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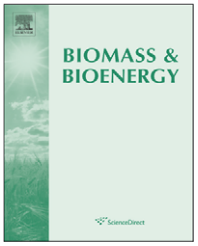

Review

Research on ethanol production and use from sugar beet in Turkey

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ABSTRACT

Emissions of greenhouse gases such as CO_2, CO, CH_4 and NO_X from fossil fuel use are implicated in climate change. The use of bioethanol is one means to reduce fossil fuel use and emissions of greenhouse gases. This study investigated research to produce ethanol from sugar beet and use as fuel in Turkey. The calculated demand for bioethanol amounted to some 220,000 m^3 where a 5% ethanol mix in petrol was used. Turkey has the potential to produce 30 million ton of sugar beet, which is sufficient to meet the bioethanol demand.

Contents

1. Introduction . . . 1
2. Material and method . . . 2
   2.1. Material . . . 2
   2.2. Method . . . 3
3. Results . . . 4
4. Discussion . . . 6
References . . . 7

1. Introduction

About 70% of Turkey's energy requirements are imported, amounting to 2.36 Ej (Exajoule) in 2000 and puts a strain on the country's economy. Raw petroleum and petroleum products imports constituted 59% of the total, natural gas 24%, coal and coal products 16.4% and electricity 0.6%. Total energy supply was 3.18 Ej in 2001 (Table 1). The main sources are petroleum (40.7%), natural gas (19.6%) and lignite (15.7%) [1].

Emissions of greenhouse gases such as CO_2, CO, CH_4 and NO_X from fossil fuel use are implicated in climate change. The use of biomass and bioethanol is a means to reduce fossil fuel use and emissions of greenhouse gases. Biomass is an important renewable energy in Turkey with a theoretical potential of 5.66–6.29 Ej y^{-1}. When technical

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Table 1 – General energy supply in Turkey [1]

	1990	Rate (%)	2000	Rate (%)	2001	Rate (%)
Petroleum	23.901	45.11	32.297	39.75	30.936	40.73
Lignite	9.765	18.43	13.219	16.27	11.929	15.71
Hard coal	6.15	11.61	9.983	12.29	7.06	9.30
Natural gas	3.11	5.87	13.729	16.90	14.868	19.58
Hydro	1.991	3.76	2.656	3.27	2.065	2.72
No commerce	7.208	13.60	6.457	7.95	6.211	8.18
Other	0.862	1.63	2.91	3.58	2.883	3.80
Total	52.987	100.00	81.251	100.00	75.952	100.00

and economic aspects are considered then the potential is some 1.05 Ej y^{-1} [2].

Biofuels are an important aspect of biomass energy. Using biofuel in Diesel and Otto engines is not new. Rudolph Diesel used biodiesel produced from peanut oil in his diesel engine at the World Exhibition in 1898 in Paris. Henry Ford designed his car called 1908T as to using ethanol and set up an ethanol facility. Using ethanol in automobiles continued till 1940 [3] but ceased thereafter because of the ready availability of cheap petrol.

Bioethanol is a high octane number biofuel which is produced from fermentation of corn, potatoes, grain (wheat, barley and rye), sugar beet, sugar cane and vegetable residues.

Bioethanol is usually used in the transport sector by mixing with gasoline at the specific rate or octane increaser (ethyl tertiary butyl ether (ETBE)). Methyl tertiary butyl ether (MTBE), which is used for increase in octane number, was prohibited in the USA and Canada because of cancerous emissions increasing the demand for bioethanol. ETBE (from 45% bioethanol and 55% isobutylene) is starting to be used in many countries instead of MTBE [4,5]. The ethanol standard for the Otto engine is given in ASTM D 4806-0 and DIN EN 228 [6,7]. Some specifications of gasoline and ethanol are given in Table 2 [8].

Ethanol is used mixed with gasoline at the rates of 5%, 10% and 85%. A total of 85% ethanol can only be used in specific engines, while mixing 5% and 10% can be used without any engine modifications. Flexible fuel vehicles (FFVs) can handle the lower proportions and are used widely in USA.

A total of 31 Mm^3 of ethanol was produced globally in 2001 with production from Brazil dominating. Of the total production 55% was from sugar plants, 37% from grain, 8% was synthetic and 2% was from the other raw materials. Some 66% was used in the fuel sector, 21% in the chemical sector and 13% in the food sector [7–9].

