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Authors
Frederick, Stephenie J.
Morrison, Jane L.C.
Small, Kenneth A.

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Stephenie J. Frederick
Jane L.C. Morrison
Kenneth A. Small

Department of Economics and
Institute of Transportation Studies
University of California, Irvine

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Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697-3600, U.S.A.
http://www.its.uci.edu

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ABSTRACT

Methanol offers much promise as an alternative fuel whose combustion produces no sulfates and fewer nitrogen oxides and particulates than diesel. As another advantage, large quantities could be manufactured from domestic coal supplies. Believing that an extensive methanol program might well begin with public transit, we estimate the costs and benefits of converting the bus fleets of California's South Coast Air Basin to methanol. Benefits are based on the reduced mortality attributable to lower sulfates and particulates; costs encompass both bus conversion and replacement. Comparing these benefits with costs over a wide range of methanol prices, we find that conversion to methanol merits further consideration as an anti-pollution strategy. We propose to extend the analysis to additional potential benefits and costs, and to other locales and types of vehicles.

INTRODUCTION

Replacing petroleum-based fuels with methanol has been suggested as a promising way to improve air quality and reduce dependence on imported oil. Methanol burns more cleanly, and it has greater supply flexibility since it can be made from natural gas, coal, or even biomass. Because current technology would allow a fairly easy conversion, the idea has found support among government agencies and environmental groups as well as in the energy and transportation industries.

Unlike diesel fuel or gasoline, methanol is an alcohol. Its cooler flame produces fewer nitric-oxide emissions and so reduces concentrations of derived pollutants such as nitrogen oxides, nitric acid, ozone, and other oxidants. Particulate emissions, a serious problem with diesel engines, are almost eliminated. Because all sulfur content is removed during manufacture, methanol produces no sulfur dioxide and therefore no sulfuric acid, a principal component of acid rain.

The last decade has witnessed extensive investigation of engine design, emissions content, materials compatibility, and methanol production methods. Test vehicles operate at several sites in California, and additional projects are planned or starting up in Jacksonville, Seattle, and New York. Yet there have been few economic evaluations of methanol conversion, and these few have been contradictory or incomplete. The California Institute of Technology's Jet Propulsion Laboratory (O'Toole, et al., 1983) concludes that methanol's market penetration will proceed very slowly, that it can reduce air pollution levels only slightly, and that methanol prices will rise substantially as demand and reliance on domestic feedstocks increase. Gray and Alson (1985) are far more optimistic, suggesting that nationwide vehicle usage of methanol made from high-sulfur coal would improve air quality, revive eastern coal-mining areas, and reduce U.S. dependence on foreign oil.

However, none of these studies attempts to quantify the benefits in economic terms. The question of whether the benefits of methanol use outweigh its costs has been left to somewhat subjective judgment. In order to further the economic evaluation of conversion policies, we therefore develop and present a simple cost-benefit analysis. To make it as clear as possible, we restrict it to a very limited but promising case: methanol conversion of public transit buses in California's South Coast Air Basin. This allows us to demonstrate, in the simplest possible way, the kinds of information and assumptions required to compare benefits and costs. At the same time, we have chosen a case that ought to highlight the advantages of methanol and provide a first test of whether analysis of more complex policies is warranted.

The South Coast Air Basin, hereafter "the Basin," comprises the counties of Los Angeles, Orange, San Bernardino, and Riverside in California. It makes a particularly interesting case study because of its national stature as a pollution center: we reasoned that if methanol use could not provide significant benefits in this heavily-populated and polluted region, it would be unlikely to provide them elsewhere.

Transit buses provide an ideal technology for a first case study: the vehicles are homogeneous, concentrated at a few public enterprises that keep good records, and fueled and maintained at a few central facilities. These same factors also facilitate the methanol conversion process; in addition, buses are an obvious target because they are highly visible polluters that operate in populous areas and emit exhaust directly at street level. A policy designed to abate air pollution might do well to begin with those vehicles that transgress most in the eyes of the public.

We estimate the benefits accruing only from a reduction in the mortality rate. Air pollution, of course, causes many other kinds of harm: it increases nonfatal illness, burns eyes and lungs, soils and damages materials, blights crops, and reduces visibility. There are two reasons for limiting the benefits considered here. First, in this initial analysis we wish to address only the most critical policy issues. Second, several careful empirical studies have established the pernicious effects of air pollution on health and have provided functional relationships that may be used in benefit-cost analysis.

In addition, we have chosen to examine only two pollutants: total suspended particulates (TSP) and sulfur oxides (SOx). These pollutants can be traced reasonably well from tailpipe to lungs, their health effects are known, and their emissions are virtually eliminated in methanol-fueled engines. Reduction of nitrogen oxides (NOx) may be an equally important feature of methanol buses, but NOx health effects occur through a complicated path of photochemical changes in the atmosphere that is more difficult to trace.

