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# BIOETHANOL AS A TRANSPORT FUEL:

# A Study to Improve Bioethanol Production in Finland

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## ABSTRACT

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Based on the rising greenhouse gas emission, depletion of the fossil fuel, climatic challenges and the high price of the crude petroleum product, the need for sustainable biofuels that will help mitigate the toxic gas emission has become a global topic. The production and utilization of bioethanol as transport fuel will serve as an alternative to reduce the overdependence on fossil fuel and mitigate the climatic issues. Understanding the technique and operations of the pretreatment process will help to improve bioethanol production and will increase the yield so that it can be used in automobiles and as blend will to a greater extend reduce the toxic gas emission and help create a stable climatic condition.

This report reviews several bioethanol pretreatment types such as chemical, physicochemical and biological. The pretreatment methods that are discussed are acid, alkaline, organosolv, ammonia fibre explosion, steam explosion, liquid hot water and biological pretreatments. The report reviews how the different pretreatment methods separate the lignin component from the hemicellulose in order to produce the sugar contents readily accessible for enzyme hydrolysis.

**Key words**

Ammonia Fibre Expansion (AFEX), Total Energy Equivalent Consumption (TEEC), Sugarcane Bargase (SCB), Terajoule (TJ), Megapascal (MPa).

**ABSTRACT**

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## 1 INTRODUCTION

The issue of global warming is the major global concern now. The overdependence on the fossil fuel is the main reason the world is facing the climate challenge. At the moment, fossil fuels are still the major means of energy production of countries around the world but several factors such as depletion in the fossil deposit, the unfavourable fluctuation of crude oil prices and the greenhouse gas emissions requires the need of shifting from fossil fuels to biofuels. Over the years, several studies have been carried out on the renewable fuels and experts are working on developing and improving the biofuel standard in order to meet the global energy demand. Diverting to using bioethanol and biodiesel in place of fossil fuels will help to reduce the toxic emission from crude oil. The use of bioethanol as transport fuel will minimize the carbon dioxide emission and create a better carbon footprint.

The conversion of various biomasses to bioethanol is affected by characteristics such as the structure and chemical composition of the biomass. The overall bioethanol production stages include pretreatment, hydrolysis, fermentation and distillation. The pretreatment stage is one of the most important steps that other production processes depend upon. There is need for proper understanding of this stage in order to improve the release of the sugar content of the biomass to enzymatic hydrolysis so that the fermentation and distillation stages will yield an optimum output.

This report will focus on the global energy situation and the energy condition in Finland as well as the different pretreatment methods such as chemical, physicochemical and biological pretreament and how it can be improved for optimum yield.

# 2 THEORITICAL BACKGROUND

The global energy condition, statistics on Finnish energy situation, the sustainable energy and biomass and its utilization will be discussed in this part of the chapters. It is a common practice around the world to review scientific work in order to set up the theoretical background and provide useful information towards development.

## 2.1 Global Energy Situation

Since the discovery of crude oil, the world has directed its energy use to the fossil fuels. The EIA in a report published in 2008 gave an analysis that the global energy demand is assumed to have 50 % increase from 2005 to 2030. It was explained that the rise in the prices of oil and natural gas which are likely to prevail during this period might slow down the growth. (Kan Siyi, Chen Bin, Chen Guoqian, 2019.)

The world has experienced a gradual rise in total primary energy consumption from 404,000 PJ (petajoule) in the year 2000 to 530,000 PJ in 2011 with an annual increase of 2.75 %. The Figure 1 shows the energy utilized and produced during this period. It was observed that the EU including the UK is the highest consumer of TEEC, about 106,000 PJ from 2003 and the USA is the next with TEEC ranging between 93,800 PJ and 105,000 PJ. China’s consumption has risen from 33,300 PJ in 2000 to 62,000 PJ in 2011 while that of other economies remained below 32,000 PJ. (Kan et al 2019.)

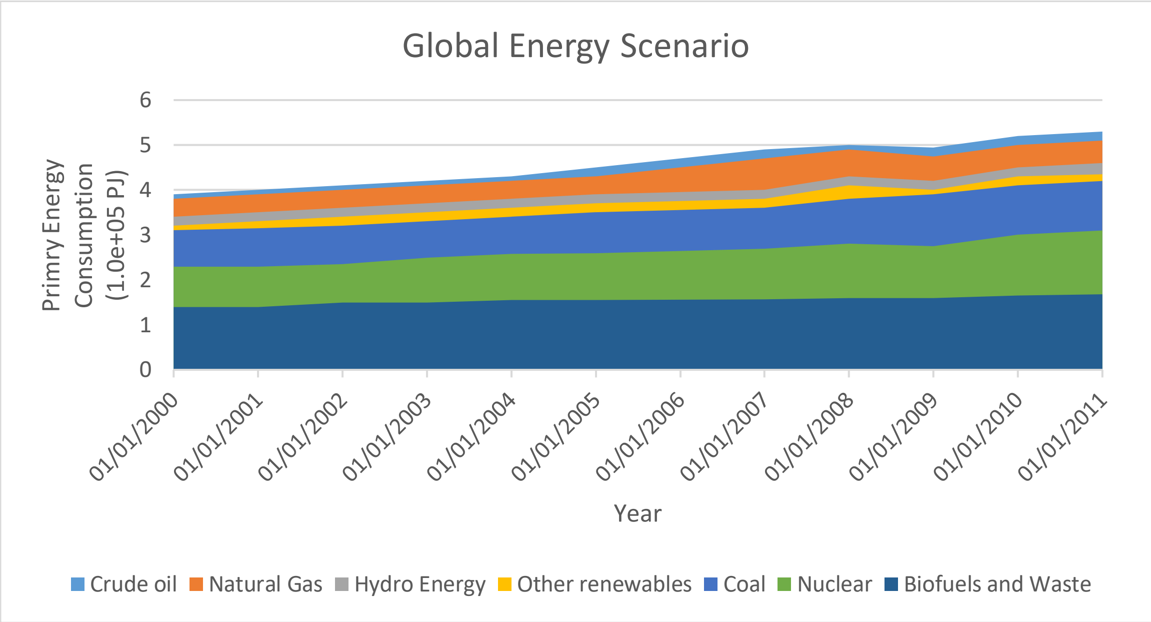


FIGURE 1. Total Global energy scenario from 2000-2011(Kan et al 2019)

