U.S. Department of Transportation
Urban Mass Transportation Administration

Bus Propulsion Alternatives Overview

Office of Technical Assistance
Office of Bus and Paratransit Systems
Washington DC 20590

Prepared by:
Transportation Systems Center
Technology Sharing Office

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INTRODUCTION

The Urban Mass Transportation Administration (UMTA) is currently investigating propulsion alternatives which would conserve petroleum-based fuels and would be practical for use by U.S. transit operators. The major options consist of:

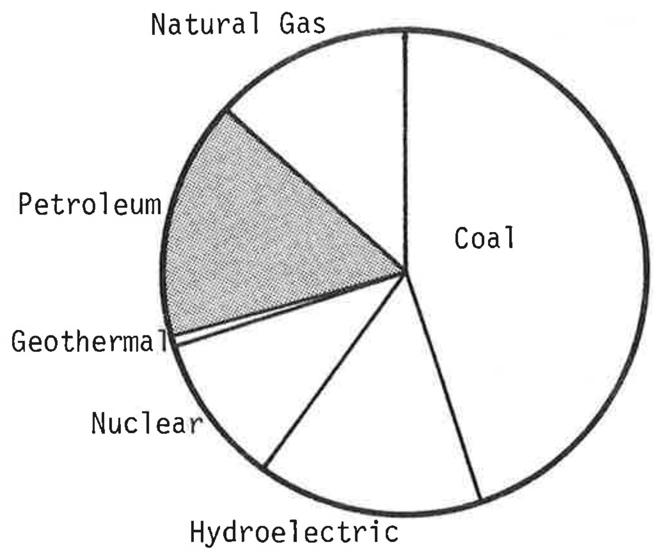
- Electric propulsion systems,
- Alternative fuels, and
- Modifications of bus components which improve the efficiency of diesel engines.

This report provides a discussion of these alternatives and a current overview of UMTA's bus propulsion projects.

Electric propulsion studies being conducted under UMTA sponsorship consider vehicles such as trolley coaches, battery buses, and a more recent innovation, flywheel buses. These vehicles all use electricity, rather than diesel fuel or gasoline, for their power. Among the alternatives being investigated are not only these vehicles, but also a number of hybrid buses in which propulsion technologies are used in a complementary way to improve performance or fuel economies. In the last few years, the relative prices of diesel fuel, coal, oil, and nuclear power have shifted so that in many parts of the country today, the cost of operating an electric bus would be nearly half the cost of operating a diesel bus. Electric propulsion is also attractive because generating plants use a variety of power sources (e.g., water, coal, oil, and nuclear power), and thus are not totally dependent on petroleum fuels. In addition, electric motors have excellent potential to recover the energy used in braking.

To determine the extent that nonpetroleum-based fuels could be used in transit buses, UMTA is also sponsoring studies and tests of alternative fuels and engines. In addition to synthetic diesel oil, the most promising of the fuels which could be used, by modifying existing diesel engines, appears to be methanol and ethanol. These are alcohols derived from several different renewable and nonrenewable sources abundant in this country — coal, wood, grains, etc. The ability to use alternative fuels is a form of insurance in the event of further threats to oil supplies.

Energy Sources for Generating Electricity



IN THE UNITED STATES, ONLY 16 PERCENT OF THE SOURCE ENERGY USED TO GENERATE ELECTRICITY COMES FROM PETROLEUM.

Finally, UMTA is sponsoring the development, testing, and evaluation of new bus components or modifications to old ones that could improve the energy efficiency of the diesel bus, and thus reduce the amount and cost of diesel fuel consumed. The numerous benefits of this approach would be realizable in the near future.

Projects that fall within the scope of bus propulsion alternatives are being conducted under the Energy Conservation and Propulsion Technology Program in the Office of Bus and Paratransit Technology. They include the following:

- Trolley coach power control systems and AC propulsion tests.
- Trolley coach emergency battery tests.

- Monitoring and assessment of commercial battery-powered buses in revenue service.
- Development and testing of a prototype flywheel energy storage system (FESS) capable of installation in a transit bus.
- Assessment of trolley coach/diesel hybrids and automatic mechanisms for connection to overhead wires.
- Engineering evaluation of converting buses for methanol use.
- Study of fuel alternatives.
- Development of fuel economy measurement procedures.