In the EU, following the obligations of the Kyoto Protocol, biofuels will contribute 20% in the transportation sector (Directive 2003/30/EC). To realize this target there will be 2% biofuel usage in 2005 increasing to 5.75% in 2010. The necessity of tax reduction to use of biofuels as blends and pure biofuel and supports the R&D studying as the same subject was recognized [10]. Spain, France and Germany are already important ethanol producer countries.

Almost all the ethanol produced in the USA is produced from corn. A total of 53 million ton of corn was used in ethanol production in 2007, compared with 13.7 million ton in 1999. World ethanol production has reached 51.4 million m^3 in 2006 increasing 10% annually from 28 million m^3 in 2000 [11]. This figure is anticipated to increase following the banning MTBE. Petrol and 10% ethanol mixture (E10) are widely used in USA. In addition, 85% bioethanol and 15% petrol mixture (E85) are used in FFVs. Carbon dioxide emissions decreased by 5.7 million ton as a consequence of the increased use of bioethanol; equivalent to taking 853 thousand cars off the road. Use of biofuels in other countries is summarized in Table 3.

The current study investigates the possibility of producing ethanol from sugar beet, which is widely cultivated in Turkey, and its potential contribution to biofuel uses at mixtures of 2–5%.

Table 2 – Some specifications of gasoline and ethanol

Specifications	Gasoline	Ethanol
Chemical formula	C_nH_{2n+2} (n: 4–12)	C_2H_5OH
Molecular weight	100–105	46.07
Composition, weight (%)		
Carbon	85–88	52.2
Hydrogen	12–15	13.1
Oxygen	0	34.7
Specific gravity (33 °C)	0.72–0.78	0.796
Density (kg l^{-1}) (33 °C)	0.719–0.779	0.792
Boiling temperature (°C)	44.4–242.5	95.5
Octane number ((R+M) 2^{-1})	86–94	100
Freezing point (°C)	−22.2	−96.1
Autoignition temperature (°C)	275	440
Latent heat of vaporization (kJ kg^{-1}–33 °C)	350	920
Heating value (kJ kg^{-1})	45,600–43,000	29,800–26,800
Stoichiometric air $fuel^{-1}$, weight	14.7	9.0

2. Material and method

2.1. Material

Ethanol is produced from agricultural raw materials including sugar and starch by fermentation. The prices of the feedstock used in ethanol production, production capacity and yield in

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Table 3 – Ethanol used in some countries

	France	Spain	Sweden	USA	Brazil
Production amount in 2001 (m^3)	0.115×10^6	0.100×10^6	0.050×10^6	8×10^6	12×10^6
Application type	Mixed up in gasoline as 15% ETBE form	Mixed up in gasoline as 15% ETBE form	Mixed up in gasoline as 5%	Ethanol mixture as E 100 and E 85	E 22 and E 100 mixture
Using raw material	Sugar beet at 75%, wheat at 25%	Barley and wheat at 100%	Wheat at 100%	Almost all from corn	Sugar cane at 100%
Ethanol price	400–450 € m^{-3}	400-450 € m^{-3}	550–650 € m^{-3}	260–320 US$ m^{-3}	200–250 € m^{-3}
Incentive pay	Tax reduction to three organizations which had had permission	Tax exemption for five years	Tax exemption for 50,000 m^3 per year	Other incentives at the level of federal and states	Many supports of government (price, quantity and subvention)
Future expectation	Planning 125,000 m^3 additional capacity increase	Planning doubled capacity increase	No planning	Waiting for became widespread putting additional incentives into practice	Waiting for improving in spite of appeared difficulties

Table 4 – Ethanol yield of some agricultural crops

	Sugar beet	Wheat	Triticale	Rye	Corn	Potatoes
Total production (million ton)	27.8	21.4	4.1	4.1	3.3	13.1
Average yield (ton ha^{-1})	61.7	7.2	5.6	4.9	9.2	43
Average price (€ ton^{-1})	47 A, 29 B, 17 C[a]	118	100	95	123	63
Ethanol yield (m^3 ha^{-1})	6.62	2.76	2.23	2.03	3.52	3.55
Ethanol yield (l kg^{-1})	0.11	0.38	0.40	0.41	0.38	0.08
Energy consumption (MJ ha^{-1})	19,806	25,142	15,554	15,554	21,184	34,403
Energy yield (MJ ha^{-1})	155,570	64,860	52,405	47,705	82,720	83,425

[a] A, B and C quota price of sugar beet.

2000 for Germany are given in Table 4 [5]. Ethanol yield and total energy yield is highest with sugar beet.

