O 99. ENVIRONMENTALLY FRIENDLY ALTERNATIVE FUEL TO REDUCE TURKEY'S PETROLEUM IMPORTS: E85 (FLEX FUEL)

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ABSTRACT: Due to the rapid depletion of petroleum-derived fuels, the reduction of consumption of these fuels and increasing the use of fuels produced from renewable sources are one of the important objectives in all countries. One of the alternative fuels that are less harmful to the environment, renewable and sustainable is bioethanol. Bioethanol is a clean fuel that can be obtained from agricultural products, agricultural production residues or other products containing cellulose. When bioethanol is mixed with gasoline at low proportions as %5-10, it can be used without any changes in spark-ignition engines. The E85 fuel consists of a mixture of 85% bioethanol and 15% gasoline. The use of this fuel in vehicles requires a small and low-cost change in the engine. Once the vehicle has been modified, the vehicle is defined as a flexible fuel vehicle and the desired fuel can be used (gasoline, E10, E15 or E85). The price of E85 fuel is approximately 25% cheaper than gasoline in international markets, while E85 fuel consumption is approximately 30% more. However, because the octane number of E85 fuel is too high, it can produce more power than gasoline. In addition, the exhaust emissions of this fuel are very low. Large agricultural areas and wide agricultural product range in Turkey is a very big advantage to produce E85. In this way, fuel need can be supply from domestic sources in Turkey.

Keywords: Flex fuel, Alternative fuel, Bioethanol, Agricultural waste

1. INTRODUCTION

With the rapid depletion of fossil fuels, many countries are looking for alternative fuel sources. Recently, a lot of research has been done about electric cars, hybrid vehicles, hydrogen cell vehicles, and vehicles using alternative fuel such as natural gas, biodiesel, and ethanol.

Flexible fuel vehicles (FFV) have an internal combustion engine designed to operate with more than one fuel. These vehicles generally use an alternative fueled gasoline mixed with ethanol or methanol fuel. In these vehicles, both fuels are stored in the same common tank. Modern flexible fuel engines automatically adjust fuel injection and spark timing according to the actual mixing ratio detected by a fuel composition sensor. FFVs have dual fuel systems that simultaneously spray both fuels into the combustion chamber. The most common fuel used by FFVs today is gasoline and ethanol. FFVs may use pure gasoline (E0), pure ethanol (E100) or a mixture fuel of both (E10, E20, E85, etc.).

In the United States of America (USA), flexible fuel vehicles are also known as "E85 vehicles". In Brazil, FFVs are popularly known as "total flexible" or simply "flexible" cars. In Europe, FFVs are also known as "flexible fuel" vehicles. Automobile manufacturers in the Brazilian and European markets, in particular, use the word "Flex" in FFV models, such as Ford Flexifuel, Volvo Flexifuel, Volkswagen Total Flex, Chevrolet FlexPower or Renault Hi-Flex. In the USA, since 2008, FFV models have the "E85/Gasoline" label on the fuel filler flap to distinguish it from gasoline models.

In Europe, flexifuel vehicles are sold in 18 European countries, including Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Spain, Sweden, Switzerland and the United Kingdom. Ford, Volvo and Saab are the oldest car manufacturers to offer the oldest flexible vehicle in the region. Other brands have started to produce in the last few years. The most E85 fuel stations in Europe are located in Sweden. Germany is ranked second in the maintenance of the number of E85 fuel stations. In 2017, Brazil produced 300 thousand vehicles using only gasoline, 30 thousand vehicles using diesel fuel and 2 million ethanol flexible fuel vehicles (Anonymous, 2019a). As of 2017, there are more than 21 million FFVs in the United States (Anonymous, 2019b).