### 2.2 Finland's Energy Situation

Finland is an advanced nation situated in the Northern European hemisphere. It is the number five most scantily populated country next to Iceland and Norway in Europe. Since the Finnish economy depends majorly on produce from industries, 50 % of the energy generated is utilized by the manufacturing sector. The increase in the Finnish population by 12 % from 1981 to 2011 is not proportionate to the energy demand and the increase is greater than 90 % from 202,712 GWh to 385,554.7 GWh. The energy utilization is mostly on fossil fuels and uranium (for nuclear power) imported from outside countries as shown in Figure 2 (Aslani et al 2014.). It was reported that the industries consumed 45 % of the total energy in 2016 while transport was 17 % and the most relevant source of primary energy was biomass which was approximately 26 %. (Jääskeläinen J., Veijalainen, N., Syri, S., Marttunen, M. & Zakeri, B., 2018)

The Finland energy statistic recorded that the total energy consumed in 2018 was 1.38 terajoule (TJ) which is equivalent to 2 % increase when compared with the year before. This increament was as a result of the rise in the use peat, fossil and renewable energy sources. There was a 3 % increase in the demand for renewable energy sources and it resulted to a share of one percent rise in the total energy consumed approximately 37 %. There was a 9 % increase in the demand of black liquor resulting in the rise of wood fuels consumption by 4 % resulting in a share of 27 %. The wood fuel is the most utilized energy source. Wind power increase by 22 % while hydroelectricity decreased by 10 %. (Statistic Finland 2018.)

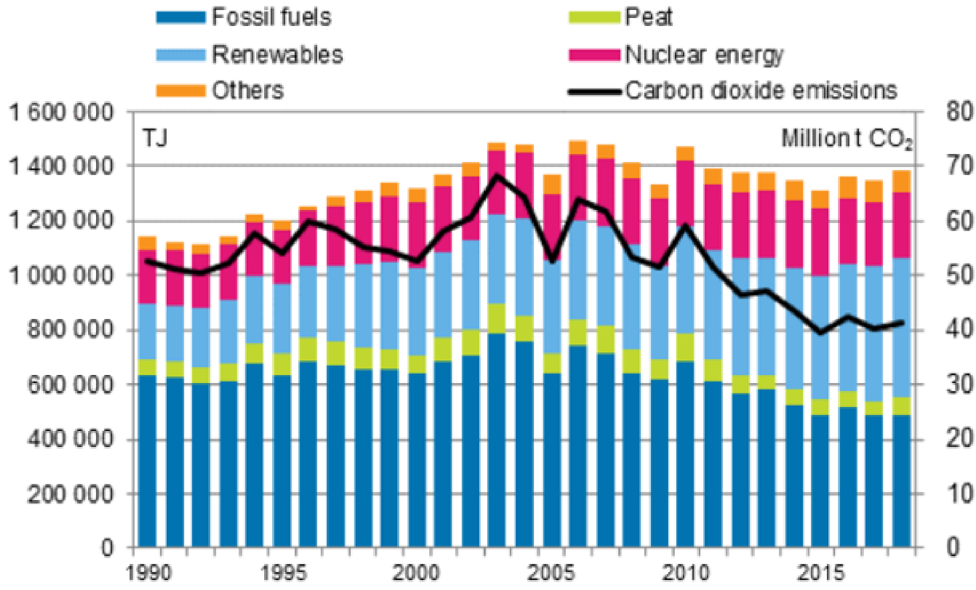


FIGURE 2. Finland Energy Statistic from 1990 to 2018 (Statistic Finland 2018)

### 2.3 Sustainable Energy

The best energy suitable for the current energy demand without posing any threat and is biofuels also known as sustainable energy. Being the best form of energy, the use of sustainable energy should be encouraged at the global level since it is safe to the environment, readily available and economical. The various forms of renewable energy sources are wind, geothermal, solar, hydropower and biomass are available worldwide. Though the distribution of these various energy sources might vary around the world, the fact is that they are available and can be reused unlike the fossil fuels which are continuously undergoing depletion and emit greenhouse gases which are harmful and detrimental to the environment. (Conserve Energy Future 2020.)

The UNDP 2020 said that sustainable energy does not only solve the health challenges and quality of life threatened by the fossil fuels but also it can serve as poverty alleviation, improvement of social wellbeing, economic development and keep the environment safe.

### 2.4 Biomass

Biomass can be referred to as biological substitute feed material to natural gas and petroleum fuel. The biomass can be explained as the most accepted term used to describe materials that are obtained from various kinds of plants and animals, including agricultural waste and microorganisms. The basic idea behind the cultivation of plant is to be used as food and animal feed, organic products, and combusted for cleaner energy. (Sherwood, 2020.)

Plant generally utilizes the sun's radiation in a process known as photosynthesis to manufacture materials. Biomass could be referred to as the material that are stored from solar radiation. The burning of the biomass thereby results in the production of heat energy. The combustion of biomass can be used directly as heat or processed to biofuels or biogas. Woody plants and their residues can be used for warming houses, for industrial use as well as electrical power generation. (EIA 2018.)

### 2.4.1 Biomass as an Energy Source

Biomass to some extent is different from other sustainable energy sources since it is burnt to generate heat and then converted to electricity or used as a starting material for making other products. Therefore, biomass has resemblance to coal, fossil fuels or natural gas as an energy source. It is gaining an increase use as energy source for power generating companies. (Sherwood, 2020.)

The Drax Group whose headquarter are in Monroe, LA, with operating activities cut across the Southeastern U.S., is a producer of flattened wooden pellets for electric power production, reducing the carbon gas emissions and dependency on coal (Drax 2020). Uddin, Taweekun, Techato, Rahman, Mofijur, Rasul, 2019 observed in their analysis that biomass could be use as the renewable energy source that can fit in the Bangladesh energy gap of the energy policy.

