Chapter

# Alcohol Fuels as an Alternative Fuels - Bringing New Heights in Sustainability

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## Abstract

Since the middle of 1970s, the enthusiasm for using alcohols as alternate convenient fuels in internal combustion engine (IC) has been increased and it has reached peak stage by the middle of 1980s. The usage of alcohol as an alternate fuel, due to its minimal undesired effects on atmosphere, has gained importance. Harmful effects on environment are caused by various fossil fuels and their exhaust emissions such as carbon monoxide, carbon dioxide, hydrocarbons, nitrogen oxides and particulate matter. Alcohol type of fuels is alternative to petroleum-based fuels due to reduced greenhouse gas emission, toxic exhaust emission and enhancement of overall energy efficiency. Moreover, they are convenient for internal combustion engines due to their high octane rating, burning velocities and wider flammability limits. In order to achieve better environmental sustainability, it is the right time to use lower molecular weight alcohols (alcohols possessing lower molecular weight, such as methanol, ethanol) replacing other additives as octane boosters in automotive fuels in the present situation.

**Keywords:** methanol, ethanol, alcohol fuel, sustainable development, environment

## 1. Introduction

Around the world, energy is one of the major sources for the improvement and development of human beings life standards and its sustainable development. With rapid growth in the world population during the past few decades, the energy requirements that have also increased at an even large rate in industrialization and transportation sectors lead to an increase in crude oil prices, which is directly affected by global economic activity [1]. Now a days, worldwide 80% of fossil fuels consumed as primary energy, of which 58% of fossil fuels are consumed by the transportation sector only [2]. Since 1973, worldwide the primary energy demand has been increased at the rate of 2.0% on average per every year. As well as, still around one third of world's population are dependent on non-commercial fuels (United Nations 2007, 1). One of the significant environmental related issues is the widespread usage or burning of fossil fuels in many industries and transportation which are major contributors to air pollution, ozone depletion, global warming, climatic changes and human health-related problems. However, $CO_2$ is an important pollutant, which is produced by improper combustion of fuel and other major pollutant is $NO_x$, which is produced from both natural and man-made processes.

Moreover, $SO_2$ is one of the major air pollutants; it is released by the burning of fossil fuels like coal, petroleum and other factory combustibles.

In the 1960s, environmental awareness was brought to public attention, when smog became a major issue in developed cities such as Mexico, Los Angeles and Tokyo City. According to National Energy Strategy in February, 1992, The United States of America used more than 185 million busses, cars and trucks for transportation, which consume two-thirds of the oil used by the United States. Likewise, in India 50% of oil was consumed for transportation in 1991; it has been increased to up to 61% by the year 2010. Day to day the oil usage was rapidly increased, it causes the severe damage of environment. In the year of 1992 June, Earth Summit conducted by the United Nations on Environment and Development (UNCED). In this summit mainly the delegates all over the world aimed to decrease the global warming.

Thus, the search for possible alternatives to fossil fuels becomes essential. In this regard, an ideal replacement would be characterized by renewable, sustainable, efficient, and cost effective energy sources with fewer emissions [3, 4]. Among many energy alternatives, alternative fuels are the most environment friendly energy source. A worrying statistical analysis is that, the global oil and gas production is approaching its maximum production level and the world is now finding one new barrel of oil for every four it consumes. Therefore, alcohol fuels are the best alternative to fossil fuels; alcohol fuels have been represented as a future leading supplier of energy sources that have the ability to increase the security of supply, reduce the amount of vehicle emissions, and offered a stable income for farmers. Right now, alcohol fuel used as alternative fuel instead of fossil fuels in different motor vehicles (busses, cars, trucks, etc.) in most of the countries and **Figure 1** shows the bus running with alcohol fuel [5].