For simplicity, we analyze a steady state in which all buses are methanol fueled, one twelfth being replaced each year due to normal attrition; and in which population, bus mileage, and value of pollution reduction remain constant. Of course, many things would change over time. Most of these would make methanol conversion more favorable: increased population and higher incomes would increase the benefits, whereas improved technology will almost certainly reduce the extra costs of equipping buses for methanol use. We refrain from speculating on future fuel price differentials. Of course, the methodology makes no attempt to address transition problems with methanol conversion, or to compare it with alternative ways of reducing emissions either now or in the future.

Our analysis, then, chooses a particularly favorable case for methanol but analyzes it conservatively. Since our results show benefits exceeding costs over a significant range of assumptions and fuel costs, we feel confident in concluding that conversion of transit buses in Southern California is a promising public policy. We also conclude that analysis of other conversion strategies, involving other vehicles and other metropolitan areas, is warranted. The methodology presented here provides a sound basis for extending the analysis to such cases, and for refining it to include additional types of benefits.

DATA & METHODOLOGY

Pollution Reduction

The first step in our analysis is to establish the percentage reductions in ambient-air TSP and SOx concentrations attributable to conversion to methanol fuel. This requires knowing the emissions per mile of each kind of bus, the total annual miles traveled by transit buses in the Basin, and the total emissions from all sources in the Basin. The results are in Table 1. Since buses account for only a tiny fraction of emissions in the Basin, conversion would reduce ambient air concentrations by a miniscule 0.43 percent of TSP and 0.226 percent of sulfates.

TABLE 1

REDUCTIONS IN AMBIENT-AIR CONCENTRATIONS OF PARTICULATES AND SULFATES DUE TO METHANOL USE

Type of Bus	Per-Vehicle Emissions (Grams/Mi) [a]	Total Annual Emissions (1000's of Kilograms) [b]	Percent Reduction in Ambient-Air Concentrations Compared to Diesel [c]
		PARTICULATES	
Diesel	6.275	948.77	
Methanol M.A.N	0.0644	9.74	0.430 %
Methanol G.M.	0.6275	94.88	NA [d]
		SULFUR OXIDES	
Diesel	0.81	122.5	
Methanol M.A.N.	0	0	0.226 %
Methanol G.M.	0	0	N/A

[a] Particulate emissions are from Ullman and Hare (1986); Grade 2 diesel fuel assumed in diesel engine. SOx emissions are derived from the sulfur content of the fuel used, which is taken to be 0.05 percent by weight, the maximum now permitted by the State of California for buses in the Basin. We assumed fuel density of 7.163 lb./gallon; fuel consumption of 1 gallon per 4 miles; and sulfur oxide molecules containing 50% sulfur by weight, as is the case for SO_2. (Details are presented in the appendix.)

[b] Per-vehicle emissions [a] x total annual vehicle miles in 1984 (151.2 million, from Wachs & Levine, (1985)).

[c] Total annual emissions (diesel buses) minus total annual emissions (methanol buses), result divided by the total annual emissions from all sources in 1983 (South Coast Air Quality Management District, 1986) which is 218.6×10^6 Kg for particulates and 54.1×10^6 for sulfur oxides.

[d] GM data are not used in our analysis because of the comparatively poor performance of the GM methanol bus, which is a preliminary prototype. In the testing performed by Ullman, Hare, and Baines, the GM's SOx emissions and a large portion of its particulate emissions were apparently due to engine oil scavenged into the exhaust.

Mortality Reduction

The second step is to establish the effect on the mortality rate of a unit decrease in the level of each pollutant. The effect of these pollutants has been established by the detailed regression analysis of Lave and Seskin (1977) and Chappie and Lave (1982) using mortality and pollution data from more than 100 U.S. metropolitan areas; and by numerous epidemiological studies reviewed and extended by Ozkaynak and Spengler (1985). The latter authors conclude that as much as six percent of the mortality in urban areas can be attributed to particulates and to sulfates, a derivative of sulfur oxides (Ozkaynak & Spengler, 1985, p. 54).

The precise relationship between emissions and ambient concentrations of particulates and sulfates is not one to one (though it is far more straightforward than for nitrogen oxides and ozone, which is one reason for omission of the latter here). In the case of particulates, recent evidence suggests that it is mainly fine particles that cause health damage (Ozkaynak & Spengler, 1985), whereas the data used by Lave and Seskin do not distinguish by particle size. Since a high proportion of the particulates emitted by diesels are fine, we probably underestimate their harmful effects by ignoring that feature; this belief is supported by a replication of the Lave and Seskin work for a more recent year, which shows that where fine particles are a smaller proportion of all particulates, a weaker relationship exists between particulates and mortality.

