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Biodiesel as an alternative motor fuel: Production and policies in the European Union

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Abstract

The purpose of this work is to investigate fuel characteristics of biodiesel and its production in European Union. Biodiesel fuel can be made from new or used vegetable oils and animal fats, which are non-toxic, biodegradable, renewable resources. The vegetable oil fuels were not acceptable because they were more expensive than petroleum fuels. Biodiesel has become more attractive recently because of its environmental benefits. With recent increases in petroleum prices and uncertainties concerning petroleum availability, there is renewed interest in vegetable oil fuels for diesel engines. In Europe the most important biofuel is biodiesel. In the European Union biodiesel is the by far biggest biofuel and represents 82% of the biofuel production. Biodiesel production for 2003 in EU-25 was 1,504,000 tons.

Keywords: Biodiesel; European Union; Production; Policies; Environmental impacts

Contents

1. Introduction . . . 2
2. Biodiesel as a motor fuel . . . 3
3. Fuel characteristics of biodiesel . . . 3
   3.1. Advantages of biodiesel . . . 4
   3.2. Disadvantages of biodiesel . . . 5
4. Biodiesel in the European Union . . . 5

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4.1. European biofuel policy 7
4.2. Biodiesel economy 8
4.3. Environmental impacts 9
5. Conclusion 10
References 11

1. Introduction

Exploring new energy resources, such as biodiesel fuel, is of growing importance in recent years [1]. More than 100 years ago, a brilliant inventor named Rudolph Diesel designed the original diesel engine to run on vegetable oil. Dr Rudolph Diesel used peanut oil to fuel one of this his engines at the Paris Exposition of 1900 [2]. Among them, biodiesel, produced from different vegetable oils (soybean, rapeseed and sunflower, for example), seems very interesting for several reasons: it can replace diesel oil in boilers and internal combustion engines without major adjustments; only a small decrease in performances is reported; almost zero emissions of sulfates; a small net contribution of carbon dioxide (CO_2) when the whole life-cycle is considered (including cultivation, production of oil and conversion to biodiesel); emission of pollutants comparable with that of diesel oil. For these reasons, several campaigns have been planned in many countries to introduce and promote the use of biodiesel [3].

The vegetable oil fuels were not acceptable because they were more expensive than petroleum fuels. With recent increases in petroleum prices and uncertainties concerning petroleum availability, there is renewed interest in vegetable oil fuels for diesel engines [4]. Vegetable oils, also known as triglycerides, have the chemical structure given in Fig. 1 comprise of 98% triglycerides and small amounts of monoand diglycerides [5].

Biodiesel (fatty acid methyl esters) is an efficient, clean, 100% natural energy alternative to petroleum fuels. Among the many advantages of biodiesel fuel include the following: safe for use in all conventional diesel engines, offers the same performance and engine durability as petroleum diesel fuel, non-flammable and nontoxic, reduces tailpipe emissions, visible smoke and noxious fumes and odors [6]. The use of biodiesel has grown dramatically during the last few years. Feedstock costs account for a large percent of the direct biodiesel production costs, including capital cost and return [7].

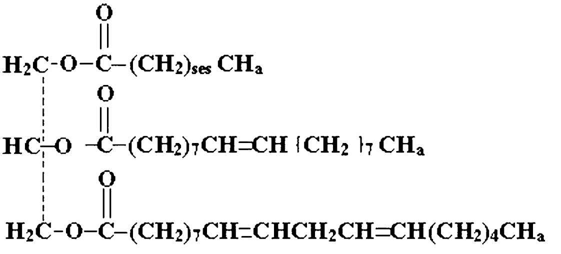

Fig. 1. Structure of a typical triglyceride molecule Source: Ref. [5].