### 2.4.2 Biomass Conversion technology

The general feed material that the technology for converting biomass to energy uses could be of great matter variability and energy content, high moisture constituent and intermittently in supply. As a result of this, the improved manufacturing technologies uses the fossil fuel to dry, preheat and maintain the fuel input when the biomass supply is interrupted (Sharma et al 2014).

The techniques for converting biomass into useful energy or other forms of valuable products are thermochemical and biochemical processes. The thermochemical process involves the conversion of biomass based on monitored temperatures and oxygen conditions, which can further be divided into pyrolysis, carbonization, gasification, and catalytic liquefaction. The biochemical process on the other hand makes use of microorganisms in converting biomass to useful products. Genetic engineering has paved way for utilizing aerobic and anaerobic fermentation techniques for energy synthesis and other useful application like wastewater treatment. (Sharma et al 2014.)

## 3 BIOETHANOL

Bioethanol which is also known as ethyl alcohol has the chemical formula of $C_2H_5OH$. It is synthesized by fermenting sugars with the aid of microorganism such as yeast. Bioethanol is a colourless liquid that can be decomposed by biological activities. It has been in larger production in the U.S. and Brazil since 1970s from the cultivation of sugarcane and corn respectively. Bioethanol is commonly mixed with gasoline to power engines. Its combustion by-products are carbon dioxide ($CO_2$) and water ($H_2O$), and this makes bioethanol a cleaner fuel because oxygen is emitted in the same amount as the $CO_2$.

Reaction equation for bioethanol combustion:

$$C_2H_5OH_{(aq)} + O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(g)} \quad (1)$$

This balance between oxygen and $CO_2$ makes bioethanol a better fuel source than the crude petrol which only gives out $CO_2$ together with other harmful gases. Therefore, mixing bioethanol with petrol results in total combustion which reduces the release of greenhouse gases. (Chin & H'ng, 2013.) The specification for bioethanol can be seen in Table 1.

TABLE 1. Specification for Bioethanol. (Busic et al, 2018)

| **Specification** | **Gasoline** | **Ethanol** |
|---|---|---|
| Octane number | 88-100 | 108 |
| Density (kg/dm$^3$) | 0.69-0.79 | 0.79 |
| Boiling point (℃) | 27-225 | 78 |
| Freezing point (℃) | -22.2 | -96.1 |
| Flash point (℃) | -43 | 13 |
| Autoignition temperature (℃) | 275 | 440 |
| Lower heating value 10$^3$ /(KJ/dm$^3$) | 30-33 | 21.1 |
| Latent vaporization heat/(KJ/kg) | 289 | 854 |
| Solubility in water | Insoluble | Soluble |

### 3.1 Bioethanol as transport fuel

One of the major global issues at the moment is finding a lasting solution to the greenhouse gas emissions. The IEA in 2004 examined that producing biofuels for transportation has not been properly quantified but did explained that studies shows implementing biofuels for transport could take over fossil fuels within 2050 to 2100. The IPCC synthesis report of 2014 explained that the emission of the green-house gases has risen due to human activities since the evolution of industries and human growing population. The discovery and use of fossil fuels have worsened the situation to higher degree. This is the reason why sustainable fuel use needs to be implemented and improved in order to ameliorate the harmful gas emissions.

The most important biofuel in the United States is ethanol extracted from corn. The government implemented that the ethanol should be blended with gasoline in the ration 2.7 % in 2006. Brazil emphasized the production of ethanol from sugarcane since the beginning of 1970 and the government implemented that ethanol blend should be used in official vehicles. The European Union in 2003 put forward a Biofuels Directive encouraging the utilization of biofuels in transportation (Pohit et al, 2009).

Bioethanol octane number is 108 higher than that of petrol with a wider limit of flammability, greater heat of vaporization giving it a greater compression ratio and reduced heating time. Besides being a cleaner fuel based on its reduced carbon emission, bioethanol has a greater advantage over petrol fuel in internal combustion engine when the characteristics listed above are considered. Some of the properties of alcohol fuels are displayed in Table 2. (Balat M., Havva B., 2009.)

TABLE 2. Properties of some alcohol fuels. (Balat & Havva, 2009)

| **Fuel property** | **Isooctane** | **Methanol** | **Ethanol** |
|---|---|---|---|
| Octane number | 100 | 112 | 108 |
| Auto-ignition temperature (K) | 530 | 737 | 606 |
| Latent heat of vaporization (MJ/Kg) | 0.26 | 1.18 | 0.91 |
| Lower heating value (MJ/Kg) | 44.4 | 19.9 | 26.7 |

Kojima & Johnson, 2006 argued that the use of ethanol in vehicles is evaluated to be economical in Australia provided the oil price stay the same as that of 2005 rates and the government involvement is required to keep the biofuels companies operational in developing countries. The observation explains the potential of bioethanol as a transport fuel and how it will help in reducing the harmful gas emission due to the use of fossil fuel.

### 3.2 Bioethanol Consumption in Finland

Gasoline and diesel are the main transport fuels on Finnish roads. In 2015, approximately 2 billion litres of gasoline were used, little lesser than 2014. The transition into diesel cars has reduced the gasoline use in Finland and in turn increases the use of diesel fuel. 2014 recorded about 3 billion litres of diesel oil usage. (Jääskeläinen, 2017.)

The Finnish government legislated in 2014 that renewable fuels supply should be increased on a yearly basis. There is variability in the amount of bioethanol mixture of the Finnish 95 E10 gasoline grade and it is placed at 10 % limit by volume. It may be 5 % in the 98 E5 gasoline grade. The Finnish act (446/2007) on the Promotion of the Use of Biofuels for Transport calculated the portion of the biofuels to be contained in the total amount of energy in gasoline, diesel oil and biofuels should be at a minimal level of 20 % by 2020. (Jääskeläinen, 2017.)