Sugar beet is grown under contract, one of the first examples of contracted growing in Turkey. Sugar beet integrates agriculture with industry and has an important indirect added value role on many sectors, by providing employment.

Sugar beet is generally grown in the high-altitude region and irrigated grain sowing area on 4 years rotation. There are 450,000 growers in 65 cities in Turkey except for Aegean, Mediterranean coast zone, Eastern Black Sea and Southern East Anatolia Region. Per capita average sowing area is 0.7 ha, and 81% of growers have less than 1 ha according to 2003 data [12].

There are 30 sugar factories; 26 of which belong to the government and 4 are privately owned. Daily beet-processing capacity 131,000 ton; the amount produced between 1997 and 2003 is given in Table 5. Turkey has the potential to produce 30 million ton of sugar beet annually. However, because of the quota and cornstarch-based sugar production, only half of the potential is actually produced.

Table 5 – Sugar beet sowing and production amount between 1997 and 2003 in Turkey [11]

Year	Sowing area (1000 ha)	Production amount (1000 ton)	Yield (ton ha^{-1})
1997	473	18,770	42.3
1998	504	22,503	48.1
1999	424	17,207	45.4
2000	410	19,189	50.9
2001	359	12,839	35.5
2002	372	16,940	49.5
2003	315	13,726	44.1

2.2. *Method*

The basic fermentation equations are given below [5]:

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} \Rightarrow \underset{\text{(Carbon dioxide)}}{2CO_2} + \underset{\text{(Ethanol)}}{2C_2H_5OH}$$

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First, saccharose, a disaccharide, is transformed into monosaccharides (fructose+glucose) in ethanol production from molasses:

$$\underset{\text{(Disaccharide-saccharose)}}{C_{12}H_{22}O_{11}} + \underset{\text{(Water)}}{H_2O} \Rightarrow \underset{\text{(Monosaccharide-fructose+glucose)}}{2C_6H_{12}O_6}$$

A schematic of ethanol production from molasses is given in Fig. 1. One liter of ethanol is produced from 3 to 3.5 kg molasses by this production method.

Ethanol can be produced either from molasses, which is a by-product after the sugar is extracted, or directly obtained from sherbet. A schematic of ethanol production from sherbet (watery and thick) is given in Fig. 2 [13]. In this case 0.079 kg (0.1 l) of ethanol is produced from 1 kg clean beet.

Investment costs for an ethanol-producing facility change according to capacity. Ethanol-producing facilities are divided into four groups according to [5]: small (60 $m^3 d^{-1}$), medium (180 $m^3 d^{-1}$), large (360 $m^3 d^{-1}$) and very large (720 $m^3 d^{-1}$). Fig. 3 shows that the unit costs of ethanol production depend on raw material, capacity and investment cost. The highest investment cost is in small-capacity facilities using wheat and barley and the lowest is in very large-capacity facilities using sugar beet molasses and sherbet. Investment cost calculations for Turkey were based on figures given in [5].

Bioethanol will be used in mixtures of 2–5%. Petrol consumption in Turkey for the last 5 years is given in Table 6 [14]; approximately 4.1 million ton were used in 2002. The amount of sugar beet to produce the ethanol required to match that demand was calculated according to Fig. 2.

3. Results

Ethanol requirement and needed investment cost: The calculation on the basis of petrol consumption was 4.4 Mm^3 between 2000 and 2002 with the amount of ethanol required being 88,000 m^3 for 2% and 220,000 m^3 for 5% ethanol in petrol.

The investment amount in order to produce 88,000–220,000 m^3 ethanol is given in Table 7. This amounts to 68 million Euro for 2% and 169 million Euro for 5%.

In order to produce this amount, 11 small, 4 medium and 2 large capacities new facilities are required to produce the 220,000 m^3 ethanol annual production yearly for the 5% mixture (Table 8).

Because sugar beet cannot be stored for long periods it has to be processed as raw sherbet during 100–120 days over which the factories operate and for the rest of the year molasses and thick sherbet are used as raw material.