Table 1
Engine emission results from the University of Idaho [9]

Emission	100% Ester fuel (B100) (%)	20/80 Mix (B20) (%)
Hydrocarbons	−52.4	−19.0
Carbon monoxide	−47.6	−26.1
Nitrous oxides	−10.0	−3.7
Carbon dioxide	0.9	0.7
Particulates	9.9	−2.8

2. Biodiesel as a motor fuel

In general, the physical and chemical properties and the performance of ethyl esters are comparable to those of the methyl esters. Methyl and ethyl esters have almost the same heat content. The viscosities of the ethyl esters are slightly higher, and the cloud and pour points are slightly lower, than those of the methyl esters. Engine tests demonstrated that methyl esters produced slightly higher power and torque than ethyl esters. Some desirable attributes of the ethyl esters over methyl esters are: significantly lower smoke opacity, lower exhaust temperatures and lower pour point. The ethyl esters tended to have more injector coking than the methyl esters [8].

Several studies show biodiesel can run in a conventional diesel engine for an extended time. Researchers in several states including Missouri and Idaho, have run diesel engines in pickups, city buses, large trucks and tractors on various mixes of biodiesel/diesel fuel. These mixtures have ranged from 2/98% (B2), 20/80% (B20) up to 100%(B100). Standard diesel engines will operate on 100% biodiesel. In cold weather, biodiesel begins to cloud and thicken at about 272 K. Biodiesel thickens at warmer temperatures than No. 2 diesel fuel, but additives are available that will lower the pour point. Pour point is the point at which flow of the fuel ceases. Mixing biodiesel with No. 1 diesel as is currently done with No. 2 will lower the pour point. Installing an in-tank or fuel line heater may also be needed to keep the fuel flowing in cold weather. A blend of biodiesel/diesel fuel has a lower pour point than 100% biodiesel, but gelling may still occur unless care as mentioned earlier is taken. Table 1 shows a summary of engine tests completed at the University of Idaho. These tests were performed with a 100% and a 20% mix of ethyl and methyl ester of rapeseed oil [9].

3. Fuel characteristics of biodiesel

Biodiesel is a natural, renewable resource. Biodiesel is a cleaner-burning diesel replacement fuel made from natural, renewable sources such as new and used vegetable oils and animal fats. Just like petroleum diesel, biodiesel operates in compression-ignition engines or Diesel engines. Biodiesel has physical properties very similar to conventional diesel [4].

The biodiesel was characterized by determining its density, viscosity, high heating value, cetane index, cloud and pour points, characteristics of distillation, and flash and combustion points according to ISO norms. The fuels are characterized by evaluation the parameters required in ASAE EP X552. The tests are specific gravity, viscosity, cloud

Table 2
Physical characteristics of biodisel and No 2. Diesel fuels [7,8]

Property	Biodiesel	No 2. Diesel
Specific gravity (kg/L)	0.87–0.89	0.84–0.86
Cetane number	46–70	47–55
Cloud point (K)	262–289	256–265
Pour point (K)	258–286	237–243
Flasf point (K)	408–423	325–350
Sulfur (wt%)	0.0000–0.0024	0.04–0.01
Ash (wt%)	0.002–0.01	0.06–0.01
Iodine number	60–135	–
Kinematic viscosity, 313 K	3.7–5.8	1.9–3.8
Higher heating value, MJ/kg	39.3–39.8	45.3–46.7

Table 3
Some properties of various fuels [9]

	Fuel weight (Lbs/gal)	Heat of combustion (BTU/gal)	Cetane number	Viscosity centistokes
No. 2 diesel	7.05	140,000	48	3.0
100% Biodiesel (B100)				
Methyl or ethyl ester	7.30	130,000	55	5.7
B20 mix (20/80)	7.10	138,000	50	3.3
Raw vegetable oil	7.50	130,000	35–45	40–50

point, pour point, flash point, heat of combustion, total acid valued, catalyst, fatty acid composition, boiling point, water and sediment, carbon residue, ash, sulfur, cetane number, copper corrosion, Karl Fischer water, particulate matter, iodine number, and the elemental analysis. The bio-diesel esters were characterized for their physical and fuel properties including density, viscosity, iodine value, acid value, cloud point, pure point, gross heat of combustion and volatility. Methyl and ethyl esters prepared from a particular vegetable oil had similar viscosities, cloud points and pour points, whereas methyl, ethyl, 2-propyl and butyl esters derived from a particular vegetable oil had similar gross heating values. However, their densities, which were 2–7% higher than those of diesel fuels, statistically decreased in the order of methyl similar to 2-propyl > Oethyl > Obutyl esters. The higher heating values of the biodiesel fuels, on a mass basis, are 9–13% lower than D2. The viscosities of biodiesel fuels are twice that of D2. The cloud and pour points of D2 are significantly lower than the biodiesel fuels. The biodiesel fuels produced slightly lower power and torque and higher fuel consumption than D2 [2]. The physical properties of biodisel and No. 2. Diesel fuels are given in Table 2. Some properties of various fuels are shown in Table 3.