With the exception of the flywheel program, these UMTA-sponsored projects do not involve new hardware development. Rather, they consist of studying, monitoring, and testing technologies for the sole purpose of evaluating and possibly adapting them for transit. The projects are designed to supplement research and development being conducted by the private sector in the United States and abroad, as well as other federally-sponsored programs.

Current UMTA technical contact persons are as follows:

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I. ELECTRIC PROPULSION ALTERNATIVES

Electric propulsion technologies which at this time can be applied to urban transit buses are based on three distinct methods of power transfer:

- Overhead Wires,
- Batteries, and
- Flywheels.

Vehicles can be designed to use any one of these methods alone, in combination with one of the others, or with an internal combustion engine.

The principal advantages of electric propulsion are low energy costs and excellent environmental characteristics. Electric vehicles can operate in tunnels and can also be used in pedestrian malls or highly congested areas where the additional fumes and noise of diesel buses cannot be tolerated. All forms of electric propulsion, however, require an investment in capital facilities to bring electric power to the vehicle.

From the standpoint of cost, route flexibility, maintenance, reliability, and environmental impact, the most promising electric vehicle at the present time appears to be a flywheel/trolley coach hybrid. UMTA's currently active hardware projects focus, therefore, on the flywheel and on low-cost improvements to the trolley coach.

Table 1 highlights the principal characteristics of different electric vehicles. A review of each vehicle follows.

A. THE TROLLEY COACH

First appearing in revenue service in the 1880's, trolley coaches experienced their heyday during the late twenties through the early fifties. In 1950, 6,500 trolley coaches were operated by 54 transit properties in the United States, accounting for 8.5 percent of all surface transit vehicles.

A variety of interrelated factors contributed to the decline of the trolley coach. During the 1950's, the overall drop in transit ridership and the poor financial position of many transit companies had the most devastating impact on trolley coach systems. Struggling transit companies could not afford to maintain or improve their worn-out trolley coach systems, much less expand them to meet the changing demands of massive population shifts to the suburbs. The advent of the more economical diesel bus offered a solution to the financial problems of trolley coach operators.

Although their numbers diminished considerably, trolley coaches did not disappear from the transit scene. For various reasons, five transit properties in the United States and five in Canada kept their trolley coaches operating.

TABLE 1. ELECTRIC BUS TECHNOLOGIES

ALTERNATIVES	OPERATIONAL STATUS 1977	ROUTE RANGE BETWEEN CHARGES	RECHARGE TIME	SPECIAL FACILITY REQUIREMENTS	LIFE-CYCLE COST COMPARED TO DIESEL BUS
TROLLEY COACH	679 operating in U.S.	Continuous with overhead wires	N/A	Overhead wires, power substations	Slightly more
BATTERY BUS	13 models; 39 vehicles operating in U.S., Europe, Japan	25-100 miles	3-8 hours to charge or 1-5 minutes to	Battery recharging/ exchange facilities	Much more
FLYWHEEL BUS	None operating	3.2 miles (Estimated)	90 seconds standing (Estimated)	Flywheel unit recharging stations	Slightly less
FLYWHEEL/ TROLLEY COACH HYBRID	None operating	Continuous operation (1-3.2 miles off wire)	Enroute or standing for 90 seconds	Partial overhead system, power substations	Slightly less
DIESEL/ TROLLEY COACH HYBRID	One operating in Germany	Continuous operation	N/A Refuel once per day	Overhead wires, power substations, diesel garage	More
BATTERY/ TROLLEY COACH HYBRID	One operating in Germany	Continuous operation (25 miles off wire)	Enroute for 25 miles on wire	Overhead wires, power substations	More
BATTERY/ DIESEL HYBRID	Two operating in Japan; one in Germany	110-190 miles (35-45 miles on battery)	Enroute; refuel once per day	Battery charging facility and diesel garage	Much more

TROLLEY COACHES HAVE BEEN OPERATING ON THE STREETS OF SAN FRANCISCO SINCE 1935. THIS MODEL, BY FLYER INDUSTRIES, WAS PURCHASED BY MUNI IN 1975-1976.