In Finland, organic waste from food industries, outlets and homes is used for ethanol production. The ethanol could be used as a blend in gasoline in the mentioned range or as E85 fuel for a specialised car type. The Finland E85 fuel has 80 to 85 percentage ethanol content and this is only utilized in FlexFuel Vehicle (FFV) which is made explicitly to be powered by ethanol. (Jääskeläinen, 2017.)

### 3.3 Bioethanol on a global scale

Olende 2007 analyse that bioethanol production in 2003 was twice that of 1993 and increases from 4.6 billion to 12.2 billion gallons within 2000 and 2005 with Brazil and U.S the major consumers. Balat and Havva in 2009 examine that the bioethanol produced worldwide increases from approximate17 billion litres in 2000 to above 46 billion litre in 2007 and this can be seen in Figure 3.

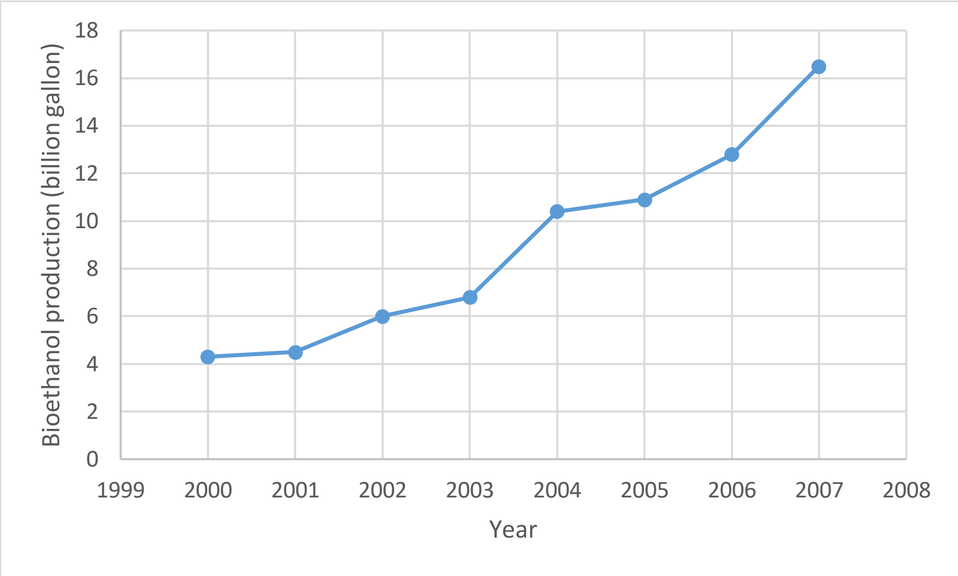


FIGURE 3. The estimated worldwide ethanol production from 2000 to 2007. (Adapted from Balat M., Havva B., 2009)

The IRNA in 2013 analyse that the largest sources for typical bioethanol production are from starch and sugar crops and it therefore takes the largest share of renewable fuel for transportation. The global bio-ethanol production in 2013 was more than the produced biodiesel by a factor of three amounting to 80 billion litres. The production of bioethanol is struggling to develop in the Sub-Saharan Africa than in other countries due to the high demand for food crops used in the production. But there is hope that by the year 2050, the potentiality for bioenergy production in Sub-Sahara Africa will grow from the present output of 347 exajoule to around 1548 exajoule. (Bai, 2012.)

The Licht (2018) gave a prospect that the market for bioethanol could be expected to rise from 1.5 to 1.7 % on annual bases for the decade provided that the government will safeguard the local biofuel companies from the international market and the bigger biofuel producers are expected to give their own contribution in order to achieve the expected growth. The Figure 4 shows the global production of bioethanol.

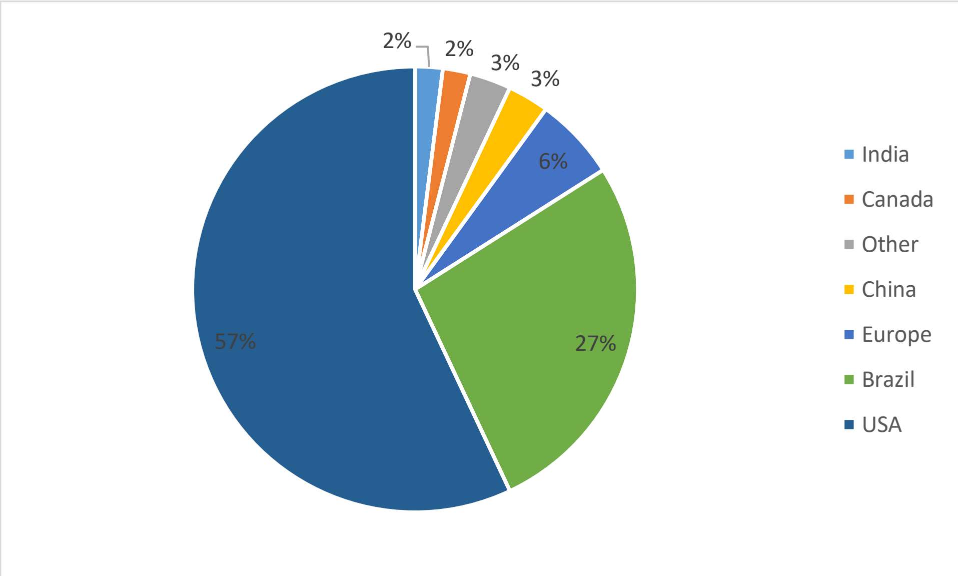


FIGURE 4. World Bioethanol Production (Adapted from Ramachandra and Hebbale 2020)

# 4 PRETREATMENT TECHNIQUES FOR BIOETHANOL PRODUCTION

The pretreatment process plays a vital role in the conversion of biomass to bioethanol (Xu Z., and Huang F., 2014). The principal purpose of pretreatment is for the disintegration of the lignin components and to allow easy access of the enzymes to act on the cellulosic materials during the process of hydrolysis. The different pretreatment methods affect the cellulose, hemicellulose and lignin differently. (Sabiha-Hanim and Abd Halim 2018.)

