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Are subsidies for biodiesel economically efficient? ☆

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Abstract

Biodiesel produces less pollution than petrodiesel; however, it is more expensive and will only be a viable alternative if market prices of the products are comparable. This paper examines whether the external benefits from biodiesel use justify subsidies required for adoption outside of niche alternative fuel markets. The authors establish a range of subsidies required to make biodiesel a viable substitute for petrodiesel. Published estimates of the emissions reductions from biodiesel and the dollar benefits of unit reductions in emissions are used to compute a per-gallon external benefit from use of biodiesel, versus petrodiesel. Under conservative estimates of the benefits from biodiesel use in non-road equipment, the external benefits outweigh the required subsidies.(JEL Q48, Q42, H2)

Keywords: Biodiesel; Subsidies; Externality

1. Introduction

Biodiesel is the product one gets when organically derived oil such as vegetable oil or animal fat chemically reacts with an alcohol to produce a fatty acid alkyl ester. These biomass-derived esters can be blended with petroleum-based diesel fuel (petrodiesel) or used as a "neat" fuel: 100% biodiesel.[1] While biodiesel is generally more expensive to produce than petroleum diesel, it also emits significantly less pollution. Subsidies are required for adoption of biodiesel outside of niche markets. In this work, the authors assess whether the external benefits from biodiesel production and use (reduced pollution) justify the required subsidy, i.e., whether biodiesel is economically efficient from a social standpoint. Despite the widely touted benefits of biodiesel, the authors are not aware of any attempts to quantify these benefits in monetary terms.

The external benefits are primarily derived from the lower volumes of some pollutants emitted from combustion of biodiesel, as compared to petrodiesel. In section two of this paper these benefits are monetized by using EPA data on the economic costs of petrodiesel. The reduction in these pollution costs from using lower-polluting biodiesel is calculated. In that sense, the external benefits of biodiesel are an avoided cost measure.

These subsidies are only economically efficient if biodiesel is the least expensive method of reducing diesel pollution. Starting in 2006, EPA regulations will require the production of ultra-low sulfur petrodiesel, and when this fuel is used in diesel engines with newly manufactured pollution control technology, harmful pollution will be reduced below that of biodiesel. Given that these regulations will force the production of petrodiesel fuel and the manufacture of diesel engines that emit less pollution than biodiesel, is there any economic justification for biodiesel subsidies?

Biodiesel may still play an important role in reducing diesel pollution, for EPA regulations require the use of this pollution reduction technology only in newly manufactured diesel engines, and do not require that existing engines be retrofitted. During the more than twenty-year period that the EPA forecasts the continued use of high

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[1] Several biodiesel trade associations have web sites devoted to explaining biodiesel and its properties. The US national trade association, the National Biodiesel Board, has a web site that can be accessed at http://www.biodiesel.org (National Biodiesel Board, 2003, 2004a–c). Also see (Wedel, 1999; Adler, 2002; Alternative Fuels Data Center, 2003; Biodiesel Industries, 2004).

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pollution diesel engines, biodiesel may reduce the economic damage from the use of diesel fuel.

Petrodiesel fuel is currently used in both on- and non-road vehicles. The authors restrict their attention to emission and usage data for non-road diesel use in the US for two reasons. First, biodiesel cannot possibly replace a significant portion of petrodiesel used in on-road engines; it can supplant a far larger share of non-road petrodiesel demand.[2] Second, the benefits of using biodiesel in non-road engines probably exceed those from on-road use. On-road petrodiesel will be ultra-low sulfur by 2006, allowing the use of mandated pollution reduction technology in new (2007) engines. Non-road engines are subject to the same regulations, but they are phased in at a later date.[3]

Once all high pollution engines are replaced, the health benefits of biodiesel will be dramatically reduced. Since this is likely to occur at a later date for non-road engines, the health benefits of biodiesel are calculated with data from non-road applications.

Section two concludes with a range of estimates of the external benefit of biodiesel use. Since reduced pollution is a benefit external to the consumption of diesel fuel, consumers are unlikely to purchase biodiesel unless a subsidy makes the price comparable to petrodiesel. Section three estimates what subsidies would have been required in the recent past in order to make biodiesel cost competitive with petrodiesel. The production cost (average variable cost) of biodiesel is calculated using historical input prices (feedstock, methanol). Estimates for the net average production costs of biodiesel are obtained by subtracting the value of byproducts (glycerin), again using historical prices. Given a range of estimates of fixed production costs, the authors calculate average total cost. After adjusting for a small difference in the BTUs per gallon, the historical wholesale price of #2 petrodiesel is subtracted from the estimated cost per gallon to obtain the difference between the price of petrodiesel and biodiesel. A subsidy of this amount will, for the time period studied, make the price of the two fuels comparable.