Recently, interest in the trolley coach has been rekindled. One reason is that electricity continues to compare more favorably with diesel fuels in the face of petroleum price escalations. Other advantages the trolley coach shares with other electric vehicles are:

- long service life (23 years),
- quiet operation,
- no exhaust emissions,
- exceptional hill climbing ability,
- energy availability in times of interrupted oil supply, and
- good potential for regenerative braking.

A unique advantage of the trolley coach is that in addition to providing power for propulsion, its motor can be used as a generator to provide braking, thus reducing wear and maintenance on the brakes. Moreover, where the system can accept it, the braking energy can be recovered to reduce overall power costs.

Probably the most serious disadvantage of the trolley coach is the propulsion system's dependence on overhead wires for power. Any type of power interruption, caused by power outages, downed wire, or damaged connecting poles, will strand the vehicle. Because the trolley coach must be connected to overhead wires at all times, it is less maneuverable in traffic than other road vehicles and has difficulty moving around obstacles. The overhead wires are unattractive, especially at crossovers and switching areas, and more important, are costly to install and maintain. In fact, the large capital investment required for the network of overhead wires, as well as for the construction of power stations, has been the major disincentive to building new trolley coach systems. Many of these disadvantages could be solved in the near future by means of trolley coach hybrids or auxiliary propulsion systems which could provide limited off-wire capability. (Hybrids are discussed later in this report.) UMTA is currently providing support for an emergency power supply project that will test the feasibility of adding a small number of batteries to trolley coaches. This will enable vehicles to travel short distances off-wire with reduced power.

Because the life-cycle costs of trolley coaches and trolley coach hybrids are competitive with the diesel bus, UMTA has provided a grant to the San Francisco Municipal Railway (MUNI) to evaluate energy-saving propulsion modifications which could be introduced in the near future, without extensive development programs. The project will compare the energy efficiency, maintenance requirements, and costs of chopper control systems with those of older vehicles. Currently used in many rail systems, solid-state chopper control systems are more energy efficient than the switched resistor (cam) controls which have been widely used in trolley coaches. A second alternative being evaluated consists of an AC inverter and an AC induction motor. Lighter and less expensive than the conventional DC traction motor, the AC motor also requires less maintenance.

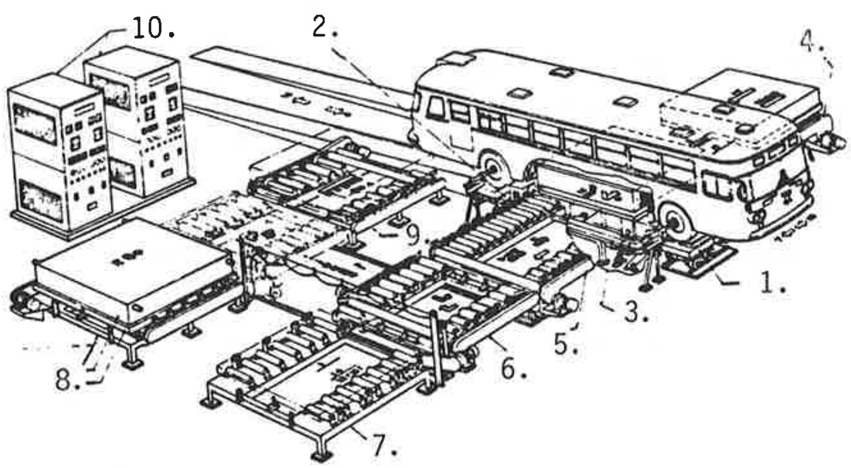
B. THE BATTERY BUS

Although battery propulsion systems date back to the late 19th century, when automobiles were powered by batteries as often as by steam engines, the battery transit bus was a much later development. Battery buses are rare in the United States. During the mid-1970's, a small number of them began operating in regularly scheduled service in Long Beach, Calif.; Roosevelt Island, N.Y; National Capitol Park, Washington, D.C.; and Lansing, Mich. Battery buses have been used more extensively overseas, particulary in West Germany and Japan, but they do not make up a significant portion of any country's bus fleet.