### 1.1 Why alcohol used as alternative fuel

At present, the future of the world ecosystem is obviously the most important issue. Recently, our young researchers improved the awareness on environmental protection and usage of alcohol fuels or non-fossil fuels for internal combustion engines. Generally, lower molecular weight alcohols, particularly ethanol or methanol, comprise one group of alternative fuels which is considered attractive for this


**Figure 1.**
*Alcohol fuel bus [5].*

purpose. The alcohol fuel has more advantages compared with fossil fuels, and they are given below:

- Both lower molecular weight alcohols can be made out of indigenous energy resources such as biomass, coal and natural gas, which are available with low cost.

- Combustion of alcohol in internal combustion engines (ICE) produces more combustion pressures compared to gasoline because of higher molal products to reactants ratio. Also, this improves power output and thermal efficiency compared to gasoline

- Greenhouse gases emissions can be reduced.

- Compared with gasoline, alcohols having higher average octane rating can increase power and fuel efficiency

- Decreases the releasing of toxic gases into the environment.

- The leaks and spillages of alcohol fuel from the oil tankers; alcohols are miscible in water and could be washed out with water for quick and easy removal. They are easily metabolized if absorbed by the ground.

- Alcohol fuels have a lower evaporative emission.

- The negligible amount of ash was released into the atmosphere by the combustion of alcohol fuel in ICE due to presence of less carbon content in alcohol fuel.

- The overall energy efficiency of fuel can be improved.

## 2. Current situations in key countries

In the year 1896 Henry Ford used pure ethanol as a fuel to run his first car. After that in 1908, he designed another famous car, i.e., Ford Model T, it is capable of moving with both combination of gasoline and ethanol [6]. Brazil was one of the largest country to implement the bio-fuel programs in the production of ethanol fuel from sugarcane in the world [7]. In the year 2006, Brazilians are utilized 18% of ethanol fuel for their country's road transport sector and by April 2008, more than 50% of fuel consumption for the gasoline market. Up to 2005, Brazil was topper in the world to produce alcohol fuel, when it was surpassed by the United States. Both the countries together (Brazil and the United States) are responsible in the year of 2011 for 87.1% world's alcohol fuel produced [8].

However, China was directly campaigning alcohol fuel in five central and north-eastern major cities in order to reduce consumption of fossil fuels. These cities are Zhaodong in Heilongjiang province, Luoyang, Nanyang in central China's Henan province, Zhengzhou, Harbin and northeast China. In the present situations, compared to any country in the world the United States produces and consumes more alcohol fuel. These days, majority of the cars on road in the United States can run with alcohol fuel and motor vehicle manufacturers already produce vehicles designed to run on much higher ethanol blends. The major countries were given in **Table 1** based on the annual production of alcohol fuel [9].

| Annual production alcohol fuel from different countries in the year of 2014 to 2016 [9] (Million US gallons per year) | | | | |
|---|---|---|---|---|
| **According to 2017 worldwide ranking** | **Country/Provence** | **2014 (Million US gallons)** | **2015 (Million US gallons)** | **2016 (Million US gallons)** |
| 1 | U.S | 14,300 | 14,806 | 15,330 |
| 2 | Brazil | 6,190 | 7,093 | 7,295 |
| 3 | European Union | 1,445 | 1,387 | 1,377 |
| 4 | China | 635 | 813 | 845 |
| 5 | Canada | 510 | 436 | 436 |
| 6 | Thailand | 310 | 334 | 322 |
| 7 | Argentina | 160 | 211 | 264 |
| 8 | India | 155 | 211 | 225 |
| ****** | Remaining the world | 865 | 391 | 490 |
| ****** | Throughout the world | 24,570 | 25,682 | 26,094 |

**Table 1.**
*Annual production alcohol fuel by various countries.*

## 3. Sources and products in alcohol fuel synthesis

### 3.1 Production of methanol

The simplest form of alcohol is methanol, it is also known as methyl alcohol, wood alcohol, or wood spirits, is frequently abbreviated as MeOH. It is a colorless, volatile, flammable liquid with a distinctive odor and polar liquid at room temperature. Methanol was miscible with gasoline or petrol, water and most of the organic compounds. It can be synthesized by different methods.