In the case of sulfur oxides, most of these emissions are transformed into sulfates through atmospheric reactions. We use the common assumption that atmospheric sulfate concentrations are proportional to sulfur oxide emissions, an assumption with some support from atmospheric simulation models, at least in the case of the clear weather that characterizes Southern California (Seigneur, Saxena, & Roth, 1984). Note that even though sulfates are a component of particulates, we can treat them separately without double counting because they are also treated as separate pollutants in Chappie and Lave's statistical work.

The most comprehensive estimates of the quantitative relationship are those by Chappie and Lave (1982). This remains the most careful and complete study of the effects of air pollution on mortality in actual urban populations, and includes data from three different years: 1960, 1969, and 1974. For each pollutant, we averaged the three estimated elasticities of mortality with respect to concentration, one for each of the three years (Chappie & Lave, 1982, p. 349). We then adjusted this average downward by .0303 (sulfate-elasticity) and .0234 (particulate-elasticity) on the basis of the difference in the 1974 results when an improved socioeconomic variable became available (Chappie & Lave, 1982, p. 352); the assumption is that including that variable in the earlier years would have made the same difference to the results for those years. (Further details are provided in an appendix available from the authors.) This procedure is conservative in that without this adjustment, the sulfate- and particulate-elasticities would have been 61 percent and 197 percent higher, respectively; or, if we had just used the best regression estimates from the 1974 data, ignoring the earlier years, the sulfate-elasticity would be about twice as high and the particulate-elasticity would vanish, with a slight overall increase in the benefits estimated in the sections below.

The resulting changes in mortality rates and in total mortality are shown in Table 2.

The Value of Mortality Reduction

The third step is to express in dollars the benefits from reducing the mortality rate. This requires multiplying the reduced mortality rate by a dollar value assigned to the reduction in risk of death. The assignment of this explicit value is crucial since it allows the quantification of benefits; hence we digress to present the conceptual basis with some care.

Many studies have stumbled on the apparent paradoxes inherent in placing a dollar value on policies that save lives. Discounted value of lifetime earnings has often been used, despite the obvious defects that most earnings are for the person's own consumption and that this measure places no value on the lives of retired people.

We follow here the now widely-accepted concept of willingness to pay: Looking at actual behavior, how much do people pay to reduce hazards, or how much extra compensation do they demand for working under hazardous conditions (Mishan, 1971; Thaler & Rosen, 1975; Marin & Psacharopoulos, 1982). Rather than ask the value of saving an identifiable person's life, we ask the value of reducing the ongoing risk of fatality that everyone faces. This is more consonant with the way in which policies actually affect people, since most policies, including air-pollution control, make very small changes in the mortality risk facing large numbers of people.

For example, suppose that a clean-air policy reduced everyone's annual risk of dying from 1 in 100, to 0.99 in 100. How much would the

TABLE 2

REDUCTION IN MORTALITY DUE TO METHANOL CONVERSION

Pollutant	Elasticity of Mortality with Respect to Ambient-Air Concentrations [a]	Reduction in Total Mortality Rate (Annual Deaths per Million) [b]	Reduction in Annual Deaths in Los Angeles Basin [c]
Particulates	0.0119	0.41	4.36
Sulfates	0.0500	0.91	9.63
Total	0	1.32	13.99

[a] Percentage change in total mortality rate, divided by percentage change in ambient-air pollutant concentration. See text for sources.

[b] Elasticity times pollutant reduction from Table 1, times total mortality rate in South Coast Air Basin (8025 per million, computed from data provided by the Departments of Public Health of Los Angeles, Orange, San Bernardino, and Riverside Counties).

[c] Reduction in total mortality rate times population of Los Angeles Basin (10.62 million).

average person be willing to pay for such a change? This is an answerable question, because we can observe people making choices involving risk changes of this magnitude, such as purchasing safety equipment or choosing among jobs involving various degrees of hazard.

(In fact, changing jobs from one of average occupational risk to one of no occupational risk involves a reduction of about this amount, .01 in 100.) If such observed behavior indicates that people are willing to pay $800 per year for this reduction (or to forego wages of that amount), we say that the "willingness to pay for a reduction in risk from .0100 to .0099 is $800."

In a community of 10,000 people, such a risk-reduction policy lowers the expected annual death rate from 100 to 99. We might say, somewhat loosely, that it saves one life per year. Since in the aggregate these people are willing to pay 10,000 x $800 = $8 million per year for the risk reduction, we sometimes say that the "value of life is $8 million." But this is just shorthand for the more precise statement above. It does not mean that Sara Jones's life is "worth" $8 million; it means that 10,000 people are willing to pay $800 each for a reduction in risk that, in aggregate, will probably save one life.