3.1. Advantages of biodiesel

A number of technical advantages of biodiesel fuel: (1) it prolongs engine life and reduces the need for maintenance (biodiesel has better lubricating qualities than fossil diesel), (2) it is safer to handle, being less toxic, more biodegradable, and having a higher flash point, (3) it reduces some exhaust emissions (although it may, in some circumstances, raise others) [10].

Biodiesel is an efficient, clean, 100% natural energy alternative to petroleum fuels. Among the many advantages of biodiesel fuel include the following: safe for use in all conventional diesel engines, offers the same performance and engine durability as petroleum diesel fuel, non-flammable and non-toxic, reduces tailpipe emissions, visible smoke and noxious fumes and odors [6]. Biodiesel is better than diesel fuel in terms of sulfur content, flash point, aromatic content and biodegradability [11].

3.2. *Disadvantages of biodiesel*

The technical disadvantages of biodiesel/fossil diesel blends include problems with fuel freezing in cold weather, reduced energy density, and degradation of fuel under storage for prolonged periods. One additional problem is encountered when blends are first introduced into equipment that has a long history of pure hydrocarbon usage. Hydrocarbon fuels typically form a layer of deposits on the inside of tanks, hoses, etc. Biodiesel blends loosen these deposits, causing them to block fuel filters. However, this is a minor problem, easily remedied by proper filter maintenance during the period following introduction of the biodiesel blend [10].

Direct use of vegetable oils and/or the use of blends of the oils has generally been considered to be not satisfactory and impractical for both direct and indirect diesel engines. The high viscosity, acid composition, free fatty acid content, as well as gum formation due to oxidation and polymerization during storage and combustion, carbon deposits and lubricating oil thickening are obvious problems. The probable reasons for the problems and the potential solutions are shown in Table 4 [12].

4. Biodiesel in the European Union

The world total biodiesel production was around 1.8 billion liters in 2003 [13]. Fig. 2 shows the world biodiesel capacity between 1991 and 2003 [14]. In Europe the most important biofuel is biodiesel. In the European Union (EU) biodiesel is the by far biggest biofuel and represents 82% of the biofuel production [15]. Biodiesel production for 2003 in EU-25 was 1,504,000 tons from nine countries (Table 5). Germany led production followed by France and Italy. All these countries increased production during 2003, in particular Germany and Italy where the impact of legislation favourable to biodiesel is helping to encourage take-up. According to the European Commission's 2004 figures, Germany produced an estimated 715,000 tons in 2003, France produced 357,000 tons, and Italy produced 273,000 tons [16].

Biodiesel production uses around 1.4 million hectares (ha) of arable land in the EU. The most important biodiesel producer is Germany (with about 40% of the production). There are approximately 40 plants in the EU, however, the number of plants and the crushing capacity is growing quite fast. The plants are mainly located in Germany, Italy, Austria, the Czech Republic, France and Sweden [15].

Pure biodiesel use is predominant in Germany. It was only in 2004 that also the sale of a mix of biodiesel and fossil diesel started there. The production capacity per year rose from 90,000 to 1,060,000 tons in 2004 and the sale reached 1,000,000 tons which makes

Table 4
Known problems, probable cause and potential solutions for using straight vegetable oil in diesels [12]