2. PROPERTIES OF BIOETHANOL FUEL AND ITS USE IN ENGINE

Bioethanol (C_2H_5OH) is a clean, colourless liquid with low toxicity. Bioethanol is chemically and physically indistinguishable from synthetic ethanol, all its properties are similar. Although synthetic ethanol and bioethanol have the same chemical structure, they are used under different names in order to understand the sources of raw materials easily. Synthetic ethanol is produced from ethylene, a petroleum product. Bioethanol, on the other hand, is a type of alcohol obtained by fermentation of substances such as sugar, cellulose or starch which can be converted to sugar, which contain ethyl alcohol. Bioethanol is added as an octane enhancer instead of lead, owing to its high octane characteristic. When bioethanol is mixed with gasoline, bioethanol is preferred as a performance enhancer because the fuel mixture burns more efficiently. The physical and chemical properties of gasoline and ethanol fuels are given in Table 1.

Table 5. The physical and chemical properties of gasoline and ethanol fuels (Balki, 2013)

Specifications	Gasoline	Ethanol
Chemical formula	$C_{6,97}H_{14,02}$	C_2H_5OH
Molecular mass (g/mol)	98.03	46.07
Oxygen weight (%)	-	34.73
Carbon/Hydrogen (C/H) ratio (%)	0.444	0.333
Density (g/cm^3, 20 °C)	0.740	0.790
Lower thermal value (kJ/kg)	42600	26900
Stoichiometric air-fuel ratio	14.6	9
Thermal value of stoichiometric mixture (kJ/kg-mixture)	3034.25	2998.89
Research octane number (RON)	95	108.6
Motor octane number (MON)	85	89.7
Octane number	90	99.15
Fuel sensitivity	10	18.9
Ignition temperature (°C)	257	363
Flash point (°C)	25	12
Vapor pressure (kPa, 20 °C)	45-90	5.9
Evaporation latent heat (kJ/kg)	349	838
Boiling point (°C, 101.3 kPa)	27-225	78.3
Ignition limits (% volume)	1.4-7.6	3.5-15
Laminar combustion rate (cm/s, HFK: 1.0, NSA)	28	40
Adiabatic flame temperature (°)	2002	1920

Bioethanol has a lower stoichiometric fuel/air ratio and a lower thermal value compared to gasoline. Therefore, when bioethanol or gasoline-bioethanol mixture is used instead of gasoline in spark ignition engines, more bioethanol or gasoline-bioethanol mixtures are required to achieve the performance achieved with gasoline. Bioethanol, which has a high octane number, has a very low cetane number and therefore can cause problems in diesel engines due to its self-ignition resistance. For this reason, it is recommended to add cetane enhancing additives if used in diesel engines. The use of bioethanol is more suitable for gasoline engines since self-ignition resistance allows the compression ratio to be increased (Koçtürk, 2011). Due to the presence of oxygen in the structure of bioethanol and low post-combustion temperatures, there are low rates of carbon monoxide and nitrogen oxides among the combustion products. The high evaporation temperature of bioethanol has a cooling effect on the absorbed fresh fuel. In this case, the volumetric efficiency of the engine increases. Due to the high volumetric efficiency, engines operating with bioethanol or gasoline-bioethanol mixture are generally higher in torque and power than gasoline-powered engines. The decrease in the temperature of the absorbed fresh

fuel and the operation of the engine in poorer mixtures cause significant reductions in CO and NO_x emissions (Koçtürk, 2011). The price of E85 fuel is approximately 25% cheaper than gasoline in international markets, while E85 fuel consumption is approximately 30% more.
The use of bioethanol in engines has many advantages. It is possible to list these advantages as follows (Aydoğan, 2011):

- It is renewable and a clean fuel source.
- It opens up new economic opportunities for many developing countries.
- Reduces dependence on petroleum-based fuels.
- Reduces dependence on foreign energy.
- Can be easily used in all engines.
- Easy to manufacture and store.
- Reduces emissions causing environmental pollution.
- Improves the agricultural activities of countries.
- Provides new employment areas for the agricultural sector.