Kahn (1986) discusses the methodological weaknesses and strengths of some of the best known attempts to estimate people's willingness to pay for risk reduction. She presents a strong case for relying on the estimates derived from labor-market analyses. For example, estimates based on markets for safety equipment have ignored the inconvenience associated with installation, maintenance, and use of the safety devices.

Kahn also presents a comprehensive analysis of sources of bias in the labor-market studies, and thereby offers a convincing basis for choosing estimates by Olson (1981) and by Viscusi (1979; 1980) that are among the highest of the various studies. Kahn in particular advocates using the "value of life" obtained by Olson for a combined sample of union and nonunion workers, which is $8 million in 1984 dollars. The subsequent and widely cited work by Viscusi (1983) also results in estimates of comparable magnitude.

Nevertheless, current practice in government analyses of safety practices uses much lower values, typically \$0.5 to \$1.5 million, resulting from the earlier studies and from the method of present discounted value of lifetime earnings. In our analysis we use both figures, \$1.5 and \$8 million, to test the sensitivity of our results. At the higher of these figures, the mortality reduction shown in Table 2 is valued at \$113 million annually, of which 69 percent is due to reduced sulfates and the rest to reduced particulates.

Implicit in this calculation is a value per kilogram of emissions removed for each pollutant, obtained by valuing the reduced deaths shown in Table 2 (last column) at this value, and dividing by the corresponding emissions reductions shown in Table 1 (middle column). At the higher value of mortality reduction, each kilogram of particulates or sulfur oxides emitted costs society \$37 or \$629 respectively: startling figures considering that a typical diesel bus emits a kilogram of sulfur oxides in about two weeks (1370 miles), and of particulates in less than two days (159 miles).

<u>Costs</u>

The fourth step is to calculate the costs of the methanol strategy. There are two main costs: a capital expenditure for conversion, and an operating expenditure for fuel.

Building methanol buses is relatively expensive because they are made as small-quantity prototypes. For example, Seattle Transit paid \$175,000 each for ten methanol buses while paying only \$126,000 each for its new diesels. But General Motors testified to Congress in 1984 that annual production of 250-300 methanol buses could bring the cost differential down to $6,000 to $7,000 (Gray & Alson, 1985, p. 125); this seems a more pertinent estimate for our study. This is also more consistent with the evidence from Florida's retrofitting experiment, where the Florida Department of Transportation estimated the actual cost of converting an existing bus, once substantial scale is attained, at $7,500-$10,000 (U.S. General Accounting Office, 1986, p. 73). However, to accommodate both possibilities and to remain conservative, we have adopted a range of $6,500 to $49,000 as the additional cost of replacing a diesel with a methanol bus.

Estimating the average life of a transit bus at twelve years, we assume that the Basin fleets will replace one-twelfth of their vehicles annually. Multiplying this number (369) by $6,500-$49,000 gives a range of the annual additional capital cost of purchasing methanol rather than diesel buses (shown in Table 3).

The instability of the world oil market implies instability in the price of diesel, increasing or diminishing its present price advantage over methanol. The current price of methanol reflects a worldwide oversupply, but a substantial increase in demand for methanol could drive its price up. In light of these uncertainties, we present our results as a function of price differentials between diesel and methanol fuels.

It is convenient and common to state the fuel prices on the basis of equivalent energy content rather than equivalent volume. A gallon of methanol contains fewer Btu (57,000) than a gallon of diesel (128,000), and so the price per gallon of methanol is multiplied by 128,000/57,000 to obtain a price per 128,000 Btu of fuel. No further adjustment is

TABLE 3

REPLACING DIESEL WITH METHANOL BUSES:
ANNUAL ADDITIONAL COST

Additional Cost per Bus Replaced	Average Bus Lifetime (Years)	Total Annual Additional Cost [a] ($ millions)
$ 6,500 [b]	12 [c]	$ 2.40
49,000 [d]	12	18.08

a Additional cost per bus x total number of transit buses in the South Coast Air Basin (4,432), result divided by average life of transit bus.

b Gray and Alson (1985), p. 125.

c Wachs and Levine (1985).

d Based on actual prices paid by Metro Transit, Seattle, Washington in 1986.