This study calculates this difference in cost using recent historical data, and will be incorrect if there are substantial changes in the cost of production of biodiesel or petrodiesel.[4] Costs are calculated at the wholesale level, which ignores the economies of scale in the distribution of petrodiesel. This may be justified for two reasons. As previously mentioned, biodiesel will never replace a majority of petrodiesel in the US market; therefore it will be produced only in those locations that minimize joint production/marketing costs. A transportation system of the scale used in petrodiesel is unnecessary. Next, biodiesel may be mixed with petrodiesel at the wholesale level and distributed using existing petrodiesel infrastructure.[5]

2. Monetization of the External Benefits from Biodiesel

Gaseous and particulate emissions from petrodiesel combustion, as well as their atmospheric transformation products, damage ecological systems and adversely affect public health. Reductions in emissions, such as those obtained by combustion of biodiesel in lieu of petrodiesel, have corresponding benefits. In this section the external monetary benefit from substituting one gallon of biodiesel for one gallon of petrodiesel are calculated using estimates from the literature on the monetary cost of particulate and gaseous emissions from non-road diesel engines, coupled with data on the relative tailpipe emissions quantities of biodiesel and petrodiesel. This benefit is an avoided cost measure—it corresponds to environmental and health costs that would have been incurred had petrodiesel been used in non-road engines instead of biodiesel.

Though not specifically addressing biodiesel, the work most relevant to this one is an addendum by the Federal Highway Administration (FHWA) (2000) to the 1997 Federal Highway Cost Allocation Study Final Report (Federal Highway Administration, 1997). Although its authors concede there is uncertainty about every aspect of the estimates, their best guess is that diesel trucks, operating on petrodiesel, impose air pollution costs of 3.9 cents per mile of travel. If Congress decided to capture those costs through a fuel tax on the assumption that trucks average 8 miles per gallon, the diesel tax would rise by 31 cents/gallon (Simonson, 2000). To the extent that non-road diesel equipment emits more pollutants than on-road trucks, this estimate will understate the cost per gallon of air pollution from non-road diesel users. However, biodiesel does not eliminate emissions; it simply reduces them. The value of emissions benefits of biodiesel, then, are smaller than the benefits from eliminating diesel combustion altogether. Regardless, the value of \$0.31/gallon is a useful metric.[6]

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[2] Biodiesel production using the entire US stock of vegetable oils and animal fats would only satisfy 13% of on-road petrodiesel demand (Energy Information Administration, 2002; Economic Research Services USDA, 2003; Energy Information Administration, 2004).

[3] Ultra-low sulfur diesel fuel will be required for highway diesel engines in 2006. Lower sulfur fuel will be required for non-road diesel engines in 2007, but ultra-low sulfur fuels will not be required until 2010. Locomotive and marine fuel will not switch to the ultra-low sulfur standard until 2012. This ultra-low sulfur fuel allows the use of pollution reduction technology that dramatically reduces the output of particulate matter. Because this fuel will be phased into highway use first, the primary benefits of biodiesel will be as a replacement for the higher sulfur non-road applications. See the EPA's National Clean Diesel Campaign website at http://www.epa.gov/cleandiesel/. The authors also believe, but are currently unable to document, that the replacement of on-road diesel engines will occur before non-road engines.

[4] This paper does not attempt to explicitly model the investment decision of biodiesel producers. See Tareen et al. (2000).

[5] Biodiesel is a better solvent than petrodiesel, and when introduced into petrodiesel storage and transportation systems it may dissolve built-up sediments. When mixed in reduced concentrations (e.g. 10%), this is unlikely to be an important problem.

[6] This is the "mid-range" estimate from the FHWA addendum. The corresponding low cost per gallon value is \$0.23, and the high estimate of on-road heavy-duty diesel air pollution costs is \$2.68/gal.

