The Cost of Improving Health by Reducing Emissions from Public Transit Buses — a Controversy

Discussion

As illustrated in Figure 2, the reduction in health damages afforded by CNG compared to ECD is modest and comes at a substantial increase in investment costs. However, while cost-effectiveness provides an indication of the social welfare efficiency of investing in either of these technologies to improve health, it does not in fact indicate which investment, if either, is desirable at an absolute sense. Conceivably, the gains of both ECD and CNG are expensive. QALYs can be saved at a lower cost by health. Doing so suggests that both ECD and CNG are expensive. QALYs can be saved at a lower cost by health. Doing so suggests that both ECD and CNG are expensive. QALYs can be saved at a lower cost by health. Doing so suggests that both ECD and CNG are expensive. QALYs can be saved at a lower cost by health. Doing so suggests that both ECD and CNG are expensive. QALYs can be saved at a lower cost by health. Doing so suggests that both ECD and CNG are expensive. 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reduce the number of quality-adjusted life years (QALYs) lost at the result of operating a fleet of 1,000 buses, with each bus traveling an average of 40,000 miles yearly. We estimate the additional resource costs for each alternative technology relative to CD, including the cost of vehicle procurement, infrastructure improvements, and operating and maintenance (O&M) costs.

Emissions from all three types of buses contribute to global climate change, and we do not consider the resulting damages in our calculations. Dividing the incremental cost by the incremental QALYs saved yields the cost-effectiveness (CE) ratio. A low CE ratio (lower dollars per QALY saved) is more desirable than a high C/E ratio (more dollars per QALY saved).

We define the CE ratio as the incremental costs per QALY saved. Costs associated with vehicle operation and emissions generated during vehicle maintenance are included in the CE ratio, while capital costs are not. Our analysis accounts for the health effects associated with pollution from particulate matter (PM), nitrogen oxides (NOx), and sulfur dioxide (SO2). PM10 includes substances that increase mortality due to cardiopulmonary factors. In addition, PM2.5 and ultrafine particles are associated with worsening asthma and other chronic lung diseases. NOx and SO2 are contributors to acid rain, which can result in a variety of health problems. NO2 is a respiratory irritant, while SO2 can be a contributor to acid rain. These health outcomes are important in the context of the current study, as these technologies are the only technologies for which ECD does not reduce NOx emissions at all. ECD reduces aggregate emissions by around one-third, while CNG reduces NOx emissions by approximately three-fourths. For NOx, CNG emissions are for the most part far smaller than CD. Taking all the emissions and their health impacts into account, our central estimates are that a fleet of 1,000 new CD buses would result in a loss of 10.6 QALYs each year. Accounting for uncertainty analyzing this calculation, we estimate that this loss might be as low as 0.1 QALYs (best case bounding assumptions) or as much as 8.5 QALYs (worst case bounding assumptions). Replacing these buses with 1,000 ECD buses would reduce this loss by 6.3 QALYs annually (range: 4.1 to 8.5 QALYs), and replacing them with 1,000 CNG buses would reduce this loss by 10.6 QALYs annually (range: 8.1 to 13.1 QALYs). Figure 1 summarizes these results.

Figure 1: Annual QALYs Lost Due to Emissions from a Fleet of 1,000 Buses

The Cost of Improving Health by Reducing Emissions from Public Transit Buses — continued

For each bus, the annualized incremental cost for ECD relative to CD is $7,700 (range: $5,800 to $9,600). For CNG, the corresponding cost is $15,300 per bus. Data from New York City suggests that the annual maintenance cost for each CNG bus is $3,200 higher than for each CD bus. (Some transit agencies have reported that maintenance costs decreased when they purchased CNG vehicles. However, inspection reveals that these agencies report comparing new CNG buses to old diesel buses, or that they report maintenance costs not of the covered warranty.)

Finally, the CNG fueling infrastructure (natural gas pipelines) must be added, adding another $2,000 in costs annually per bus.

For ECD, the cost per QALY saved may be as small as $0.10 to $0.30 (worst case bounding assumptions), no health benefits per incremental dollar. For CNG, the corresponding cost is $5.8 million per QALY in an area with low land acquisition costs. Directly comparing the two technologies, the incremental cost-effectiveness of CNG relative to CD is estimated to be $5.8 million per (low-cost) or as much as $8.5 million per (high-cost) QALY saved. However, inspection reveals that these agencies report comparing new CNG buses to old diesel buses, or that they report maintenance costs not of the covered warranty.

Interestingly, two issues that garner substantial interest are the effects of diesel exhaust on long-term health and the contribution of climate change to global warming. While these topics are beyond the scope of this study, we focus on the costs and benefits associated with the transition to alternative fuels. However, inspection reveals that these agencies report comparing new CNG buses to old diesel buses, or that they report maintenance costs not of the covered warranty.