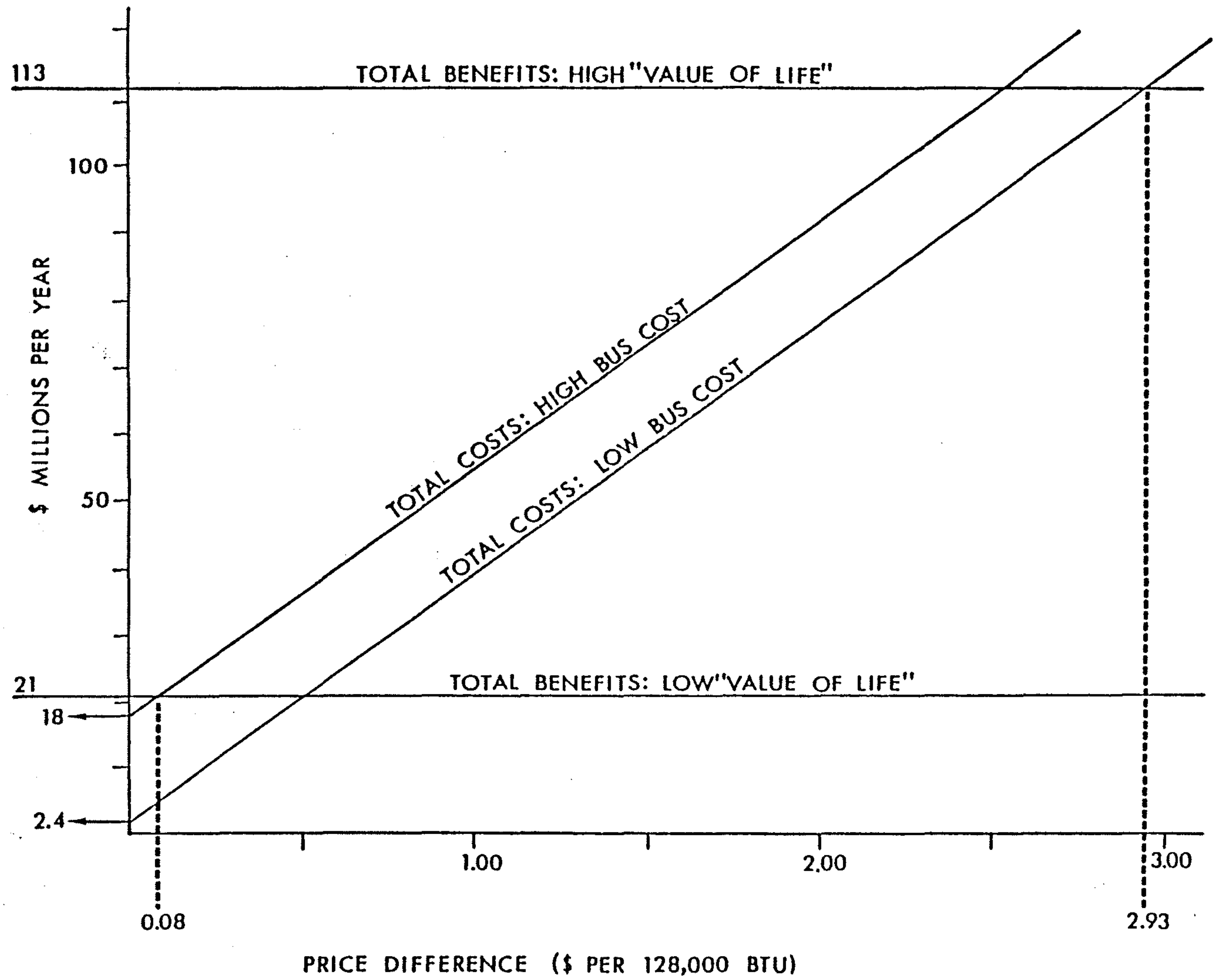
required because the fuel efficiencies of methanol and diesel engines are comparable (U.S. Environmental Protection Agency, 1982). The total annual fuel-cost differential is found by multiplying the price differential, so stated, by the annual number of gallons of diesel fuel currently burned by all of the transit buses in the Basin (37.8 million).

It should be noted that some costs are neglected in our analysis. Since methanol is toxic, burns with an invisible flame, and produces harmful vapors, there may be an additional cost to handle it safely. In addition, because of the discrepancy in energy content, buses will require twice as many gallons of methanol as diesel, which will increase the costs of refueling and storage (costs of larger fuel tanks on the buses themselves are already taken into account). However, these and similar costs appear to be relatively small.

RESULTS

The results are portrayed in Figure 1 as functions of the excess of methanol price over diesel price. There are two alternative assumptions on "value of life" ($8 million and $1.5 million), leading to two alternative estimates of benefits, shown as the <u>horizontal</u> lines. There are two alternative assumptions on differential bus acquisition cost ($6,500 and $49,000), leading to two alternative estimates of costs, shown as the <u>sloped</u> lines. Costs of course rise as the methanol price becomes larger relative to diesel.