#### *3.1.1 Synthesized from biomass*

MeOH can be synthesized industrially from biomass like plants, fruits and animal wastes through anaerobic metabolism by many bacteria. Also, methanol was formed as a by-product during the ethanol fermentation process. Moreover, mainly in China and South Africa methanol can be produced from coal because of majority coal deposits was found in both countries and throughout the world. Most of the industrialists preferred for synthesis of MeOH from biomass due to process simplification, reduction of cost and energy consumption. The production scheme of methanol [10] was given in **Figure 2**.

#### *3.1.2 Methanol from catalytic synthesis*

The reactions relevant for the production of methanol have been known for a longtime. A mixture of $CO_2$, CO and $H_2$ can react with each other to form methanol and water as a byproduct. Equations (1) and (2) show the stoichiometry of these reactions and their reaction enthalpy [11].

$$CO + 2H_2 \leftrightarrows CH_3OH \quad \Delta H_{298.15\,K,5MPa} = -90.7\,kJmol^{-1} \tag{1}$$

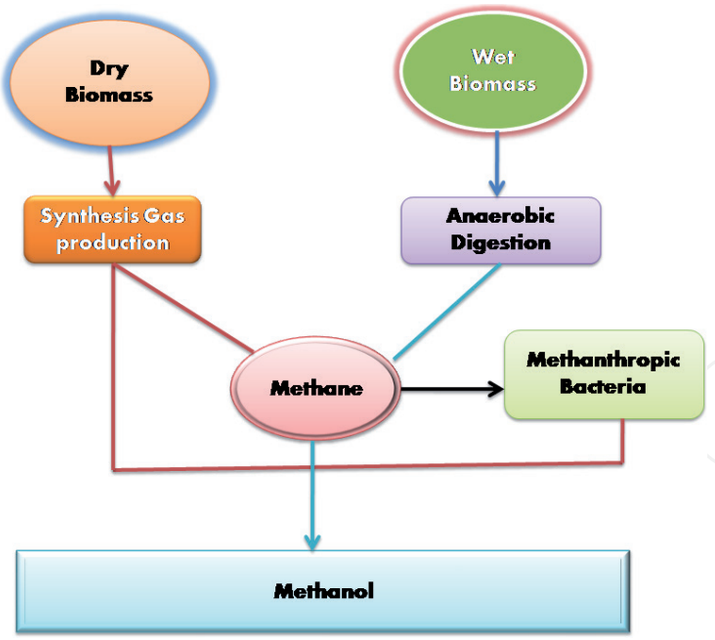


**Figure 2.**
*The schematic representation of methanol production [10].*

$$CO_2 + 3H_2 \leftrightarrows CH_3OH + H_2O \quad \Delta H_{298.15\,K,5MPa} = -90.7\ kJmol^{-1} \tag{2}$$

### 3.2 Production of ethanol

Ethanol also called as grain alcohol or ethyl alcohol**.** The purest form of ethanol is colorless liquid, flammable and boiling point 78.5°C. Compared to many other fuels, ethanol burns more cleanly and produces carbon dioxide and water. Hence, ethanol was considered as eco-friendly fuel for transportation process. Moreover, ethanol has high octane rating than gasoline, requiring changes to the spark timing in engines.