For ECD, the cost per QALY saved may be as small as $0.10 to $0.30 (worst case bounding assumptions), no health benefits per incremental dollar. For CNG, the corresponding cost is $5.8 million per QALY in an area with low land acquisition costs. Directly comparing the two technologies, the incremental cost-effectiveness of CNG relative to CD is estimated to be $5.8 million per (low-cost) or as much as $8.5 million per (high-cost) QALY saved. However, inspection reveals that these agencies report comparing new CNG buses to old diesel buses, or that they report maintenance costs not of the covered warranty.
reduce the number of particles held by 90% (i.e. 
reduction in the size of the exhaust produced) and at the same time achieve a 90% reduction in NOx. The 
reduction in PM emissions is achieved due to the ability of the diesel particulate filter (DPF) to trap the small PM particles emitted by the diesel engine. The sulfur in the fuel also reacts with the PM to form a sulfate, which is then trapped by the DPF. The reduction in NOx emissions is achieved through the use of a selective catalytic reduction (SCR) system, which uses a reducing agent (usually aqueous ammonia) to reduce NOx to nitrogen and water. The sulfur in the fuel also reacts with the NOx to form sulfate, which is then trapped by the SCR system.

The effectiveness of these technologies in reducing emissions and health impacts is illustrated in Figure 1, which shows the annual QALYs lost due to emissions from a fleet of 1,000 buses. The figure shows that the use of CNG technology would result in a significant reduction in QALYs lost, while the use of ECD technology would result in a smaller reduction. The figure also shows that the use of clean diesel technology would result in an increase in QALYs lost, due to the increase in NOx emissions.

In conclusion, the use of alternative fuels and technologies in public transit systems can result in significant health and environmental benefits. The use of CNG technology is particularly effective in reducing PM and NOx emissions, while the use of ECD technology is effective in reducing PM emissions. The use of clean diesel technology is less effective in reducing PM and NOx emissions, and in fact results in an increase in QALYs lost due to the increase in NOx emissions.

References:

Appendix A: Calculations

For each bus, the estimated incremental cost per ECD is calculated as follows:

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\text{Incremental Cost per ECD} = \text{Cost per CNG} + \text{Cost of DPF} + \text{Cost of SCR System} - \text{Cost of CD}
\]

where:
- \( \text{Cost per CNG} \) is the annualized cost of owning and operating a CNG bus.
- \( \text{Cost of DPF} \) is the annualized cost of owning and operating a DPF system.
- \( \text{Cost of SCR System} \) is the annualized cost of owning and operating an SCR system.
- \( \text{Cost of CD} \) is the annualized cost of owning and operating a CD bus.

These calculations assume that the costs of owning and operating a CNG bus are higher than those of a CD bus, and that the benefits of owning and operating a CNG bus are higher than those of a CD bus. The calculations also assume that the benefits of owning and operating an SCR system are higher than those of a DPF system, and that the costs of owning and operating an SCR system are higher than those of a DPF system.

The results of these calculations indicate that the use of CNG technology is more cost-effective than the use of CD technology, and that the use of CNG technology is more cost-effective than the use of ECD technology. The results also indicate that the use of clean diesel technology is less cost-effective than the use of CD technology, and that the use of clean diesel technology is less cost-effective than the use of ECD technology.

In conclusion, the use of alternative fuels and technologies in public transit systems can result in significant health and environmental benefits. The use of CNG technology is particularly effective in reducing PM and NOx emissions, while the use of ECD technology is effective in reducing PM emissions. The use of clean diesel technology is less effective in reducing PM and NOx emissions, and in fact results in an increase in QALYs lost due to the increase in NOx emissions. Therefore, the use of alternative fuels and technologies in public transit systems is strongly recommended.
reduce the number of particles half the size of 10 ym (QALYs) lost at the result of operating a fleet of 1,000 buses, with each bus traveling an average of 40,600 miles annually. We estimate the additional resource costs for each alternative technology related to CD, including the cost of vehicle procurement, infrastructure improvements, and operations (fuel and maintenance).

Emissions from all three types of buses contribute to global climate change, and we include the resulting monetized damage associated with CNG ($200 per year) emissions than do CD vehicles. The incremental cost-effectiveness (CE) ratio. A low CE ratio (fewer dollars spent per QALY saved) is more favorable than a high CE ratio (more dollars spent per QALY saved). We define the CD technology as a new conventional diesel bus equipped with both an oxidizing catalyst and a diesel particulate filter (DPF). A DPF removes PM and sulfur dioxide (SO2). PM is thought to substantially contribute to smog. Ozone may contribute to mortality due to cardiopulmonary factors. In addition, EPA and other regulatory agencies judge that diesel engine NOx is important to health because of the chemical reactions that take place during the catalytic converter process.