In addition to these advantages, some disadvantages of using bioethanol in engines are mentioned. One of these is that it cannot be used directly or high-proportion in internal combustion engines. If a high proportion of bioethanol and gasoline are to be mixed, the engine must be modified. These modifications also result in additional costs. These disadvantages do not affect the use of bioethanol at a high rate. Modifications to the engine can be easily made by the vehicle users and some kits have been developed for this purpose. These kits contain control unit, ethanol sensor, wiring harness, connectors, fuel hose, and clamps. By replacing these parts, the gasoline engine becomes compatible with the use of fuels such as E85, E50, and E10. Thus, the vehicle becomes a flexible fuel vehicle. In addition, it has been the most preferred method in the world by blending with petroleum based fuels at low rates without the need for modification in engines. Another disadvantage is that the product price of bioethanol is higher than that of petroleum-based fuel. However, it is stated that in recent years, bioethanol is produced from cheap raw materials and its prices have decreased. Thus, it can be sold to prices very close to petroleum-based fuels. The use of agricultural products consumed as foodstuffs as raw materials in bioethanol production causes both food prices to rise and fuel prices to be higher than petroleum-based fuels. In recent years, some studies on bioethanol production from cellulose-containing wastes have been carried out to overcome this problem. Particularly in agricultural areas, residues from crops appear to be the largest bioethanol potential during harvest.
The raw materials used in bioethanol production are divided into three classes:

- Raw materials containing sucrose (sugar beet, sugar cane, sorghum, etc.),
- Starchy products (wheat, corn, barley etc.),
- Lignocellulosic biomass (wood, straw, grass, etc.).

It is possible to convert agricultural wastes and cellulose-containing wastes (trees, straw, etc.) economically into bioethanol. Biomass is converted to bioethanol by pre-treatment, hydrolysis, fermentation and distillation process steps. Bioethanol obtained from sugar and starch is a technology that has been experienced for many years in terms of production technology. Therefore, bioethanol produced from the raw materials of sugar and starch is called first generation bioethanol. The production processes of bioethanol produced from lignocellulosic raw materials, defined as the second generation, are still not fully optimized. Today, the production technology of the second generation bioethanol is still in development.
Our country is a rich country in terms of agricultural areas and cultivable agricultural products. Agriculture of energy-producing oilseed plants, non-food parts of agricultural products or harvest residues can be used for bioethanol production. If bioethanol is used in blended gasoline or diesel engines in low ratios, it is very important both in terms of reducing environmental pollution and remarkably reducing oil imports of our country. Although the use of bioethanol is perceived as new to begin, its history goes back to the invention of the engine. At the end of the 1800s, internal combustion engines developed by Nicholas Otto and Henry Ford were working with ethanol (Melikoğlu and Albostan, 2011). In recent years, due to its high octane number, ethanol has been used as an octane

enhancer in gasoline and has replaced lead. In the event that 10% by volume of ethanol is blended with gasoline, the resulting blended fuel (E10) can easily be used in spark ignition engines. If more than 10% of bioethanol is added to gasoline, the fuel line pipes in the engine must be replaced with ethanol-compatible pipes. If more than 20% of bioethanol is added to the gasoline, the engine may also require changes to the injection elements. The fuel injection time and frequency should be readjusted according to the oxygen content of the fuel, especially when using E85.