#### *3.2.1 Ethanol from cane and other sugar plants*

Fermentation is the fundamental method to synthesize the ethanol used in industries. Sugarcane molasses was the important raw material for ethanol production, which is byproduct of sugar industry [3]. Also, in fermentation process grain starches (wheat and corn), potato mashes, fruit juices, non-sugar lignocelluloses fractions of crops such as grasses and plants used as raw materials. Generally, molasses contain up to 50% simple sugar that can be easily fermented into ethanol and it is an ideal raw material for ethanol production with high availability and low cost. However, once the raw materials are delivered to the ethanol production plant, it is stored in the warehouse and conditioned to prevent from early fermentation and contamination [12]. Moreover, an enzyme such as microscopic yeasts plays a vital role in the fermentation process to convert carbohydrates to ethanol in the absence of oxygen. The possible equations in the process of fermentation by yeast in the absence of Oxygen are shown here under [13]. The synthesis route of ethanol [14] is represented in **Figure 3**.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6 \tag{3}$$

$$2C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \tag{4}$$

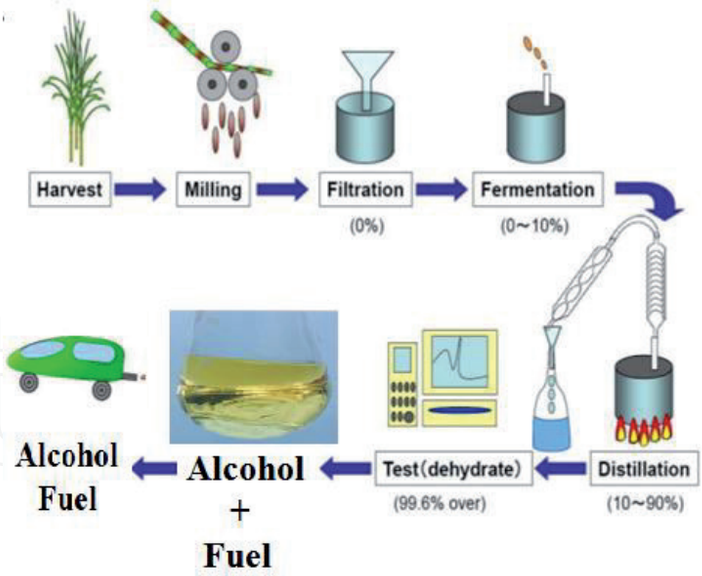


**Figure 3.**
*The schematic representation of ethanol production [14].*

### 3.3 Usage of alcohol fuels as gasohol

Traditionally, after the production of industrial methanol or ethanol, it has been used for alcohol fuel blending to manufacture gasohol. However, after fermentation and distillation process, it can be blended with petrol/gasoline in distinct proportion. The 10% ethanol was blended with 90% gasoline is considered as Low-level ethanol blends like E10, it can be used in conventional vehicles. Moreover, 85% ethanol was blended with 15% gasoline is considered as high-level blends, such as E85, it can be used in specially designed motorized vehicles like flexible fuel vehicles [15].

Alcohol fuel effectively used as an alternative liquid transportation fuels by varying their properties by the addition of certain additives, which must be physically and chemically compatible with the base alcohol fuel and have the same or higher specific energy content. Especially, both MeOH and ethanol are poorly miscible in gasoline containing traces of water, but completely miscible with water. The alcohols are blended with gasoline in presence of water, which may leads to a phase separation problem. In this situation to avoid the phase separation problem, few additives was added to alcohol fuel like higher alkanols such as 1-butanol, n-decanol, iso-propanol, different anionic fatty acid surfactants and various commercial non-ionic surfactants. Here, the avoidance of phase separation would have exact benefits for overall drivability, as well as in corrosion of water-sensitive components such as aluminum. In spark ignition engines, alcohol fuel can run at a much higher exhaust gas recirculation rates and with higher compression ratios [16].

