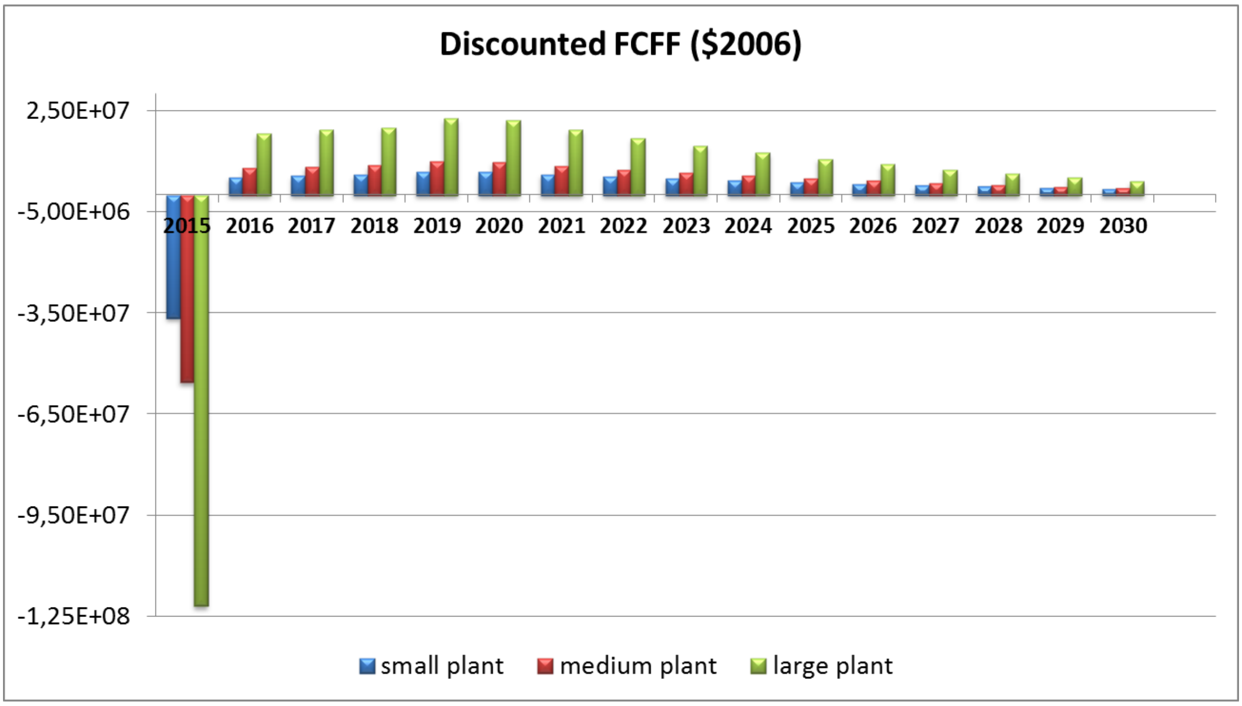

Figure 24: Free Cash Flow to the Firm for a first generation ethanol plant

World market share by type of biofuel - IEA - BLUEMAP scenario		
	market share - 2030	market share - 2050
Ethanol - conventional	6%	0%
Ethanol - cane	33%	13%
Ethanol - advanced	22%	36%
Biodiesel - conventional	6%	0%
Biodiesel - advanced	16%	21%
Biomethane	3%	15%
Biojet	14%	15%
Total	100%	100%

Figure 25:Market share of each type of alcohol according to IEA (IEA, 2011, Technology Roadmap – Biofuels for transport)

Type of plant	plant size (GAL produced /year)	plant size (EJ produced /year)	investment required ($2015)
Methanol	1,00E+08	6,00E-03	2,95E+08
Ethanol 1G	1,00E+08	8,02E-03	1,43E+08
Ethanol 2G	6,10E+07	4,89E-03	4,82E+08
Butanol	1,11E+08	1,16E-02	5,17E+08

Figure 26: investment needed for each type of plant[xxv]

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