3. BIOETHANOL PRODUCTION IN THE WORLD AND TURKEY

Petroleum-derived fuels are depleting rapidly. Reducing the consumption of these fuels and increasing the fuels produced from renewable sources and less harmful to the environment are the main targets of almost all country administrations. One of the alternatives developed to achieve these targets is bioethanol. Bioethanol is a renewable, sustainable fuel that can be obtained from agricultural products and agricultural production residues and is a clean fuel that can reduce polluting emissions.
The United States of America (USA) has the largest share in biofuel production worldwide. The majority of biofuels produced worldwide in 2017 are produced by the USA (47%) and Brazil (23%), with the remainder being produced by Germany, France, Spain (EU-13%) and China (3%) (Anonymous, 2019c). According to the 2018 data, the USA ranked first in ethanol production with 60.9 billion litres, while Brazil ranked second with 30 billion litres (Figure 1). Thanks to the agreements made between the USA and Brazil, 66% of the bioethanol produced in Brazil is sold to the USA (Koçtürk, 2011). The European Union (EU) and China are among the largest producers with ethanol production of more than 4 billion litres. In Turkey, significant improvements were observed in the production of biofuels from domestic vegetable sources over the last decade, it has entered the rapidly rising trend in the last few years.

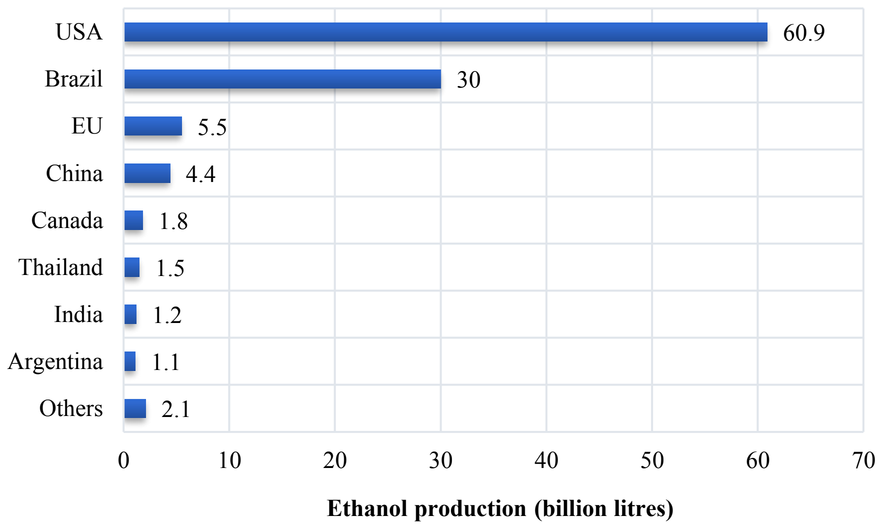

Figure 5. Ethanol production in the world (Anonymous, 2019d)

In the EU, the use of biofuels is being gradually increased, and in 2020, at least 10% of the fuel used in transportation is intended to be supplied from biofuels. In 2030, this ratio is planned to be increased to 25%. According to 2017 data, there are a total of 6.84 billion litres of bioethanol plants in the EU, including 2 billion litres in France, 1.18 billion litres in Germany and 0.98 billion litres in the United Kingdom (UK). In these facilities, 5.84 billion litres of bioethanol was produced. As can be seen in Figure 2, 39% of the raw materials used in bioethanol production are corn and 30% are wheat. 4% of the raw materials consist of raw materials containing lignocellulose (Anonymous, 2019e). Among the EU countries, France ranks first with 29% in terms of production capacity, while Germany ranks second with 17%.
In terms of bioethanol consumption in EU countries, Sweden is the country that uses the most bioethanol. In Sweden, 85% of bioethanol can be used by blending with gasoline (E85). In fact, the Saab automobile manufacturer produces special vehicles that run on E85 fuel. Afterward, Ford's vehicles

were also made compatible with E85. After Sweden, the E85 was beginning to sold in the USA, Canada, Brazil, and the UK and used in compatible vehicles. The use of bioethanol in Turkey has been mandatory since 1st January 2013. According to the first communiqué issued by the Energy Market Regulatory Authority in Turkey, 2% by volume of bioethanol produced from domestic agricultural products is required to be blended with gasoline. On 1st January 2014, the required mixing ratio of bioethanol was updated to 3%.