Like trolley coaches, battery buses are quiet, nonpolluting, and powerful enough to climb hills exceptionally well. They also have long lives (roughly 25 years, except for the batteries) and are easily maintained. Their smooth, rapid acceleration makes them ideal for multistop runs. Most battery buses cannot travel more than 100 miles (about half the range of the diesel bus) without battery recharge or replacement. One possible but expensive solution, therefore, is to increase the fleet size or arrange service schedules so that each bus is used for roughly a half day (seven hours or less). This allows batteries to be recharged during off-peak periods when the buses are not in use. Batteries can be fully recharged overnight before morning runs. Another, more attractive alternative, which allows for greater use of the vehicles, is to exchange fully charged batteries for exhausted ones. This usually takes less than five minutes and can be done between runs from a suitably located service station.

At this time, battery buses do not hold as much promise as trolley coaches for either energy conservation or cost savings. Although their propulsion systems need not be powered by petroleum fuel, their passenger comfort heating systems often are, and these may consume significant amounts of energy. In addition, the battery bus propulsion system is less energy efficient than the trolley's because of the necessity of converting electric power to and from chemical storage. The lead-acid batteries which are currently suitable are heavy and add considerably to energy requirements. The batteries are not capable of being recharged rapidly and cannot be used effectively to recover vehicle braking energy. Finally, battery bus operations require a battery charging and/or exchange facility and the replacement of battery sets every four to six years.

In spite of the cost disadvantages, the clean, quiet operation of battery buses may make them very attractive for some applications in the United States. For this reason, UMTA is monitoring foreign and domestic developments and is updating its 1976 assessment of battery buses (including hybrid versions). UMTA is also sponsoring the testing and evaluation of three battery buses in service on Roosevelt Island, N.Y.



1. & 2. Positioner	7. Set Aside Stand
3. Exchange Elevator	8. Charge Stand No. 1
4. Receiving Stand	9. Charge Stand No. 2
5. Waiting Stand	10. Charger
6. Conveyer	

BATTERY BUS OPERATIONS REQUIRE A COMPLEX BATTERY CHARGING FACILITY SUCH AS THIS ONE.

C. THE FLYWHEEL BUS

Although flywheels were used for urban mass transportation in Europe as early as the 1950's, flywheel-propelled buses are still in developmental stages, both in the United States and abroad. The critical component for a flywheel bus is an energy storage system containing a flywheel coupled to a motor-alternator and contained in an evacuated case. When brought up to speed by an outside source of electric power, the flywheel can store enough power to propel a full-sized bus at least three miles in city traffic. The 90-second charging operation is relatively simple and can be done while passengers are boarding and alighting.

Flywheel buses could offer the same appeal as other electric vehicles. They are quiet and nonpolluting. They do not depend on petroleum fuel for power, and, compared to diesel buses, they would probably have a longer service life and lower maintenance costs. Energy savings are accomplished by means of regenerative braking, that is, the storage and reuse of energy traditionally wasted during braking.

Flywheel buses, however, share with battery buses some of the inconveniences of recharging. A flywheel bus would need electric power sources along the route, and schedules would have to be coordinated with recharging operations. Although recharging would be more frequent for a flywheel, it would require only a fraction of the time needed for batteries. In fact, it is this rapid energy storage capability that makes the flywheel valuable for conserving energy.

Until recently, the size, weight, and costs of a flywheel suitable for an urban bus have greatly inhibited its use. However, changes in energy costs and improvements in materials and electric propulsion technologies now make the estimated life-cycle costs competitive with those of a diesel bus.

UMTA has been involved in flywheel energy storage system (FESS) research and development since 1976 when it awarded parallel contracts to two manufacturers to share in the costs of developing concepts and technologies for flywheel propulsion systems. At this time, the program is slightly beyond the mid-point of a four-year planned program. A prototype FESS sealed unit is currently being fabricated by Garrett AiResearch Corporation for bench tests. If these tests are successful, the next phase will consist of vehicle tests using a modified trolley coach.

Ultimately, the decision to employ a FESS or any other form of electric propulsion must be based on the specific economics and characteristics of each city. To save parallel efforts, the FESS Program includes development of an analytical model which can be used for site specific cost studies. The model examines various route profiles, fuel and power prices, vehicle performance characteristics, and propulsion types.