In another related study, Franke and Reinhardt (1998) performed a life-cycle analysis of biodiesel (rapeseed methyl ester, or RME) versus petrodiesel, and reported the net benefit or cost of RME production and use for 23 parameters, including NOx, particulate matter, and CO_2-equivalents. They provide a subjective assessment of the overall environmental impact of RME, without quantifying avoided external costs.

For a thorough discussion of the pollutants from petrodiesel engines, and their adverse effects, the authors refer the reader to "Public Health and Environmental Benefits of EPA's Proposed Program for Low-Emission Non-road Diesel Engines and Fuel" (Environmental Protection Agency, 2003) and "The Diesel Dilemma: Diesel's Role in the Race for Clean Cars" (Monahan and Friedman, 2004).

2.1. Monetary costs of diesel emissions

To price the external benefits of biodiesel the authors calculate, in tons per gallon, the quantities of pollutants reduced (or increased in the case of Nitrate) from substituting biodiesel for petrodiesel. The monetary cost of each pollutant, in dollars per ton, is drawn from an EPA non-road diesel regulatory impact analysis related to the Nonroad Diesel Engines Tier 4 Standards. The EPA study evaluated the costs and benefits of requiring ultra low sulfur petrodiesel and pollution reduction technologies. The emissions reductions under the EPA rule are quantitatively similar to those obtained from substitution of B100 (100% biodiesel) for 2-D (the standard grade of petrodiesel); thus, this study uses the EPA's estimates of the cost of petrodiesel pollution. For each pollution type, the tons per gallon reduction in pollutants are multiplied by the avoided cost per ton. This results in dollar costs avoided per gallon for each type of pollution. Gross benefits of biodiesel, in dollars per gallon, are then calculated by summing over all of the pollutants.

The monetary costs of pollutants must be understood with several caveats. First, the costs quantified by the EPA are highly uncertain due to data and methodological limitations, and should be viewed as indicative only of the order of magnitude of costs. Chemical processes that transform emissions into ozone, particulate matter, and other pollutants are very complex, as is the transport of pollutants from their source to where they ultimately affect human health. Sources of some pollutant types are not well understood, and scientific data on relationships between air pollution and premature death are also weak in many cases.[7]

Second, there is considerable debate about valuing economic costs of premature deaths associated with air pollution. This debate is important because costs associated with premature deaths from particulate matter account for the majority of total air pollution-related costs. In policy and regulatory analyses, the EPA uses a value of \$6.3 million in constant year 2000 dollars to represent the cost of a premature death (i.e., the value of a statistical life, or VSL).

Third, the EPA is unable to quantify the health or welfare benefits of reduced CO, air toxics or ozone. It uses best-available-practices to quantify or monetize emissions benefits; however, it currently does not have appropriate tools for modeling changes in ambient concentrations of CO or air toxics to include in a national benefits analysis. Because these costs of petrodiesel combustion are not included, this study's calculation of the monetary benefits of biodiesel may significantly understate the true benefits.

A thorough description of the EPA's methodology or the Nonroad Diesel Engines Tier 4 Standards is well beyond the scope of this paper, and the authors refer the reader to the source document.[8] The EPA study estimates the economic benefit from proposed pollution reduction regulations. These benefits are avoided costs—premature deaths and medical costs avoided as the result of lower levels of air pollution. In estimating these benefits, the EPA models the change in air pollution levels, local population and income over time and in all counties of the contiguous 48 states, both with and without the new regulations from 2007 to 2030. Using estimates on the relationship between air pollution levels and rates of premature mortality and health care costs, the study calculates the economic benefit of the reduced pollution levels resulting from the proposed regulation.

Two benefit estimates are provided by the EPA—a 'base' estimate and an 'alternative' estimate. It is currently unknown whether there is a delay between changes in chronic PM exposures and changes in mortality rates. The base estimate assumes a five-year distributed lag structure, with 25% of premature deaths occurring in the year immediately following PM exposure, another 25% coming in the second year, and 16.7% in each of the remaining years. The alternative estimate focuses on premature mortality and chronic-bronchitis occurring within a few days of the PM exposure. The alternative estimate uses the value of a statistical life year (VSLY) rather than a VSL approach, and considers the number of statistical life years lost from air pollution. The alternative assumptions are significantly more conservative than those underlying the base estimates, and estimated benefits are one-quarter or less of the base estimates.