It is clear that the alternative assumptions shown make a great deal of difference to the conclusion. We have argued that the higher "value of life" estimate ($8 million) and the lower capital-cost estimate ($6,500) are the more accurate ones. If that is true, benefits exceed costs even when methanol prices (per energy content of a gallon of diesel) are as much as $2.93 higher than diesel. Over the past year, the average price differential has been $1.00, at which point benefits exceed costs by a ratio of three to one.



BENEFIT-COST ANALYSIS IN TERMS OF
METHANOL-DIESEL PRICE DIFFERENCE

FIGURE 1

On the other hand, the comparison at the lower estimate of "value of life" is not as favorable: Only if the price difference drops to $0.50 do benefits outweigh costs, assuming General Motors' estimate of $6,500 as the extra cost of building a methanol-fueled bus. Many possible benefits of methanol have been omitted; for example, methanol use in buses would reduce NOx emissions as well as weaken the impact of direct street-level exhaust. Neither have we addressed the advantages of improved visibility and lessened morbidity, soiling, materials damage, and crop damage. These must all be taken into account in deciding whether a policy of methanol conversion would still be worthwhile given the less favorable assumptions on the value of mortality reduction.

CONCLUSION

Our first cut at a cost-benefit analysis of a methanol conversion strategy leads to several tentative conclusions. On the substantive side, there is real promise for a policy of converting transit buses in the Los Angeles basin. Given recent evidence about people's willingness to pay for lower mortality risk, the policy is justified over a wide range of methanol prices. Using the older estimates of "value of life," the case is not as clear cut. But both evaluations are quite conservative because the analysis was limited to the negative effects of only two pollutants--sulfates and particulates--and examined only one positive effect, the change in mortality.

In terms of a research agenda, then, three sources of uncertainty need further work. One is the effect of methanol use on other pollutants, particularly photochemical oxidants; these are often thought to cause the worst problem in the South Coast Air Basin, so a careful analysis of the potential for reducing them through lessened nitric-oxide emissions might show considerable benefits.

The second is the possible existence of important benefits from reduced sickness, reduced materials and crop damage, and improved visibility.

The third is the question of whether the same benefits can be attained in other ways such as by using diesel fuel with less sulfur and aromatic hydrocarbons; or by fitting buses with particulate traps and catalytic converters. The work of Weaver and his colleagues (Weaver, Klausmeir, & Erickson, 1986; Weaver, Miller, Johnson, & Higgins, 1986) suggests that starting with diesel fuel typical of the United States, adopting a low-sulfur and low-aromatic fuel (similar to that taken as our baseline and already required in the Los Angeles basin) is the most cost-effective means of reducing particulate emissions. They also suggest that in terms of the incremental cost of making further particulate reductions, particulate traps compare favorably with methanol. An extension of our methodology could provide further evidence on the comparative merits of these strategies, taking into account more pollutants than did Weaver.

A deeper policy question underlying our analysis of transit buses is what benefits might be achieved from a wider methanol conversion strategy including cars, trucks, and perhaps stationary sources as well. The answer cannot be confidently predicted: Whether the favorable case for methanol extends to other types of vehicles or other locations is likely to depend critically on extensions of the research methodology.

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APPENDIX

In order to facilitate the replication of any part of this analysis, we provide this detailed derivation of variables used in this analysis together with precise methods used to extrapolate information from various sources.

1. South Coast Air Basin Public-Transit Fleets, 1984.

(from Wachs & Levine, 1985)

Total fleet: 4,444 buses, less 12 which use gasoline, leaves 4,432 diesel-fueled buses.

Total annual diesel bus miles driven:

	145,430,406	(Commerce and Long Beach not included)	
+	203,800	Commerce	
+	5,928,000	Long Beach	
-	363,241	miles driven by gasoline-fueled buses	
	151,198,965		(1)

2. Derivation of Sulfur Oxide Emissions and Their Reduction.

(for Table 1)

1 gallon of #2 diesel weighs 7.163 lbs. and contains a fraction, 0.0005 sulfur by weight (assuming fuel is at exactly the sulfur limit set by the state for Southern California.)

Diesel buses average 4 MPG of fuel.

Therefore the weight of elemental sulfur per mile is:

$$0.0005\ (7.163\ \text{lb/gal})\ (453.592\ \text{gm/lb})\ /\ (4\ \text{miles/gal}) = 0.406\ \text{grams/mile} \qquad (2)$$

Approximately 90 percent of the sulfur emitted is in the form of SO_2 (Butler, 1979, p. 79). Assume that the rest is in the form of molecules with the same average atomic weight.