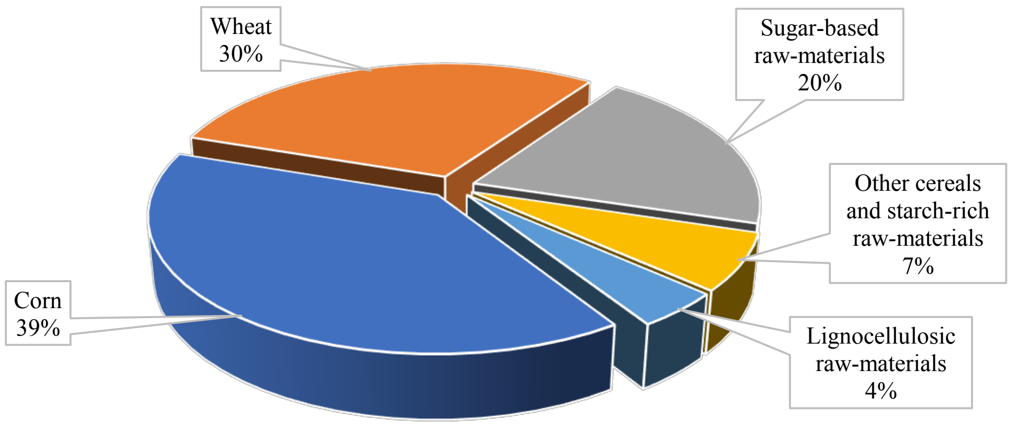

Figure 2. The raw materials used in bioethanol production

According to the data of the Ministry of Agriculture and Forestry, Department of Tobacco and Alcohol, the amount of bioethanol produced in our country and the sales of bioethanol in our country are very close to each other. Although very low exports have been achieved in some periods, the needs are met through internal resources. According to these data, the amount of bioethanol production increased by 48% in 2014, when the compulsory bioethanol mixing ratio increased from 2% to 3%. As shown in Figure 3, the volume of bioethanol sales rose to 77.8 million litres in 2014, while it was 52.6 million litres in 2013. According to the data of 2017, 93.5 million litres of bioethanol were produced and sold in the three facilities which produce bioethanol in our country. According to the 2018 data, production and sales volumes decreased slightly. Approximately 92.6 million litres of bioethanol were produced in 2018. According to the records of the Ministry of Agriculture and Forestry, the number of producer enterprises increased to four in the last quarter of 2018 (Anonymous, 2019f). With the increase in the number of facilities, bioethanol production is expected to increase in 2019.

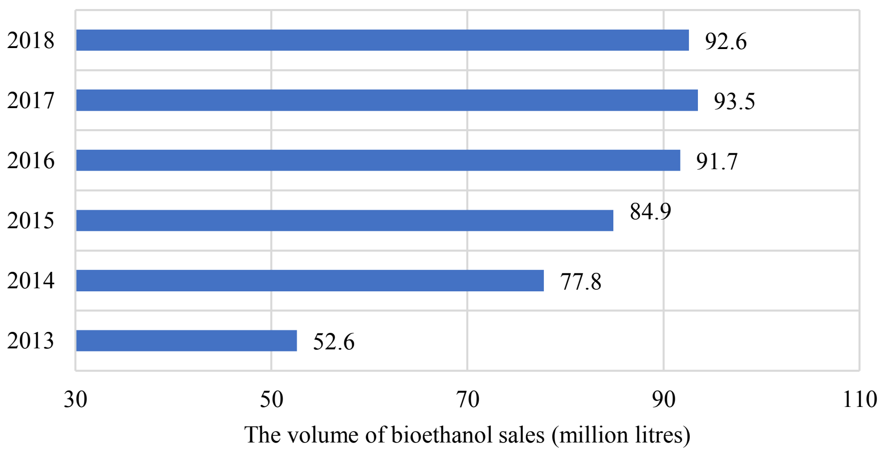

Figure 3. The volume of bioethanol sales in Turkey (Anonymous, 2019f)

When agricultural products are used as raw materials, the lowest bioethanol amounts to be produced are given in Table 2 (Koçtürk, 2011). Bioethanol fuels produced from different raw materials generally exhibit similar physical and chemical properties. Table 1 shows the physical and chemical properties of ethanol. The properties of bioethanol are very close and similar to the values given in this table.