Problem	Probable cause	Potential solution
Short-term		
1. Cold weather starting	High viscosity, low cetane, and low flash point of vegetable oils	Preheat fuel prior to injection. Chemically alter fuel to an ester
2. Plugging and gumming of filters, lines and injectors	Natural gums (phosphatides) in vegetable oil. Other ash	Partially refine the oil to remove gums. Filter to 4-microns
3. Engine knocking	Very low cetane of some oils. Improper injection timing.	Adjust injection timing. Use higher compression engines. Preheat fuel prior to injection. Chemically alter fuel to an ester
Long-term		
4. Coking of injectors on piston and head of engine	High viscosity of vegetable oil, incomplete combustion of fuel. Poor combustion at part load with vegetable oils	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load. Chemically alter the vegetable oil to an ester
5. Carbon deposits on piston and head of engine	High viscosity of vegetable oil, incomplete combustion of fuel. Poor combustion at part load with vegetable oils	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load. Chemically alter the vegetable oil to an ester
6. Excessive engine wear	High viscosity of vegetable oil, incomplete combustion of fuel. Poor combustion at part load with vegetable oils. Possibly free fatty acids in vegetable oil. Dilution of engine lubricating oil due to blow-by of vegetable oil	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load. Chemically alter the vegetable oil to an ester. Increase motor oil changes. Motor oil additives to inhibit oxidation
7. Failure of engine lubricating oil due to polymerization	Collection of polyunsaturated vegetable oil blow-by in crankcase to the point where polymerization occurs	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load. Chemically alter the vegetable oil to an ester. Increase motor oil changes. Motor oil additives to inhibit oxidation

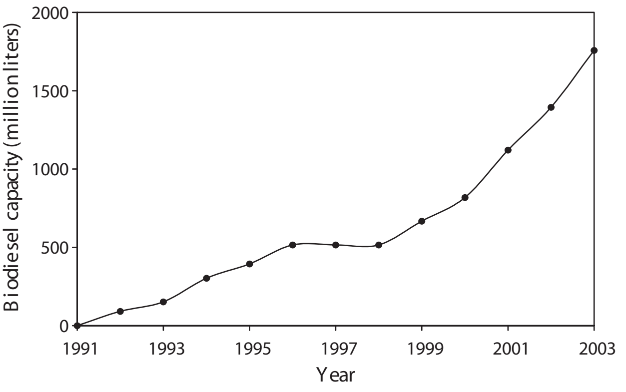

Fig. 2. World biodiesel capacity, 1991–2003 (Source: Ref. [14]).

Table 5
EU-25 biodiesel production (tons) [15,16]

Country	2002	2003	2004[a]
Germany	450,000	715,000	1,088,000
France	366,000	357,000	502,000
Italy	210,000	273,000	419,000
Czech Republic	68,800	70,000	47,000
Denmark	10,000	41,000	44,000
Austria	25,000	32,000	100,000
United Kingdom	3,000	9,000	15,000
Spain	–	6,000	70,000
Sweden	1,000	1,000	8,000
Poland	–	–	1,200
Hungary	–	–	2,000
Total (EU-25)	1,133,800	1,504,000	2,296,200

[a]Estimates

Germany the largest biodiesel producer in Europe. In January 2004, there were 1800 filling stations for biodiesel existing. The production capacity varies greatly—between 2000 and 150,000 tons/year. In France, biodiesel production started in 1992. In 2004, the production capacity was 520,000 tons, which makes France the second largest biodiesel producer in Europe. In contrast to Germany, French biodiesel is exclusively sold as a mix with either up to 5% or up to 30% biodiesel added to fossil diesel [17].

Europe's biggest biodiesel plant is going to be completed early 2005 in Teesside, and a second plant 1 year later. The £ 21 m plant, with the capacity to produce 250,000 tons of biodiesel a year, uses renewable vegetable oils such as oilseed rape, palm and soy as raw materials. The project would use technology licensed from energea of Austria. This is based on continuous flow biodiesel production, expected to be significantly more efficient and cheaper than traditional batch processing [18].

4.1. European biofuel policy

The general EU policy objectives considered most relevant to the design of energy policy are: (1) competitiveness of the EU economy, (2) security of energy supply, and (3) environmental protection. All renewable energy policies should be measured by the contributions they make to these goals. Current EU policies on alternative motor fuels focus on the promotion of biofuels. In a proposed biofuels directive the introduction of a mandatory share scheme for biofuels, including as from 2009 minimum blending shares. In the Commission's view mandating the use of biofuels will (i) improve energy supply security and (ii) reduce greenhouse gas (GHG) emissions and (iii) boost rural incomes and employment. Current regulations would preclude a notable negative impact on the rural environment [19].