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[7] The EPA report upon which the authors' calculations are based discusses these limitations and uncertainties at length, either in the main text or in technical appendices. It also discusses the various empirical studies that have attempted to estimate economic costs for different pollutants and issues involved in extrapolating results of those case-specific studies to nationwide cost estimates.

[8] The authors do note that the EPA methodology is extremely sophisticated, and apparently very thorough. It accounts for, among other things, adjustments in income over time, demographic changes, and geographical variations in the effects of emissions.

For both the alternative and base estimates, two cases are provided, corresponding to two discount rates of future occurrences. For each estimate, effects that are forecast to occur after the year 2030 are discounted at rates of 3% and 7%—the rates recommended by the EPA and Office of Management and Budget, respectively, for economic analysis.

2.2. *Benefits per unit emissions reduction*

Based on the assumptions provided above, the monetary benefits forecast by the EPA in 2030 as the result of implementation of the ultra low sulfur/new pollution technology rule, are provided in Table 1 [9]

The EPA determined population-weighted changes in NO*x*, SO_2, and direct PM contributions to health and environmental benefits, as a percentage of total benefit. For the year 2030, these percentages are: 16.8%, 20.5%, and 62.7%, respectively. That is, 16.8% of the estimated health and welfare benefits are attributable to changes in ambient nitrates. Table 2 shows the breakdown of benefits by pollutant in the year 2030.

The forecasted emission reductions associated with the EPA rule are provided in Table 3. The estimated benefits in millions of year 2000 dollars per ton of pollutant reduced, calculated by dividing each figure in Table 2 by the appropriate figure from Table 3, are provided in Table 4. These are millions of dollars of costs per short ton of pollution emitted. The economic costs of this pollution are estimated in the EPA study across the 2007–2030 time period and across all continental United States locations. While a ton of pollutant will impose different economic costs depending where and when it is emitted, the Table 4 estimates only provide an average, not marginal, cost of pollution. This will be most valid if further reductions in pollution levels provide similar benefits to the average level of benefit.

Table 1
Estimated 2030 benefits for non-road diesel engine standards (2000 $ millions)

	Base estimate	Alternative estimate
3% Discount rate	$80,600 + B	$16,000 + B
7% Discount rate	$74,500 + B	$17,000 + B

Table 2
Estimated 2030 benefits by pollutant (2000 $ millions)

	Base estimate		Alternative estimate	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
Sulfate	$16,523	$15,273	$3,280	$3,485
Nitrate	$13,541	$12,516	$2,688	$2,856
Primary PM	$50,536	$46,712	$10,032	$10,659

Table 3
Emission reductions in 2030 (short tons)

NOx + NMHC	854,392
PM	138,813
SOx	389,337

Table 4
Benefits per unit of emission reduction (2000 $ millions/short ton)

	Base estimate		Alternative estimate	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
Sulfate	$0.04	$0.04	$0.01	$0.01
Nitrate	$0.02	$0.01	$0.00	$0.00
Primary PM	$0.36	$0.34	$0.07	$0.08

2.3. *Emissions per gallon*

The most readily available information on the reduced pollution of biodiesel is expressed as a percentage reduction in pollutant emission with respect to petrodiesel (e.g., an engine combusting B100 emits 50% of the CO that an engine combusting petrodiesel emits). To quantify the benefits of biodiesel, the amount of pollutants emitted by non-road diesel engines per gallon of petrodiesel must first be calculated.

This information is computed from data in the 'emissions inventory' chapter of the Environmental Protection Agency (EPA), (2004) report. In that chapter, fuel consumption projections are provided for non-road diesel engines, as are projected emissions. Non-road diesel engines are subdivided into four types: land-based diesel, recreational marine vessels, locomotives, and commercial marine vessels. Table 5 shows the estimated fuel consumption and emissions by pollutant in the year 2030, for each of the four equipment types.[10]

As emissions per gallon of fuel vary across the four equipment types, a weighted average of emissions per gallon is computed for each pollution type. Values are weighted by fuel consumption by each type of equipment as a percentage of the total. Emissions per gallon for each equipment type, and the weighted average, are presented in Table 6.

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[9] The term 'B' represents the monetary value of the unmonetized health and welfare benefits, a detailed listings of which are provided in Table 9-1 in the EPA analysis.

[10] The authors only possess 48-state estimates (excluding Alaska and Hawaii) of NO*x*, VOC, and CO emissions for locomotives and commercial marine vessels. Consequently, all values provided in the table for these two equipment types are 48-state forecasted values.

