Converting Transit to Methanol: Costs and Benefits for California's South Coast Air Basin

STEPHENIE J. FREDERICK, JANE L. C. MORRISON, AND KENNETH A. SMALL

Methanol offers much promise as an alternative fuel whose combustion produces no sulfates and fewer nitrogen oxides and particulates than diesel fuel. Another advantage is that large quantities could be manufactured from domestic coal supplies. On the basis of the assumption that an extensive methanol program might well begin with public transit, the costs and benefits of converting the bus fleets of California's South Coast Air Basin to methanol are estimated. Benefits are based on the reduced mortality attributable to lower sulfates and particulates; costs encompass both bus conversion and replacement. When these benefits are compared with costs over a wide range of methanol prices, conversion to methanol is found to merit further consideration as an antipollution strategy. It is proposed that the analysis be extended to additional potential benefits and costs and to other locales and types of vehicles.

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 has greater supply flexibility because 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 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 *(1)* 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 *(2)* 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. To further the economic evaluation of conversion policies, a simple cost-benefit analysis is therefore developed and presented. To make it as clear as possible, it is restricted to a very limited but promising case: methanol conversion of public transit buses in California's South Coast Air Basin. This allows a demonstration, in the simplest possible way, of the kinds of information and assumptions required to compare benefits and costs. At the same time, a case is chosen 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 referred to as "the Basin," includes the urbanized parts of Los Angeles, Orange, San Bernardino, and Riverside Counties in California. The Basin makes a particularly interesting case study because of its national stature as a pollution center; the reason being 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.

The benefits accruing only from a reduction in the mortality rate are estimated. 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, only the most critical policy issues are addressed. 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.

Institute of Transportation Studies, University of California, Irvine, Irvine, Calif. 92717.

In addition, only two pollutants are examined: total suspended particulates (TSP) and sulfur oxides (SO_x). 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 (NO_x) may be an equally important feature of methanol buses, but NO_x health effects occur through a complicated path of photochemical changes in the atmosphere that is more difficult to trace.

For simplicity, the authors analyzed a steady state in which all buses are fueled with methanol, one-twelfth being replaced each year because of 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. The authors refrained from speculation on future fuel price differentials. 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.

The analysis, then, chooses a particularly favorable case for methanol but analyzes it conservatively. Because the results show benefits exceeding costs over a significant range of assumptions and fuel costs, conversion of transit buses in Southern California appears to be a promising public policy. Also, 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.

TABLE 1 REDUCTIONS IN AMBIENT AIR CONCENTRATIONS OF PARTICULATES AND SULFATES AS A RESULT OF METHANOL USE

Type of Bus	Per-Vehicle Emissions (grams/mi)[a]	Total Annual Emissions (000s kg)[b]	Percent Reduction in Ambient-Air Concentration Compared to Diesel[c]
Particulates			
Diesel	6.275	948.77	
Methanol (M.A.N.)	0.0644	9.74	0.430%
Methanol (GM)	0.6275	94.88	NA[d]
Sulfur Oxides			
Diesel	0.81	122.5	
Methanol (M.A.N.)	0	0	0.226%
Methanol (GM)	0	0	NA

[a]Particulate emissions are from Ullman et al. *(19)*; Grade 2 diesel fuel assumed in diesel engine. SO_x 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. Fuel density is 7.163 lb/gal; fuel consumption is 1 gal/4 mi; and sulfur oxide molecules contain 50 percent sulfur by weight, as is the case for SO_2. (Details are presented in an appendix available from the authors.)
[b]Per-vehicle emissions [a] x total annual vehicle miles in 1984 [151.2 million *(20)*].
[c]Total annual emissions (diesel buses) minus total annual emissions (methanol buses) result divided by the total annual emissions from all sources in 1983 *(21)*, which is 218.6×10^6 kg for particulates and 54.1×10^6 for sulfur oxides.
[d]GM data are not used in the analysis because of the comparatively poor performance of the GM methanol bus, which is a preliminary prototype. In the testing performed by Ullman et al. *(19)*, the GM's SO_x emissions and a large portion of its particulate emissions were apparently caused by engine oil scavenged into the exhaust.

DATA AND METHODOLOGY

Pollution Reduction

The first step in the analysis is to establish the percentage reductions in ambient air TSP and SO_x concentrations attributable to conversion to methanol fuel. This requires knowing the emissions per mile of each type 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 given in Table 1. Because buses account for only a tiny fraction of emissions in the Basin, conversion would reduce ambient air concentrations by a minuscule 0.43 percent of TSP and 0.226 percent of sulfates.