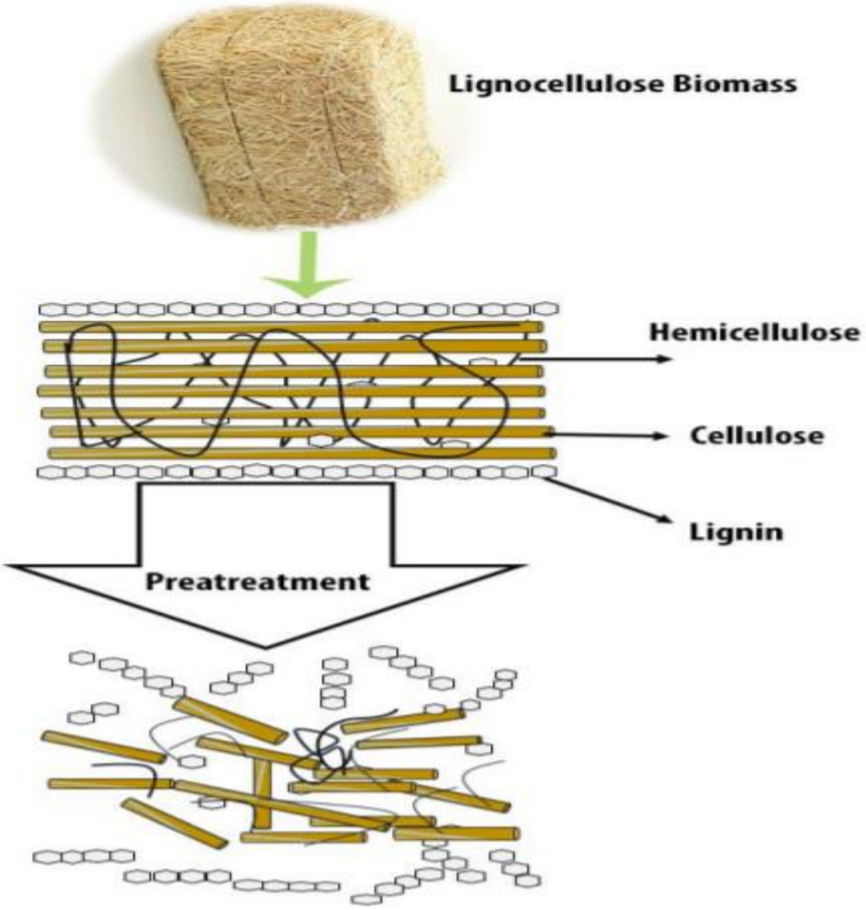


Figure 5. The pretreatment processes. (Tayyab et al 2018)

For an efficient bioethanol production, it is important to select an appropriate pretreatment method. This section will discuss some of the various pretreatment methods such as chemical, physico-chemical and biological methods that are used to produce bioethanol.

## 4.1 Chemical Pretreatment Method

The chemical pretreatment method involved using chemicals to breakdown the lignin component presents in plant biomass. The various chemical pretreatment methods such as acid, alkaline, organosolv and ozonolysis will be discuss in the subchapters.

### 4.1.1 Acid pretreatment

The acid pretreatment used may be either concentrated or diluted acids. The diluted acid is the most commonly employed due to the high amount of acid and the problem of detoxification. The dilute acid pretreatment is done using diluted acids within 0.5 to 6 % at 120 to 170 °C with varying time frame which maybe up to an hour depending on the conditions and requirements. (Sabiha-Hanim and Abd Halim 2018.)

The dilute acid pretreatment is required to reduce the strength of the glycosidic bonds holding the molcules present in the biomass, thereby releasing the sugar and making the plant cell wall more porous for enzyme catalysis (Jiang et al, 2013). This pretreatment method is mostly employed due to its reduced cost and acid availability, though there are some likely side effects associated such as the forming of furan and small chain organic acid derivatives which can inhibit microorganism fermentation (Qinq and Wyman 2011). The Table 3 shows the various types of acid used, the sugar yield and their pretreatment conditions.

TABLE 3. The pretreatment conditions for different acids used. (Adapted from Sabiha-Hanim and Abd Halim 2018.)

| **Type of acid** | **Pretreatment conditions** | **Yield of sugar** | |
|---|---|---|---|
| | | **Mg/g** | **g/L** |
| Sulfuric acid | 1.5% $H_2SO_4$, 170℃, 15 min | 350 | |
| | 0.5% $H_2SO_4$, 120℃, 120 min | 452.27 | |
| | 2.0% $H_2SO_4$, 155℃, 10 min | | 22.74 |
| | 0.5% $H_2SO_4$, 130℃, 15 min | 414.9 | |
| | 1.25% $H_2SO_4$, 121℃, 2 h | | 59.1 |
| | 0.5% $H_2SO_4$, 121℃, 60 min | | 24.5 |
| | 2.5% $H_2SO_4$, 140℃, 30 min | | 30.29 |
| Hydrochloric acid | 0.5% $H_2SO_4$, 120℃, 120 min | 37.21 | |
| Phosphoric acid | 0.5% $H_3PO_4$, 130℃, 180 min | 404.5 | |
| | 4% $H_3PO_4$, 122℃, 300 min | | 23.2 |
| Nitric acid | 6% $HNO_3$, 122℃, 9.3 min | | 23.51 |

### 4.1.2 Alkaline pretreatment

The alkaline pretreament is used for simple application and within little time a high conversion output is achieved. It uses reduced temperature (around 25 ℃) and pressure when compare to other methods and does not degrade much sugar, though inhibiting agents need to be removed for improved conditions. The alkali used include sodium hydroxide, potassium hydroxide, hydrazine ($NH_2NH_2$), dry ammonia ($NH_3$), as well as calcium hydroxide [$Ca(OH)_2$]. For bioethanol production, sodium hydroxide (NaOH) alkali is the most efficient alkaline chemical method used and can increase the swelling through larger area accessibility, and also reduce crystalline and polymerization limit. (Abdul Yusuf & Inambao 2019.)