Table 5
Emissions and fuel consumption in 2030 (short tons; millions of gallons)

Source	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO	Fuel
Land-based non-road	152,475	140,277	1,238,701	299,199	97,882	798,316	19,471
Locomotives (48 States)	NA	15,692	534,520	58,913	31,644	119,302	3,682
Commercial Marine Vessels (48 States)	NA	47,772	814,827	37,943	41,354	176,533	2,257
Recreational marine	1,064	979	42,160	4,739	1,559	6,602	292
Sum	153,539	204,720	2,630,208	400,794	172,439	1,100,753	25,702

Table 6
Short tons emissions per million gallons fuel

Source	PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC	CO	Fuel (% total)
Land-based non-road	7.83	7.20	63.62	15.37	5.03	41.00	75.76
Locomotives (48 States)	NA	4.26	145.17	16.00	8.59	32.40	14.33
Commercial marine vessels (48 states)	NA	21.17	361.02	16.81	18.32	78.22	8.78
Recreational marine	3.64	3.35	144.38	16.23	5.34	22.61	1.14
Weighted tons/million gallons	5.97	7.93	100.69	15.41	6.65	42.57	

2.4. *Benefits per gallon of biodiesel*

Using the emission reduction percentages from the Environmental Protection Agency (EPA) (2002) "Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions," in conjunction with the information in Table 6, the reduction in unit emissions per gallon of biodiesel combusted is reported in Table 7.[11] According to this EPA report, biodiesel emissions of fine particulate matter, NOx, and Sulfates are 30% lower, 13% higher, and 100% lower, respectively, than petrodiesel.

There are four values for the external benefits of biodiesel per gallon—two each for the EPA base and alternative estimates. Benefits per gallon by pollutant, and total benefits per gallon, are provided for each case in Table 8. These values are obtained by multiplying the unit emissions reductions, in short tons per million gallons, by the estimated benefits per unit emissions reduction, in millions of 2000 dollars per short ton.

Thus, under the assumptions of this study, the estimated external benefits of combusting B100 in place of 2-D range from \$0.32 to \$1.29/gallon.

Table 7
Emissions reductions from biodiesel

	$PM_{2.5}$	NO_x	SO_2
Percentage Reduction	−30%	+13%	−100%
Unit Reduction (short tons/million gallons)	2.38	−13.09	15.41

3. Calculation of costs of biodiesel

Section 2 calculated external benefits, in dollars per gallon, of using biodiesel as a substitute to petrodiesel. Subsidies within this range are economically efficient, for they cause the consumer to use biodiesel whenever the value of the reduction in the pollution is greater than value of the extra resources used to produce biodiesel. But that still leaves open the question of whether manufacturers are able to produce biodiesel at a price comparable to petrodiesel with the aid of these subsidies. Are these subsidies enough to ensure biodiesel production?

In order to address this question, this study calculates, using market prices, the relative cost of petrodiesel and biodiesel. Comparison of time series of wholesale #2 petrodiesel (2-D) prices and calculated biodiesel costs yields the subsidy required to make 2-D and B100 cost-competitive. This subsidy is the threshold for external benefits from biodiesel consumption, above which biodiesel is considered to be economically efficient.[12]

Base catalyzed transesterification—the most common biodiesel production process—requires three feedstock: a vegetable oil or fat, an alcohol, and a catalyst. Given the dominance of soy production in the US, soybean oil is selected as the oil feedstock. Biodiesel from soy is typically produced using methanol, although ethanol may also be used. In some production processes the methanol is recycled; cost estimates with and without recycling are estimated. Regardless, methanol costs are a relatively small portion of average variable costs.

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[11] Also see (Korotney, 2002).

[12] As opposed to calculating the cost of biodiesel, it would be possible to gather historical biodiesel prices. While there are certain advantages to this approach, given the very limited distribution of biodiesel, it is unlikely that this market is perfectly competitive, and therefore the market price of biodiesel is likely to have been above the marginal cost of production.