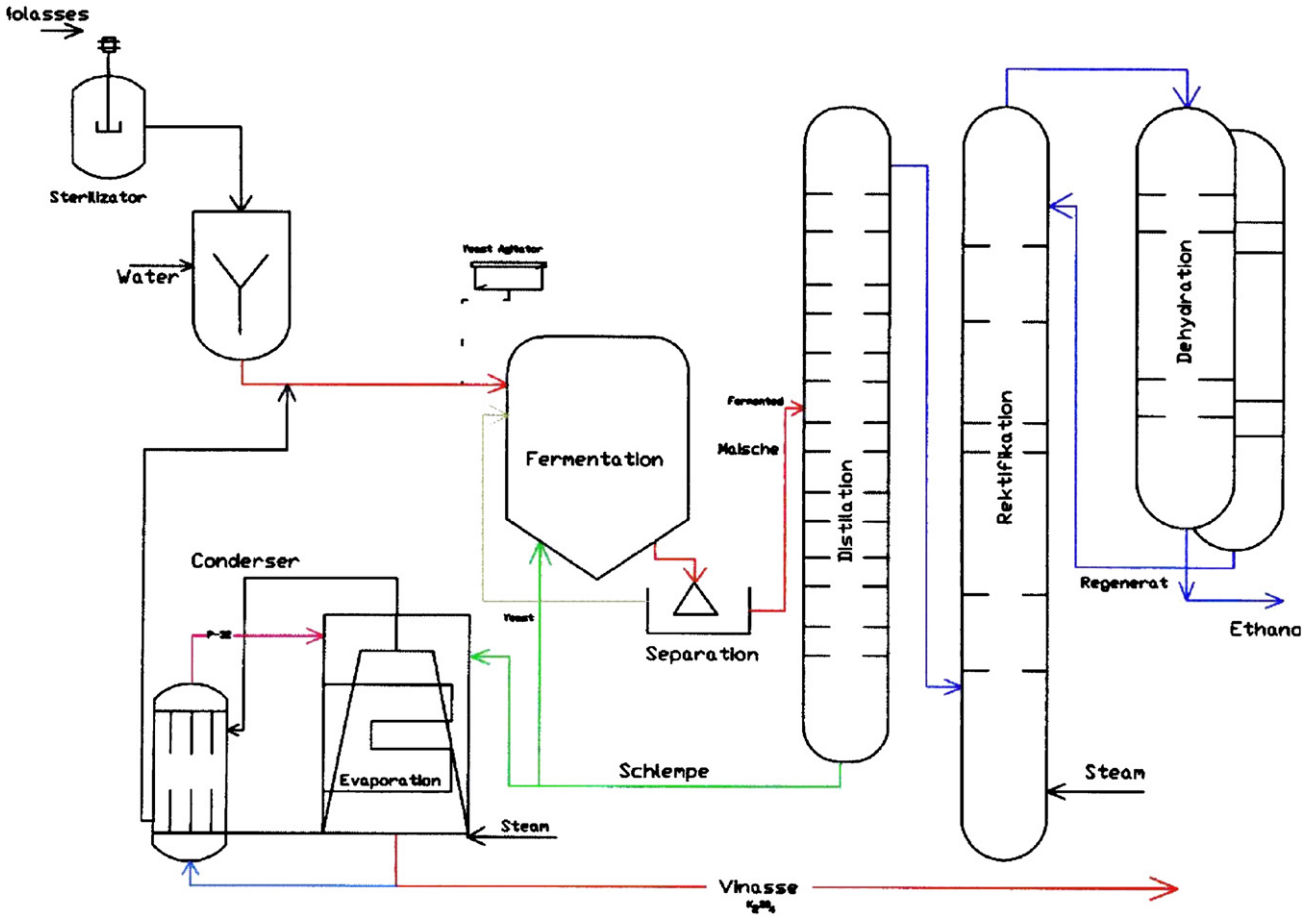

Fig. 1 – Schematic diagram of ethanol production from molasses [5].