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 *(3)* and Chappie and Lave *(4)* who used mortality and pollution data from more than 100 U.S. metropolitan areas, and by numerous epidemiological studies, reviewed and extended by Ozkaynak and Spengler *(5)*. The latter authors conclude that as much as 6 percent of the mortality in urban areas can be attributed to particulates and to sulfates, a derivative of sulfur oxides (*5*, 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 *(5)*, whereas the data used by Lave and Seskin do not distinguish by particle size. Because a high proportion of the particulates emitted by diesels are fine, their harmful effects are probably underestimated 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. The common assumption is that atmospheric sulfate concentrations are proportional to sulfur oxide emissions. This assumption has some support from atmospheric simulation models, at least in the case of the clear weather that characterizes Southern California *(6)*. Note that even though sulfates are a component of particulates, they can be treated 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 *(4)*. Their work remains the most careful and complete study of the effects of air

pollution on mortality in actual urban populations and includes data from 1960, 1969, and 1974.

For each pollutant, the three estimated elasticities of mortality with respect to concentration were averaged, one for each of the three years (*4*, p. 349). This average was then adjusted downward by 0.0303 (sulfate elasticity) and 0.0234 (particulate elasticity) on the basis of the difference, in the 1974 results, caused by adding a socioeconomic variable that was unavailable in the earlier years' data (*4*, p. 352). The assumption is that including that variable in the earlier years would have made the same difference in 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 be 61 and 197 percent higher, respectively. Alternatively, if the best regression estimates from the 1974 data were used, 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 next sections.

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

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 (8,025 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).

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 because it allows the quantification of benefits; hence it is necessary to 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.

Here the now widely accepted concept of willingness to pay is followed: How much do people pay to reduce hazards, or how much extra compensation do they demand for working under hazardous conditions (*7–9*)? 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 because most policies, including those concerned with 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 average person be willing to pay for such a change? This is an answerable question, because people can be observed 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), then the willingness to pay for a reduction in risk from 0.0100 to 0.0099 is $800.

In a community of 10,000 people, such a risk-reduction policy lowers the expected annual death rate from 100 to 99. It could be stated, somewhat loosely, that it saves one life per year. Because in the aggregate these people are willing to pay 10,000 × $800 = $8 million/year for the risk reduction, it could be said that the "value of life is $8 million." This is just shorthand, however, for the more precise earlier statement. 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 (*10*) 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 (*11*) and Viscusi (*12, 13*) 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 (*14*) 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 this analysis both figures, $1.5 and $8 million, are used to test the sensitivity of the results. At the higher of these figures, the mortality reduction given in Table 2 is valued at $113 million annually, of which 69 percent results from reduced sulfates and the remainder from reduced particulates.

Implicit in this calculation is a value per kilogram of emissions removed for each pollutant, obtained by valuing the reduced deaths given in Table 2 (last column) at this value and dividing by the corresponding emissions reductions given 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 2 weeks (1,370 mi) and of particulates in less than 2 days (159 mi).

Costs

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 manufactured in small quantities. For example, Seattle Transit paid $175,000 each for 10 methanol buses while paying only $126,000 each for new diesels. General Motors, however, in testimony to Congress in 1984, indicated that annual production of 250 to 300 methanol buses could bring the cost differential down to between $6,000 and $7,000 (*2*, p. 125). This appears to be a more pertinent estimate for this study. This estimate is also more consistent with the evidence from Florida's retrofitting experiment in which the Florida Department of Transportation estimated the actual cost of converting an existing bus, once substantial scale is attained, at $7,500 to $10,000 (*15*, p. 73). However, to accommodate both possibilities and to remain conservative, a range of $6,500 to $49,000 is adopted here as the additional cost of replacing a diesel with a methanol bus. In estimating the average life of a transit bus at 12 years, it is assumed that one-twelfth of the vehicles in the Basin fleet will be replaced annually. Multiplying this number (369) by $6,500 to $49,000 gives a range of the annual additional capital cost of purchasing methanol rather than diesel buses (Table 3).

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 multiplied by 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 (*2*, p. 125).
[c]Wachs and Levine (*20*).
[d]Based on actual prices paid by Metro Transit, Seattle, Washington, in 1986.