Our analysis accounts for the health effects associated with emissions of particulate matter (PM), nitrogen oxides (NOx), and sulfur dioxide (SO2). PM4 (particles < 2.5 microns in diameter) can be a contributor to lung cancer. NOx can become a “secondary particulate” when it is converted to nitric acid and combined with ammonium, then adding to PM exposure. When it reacts with sulfur dioxide (SO2) to form sulfuric acid (H2SO4), a component of acid rain, it may contribute to lung cancer, asthma, and other respiratory disorders. In addition, NOx and other air pollution agents that lead to death may contribute to lung cancer that is not amenable to diagnosis (CD). This PM4 is not removed through the catalytic converter process. Existing NOx emissions from diesel engines contribute little to our quantitative estimates. When NOx is not converted to secondary PM, it is converted to nitrate and combined with ammonium, thus contributing to “upstream” activities — i.e., those that affect population exposure to air pollution.
As illustrated in Figure 2, the reduction in health damages afforded by CNG compared to ECD is modest and comes at a substantial increase in annual costs. However, while cost-effectiveness provides an indication of the relative efficiency of investing in either of these technologies to improve health, it does not by itself indicate whether or not to invest. Other considerations such as the quality of life impacts described earlier must also be kept in mind that results are imprecise, as reflected by the wide range of plausible results described earlier.

Discussion

5 The Cost of Improving Health by Reducing Emissions from Public Transit Buses—continued

One way to address this issue is to compare these technologies with other investments that improve public health. Doing so suggests that both ECD and CNG are expensive. QALYs may be too small to justify their costs. Alternatively, in some cases the reduction achieved by CNG is more expensive than the reduction achieved by ECD; this finding is consistent with the median cost per QALY saved for SAE QALYs per year may be worth the added annual cost of $13 million (low land cost areas) or $59 million (high land cost areas).

Therapeutics

alternative propulsion systems represent a major challenge in engine design, fuel, and exhaust treatment. In the time of AI as a Perspective, we discuss a recent Harvard Center for Risk Analysis (HCRA) study that evaluates two of the most prominent alternative technologies: low-sulfur diesel (ECD) and compressed natural gas (CNG). For each of these technologies, we quantify both the health benefits and associated costs. We find that CNG has a modest edge over ECD in terms of its health benefits. However, CNG comes at a substantially cost relative to ECD. The complete study appeared in the April 15, 2003 issue of Environmental Science and Technology. Our analysis draws on a wide range of information in the scientific literature, and was guided by input from an advisory panel that included members from academic, industry, and public transit agencies.

Alternative Propulsion Technologies Evaluated

We examined a hypothetical transit agency purchasing new buses based on three propulsion technologies—conventional diesel (ECD), CNG, and ECD and CNG by comparing the mortality and morbidity impacts of these estimates to the mortality and morbidity impacts of CD

Risk in Perspective

The Cost of Improving Health by Reducing Emissions from Public Transit Buses—continued

The increased use of private vehicles is one potential “adverse side effect” of implementing alternative-energy technologies. Understanding whether the health and other side effects offset the benefits of investing in cleaner buses depends on quantifying the technology’s costs and benefits, while in the goal of the type of analysis described in this issue of Risk in Perspective. While there are other factors that influence such comparisons, considerations of economic efficiency—the health returns per dollar invested—is an important part of this analysis.

For more information on HCRA visit our website at:

www.hcra.harvard.edu
The Cost of Improving Health by Reducing Emissions from Public Transit Buses — continued

Discussion

As illustrated in Figure 2, the reduction in health damages afforded by CNG compared with ECD is more expensive than the reduction achieved by ECD; this difference is significant only for the urban area. However, while cost-effectiveness provides an indication of the relative efficiency of investing in one of these technologies to improve health, it does not by itself indicate which investment, if either, is desirable in an absolute sense. Consequently, the quality of the ECD

Figure 2: Annual Health Damages and Incremental Costs for a Fleet of 1,000 Buses*  

**Bubble area is proportional to QALYs lost for each technology.** Cost for CNG ($15 million per year) is for areas with low land costs. For areas with high land costs, the annual cost of $13 million (low land cost areas) to $19 million (high land cost areas).

Alternative Propulsion Technologies Evaluated

We conducted a study in which a hypothetical transit agency purchasing new buses can choose among three propulsion technologies—compressed natural gas (CNG), emission controlled diesel (ECD), and zero-emissions (ZEV). The agency could invest in different combinations of these technologies to achieve its goals.

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