Table 8
External benefits of biodiesel (2000 dollars/gallon)

	Base estimate		Alternative estimate	
	3% Discount rate	7% Discount rate	3% Discount rate	7% Discount rate
Sulfate	\$0.62	\$0.62	\$0.15	\$0.15
Nitrate	(\$0.26)	(\$0.13)	\$0.00	\$0.00
Primary PM	\$0.86	\$0.81	\$0.17	\$0.19
Total	\$1.21	\$1.29	\$0.32	\$0.34

The catalyst for the reaction can be either sodium or potassium hydroxide (NaOH or KOH, respectively). The authors have obtained cost data for the former, which is more typical. However, though prices have varied considerably over the past several years—from \$60 per short ton to \$300/short ton—the catalyst amounts to approximately 1/10th of a cent per gallon of biodiesel. Consequently, the cost of the catalyst is ignored in the calculation of biodiesel price.

While feedstock comprises the majority of biodiesel average total cost, there are substantial fixed costs. Production costs are calculated for two average fixed cost values from the literature—\$0.20 and \$0.40/gallon (Iowa State Mechanical Engineering Department, 2004). Other estimates in the literature range from \$0.22 to \$1.77/gallon (Duffield and Shapouri, 1998; Van Dyne and Blasé, 1998; Bender, 1999). Some of the cost variation is due to economies of scope in combined soy meal/oil facilities. Of these fixed costs, facility construction costs are estimated at \$0.06 to \$0.13/gallon (American Bio–Fuels, 2002).[13]

In order to calculate the cost of biodiesel, an input–output model from Van Dyne and Blasé (1998) is used:

- Inputs: 9 gallons soybean oil + 1 gallon methanol + small amount NaOH
- Outputs: 9 gallons B100 + 1 gallons crude glycerin + small amount of residual alcohol, waste water, and catalyst

Soybean oil prices are expressed as cents per pound, and there are 7.7 pounds of soybean oil/gallon (Duffield and Shapouri, 1998). Price data are from the Economic Research Service, USDA (Economic Research Services USDA, 2002, 2003). Methanol prices are expressed in cents per gallon, so require no conversion. Source: Oxy-Fuel News (various issues, accessed via Lexis-Nexis).

A complication exists with the glycerin co-product. Different production techniques result in either refined or unrefined glycerin, and in variable quantities. The most reliable data is for unrefined glycerin output, and this is converted to refined glycerin output using a multiplier cited in the literature. Refined glycerin prices are expressed in cents per pound, so it is necessary to calculate the pounds of glycerin per gallon. Glycerin price data are from Purchasing Magazine (various issues, accessed via Lexis-Nexis). For the conversion to refined glycerin, using the data in footnote G, Table 1 from Bender (1999), it may be reasonable that 75% of crude glycerin is recoverable as refined glycerin. This omits the cost of glycerin refining.

All prices are converted to dollars per gallon, and the input price of a gallon of biodiesel equals:

$$\frac{[(\text{price of soybean oil}) * 9 + (\text{price of methanol}) - (\text{price of glycerin}) * (0.75)]}{9}.$$

Data for 2-D is the Gulf Coast No. 2 diesel low sulfur spot price, in cents/gallon, from the Energy Information Administration (2004). For these and all other data, the authors examine monthly averages for the period January 1999–February 2003.

Fig. 1 shows the price of petrodiesel and estimated production cost of biodiesel for January 1999–February 2003. Two biodiesel series are presented—one with no methanol recovery and a \$0.40/gallon operating and capital cost, and a second with \$0.20/gallon operating and capital cost and 50% methanol recovery. The latter is a lower bound for biodiesel production costs, while the former is the upper bound assumed in this paper.

Fig. 2 shows the subsidy that would have been required, over the period examined, to make biodiesel cost-competitive with petrodiesel. These data are adjusted for the decreased fuel economy of biodiesel (see below); 1.08 gallons of biodiesel are required to replace one gallon of petrodiesel.

Under these assumptions, for a period of several months at the end of 2000 and the beginning of 2001, biodiesel was cheaper on a per gallon wholesale basis than petrodiesel. For the entire time series the average required subsidies were \$0.2916/gallon and \$0.5385/gallon, for the lower bound and upper bound estimates, respectively.

While subsidies in this range make the price of petrodiesel and biodiesel comparable, there are some product differences that make them imperfect substitutes. All of these are benefits and costs incurred by the consumer, and this analysis either adjusts the required subsidy, or ignores the difference as of secondary importance.

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[13] Construction costs range from \$0.30 to \$0.60/gallon of construction costs, depending on the size of the production facility. If these are multiplied by 0.22 for a 15-year facility lifespan, construction costs amount to \$0.06–\$0.13/gallon.