Table 2. Bioethanol production potential of various raw materials (Koçtürk, 2011)

Raw Materials	Bioethanol yield (litres/ton)	Raw Materials	Bioethanol yield (litres/ton)
Sugar cane	70	Rice	430
Sugar beet	110	Barley	250
Sweet potato	125	Wheat	340
Potato	110	Sweet sorghum	60
Cassava	180	Pulp and other cellulosic biomass	280
Corn	360		

Agricultural residues such as sawdust and crop residues (rice straw, wheat straw, corn stalk, sugar cane waste, etc.) are abundant, renewable and cost-effective raw materials for ethanol production. Bioethanol samples produced from agricultural residues are available in the literature. For example; bioethanol was produced experimentally from rice straw (Das et al. 2013), corn residue (Saha et al. 2013), sorghum pulp (Cao et al. 2012) and empty fruit bunches of palm trees (Jung et al. 2013). 550 grams of fermentable sugar was obtained from one kilogram of corn residue, from which bioethanol was produced. 270 grams (340 millilitres) of ethanol was obtained from one kilogram of corn residue (Saha et al. 2013). In another research project conducted in our country, the total potential of agricultural wastes and residues in our country was investigated. Table 4 shows the research results and the energy potential of these raw materials (Uzun, 2013). According to the information given in Table 4, if 221.2 litres of bioethanol can be produced from one ton of wheat stalk, 5.8 billion litres of bioethanol can be produced from total waste wheat stalks in our country. Considering the other agricultural wastes and residues, it is seen that there is a potential to obtain up to 10 billion litres of alternative fuel in our country.

Table 3. Theoretical bioethanol yield of various raw materials (Acar, 2019)

Raw materials	Theoretical bioethanol yield (liter/ton-raw material)
Tea Powder	91.7
Hazelnut husk	115.5
Rice straw	192.4
Rice paddy waste	156.8
Corn stalk	212.9
Cotton Stalk	139,4
Sugar beet leaves	81.9
Wheat stalk	221.2
Sunflower stalk	180.1
Olive residues	127.4

Table 4. The total potential of agricultural waste and residues in Turkey (Uzun, 2013)

Agricultural waste	**Annual potential (million tons)**
Wheat stalks	26.4
Barley stems	13.5
Corn stalks	4.2
Cotton stalks and bolls	2.9
Sunflower stalks	2.7
Sugar beet scraps (leaves)	2.3
Hazelnut shells	0.8
Oat stems	0.5
Rye stalks	0.4
Rice stalks	0.4
Fruit shells	0.3

4. CONCLUSION AND DISCUSSION

Especially in the USA, Brazil, and Sweden, the use of flexible fuel vehicles is very high. Almost 90% of the vehicles produced in Brazil are produced as flexible fuel vehicles. In this country, bioethanol obtained from agricultural products is used in flexible fuel vehicles. In addition, Brazil exports a large portion of its bioethanol to the USA.

In 2018, nearly 3 billion litres of gasoline were consumed in Turkey. In our country, there is a potential to produce more than 10 billion litres of bioethanol by using agricultural products and agricultural wastes. Our country's realization of this potential as soon as possible will make a major contribution in reducing its dependence on foreign sources.

When the size of the agricultural areas in our country and the agricultural production potential are taken into consideration, the agriculture of the raw materials that can be produced bioethanol should be increased. Existing agricultural residues can produce more bioethanol than gasoline consumed in our country. The government can require the production of flexible fuel vehicles to diminish petroleum imports in Turkey. At the same time, the government may make legal arrangements for the production of flexible fuels such as E85 from domestic sources, work can be initiated to open E85 fuel stations, and may prepared new incentives for the construction of bioethanol production facilities.

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