Atomic weight of Sulfur: 32

Atomic weight of Oxygen: 16

Therefore:

Emissions of sulfur oxides (SO_x) per mile =
(.406 gm S/mile) x [(32+2 (16))/32] x (gm SO_x/gm S) =
0.81 gm/mile (3)

3. Adjustments to the Elasticity of Mortality with Respect to Ambient Concentrations.

Define:

TMR = Total mortality rate

$\overline{TMR}$ = Mean of TMR

NMR = Natural mortality rate

$\overline{NMR}$ = Mean of NMR

SO_4 = Sulfates

TSP = Particulates

Estimated elasticities of TMR with respect to SO_4 and TSP, (Chappie & Lave, 1982, p. 349):

Year	SO_4 Elasticity	TSP Elasticity	
1960	.059	.056	
1969	.050	.044	
1974	.132	.006	
Average	.0803	.0353	
Corrected Average	.0500	.0119	(4)

Since the elasticity for each year and each pollutant is a sum of three separate estimated elasticities, standard errors cannot be calculated from the reported data.

The "corrected average" is obtained as follows. Additional 1974 regression results were reported with a number of additional variables most importantly including an education variable that was not available in the earlier years (Chappie & Lave, 1982, p. 352, column 2-7). The SO_4- and TSP-elasticities with these changes were 0.111 and -0.019. Hence some of the effects measured in earlier years may have been due to spurious correlation with these omitted variables. Although we think it is important to reduce the variance in any one year's estimate by averaging over all three years, the differential between the 1974 elasticities estimated with and without socioeconomic variables provides a reasonable estimate of the omitted-variable bias that exists in each of the three years' results listed above. Hence we assume that the bias is equal to the difference between the estimated elasticity for 1974 with and without the inclusion of the socioeconomic variables (Chappie and Lave, 1982, p. 352, Table 2, equations 2.1 and 2.7). The former is (0.111), as listed above. The latter is (0.132), for the elasticity of the natural mortality rate; since the other components of the total mortality rate (accidents, homocide, suicide) are unaffected by pollution, this is converted to elasticity of TMR by multiplying by

$\overline{NMR}/\overline{TMR} = 794.7 / 867.4$. Hence,

$$\text{Bias in S04-elasticity} = 0.132 - (0.111)(794.748)/867.4$$
$$= 0.0303$$
$$\text{Corrected average S04-elasticity} = 0.0803 - 0.0303 = .0500 \qquad (5)$$

Similarly,

$$\text{Bias in TSP-elasticity} = 0.006 - (-0.019)(794.748)/867.4$$
$$= 0.0234$$
$$\text{Corrected average TSP-elasticity} = 0.0353 - .0234 = .0119 \qquad (6)$$

4. Value of Reduced Emissions.

Table 2, last column, gives the expected reduction in number of deaths due to the emissions reduction given by the difference between "Diesel" and "Methanol M.A.N" in Table 1. This emissions reduction, multiplied by the "value of life" gives the following:

Benefits per Amount Emissions Removed
($/Kilogram)

	Most Probable "value of life"	Low "value of life"	
Particulates	$ 37.1	$ 7.0	
Sulfur Oxides	629	118	(7)

Note: An equivalent and more direct calculation is as follows:

$$\text{Benefits/Kg Emissions} = [V_L \times \Delta(\text{TMR}) \times (\text{POP})] / \Delta E \qquad (8)$$

Our linear assumptions relating ambient concentrations to emissions imply:

$$\Delta C / \Delta E = C / E \qquad (9)$$

where V_L is "value of life", C is ambient concentrations, TMR is total mortality rate, POP is total population, E is total emissions of that pollutant, and Δ means "change in." Therefore equation (8) becomes:

$$\begin{aligned}\text{Benefits/Kg Emissions} &= V_L \times [\, \Delta(\text{TMR}) \,/\, \Delta C] \times C/E \times (\text{POP}) \\ &= V_L \; [C \,/\, (\text{TMR}) \times \Delta(\text{TMR}) \,/\, \Delta C] \\ &\quad \times [(\text{TMR}) \times (\text{POP})] \,/\, E \qquad (10)\end{aligned}$$

The term $[C \,/\, (\text{TMR}) \times \Delta(\text{TMR}) \,/\, \Delta C]$ is the elasticity given in Table 2, column a. Aside from rounding error, this gives the same results, using TMR = 8025 per million; POP = 10.62 million; and E = 54.1 million Kg/year for sulfur oxides and 218.6 million kg/year for TSP.

Note that if we were to use the unadjusted average of the three estimated elasticities of mortality with respect to pollutants (see text), benefits from methanol conversion would be about twice as high. If we were to use the unbiased 1974 results only, benefits from particulate control would vanish (indeed become negative), but those from sulfate control would be more than doubled, leaving overall benefits slightly higher. Hence, we have used the most conservative of the available reasonable alternatives.