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

It is convenient and common to state 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 required because the fuel efficiencies of methanol and diesel engines are comparable (*16*). The total annual fuel cost differential is found by multiplying the price differential computed in this way 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 the analysis. Because 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 of the analysis are shown 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 horizontal 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 sloped lines. Costs, of course, rise as the methanol price increases relative to the diesel price.

It is clear that the alternative assumptions shown make a great deal of difference to the conclusion. The authors 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.

On the other hand, 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 NO_x emissions as well as weaken the impact of direct street-level exhaust. Also omitted are the advantages of improved visibility and lessened morbidity, soiling, and materials and crop damage. All these benefits must 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

This first try 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

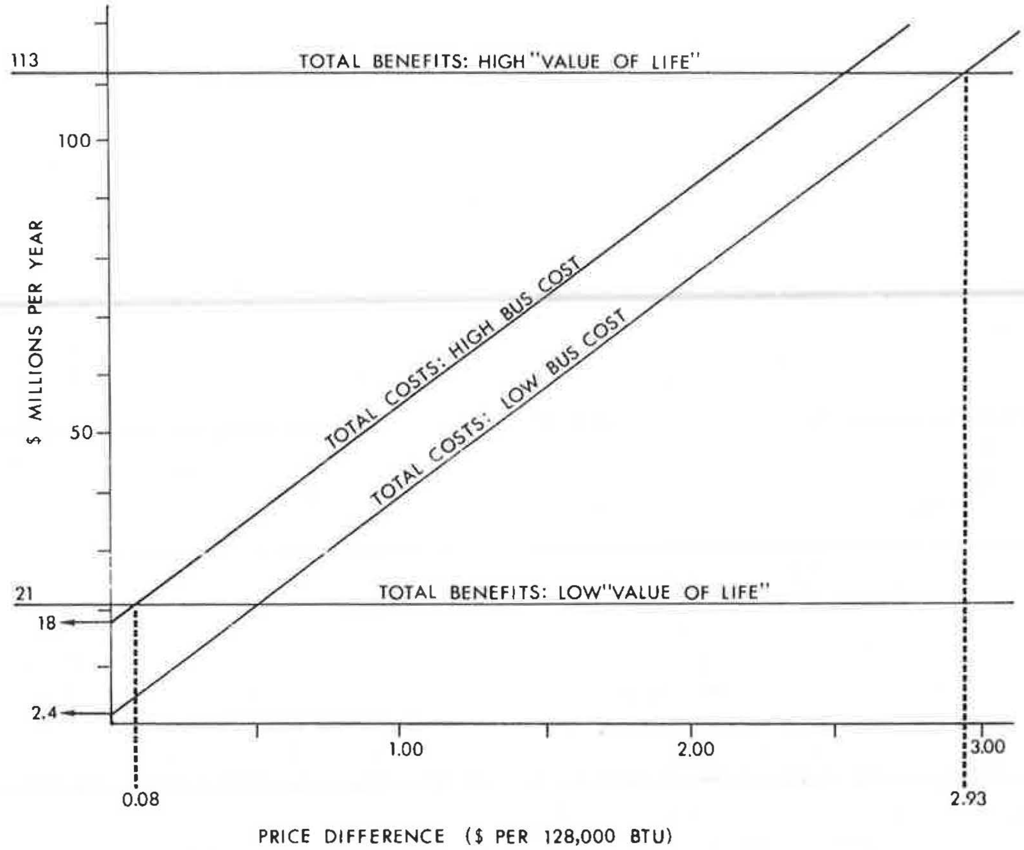

FIGURE 1 Benefit-cost analysis in terms of methanol-diesel price difference.

people's willingness to pay for lower mortality risk, the policy is justified over a wide range of methanol prices. When the older estimates of value of life are used, the case is not as clear cut. Both evaluations are quite conservative, however, 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, three sources of uncertainty need further work. One is the effect of methanol use on other pollutants, particularly photochemical oxidants. These are compounds often believed to cause the worst problem in the South Coast Air Basin; therefore, 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 *(17, 18)* suggests that starting with diesel fuel typical of that used in the United States and adopting a low-sulfur and low-aromatic fuel (similar to that taken as the baseline in this analysis 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 the methodology described here could provide further evidence on the comparative merits of these strategies, taking into account more pollutants than did Weaver.

A deeper policy question underlying this analysis of transit buses is the benefits that 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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