

## EXECUTIVE SUMMARY

### STUDY OBJECTIVES

The Connecticut Academy of Science and Engineering (the “Academy”) was asked by the Connecticut Department of Transportation (CONN-DOT) to update the *Study of Bus Propulsion Technologies Applicable in Connecticut (“BPT2001”)* of February 2001, prepared for CONN-DOT and CTTRANSIT™, focusing on propulsion technology developments that will be available for fleet purchase in the “near term” (~1 to 4 years).

This update includes changes and updates on:

- Conventional diesel technology
- Hybrid diesel-electric propulsion technology
- LNG and CNG fuel options
- All-electric propulsion, including the requirements of:
  - Minimum range capability of 120 miles
  - Fast recharge capability
- A review of the zinc/air battery propulsion technology

The conventional diesel, hybrid diesel-electric, liquefied natural gas (LNG) and compressed natural gas (CNG) sections of this report, as in the original report, discuss:

- Bus Availability
- Bus Emissions: A review of several comparison studies
- Bus Reliability: A review of two studies
- Bus Costs

### *Overview*

The current markets and findings are similar to those found in the Academy’s earlier *BPT2001* report. However, there are specific issues and developments that have occurred since the issuance of the *BPT2001* report that are of interest, as follows:

- Recent operational experience of conventional diesel buses, equipped with state-of-the-art exhaust gas treatment systems and running on ultra-low-sulfur-fuel, has validated the *BPT2001* report’s expectation that these buses are capable of very reliable operation and very low levels of emissions.
- A second-generation hybrid diesel-electric bus is currently available on the market. The design of this bus (a parallel-style hybrid, in which the drive wheels are powered by both a diesel engine and an electric motor) offers some operational advantages over the first generation hybrid bus (a series-style hybrid, in which only the electric motor powers the drive wheels), however, its reliability needs to be established.

### ***Bus Availability***

Heavy-duty 40-foot transit buses continue to be available and are sold with conventional diesel, hybrid diesel-electric, CNG, and LNG fueled propulsion systems.

### ***Bus Emissions***

Conventional diesel buses equipped with state-of-the-art exhaust gas treatment systems and running on ultra-low-sulfur fuel, similar hybrid diesel-electric buses, CNG buses, and LNG buses are all capable of operation at very low emission levels for Particulate Matter (PM) and Carbon Monoxide (CO). However CNG and LNG buses have considerably higher emission levels of Total Hydrocarbons (THC) and Non-Methane Hydrocarbons (NMHC).

### ***Bus Reliability***

Conventional diesel buses remain the standard for reliable bus operation. In comparison tests reported by the New York City Transit Authority, the “Orion” hybrid diesel-electric buses, recently demonstrated Mean Time Between Failure (MTBF) values slightly greater than one-half those of conventional diesel buses (~1300 hours vs. ~2300 hours). In similar tests reported by the San Francisco Municipal Railway, the values for MTBF were ~400 to 450 hours for both CNG and hybrid buses vs. ~650 hours for diesel buses.

### ***Bus Cost***

Both CNG and hybrid diesel-electric buses have higher purchase prices than equivalent conventional diesel buses (~\$390K for CNG and hybrids vs. ~\$340K for diesel). Note that, as indicated by these prices, the additional cost premium compared to diesel for either CNG or hybrid buses purchased in quantity, is now about the same. This is in contrast to the earlier *BPT2001* report in which the cost of CNG buses (and therefore the premium also) was substantially less than hybrid buses. Additionally, as stated in the *BPT2001* report, the infrastructure costs for the operation of CNG buses are higher to substantially higher than for other types, varying on a case-by-case basis.

### ***All-Electric Buses***

There are currently only two types of all-electric or essentially all-electric, battery-powered, buses available on the market with specified ranges of 100 miles or greater. There is only one supplier for each type of bus:

- A 30-foot bus, a demonstration project in Santa Barbara, CA, has reportedly been well received by both drivers and riders.
- A 40-foot bus is brand new to the market, and has some operational issues that make it unattractive for fleet operation.

## **RECOMMENDATIONS**

Consistent with the recommendations of the *BPT2001* report, Connecticut should continue to concentrate its bus acquisition program on the purchase of conventional diesel buses equipped with state-of-the-art exhaust gas treatment systems and running on ultra-low-sulfur fuel. All of

the recent experience and research points to this technology as a widely available, low emission level, and very reliable solution with the lowest purchase and infrastructure costs.

Also, reinforcing the findings of the *BPT2001* report, it is recommended that Connecticut explore the hybrid diesel-electric technology by purchasing a small number of such buses and evaluating their operation on state bus routes. However, it is now recommended to proceed more slowly with this option than was indicated in the *BPT2001* report. The reliability of the first generation of these buses has been significantly poorer than equivalent conventional diesel buses, and the number of suppliers continues to be small. Nevertheless, the inherent technical and operational advantages of hybrid diesel-electric buses merit continued exploration of this option, with the expectation that future generations of these buses will overcome the reliability issues, and that there will be an adequate number of suppliers.

Finally, it is recommended that Connecticut continue to monitor the development progress of all-electric buses.