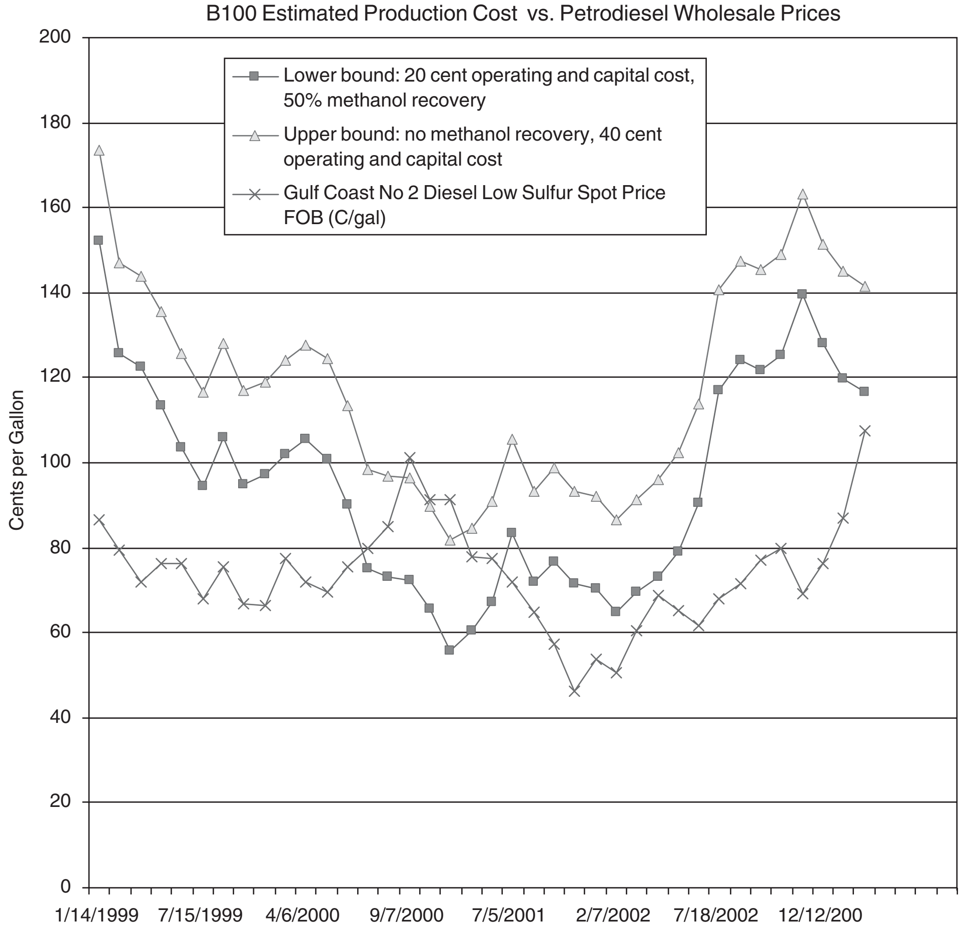

Fig. 1.

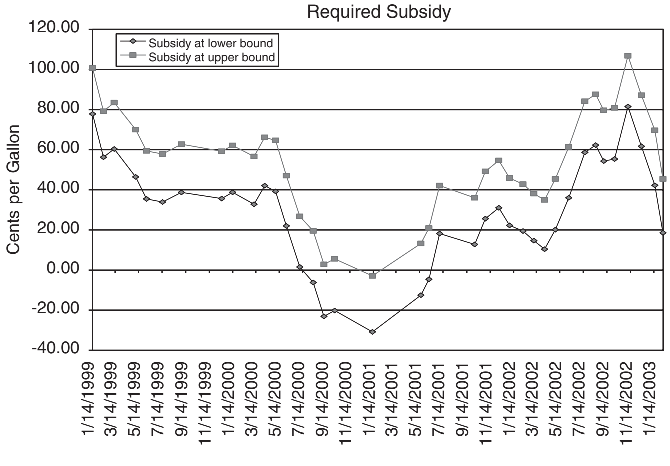

Fig. 2.