D. HYBRID ELECTRIC VEHICLES

Hybrid electric vehicles are a relatively recent development in the transit industry. Nearly any combination of propulsion systems is possible, and most have been tried somewhere. Because changing technologies and energy costs make it unwise to ignore any of the possibilities, UMTA's Office of Bus and Paratransit Technology conducts periodic reviews of developments and assists U.S. transit operators in testing new models.

To avoid confusion, the term "hybrid" is used for vehicles which are designed for full performance with either of their propulsion systems. Vehicles with low-powered energy or auxiliary systems are not considered hybrids; rather, they represent improvements over conventional vehicles.

1. Flywheel/Trolley Coach Hybrid

Recent cost projections (Table 2) indicate that total life-cycle costs for a new flywheel/trolley coach system would be lower than the costs for either a new trolley coach or diesel bus system. Reflected in these lower costs are: 1) a significant reduction in the overhead wire system needed, 2) efficient use of regenerative braking power, and 3) the widening gap in prices for electricity relative to diesel fuel.

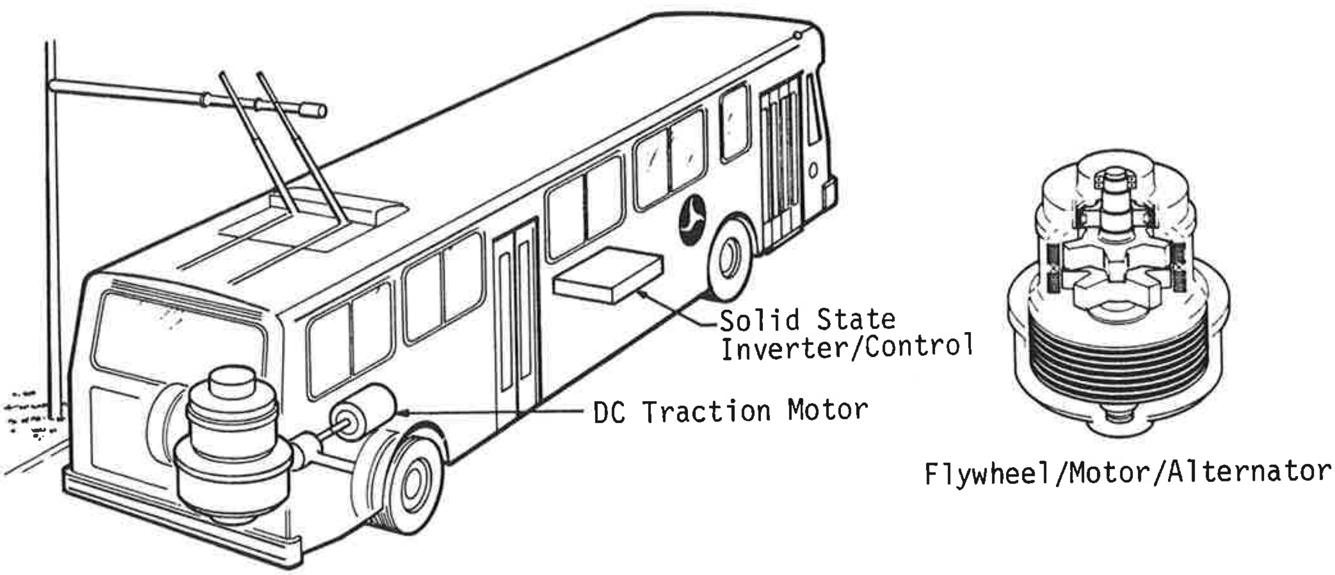
The principal advantages of this hybrid, however, lie in the off-wire capability of the vehicle and the elimination of unsightly and expensive overhead wires for crossovers, switches, and sharp turns. The vehicle's flywheel may be recharged enroute on relatively short stretches of straight overhead wire (less than 10 percent of the route), and extended stops would not be necessary. A sampling of the transit industry indicates sufficient interest in this hybrid to warrant field tests if performance of the FESS is satisfactory.

TABLE 2. COST COMPARISON FOR THREE VEHICLE CONFIGURATIONS*

COST ITEM	FLYWHEEL/TROLLEY COACH	TROLLEY COACH	DIESEL BUS
Capital	38	58	44
Energy	14	18	32
Vehicle Maintenance	35	30	40
Overhead Maintenance	4	12	N/A
Total Life-Cycle Costs (undiscounted)	91	118	116

*In cents/service mile.