Elements of the European biofuels policy [20]:

- A Communication presenting the action plan for the promotion of biofuels and other alternative fuels in road transport.

Table 6
The targets for biofuels consumption stated in the initial commission proposal for a biofuels directive [19]

Year	Of which as a minimum in the form of blending	
	(%)	(%)
2005	2	–
2006	2.75	–
2007	3.5	–
2008	4.25	–
2009	5	1
2010	5.75	1.75

- The Directive on the promotion of biofuels for transport which requires an increasing proportion of all diesel and gasoline sold in the Member States to be biofuel.
- The biofuels taxation, which is part of the large draft Directive on the taxation of energy products and electricity, proposing to allow Member States to apply differentiated tax rates in favour of biofuels.

The EU have also adopted a proposal for a directive on the promotion of the use of biofuels with measures ensuring that biofuels account for at least 2% of the market for gasoline and diesel sold as transport fuel by the end of 2005, increasing in stages to a minimum of 5.75% by the end of 2010 [21]. The targets for biofuels consumption stated in the initial Commission proposal for a Biofuels Directive is given Table 6 [19]. The French Agency for Environment and Energy Management (ADEME) estimates that the 2010 objective would require industrial rapeseed plantings to increase from currently 3 million ha in the EU to 8 million ha [22].

In Germany, the current program of development of the biodiesel industry is not a special exemption from EU law, but rather is based on a loophole in the law. The motor fuels tax in Germany is based on mineral fuel. Since biofuel is not a mineral fuel, it can be used for motor transport without being taxed. Unlike France and Italy, where biodiesel is blended with mineral diesel, biodiesel sold in Germany is pure, or 100%, methyl ester. There is no mineral tax on biodiesel in Germany, so when diesel prices were high and vegetable oil prices were low biodiesel became very profitable. Additionally, there have been no restrictions on the quantity of biodiesel that can be exempted from the mineral fuel tax, so there has been a huge investment in biodiesel production capacity [22]. In 2005 capacity is supposed to increase to 1,600,000 tons [17].

4.2. *Biodiesel economy*

The cost of biodiesel is higher than diesel fuel. Currently, there are seven producers of biodiesel in the United States. Pure biodiesel (100%) sells for about US$1.50 to US$2.00 per gallon before taxes. Fuel taxes will add approximately US$0.50 per gallon. A mix of 20% biodiesel and 80% diesel will cost about 15–20¢ more per gallon over the cost of 100% diesel [9]. Cost of biodiesel production is a generally accepted view of the industry in Europe that biodiesel production is not profitable without fiscal support. Table 7 shows cost and return scenario for a 60,000 ton biodiesel plant [22].

Table 7
Cost and return scenario for a 60,000 tons biodiesel plant [22]

	Million Euros[a]
Income	
60,000 tons biodiesel@€617/ton	37.03
7500 tons 80% glycerine@€500/ton	3.75
Undetermined amount of free fatty acids sold as livestock feed	40.78
Total Income	
Expenses	
60,900 tons vegetable oil@€520/ton	31.67
6000 tons methanol@€265/ton	1.59
Undetermined amount of NaOH included in variable costs	
Undetermined amount of HCl included in variable costs	4.70
€30 million investment amortized over 10 years at 10% interest	
Variable costs equal to fixed costs	4.70
Total cost	42.66

[a] 1 Euro *Z*1.17 US dollars.

A review of 12 economic feasibility studies shows that the projected costs for biodiesel from oilseed or animal fats have a range US$0.30–0.69/l, including meal and glycerin credits and the assumption of reduced capital investment costs by having the crushing and/or esterification facility added onto an existing grain or tallow facility. Rough projections of the cost of biodiesel from vegetable oil and waste grease are, respectively, US$0.54–0.62/l and US$0.34–0.42/l. With pre-tax diesel priced at US$0.18/l in the US and US$0.20–0.24/l in some European countries, biodiesel is thus currently not economically feasible, and more research and technological development will be needed [2].