One disadvantage of biodiesel is that it has lower energy content than petrodiesel, and as a result, will require more fuel to produce the same power as petrodiesel fuel. The energy content of biodiesel, in conjunction with its high cetane number and greater viscosity than petrodiesel, results in between 2% and 8% lower fuel economy (Gas Technology Institute, 2001). As mentioned above, the per gallon cost of biodiesel has been adjusted by using 1.08gallons of biodiesel for every gallon of petrodiesel.

The following differences between biodiesel and petrodiesel have not been included. Biodiesel's cetane number is higher than that of petrodiesel, generally resulting in smoother engine operation. All diesel fuel injection equipment has some reliance on diesel fuel as a lubricant. Biodiesel has high lubricity. Even when added to petrodiesel fuel in an amount equal to 1–2% by volume, it can convert fuel with poor lubricating properties, such as ultra-low-sulfur diesel fuel, into an acceptable fuel (Office of Technology Access US Department of Energy, 1999).

Diesel fuels are among the heavier components of crude petroleum oils. This gives diesel fuel its high energy content and power, but also causes problems with diesel vehicle operation in cold weather. Even in comparison to petrodiesel, neat biodiesel has poor cold flow properties.

Esters, including biodiesel, are solvents, and there is some concern that solvent activity of biodiesel could dislodge deposits in storage tanks and pipelines, leading to contamination. Similar concerns exist for materials compatibility in diesel engines; in particular, prolonged use of biodiesel may soften or corrode rubber or nitrile components, and may also require more frequent changes of fuel filters.

Biodiesel has some safety advantages over petrodiesel. It has a flash point that is considerably higher than that of petroleum-based diesel fuel, so the fire hazard associated with transportation, storage, and utilization of biodiesel is much less than that of other commonly used fuels. Neat biodiesel is classified as non-toxic to humans, with the lethal dose being 10 times that of table salt. Additionally, as neat biodiesel is biodegradable, it is less damaging than petrodiesel to aquatic environments.

4. Conclusions

The answer to the authors' question, whether subsidies for biodiesel are economically efficient, is a qualified 'yes.' The benefit values provided in section 2 are lower bounds; in particular, the $0.32/gallon alternative case estimate almost certainly understates the true value. The alternative EPA estimate assumptions are extremely conservative, and for technical reasons the benefits of reductions in several pollutants are omitted. While the average 'upper bound' estimate for the subsidy required to make B100 and 2-D cost-competitive is $0.5385/gallon, the authors are confident that, at worst, the external benefits of biodiesel used in non-road equipment equate to the required subsidy.

The economic benefits of biodiesel will decline as existing diesel engines are replaced by those using mandated pollution-reduction technologies. The EPA currently forecasts that this engine replacement will be complete in both on and non-road applications by 2030. This suggests that biodiesel subsidies should be targeted to fuel used in high pollution engines, and should be phased out as the 2030 date approaches.

An efficient subsidy scheme would set the per gallon biodiesel subsidy equal to the external benefits of biodiesel—an amount on the order of 80 cents/gallon using current prices. This would result in biodiesel being produced and marketed only in those situations in which the added costs of producing and marketing biodiesel are less than the external benefits. To whatever extent petrodiesel costs increase without corresponding increases in biodiesel, additional quantities of biodiesel will be drawn into the market as replacement for petrodiesel. Currently subsidies are provided to soybeans when they are converted to biodiesel. A more efficient policy is to subsidize the fuel directly, and allow producers to use whichever inputs are most cost effective.

Would this result in a dramatic shift from petrodiesel to biodiesel? To produce significant amounts of biodiesel, large areas of land would need to be converted to crop production. For example, it would require approximately 231 million acres of soybeans, given recent average yields, to produce enough biodiesel to replace land-based non-road petrodiesel in the US This equates to over 361 thousand square miles—2.2 times the land area of California. It is clearly infeasible to produce this much soy, and use of such large areas of land would restrict other uses such as food and fodder production, and reserves for preservation of biodiversity. If biodiesel were produced at the exclusion of all other uses for vegetable oils and animal fats, annual production would total approximately 6.3% of annual diesel fuel consumption; diesel fuel, in turn, comprises a small portion of annual petroleum consumption.

During the period in which new pollution-reduction technology is being phased in (until 2030), older diesel engines will still contribute substantial pollution, causing economic harm. Biodiesel use in older engines may substantially reduce this harm, and given subsidies equal to the external benefits, the results of this study indicate a significant quantity of biodiesel is likely to be produced.

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