

A STUDY OF BUS PROPULSION TECHNOLOGIES APPLICABLE IN CONNECTICUT

EXECUTIVE SUMMARY

STATEMENT OF INQUIRY

The Connecticut Department of Transportation (CONN-DOT) and Connecticut Transit (CTTRANSIT™) plan to replace the existing 400-bus fleet serving Hartford, New Haven, and Stamford over the next decade. Both organizations wish to introduce new bus propulsion technologies that will meet both transportation and environmental needs.

The Connecticut Academy of Science and Engineering (the "Connecticut Academy") was asked to evaluate available and emerging bus propulsion technology, and to suggest bus purchase scenarios to assist CONN-DOT and CTTRANSIT™ with decisions involving the purchase of 200 new buses between 2003 and 2008.

SUMMARY OF FINDINGS

This study was based on an extensive literature review of salient bus technology, surveys of and visits to manufacturers, meetings with bus operators, and discussions with various representatives of groups such as the Northeast Advanced Vehicle Consortium (NAVC) and the Clean Cities Coalition. This information was then analyzed in terms of bus availability, range, reliability, cost, emissions, and compatibility with CTTRANSIT™'s operating environment.

Many bus propulsion systems were reviewed, including diesel, electric trolley, compressed natural gas, methanol, liquefied natural gas, liquefied petroleum gas, ethanol, diesel-electric hybrid, and fuel cells. An initial screening led to detailed analyses of the following technologies:

- ***The existing diesel system***, to provide a benchmark for cost, reliability, and emission comparisons;
- ***The "clean diesel" system*** that uses ultra-low-sulfur fuel and Continuously Regenerating Technology (CRT™) exhaust filters;
- ***The hybrid diesel-electric system*** being tested in several cities, and ordered with both regular and ultra-low-sulfur diesel fuel in New York City;
- ***The compressed natural gas (CNG) system; and***
- ***The fuel cell-based system.***

The analysis applied here did not focus on the specifics of the emissions technology, as it is developing to meet EPA set standards. Because of the numerous and rapid changes taking place in the development and introduction of emissions-reducing technologies, it was judged that this study could not adequately address the science of emissions and "pick the winners". Rather, the committee has chosen to chart a course for minimizing the fiscal risk of choice.

Diesel-powered buses now comprise almost 80% of the U.S. bus fleet. These buses offer excellent reliability and availability, low purchase costs (about \$280,000 for a 40-foot bus), and good fuel mileage. However, while substantially cleaner than a decade ago (about 80% less particulate matter and 20% less nitrogen oxide emissions), diesel-powered buses currently being manufactured emit more emissions than buses powered by other technologies. They will not meet the 2004 Federal Environmental Protection Agency (EPA) standards unless emissions are further reduced. Such reductions can be achieved through the use of ultra-low-sulfur fuel and Continuously Regenerating Technology (CRT™) exhaust filters. Although these modifications involve modest additional fuel costs (about 10 cents per gallon), they result in substantially reduced emissions.

Hybrid diesel-electric buses have recently become commercially available. These buses combine the best features of diesel and electric propulsion. They offer the advantages of very low emissions, especially when operated on ultra-low-sulfur fuel; excellent fuel efficiency, especially in frequent-stop urban service; and excellent acceleration from a stop. However, they have the disadvantages of being a relatively new technology with limited operating experience in revenue service, having high initial vehicle cost, and having limited service reliability, especially regarding batteries.

Compressed natural gas (CNG) is the most widely used alternative fuel. CNG buses offer the advantages of general availability of vehicles and fuel (fuel is domestically produced), more than a decade of operating experience, and very low particulate matter emissions. However, CNG has several disadvantages, including considerable infrastructure costs for handling fuel and upgrading safety systems, reported lower reliability and fuel efficiency, and variable nitrogen oxide emissions, depending on system adjustments.

Fuel cells are an emerging technology that will probably become available for revenue service within this decade. They offer the advantages of very low emissions and quiet operation. However, they have the disadvantages of very high purchase costs, very limited operating experience, and an absence of established commercial sources.

The costs and emissions for these technologies were estimated and compared with the costs and emissions for conventional diesel propulsion to quantify the anticipated increase or decrease in the costs and emissions for each propulsion system. These values, in turn, were applied to five bus purchase options from which aggregate cost increases (including infrastructure, vehicles, fuel, and maintenance) and emission reductions were computed for the six-year period from 2003 to 2008.

RECOMMENDATIONS

Based on these comparisons, the study committee compiled five bus purchase options (A through E). Options A and B denote the use of conventional and new state-of-the-art diesel, respectively, with the use of ultra-low-sulfur fuel; Option C includes a mix of diesel buses and diesel-electric hybrid buses, both using ultra-low-sulfur fuel; Option D involves the use of mostly diesel-electric hybrids; and Option E involves utilizing CNG buses.

Of the five options presented in the study, the committee recommends the following:

➤ ***First choice: Option C, a mix of state-of-the-art diesel buses and hybrid diesel-electric buses.***

This option appears to represent the best balance between:

- aggressively pursuing lower emission levels
- striving for cost-effective mixes; and
- maintaining a fleet of reliable, available buses.

This fleet mix matches the mixed market needs of CONN-DOT and CTTRANSIT™. The diesel-electric hybrids can operate in local service, while the “clean diesels” using ultra-low-sulfur fuel can operate along express routes and hilly terrain. Articulated buses are available using the basic diesel propulsion. Moreover, the mixed fleet minimizes any risk relative to the diesel-electric hybrid technology. However, if the development of hybrid diesel-electric buses should progress more rapidly than our current evaluation suggests, then an even more aggressive position regarding hybrid buses might be pursued.

➤ ***Second choice: Option A and/or B, a mix of conventional and state-of-the-art diesel buses, with the possibility of moving more aggressively into ultra-low-sulfur fuel buses fitted with advanced exhaust treatment systems.***

This option represents the best choice in the event that:

- diesel buses are able to meet the future EPA standards for emissions; and
- hybrid diesel-electric buses are not able to meet the current expectations regarding reliability, availability, and cost (for example, if the costs of diesel-electric hybrid buses do not fall below ~\$350,000 by 2004).

➤ ***Third choice: Option E, CNG buses, with an introductory year of diesel buses.***

This option represents the best choice in the event that:

- diesel buses are not able to meet the future EPA standards for emissions, even using ultra-low-sulfur fuel; and
- hybrid diesel-electric buses are not able to meet the current expectations regarding reliability, availability, and cost.

In addition, CONN-DOT and CTTRANSIT™ should consider the purchase and testing of fuel cell-powered buses, at times and in numbers that are yet to be determined. Fuel cell-powered buses have considerable potential for operation as very quiet buses with very low on-board emissions. Viewed in this context, fuel cell-powered buses are an extension of hybrid technology. However, major advances are required in areas of cost reduction, reliability, and range before these buses will be appropriate for wide-scale transit applications. These buses should be considered for purchase as this technology emerges.

Finally, the study committee recommends that CONN-DOT and CTTRANSIT™ continue to closely monitor bus propulsion technologies due to the very rapid pace of change anticipated in transit bus propulsion, with improvements expected for many of the technologies examined here.