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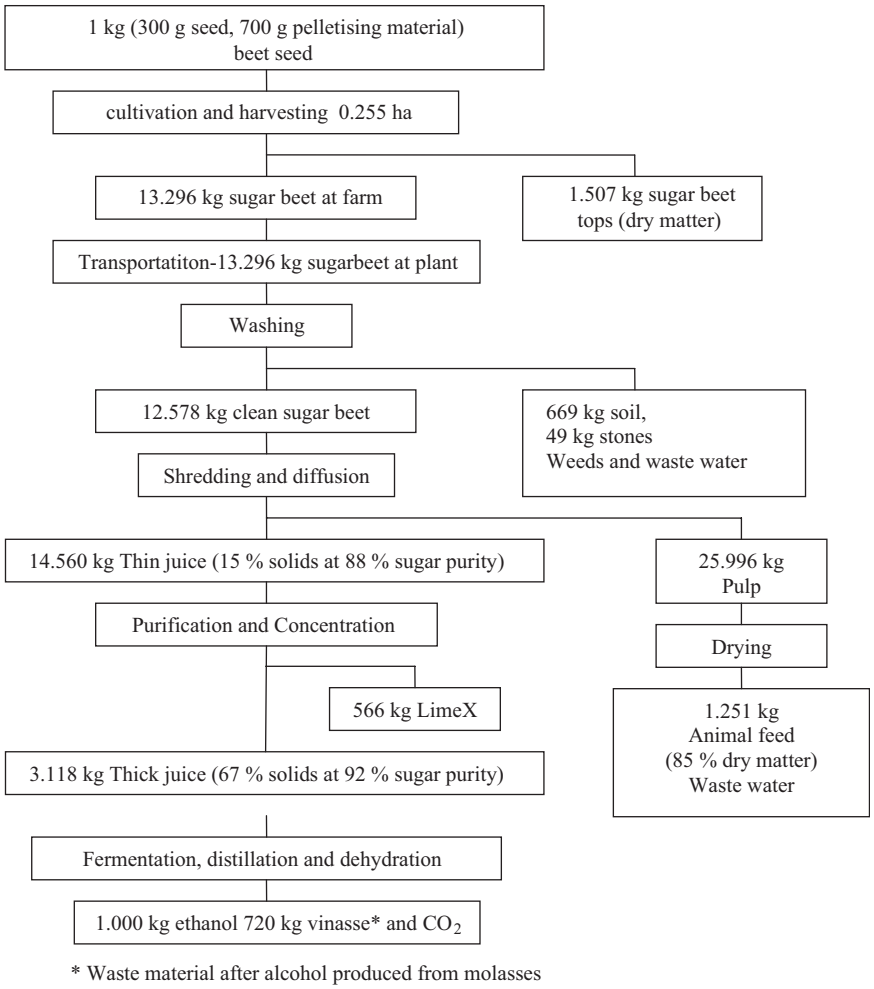

Fig. 2 – Schematic diagram of ethanol production from sherbet [12].

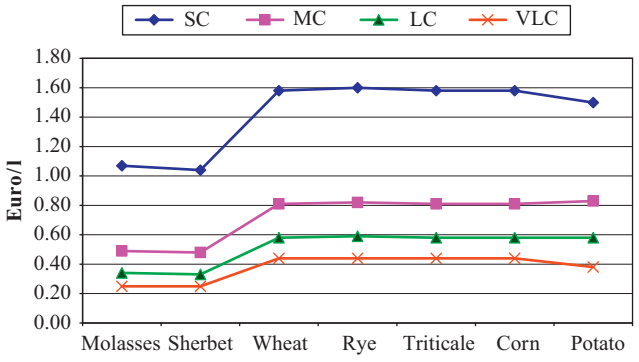

Fig. 3 – Unit cost of ethanol production from different raw materials [5].

Table 6 – Petrol consumption in Turkey [13]

	Consumption (million m^3)				
	1998	1999	2000	2001	2002
Normal petrol	2.9	2.3	1.6	1.2	0.6
Super petrol	2.0	2.0	1.4	1.0	1.2
Unleaded petrol	1.1	1.5	1.9	2.1	2.3
Total	6.0	5.8	4.9	4.3	4.1

Table 7 – Required capacity and investment cost

Mixture rate	Ethanol requirement (m^3)	Unit investment cost (Euro l^{-1})	Investment amount (million Euro)
2%	88,000	0.77	67.8
5%	220,000	0.77	169.4

The established capacity of the existing six alcohol plants is 220 m^3. However, four of these (180 m^3 capacity) have been closed due to environmental problems.

Cost of producing ethanol: Ethanol production cost was calculated to be higher than the refinery cost of the petrol in all countries which produce bioethanol. Raw material input constitutes 50–70% of the ethanol cost and varies with the

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Table 8 – Required facility amount and capacity

Mixture rate	Ethanol requirement (m^3)	Required facility amount		
		Small capacity ($60\,m^3\,day^{-1}$)	Medium capacity ($180\,m^3\,day^{-1}$)	Large capacity ($360\,m^3\,day^{-1}$)
2%	88,000	4	1	1
5%	220,000	11	4	2