The effectiveness of the alkaline pretreatment method is higher on hardwood, herbaceous plants, agricultural remains with reduced lignin than on softwood containing high lignin as recorded by Chen et al, 2013.

It was recorded by Mishima et al in 2008, that the method with the highest efficiency when twenty chemicals were used for pretreatment to upgrade enzyme hydrolysis of water hyacinth is alkaline and oxidative pretreatment method. The table 4 shows the alkaline pretreament condition and the amount of lignin removed.

Kallioinen (2014), analysed that the enzymatic hydrolysis performed after alkaline oxidation yielded 84 % glucose which shows how promising the alkaline pretreatment operates. Cheng et al in 2011, explained that the alkaline pretreatment method leaves some amount of lignin that might inhibit enzymatic hydrolysis. The Table 4 shows the treatment conditions on sugarcane Bargase.

TABLE 4. Alkaline pretreatment conditions on sugarcane Bargase (SCB). (Adapted from Sabiha-Hanim and Abd Halim 2018)

| **SCB (lignin % w/w)** | **Pretreated SCB (lignin % w/w)** | **Pretreatment condition** |
|---|---|---|
| 21.5 | 10.6 | 1.0 % NaOH, 120 ℃, 10 min |
| 27.9 | 9.2 | 0.9 % NaoH, 80 ℃, 2 h |
| 25.4 | 7.8 | 2 % NaOH, 121 ℃, 30 min |
| 18.0 | 1.8 | 15 % NAOH, 175 ℃, 15 min |
| 17.8 | 4.3 | 4 % NaOH, 121 ℃, 30 min |
| 25.0 | 9.0 | 2.5 % NaOH, 126 ℃, 45 min |
| 30.1 | 18.5 | 1.0 % NaOH, 120 ℃, 60 min |
| 23.4 | 5.2 | 5 % NaOH, 121 ℃, 60 min |
| 25 | 6 | 1 % NaOH, 100 ℃, 30 min |
| 34.3 | 5.7 | 1% NaOH, 100 ℃, 1 h |
| 22.0 | 9.5 | 2 % NaOH, 120 ℃, 40 min |

### 4.1.3 Organosolv pretreatment

The organosolv is used for the separation of lignin and hemicellulose by cooking of the lignocellulose biomass in a combine water and organic solvent to dissolve them in the cooking liquid. By diluting the liquor with water, the lignin component can be recovered and a solution containing cellulose and hemicellulose materials are left behind. By distilling the liquid stream, the organic materials can be regained. The process is environmentally friendly, reduces wastage volume by recovering lignin as a purified produce and does not need the inorganic chemicals used in other pretreatment method. (Nitsos et al, 2018.)

The Figure 6 shows the process diagram for the ethanol organosolv pretreatment process.

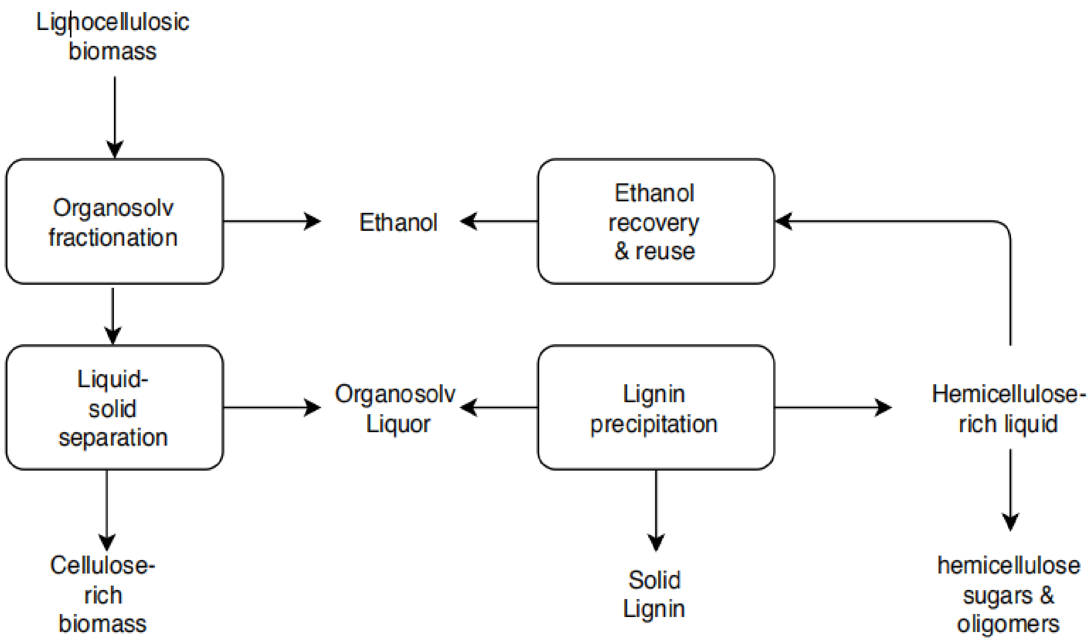


FIGURE 6. The ethanol organosolv pretreatment process. (Adapted from Nitsos et al, 2018)

Agnihotri et al in 2015 explained that when the ethanol organosolv pretreatments were carried out on sugarcane bagasse repeatedly, the level of lignin removal rises as the temperature increases such that 65 % delignification was attained at 235 ℃ for Norway spruce and 80 % at 210 ℃ for sugarcane bagasse. It was analysed that aside from ethanol, glycerol can also be used in the organosolv pretreatment as analysed by Martin et al in 2011. Their result shows that within the overall conditions utilized, the maximum cellulose conversion was obtained when the glycerol pretreatments was used without any chemicals, producing 85 to 94 %. Matsakas et al in 2018 analysed that organosolv gives an outstanding performance for delignification but has shortcomings for deconstructing biomass.

### 4.2 Physicho-chemical Pretreatment Method

The physicho-chemical pretreatment method uses physical quantities such as temperature and pressure in the process. Three pretreatment method which include ammonia fibre expansion, steam explosion and liquid hot water pretreatment will be discuss under the physico-chemical method.