REFERENCES

Butler, John D. Air Pollution Chemistry. London and New York: Academic Press, 1979.

Chappie, Mike, and Lester B. Lave. "The Health Effects of Air Pollution: A Reanalysis," Journal of Urban Economics, 12 1982, pp. 346-376.

Gray, Charles L., Jr., and Jeffrey A. Alson. Moving America to Methanol. Ann Arbor, MI: University of Michigan Press, 1985.

Kahn, Shulamit. "Economic Estimates of the Value of Life." IEEE Technology and Society Magazine, Vol. 5, June 1986, pp. 24-31.

Lave, Lester B., and Eugene P. Seskin. Air Pollution and Human Health. Baltimore, MD: The Johns Hopkins University Press, 1977.

Marin, Alan, and George Psacharopoulos. "The Reward for Risk in the Labor Market: Evidence from the United Kingdom and a Reconciliation with Other Studies," Journal of Political Economy, Vol. 90, No. 4, 1982, pp. 827-853.

Mishan, E.J. "Evaluation of Life and Limb: A Theoretical Approach," Journal of Political Economy, Vol. 79, 1971, pp. 687-705.

Olson, Craig. "An Analysis of Wage Differentials Received by Workers on Dangerous Jobs," The Journal of Human Resources, Vol. 16, 1981, pp. 167-185.

O'Toole, R., et al. California Methanol Assessment, Volume 1: Summary Report. JPL Publication No. 83-18. Pasadena, CA: Jet Propulsion Laboratory and California Institute of Technology, Division of Chemistry and Chemical Engineering, March 1983.

Ozkaynak, Haluk, and John D. Spengler. "Analysis of Health Effects Resulting from Population Exposures to Acid Precipitation," Environmental Health Perspectives, Vol. 63, 1985, pp. 45-55.

Seigneur, Christian, Pradeep Saxena, and Philip M. Roth. "Computer Simulations of the Atmospheric Chemistry of Sulfate and Nitrate Formation," Science, Vol. 225, 7 September 1984, pp. 1028-1030.

South Coast Air Quality Management District. Draft 1983 Emissions Inventory, South Coast Air Basin. Working Paper No. 1, 1987 Air Quality Management District revision. El Monte, California: May 1986.

Thaler, Richard, and Sherwin Rosen, "The Value of Saving a Life: Evidence from the Labor Market," in Nestor J. Terleckyj, ed.: Household Production and Consumption. New York: Columbia University Press, 1975, pp. 265-298.

Ullman, Terry L., Charles T. Hare, and Thomas M. Baines. Emissions from Two Methanol-Powered Buses. (SAE Technical Paper Series, No. 860305) 1986.

U.S. Environmental Protection Agency. Preliminary Perspective on Pure Methanol Fuel for Transportation. Report No. EPA 460/3-83-003. Ann Arbor, MI: U.S. Environmental Protection Agency, Office of Mobil Sources, Emission Control Technology Division, September 1982.

U.S. General Accounting Office. Alternative Fuels: Status of Methanol Vehicle Development. Briefing Report to the Chairman, Subcommittee on Fossil and Synthetic Fuels, Committee on Energy and Commerce, U.S. House of Representatives. Report No. GAO/RCED-87-10BR. Washington, DC: U.S. General Accounting Office, October 1986.

Viscusi, W. Kip. Employment Hazards: An Investigation of Market Performance. Cambridge, MA: Harvard University Press, 1979.

Viscusi, W. Kip. Risk by Choice. Cambridge, MA: Harvard University Press, 1983.

Viscusi, W. Kip. "Unions, Labor Market Structure, and the Welfare Implications of the Quality of Work," Journal of Labor Research. Vol. 1, Spring 1980, pp. 175-192.

Wachs, Martin, and Ned Levine. Vehicle Fleets in the South Coast Air Basin. Survey performed for the South Coast Air Quality Management District, University of California, Los Angeles, 1985.

Weaver, Christopher S., Robert J. Klausmeir, and Lynn M. Erickson. Feasibility of Retrofit Technologies for Diesel Emissions Control. (SAE Technical Paper Series, No. 860296) Warrendale, PA: Society of Automotive Engineers, 1986.

Weaver, Christopher S., Craig Miller, William A. Johnson, and Terrence S. Higgins. Reducing the Sulfur and Aromatic Content of Diesel Fuel: Costs, Benefits, and Effectiveness for Emissions Control. (SAE Technical Paper Series, No. 860622) Warrendale, PA: Society of Automotive Engineers, 1986.