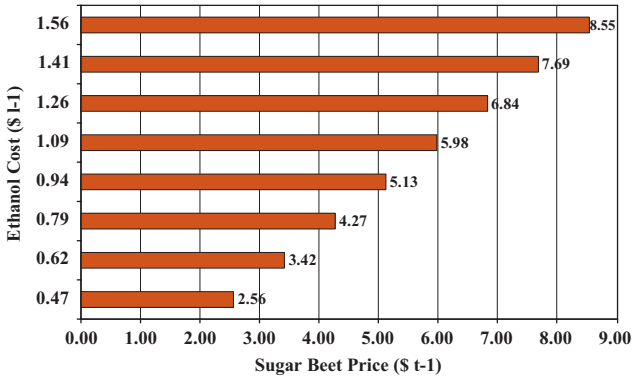

Fig. 4 – Sugar beet price and ethanol cost. *1 US$ equal to 1.17 TL on January 4, 2008.

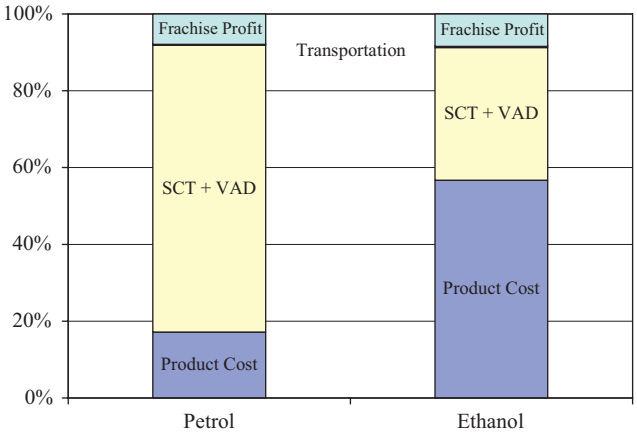

Fig. 5

size of plant. The cost of ethanol per liter of the Turkish Sugar Factories Corp. was 0.64$ in 2003 (1 US$ equal to 1,421,717 TL on June 1, 2003). Components of the cost were as follows: raw material (60.17%), labor (8.51%), others (30.78%) [15]. Components of the selling cost of unleaded petrol (octane number 95) where the selling price was 1.61 $ per liter were petrol: (24.8%), value added tax (15.3%), special consumption tax (51.3%), transportation (0.5%) and 8.2% was franchiser profit [16].

Ethanol production cost is approximately 1.09$ per liter, whereas the sugar beet grower cost is 5.98$ per t. Comparison of this ethanol production cost with the cost components of selling petrol is given in Fig. 4. The highest tax rate, which is applied to ethanol, must be 35% in order to let the ethanol price equal that of petrol as shown (Fig. 5).

4. Discussion

Turkey is dependant on imports of energy with 70% of its energy demand imported. This costs Turkey 6 billion US$ in 2003 [17]. Turkey signed the United Nations Climate Changes Skeleton Agreement and must now control its emissions. It also needs to have 2% bioethanol in the transport sector under EU Directives.

Turkey is initiating arrangements to encourage use of bioethanol. Biofuels became a real topic of discussion in the Petrol Market Law (5015) published in 2003. Ethanol and biodiesel, which are locally produced as from agricultural products, now have legal protection. However, the rate of mixture in petrol and diesel oil and the tax rate applying to biofuels have yet to be determined. Validity period of tax exemption must be arranged as soon as possible. As ethanol production cost is not competitive with petrol incentives need to be provided to encourage its production such as capital grants or tax exemptions.

There are many advantages to use ethanol as a fuel even though the ethanol production cost from sugar beet is higher than petrol. The advantages of using biofuels at 5% mixtures are

- enhances the rural economy,
- provides higher added value by producing 10–15% more sugar beet than that at present,
- provide benefits to other sectors using by-products,
- economical benefits of agricultural and the other inputs trading,
- decreasing of foreign dependency on imports as producing renewable fuels locally,
- reduces atmospheric emissions.

In conclusion, Turkey utilizes approximately 25 Mton of raw petroleum of which 91% is imported. Petroleum prices are increasing and putting an additional burden on the national economy. The cost of 1$ per barrel price increase on Turkey's economy is approximately 200 million US$. Therefore, to find a solution which will decrease the level of Turkey's petroleum bill is essential. Producing bioethanol to mix with petrol will decrease the costs. Turkey's sugar beet production potential is

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sufficient to meet the current demand. The Sugar Law (4634) will be needed to be amended to ensure that the appropriate amounts of sugar beet are grown. Turkey will not have to import 1.78 Mton of crude petroleum with a saving of approximately 500 million US$ for a 5% mixture of ethanol in petrol.

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