### 4.2.1 Ammonia Fibre Expansion pretreatment (AFEX)

This pretreatment process utilizes liquid ammonia mix with biomass at temperature range of 70-200 ℃ and control pressure of 100-400 psi after which the pressure is quickly released as depicted in Figure 7. The main operating features are the reaction temperatures, residential time, ammonia loading and water loading. The operation increases the enzyme activities to a significant extent by removing and depolymerizing lignin component, hydrolysing the hemicellulose, decrystallizing cellulose and increasing the amount and size of pores in the cell wall. (Bals et al, 2011.)

Abdu & Inambao in 2019 explained that lignocellulose digestion was increased and there was high output due to enzyme hydrolysis in the AFEX pretreatment. In this process, the residual ammonia was observed not to have any inhibition on the other processes and can even serve as a positive effect during fermentation (Baig et al, 2017).

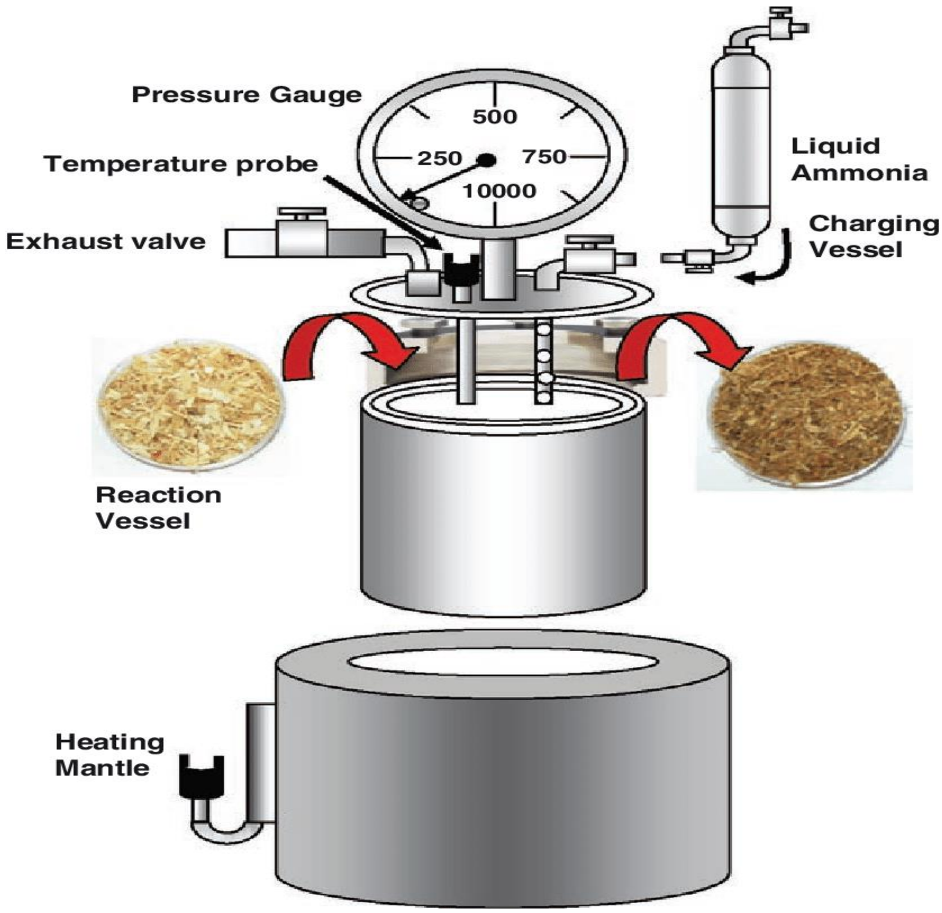


FIGURE 7. Setup for AFEX Reactor (Balan et al, 2009)

### 4.2.2 Steam explosion pretreatment

The steam explosion is usually the frequently used pretreatment process for lignocellulose materials. It uses high pressure saturated steam to treat chopped biomass in the process and the pressure is lowered subjecting the biomass to explosive compression. The temperature and pressure for the operation are 160-260 ℃ and 0.69-4.83 MPa for few minutes after which the materials are exposed to atmospheric pressure. This process results in the separation of hemicellulose and lignin as a result of the high temperature used thereby enhancing the cellulosic hydrolysis. Within 24 hours the hydrolysis yield was found to be 90 %. (Sun et al, 2002.)

Pielhop et al, 2016 explained that two factors which include pretreatment severity and the pressure difference in the explosive mechanism affect the steam explosion pretreatment. Kallioinen, 2014 explained that the enzymatic hydrolysis performed after steam explosion pretreatment yielded 52 % of whole glucose. Matsakas et al in 2018 analysed in their report that steam explosion pretreatment provides a good treatment process but its potential is reduced in fractionation.

### 4.2.3 Liquid hot water pretreatment

The liquid hot water pretreatment operates without catalyst and no rapid decompression is needed. Pretreatment of water is used to retain the aqueous level at high temperature and pressure. The temperature and pressure ranges adopted are usually 170-230 ℃ and above 5 megapascal (MPa) respectively. The process allows the accessibility of the cellulose product by separating the hemicellulose from the lignocellulose. Liquid hot water pretreatment has seen to give large amount of hemicellulose sugars usually in the oligomeric form and reduces the unwanted side products. (Maurya et al 2015.)

Qiang et al, 2014 explained that the pH range of the liquid hot water is between 4-7. Mosier et al, 2005 analyzed that the time period and temperature are important factors that determine the hemicellulose sugar recovered and the outcome of the enzyme hydrolysis. It was explained that though the liquid hot water process has some promising advantages over other pretreatment method which includes moderate temperature, high amount of hemicellulose is recovered, little products of inhibition and cost effectiveness but the amount of sugar released is low (Sabiha-Hanim and Abd Halim 2018).