The combustion MeOH:

$$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O + \text{Heat} \quad (5)$$

The combustion ethanol:

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + \text{Heat}. \quad (6)$$

The properties of gasoline, MeOH and ethanol such as air–fuel ratio, density, combustion energy, Percentage of oxygen, Reid Vapor Pressure (RVP), Research Octane Number (RON) and Motor Octane Number (MON) [17, 18] were listed in **Table 2**.

| Properties | Gasoline | Methanol | Ethanol |
|---|---|---|---|
| Air–fuel ratio | 14.6 | 6.5 | 9.0 |
| Density (kg/l) | 0.74 | 0.796 | 0.794 |
| Combustion energy (Btu/lb) | — | 10, 260 | 13,160 |
| %of $O_2$ (wt%) | — | 49.9 | 34.7 |
| RVP (kPa) | — | 250 | 130 |
| Research octane number (RON) | 91–99 | 136 | 129 |
| Motor octane number (MON) | 81–89 | 104 | 102 |

**Table 2.**
*Properties of liquid fuels [17, 18].*

**Table 2** illustrates that, alcohols having lower air–fuel ratio compared with gasoline, which helps to alcohol fuel to produce more power inside of an engine when these fuels are burned. However, the efficiency and quality of fuel are expressed in terms of difference between Research Octane Number (RON) Motor octane number (MON). Generally, RON is greater than MON in most of the fuel components. The RON and MON of alcohol fuel were measured in test engines at a relatively low speed (600 rpm) to simulate city driving speed with frequent acceleration and at a higher speed (900 rpm), which simulates highway driving respectively. The maximum octane sensitivity value defined as the difference between RON and MON of gasoline. While, methanol has the highest percentage of oxygen, its sensitivity is 30 when compared with ethanol, having a sensitivity of 15. Moreover, the percentage of oxygen and Reid vapor pressure (RVP) of ethanol was less than that of methanol. In this regard, ethanol has more advantages when comparing with sensitivity, % of $O_2$ content and RVP with those other fuels.

## 4. Economic, environmental issues and sustainable development

### 4.1 Economic aspects

Oil plays an important role in everyday life in terms of supplying goods or food, transportation sector and labor etc. Throughout the world, the oil deposits are located in limited number of countries, many of which struggled from political and economic instabilities. In addition, the trade between oil exporters and importers are increasingly tense and vulnerable. Therefore, alcohol fuel is one of the best alternatives replacing fossil fuels. The production of alternative fuel considerably cost less because of alcohol produced from the cost effective biomass, coal and natural gas. Consequently, the production of alcohol fuel spreads into a wider geographical area, contributing to an alcohol fuel supply that is less vulnerable to disruption. Alcohol fuel also offers an opportunity for a more dispersed and equitably distributed revenue stream [14]. Therefore, for those countries with more dependencies on fossil fuels, alcohol fuel can be a more vital substitute.

### 4.2 Environmental issues

Alcohol fuel shows a significant impact in diminishing the threat of global climate change. Mainly, the fossil fuels are used for the transportation sector, which may lead the exhaustion of air pollutants like nitrogen oxides ($NO_x$), hydrocarbons, particulate matter, carbon monoxide and carbon dioxide, etc. Those air pollutants are seriously

responsible for climate change, greenhouse gas (GHG) emissions, global warming, ozone layer depletion and human health-related issues [19]. Thus, it is necessary to search alternatives for reducing the demand for fossil fuels and the associated transportation sector-related warming emissions for future generations. Alcohol fuel is one of the best alternative fuels in the transportation sector to reduce the dangerous exhaustion resources into the environment. Scientists have been investigated the effects of GHG emissions on the large amount of natural land that is being changed to cropland globally to support alcohol fuels development. The first time of these studies, conducted at the University of Minnesota, examined the carbon debt released by direct land use changes when pristine lands are clear for new crops aimed for alcohol fuel production.

### 4.3 Sustainable development

It is essential to ensure that there is no conflicts between the actions of each country planning's and sustainable development in both the short and long run. There are three pillars for sustainable development, i.e., social, economic, and environmental, and each policy must consider all three [20]. The term "Development" indicates that, the notion of a clean or healthy environment and priority in terms of social development, along with the satisfaction of economic needs and that the present generation must not, through the damage of ecological processes essential to life, endangers the capability of future generations to be at least as well as the current generation. Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development emerged on the international level though since from three decades. Moreover, recently international debates have much more priority about sustainable development and energy [20].