4.3. Environmental impacts

Producing and using biofuels for transportation offers alternatives to fossil fuels that can help provide solutions to many environmental problems. Using biofuels in motor vehicles helps reduce GHG emissions. Fullcycle analysis indicates that, on average, biofuels emit less CO_2 than conventional fuels [23]. Due to the low or zero content of pollutants such as sulfur in biofuels, the pollutant (SO_2, etc.) emission of biofuels is much lower than the emission of conventional fuels. The use of biofuels, however, has some environmental drawbacks. The raw materials of biofuels are plants produced by the agriculture having some negative impacts on the environment [24].

Using biodiesel in a conventional diesel engine substantially reduces emissions of unburned hydrocarbons, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter. These reductions increase as the amount of biodiesel blended into diesel fuel increases. The best emissions reductions are seen with B100. Scientists believe CO_2 is one of the main greenhouse gases contributing to global warming. Neat biodiesel (100% biodiesel) reduces CO_2 emissions by more than 75% over petroleum diesel. Using a blend of 20% biodiesel reduces CO_2 emissions by 15% [7].

The use of biodiesel decreases the solid carbon fraction of particulate matter (since the oxygen in biodiesel enables more complete combustion to CO_2) and reduces the sulfate

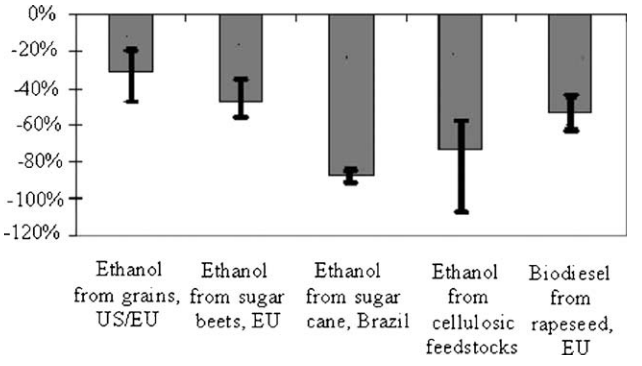

Fig. 3. Range of estimated greenhouse gas reductions from biofuels. Note: Relative well-to-wheels CO_2-equivalent GHG emissions per kilometer from vehicles with various biofuel/feedstock combinations, compared to similar conventional-fuelled vehicles. Source: Ref. [25].

fraction (biodiesel contains less than 24 ppm sulfur), while the soluble, or hydrocarbon, fraction stays the same or increases. Emissions of nitrogen oxides (NOx) increase with the concentration of biodiesel in the fuel. Some biodiesel produces more NOx than others, and some additives have shown promise in modifying the increases [7].

One of the principal reasons for the support biodiesel manufacture is getting from the EU and national governments within the EU is that the use of biodiesel reduces the net production of greenhouse gases. There is, however, a notable lack of agreement as to the amount of greenhouse gas savings that are actually achieved. The EU Directorate General published a figure of 60% reduction in CO_2 emissions [22].

Biodiesel and ethanol provide significant reductions in GHG emissions compared to gasoline and diesel fuel, on a 'well-towheels' basis. While a range of estimates exists, Fig. 3 shows that most studies reviewed find significant net reductions in CO_2-equivalent emissions for both types of biofuels. More recent studies tend to make estimates toward the higher-reduction end of the range, reflecting efficiency improvements over time in both crop production and ethanol conversion [25].

5. Conclusion

Biodiesel, derived from vegetable oil or animal fats, is recommended for use as a substitute for petroleum-based diesel mainly because biodiesel is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable. The use of biodiesel has grown dramatically during the last few years. Feedstock costs account for a large percent of the direct biodiesel production costs, including capital cost and return. Biodiesel has a viscosity much closer to diesel fuel than vegetable oil. The cost of biodiesel is higher than diesel fuel.

Biodiesel production for 2003 in EU-25 was 1,504,000 tons. Pure biodiesel use is predominant in Germany. According to the European Commission's 2004 figures, Germany produced an estimated 715,000 tons in 2003, France produced 357,000 tons, and Italy produced 273,000 tons.

The EU have also adopted a proposal for a directive on the promotion of the use of biofuels with measures ensuring that biofuels account for at least 2% of the market for gasoline and diesel sold as transport fuel by the end of 2005, increasing in stages to a minimum of 5.75% by the end of 2010.

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