## 4.3 Biochemical Pretreatment Method

Philbrook, Alissandratos, and Easton in 2013 explained that the use of microorganisms in the pretreatment process has several advantages when compared to the other pretreatment types. Microorganism operates at a moderate condition which would not require electricity or heat supply. This process does not produce chemicals that hinder the enzymatic hydrolysis as seen in other pretreatment types (Roberto, Mussatto, and Rodrigues, 2003).

Fungi has presented a promising effect in the breakdown of lignin material; therefore, many research works have concentrated on using fungi in biomass digest. Varieties of white-rot fungi spicies such as Echinodontium taxodii, Coriolus versicolor and Trametes versicolor have been examined for their capability of degrading lignin components to enhance cellulose digestion in bamboo plant remains (Philbrook et al, 2013).

Vats, Maurya, Shaimoon, Agarwal, and Negi in 2013 explained that the fungi can be isolated from a live plant, lignocellulose waste as well in the soil. The brown-rot type act on cellulose while the white and soft rot breakdown lignin and cellulose in waste matter. The white-rot fungi produce enzymes capable of degrading the outer covering of wood (Sun et al, 2002). Cheng et al, 2011 explained that the biological pretreatment is assumed to be the most preferred method from economic point of view, it however consumes longer time.

## 5 IMPROVING BIOETHANOL PRODUCTION

The population of Finland is dispersed with a large area of around 33.8 million hectares. It is the number fifth in Europe by size and its location is between 60-70 degrees north latitude as shown in Figure 7. About 87 % of the Finnish land is covered with forest, 9 % of the land is for farming and 4 % is for human settlement and transport connections.  The Finland's energy pattern is affected by the cold climatic condition, lower population size, the method of industrialization and the available natural materials. (IEA BIOENERGY, 2014.)

The nature of the Finnish climate, topography and industrialization affects the energy distribution and in section 2.2, it was recorded from Jaaskelainen et al in 2018 that 45 % of the total energy consumed in 2016 was from the manufacturing sector while 17 % from transportation. The National Energy and Climate Strategy planned by the Finland Government aimed at reducing the greenhouse gas emission to 80-95 % by 2050 and to raise the renewable energy sources in transportation to 40 % by 2030. The government also plan to increase the number of electric cars to 250,000. (Jaaskelainen et al 2018.)

Since the transport sector cover a large proportion of the annual energy consumption, improving the biofuel generation especially, the production of bioethanol and biodiesel will help to mitigate the toxic gas emission and provide a sustainable biofuel product. Valmet and St1 are Finnish companies that plan on building plants for producing bioethanol from cellulosic materials. (Valmet Forward 2020.)


FIGURE 8. The location of Finland. (WorldAtlas, 2020)

Valmet company which is very known for its production of paper and pulp has opened a cellulosic ethanol production in Germany in 2012. The company has its location in Espoo Finland as can be seen in Figure 9 and it provides technologies for cellulosic bioethanol production. Valmet operates on improving the pretreatment stages for optimal ethanol production from lignocellulose materials. (Valmet Forward 2020.)


FIGURE 9. Valmet location in Finland. (Valmet Forward 2020)

The St1 cellulosic (sawdust) ethanol plant at Kajaani as depicted in Figure 10 is aimed at producing 10 million litres of ethanol at maximum capacity within a year. The company has completed its environmental impact assessment on three other plants to be built in Pietarsaari, Kajaani and Norway. For these new plants, the feed materials will be sawdust and wood remain. (Finnish Forest Association 2019.)

The pretreatment stages which are followed by enzyme hydrolysis and fermentation need proper monitoring. A thorough study and understanding of the pretreatment process for second-generation biomass which involve using cellulosic biomass for bioethanol production will increase the yield and provide other pure side products from the removed lignin components.

FIGURE 10. St1 Plant in Kajaani. (Finnish Forest Association 2019)

# 6 DISCUSSION AND CONCLUSIONS

Ethanol is still the most preferred biofuel to the widely used gasoline. Regardless of the lower energy equivalent as compared to gasoline, it is a cleaner fuel with less toxic gases. Several drawbacks are associated with bioethanol production, but the improved technologies will help ameliorate that. The pretreatment process for lignocellulosic feeds needs to be studied properly for optimum glucose yield in order to have an efficient enzyme reactivity.

It will be seen from literature that several pretreatment methods have been discussed and studied for improved bioethanol production. The reason for the pretreatment process is to enable the hemicellulose fraction available for enzymatic catalysis. In depth study of the pretreatment processes will guide to perform the process for optimum yield of bioethanol production and these processes could be combined for optimum lignin removal. There is need to look into the merits and demerits of the different pretreatment methods.

As explained in the pretreatement techniques section, it will be seen that the dilute acid has less corrosion problem in comparison to the concentrated acid and form lower inhibiting products. Though the concentrated acid yields more glucose, but acid recovery remains a challenging factor. The alkaline method gives a high output in a short period of time for most of the biomasses except on softwood where the lignin content is high, and it also required that the inhibiting agents need to be removed. The organosolv produce high yield of hemicellulose for hydrolysis but the cost of operation is very high, and the solvent used needs to be washed-out and reused. The AFEX enlarges the surface area and produces low inhibiting materials yet it requires a very high cost of maintenance. The steam explosion is economical and produce high glucose and hemicellulose when two-steps process is used but involved more toxic products and the hemicellulose breakdown is partially. The liquid hot water is a promising method, but the sugar turnover is very low. The biological method uses reduced energy and breakdown lignin and hemicellulose but involved lower hydrolysis and needs more time duration.

The methods most currently used are the chemical and the physicochemical. Several studies have shown that different pretreatment methods could be combined for a better yield of products for enzyme hydrolysis. There is a need to provide ways to reduce the cost of pretreatment for bioethanol production. This could be achieved by efficiently converting and utilizing the hemicellulose sugars for optimum sugar yield in order to increase the ethanol output during fermentation. It will be good to perform more studies to understand the plant cell wall, its composition and structure in order to know the effective enzyme breakdown of biomass wall and the effective chemical and physicochemical pretreamtment methods applicable.

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