Energy plays a crucial role in sustainable development and reduction of poverty. It has an impact on all development's dimensions—economic, social and environmental—along with livelihoods, productivity of agricultural and access to water, education and health. These days, the lasting increase of the world's population brings up serious concerns. The sufficient and reasonable energy provision plays an important role in improvement of economy, changing from agricultural economies to advanced industrial and service based societies. Also, energy is an essential for social and economic good developments and indispensable to most forms of industrial and commercial wealth generation.

Though, present energy supply and consumption depends on finite resources of fossil fuels, and are considered to be environmentally unsustainable. On the other hand, there is no any kind of energy production or conversion technology which is completely without risk or waste. Generally, the energy chain was started with resource extraction and ended with the rule of energy services, pollution, health related issues and harmful environmental impacts. However, at the point of usage of resources, a certain technology might not produce dangerous materials, but emissions and wastes are always associated with its manufacture and other stages of the life cycle. Therefore, the situation highlights the need for sustainable alcohol fuels, using feedstocks that reduce competition for major croplands.

These are forest, farm and municipal waste streams; energy crops grown on marginal lands, and algae. Moreover, the second generation alcohol fuels feedstock is expected significantly reduce GHG compared with first generation alcohol fuels like corn ethanol. The relation between alcohol fuel and sustainable development is shown in **Figure 4**. In all types of energies, burning of fossil fuels is chiefly responsible for air pollution, climate changes, local acidification, human health related problems [21]. Still, while accepting that the basic responsibility for sustainable energy policy rests with governments, a participating approach including all


**Figure 4.**
*The cyclic representation of between alcohol fuel and sustainable development.*

stakeholders is desirable to facilitate progress [20]. The fundamental principles guiding the approach to energy for sustainable development were summarized by the UN Economic and Social Council (UN ESC) society. The group of international communities can simplify the movement from the current energy system to a more sustainable development by supporting exchange of technology, capability building, and investments in developing countries [22]. The UN ESC summarized seven challenges that are given bellow:

1. Progress in the utilization of renewable energy sources.

2. Enhancement of the availability of energy.

3. Increment of energy efficiency.

4. Establish the more advance and sophisticated fossil-fuel technologies.

5. Expansion of nuclear energy technologies.

6. Development of the rural energy situation.

7. Decreasing the emissions in transportation and development of energy efficiency.

## 5. Conclusion

The production of alcohol fuel has gradually increased and become an important industry in various countries such as the United States, Brazil, and China. Methanol was produced from biomass or coal and natural gas while ethanol is mainly produced from food crops or sugarcane molasses by fermentation process. So that, rural area's sugarcane industry is one of the major industrial corridors, meanwhile the agriculture economy was increased and generates employment for more people by the collaborating with sugar industry either directly or indirectly.

After production of methanol or ethanol, it was blended with petrol/gasoline in different proportion like E10 considered as low-level ethanol blends and E85

considered as high-level ethanol blends. Day to day, the usage of alcohol fuels has been rapidly increased due to their positive impacts such as reducing GHG emissions, reduction in the emission of toxic gases, and helping to mitigate climate change. Likewise, it has an impact on sustainable development in economic, social and environmental aspects. Therefore, alcohol fuel can be used as best transportation fuel instead of gasoline, but it is still years far away from extensive adoption. More researches and improvements are necessary if we are to use alcohol as a fuel of the future.

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## Abbreviations

| | |
|---|---|
| UNCED | United Nations on Environment and Development |
| IC | internal combustion engine |
| MeOH | methanol |
| RON | research octane number |
| MON | motor octane number |
| RVP | Reid vapor pressure |
| GHG | greenhouse gas |
| UN ESC | UN Economic and Social Council |

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