Source: "Flywheel Energy Storage System (FESS) Phase II." A presentation to UMTA by Garrett AiResearch, May 6, 1981.

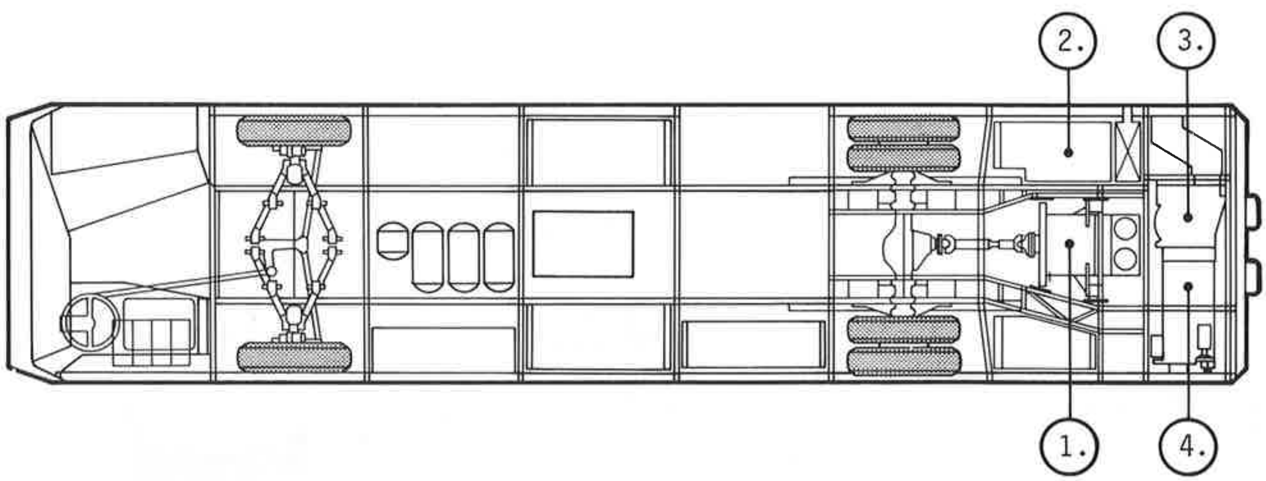


THE FLYWHEEL CAN BE CHARGED-UP QUICKLY TO PROVIDE ELECTRIC POWER FOR A DC TRACTION MOTOR.

2. Diesel/Battery/Trolley Coach Hybrids

Two other types of trolley coach hybrids, one using a diesel engine and the other, a battery set, have been deployed successfully in Esslingen, Germany. They have been used there to extend route segments and to operate express service, with the hybrid vehicles passing conventional trolley coaches while running on the diesel engine or batteries. The battery/trolley coach hybrid is operated 16 hours a day, a much longer period than conventional battery buses can operate. Batteries are recharged while the vehicle is running on-wire (roughly 50 percent of the time).

Although either of these hybrids may be a cost-effective addition to an existing trolley coach system, life-cycle costs for an entirely new system are not clearly competitive with the diesel bus. To assess the costs and operational characteristics of these hybrids, UMTA is sharing the costs of testing diesel/trolley coach hybrids at the Seattle METRO. Of special interest is the automatic overhead wire contact system which could be used with other forms of electric vehicles.



1. Electric Drive Motor
2. Power Controls
3. Diesel Engine
4. Generator Motor

THIS DRAWING SHOWS A SAMPLE LAYOUT OF THE TWO PROPULSION SYSTEMS OF A DIESEL/TROLLEY COACH HYBRID.

Tests currently planned by Seattle METRO will use an articulated vehicle, the Renault PER-180 diesel/trolley coach hybrid. The articulated configuration has space and load distribution characteristics which permit use of a full-sized diesel motor. The full power capability will enable METRO to conduct a better evaluation of route expansion and express service capabilities than would have been possible using the standard sized (ER-100) version which was originally planned.

Arrangements are also underway to test the Renault ER-180 articulated battery/trolley coach hybrid at the Miami Valley Regional Transit Authority in Dayton. The battery hybrid, still in a prototype state, uses nickel-cadmium batteries and can provide about 75 percent of full power for approximately three miles. This version will offer considerable route flexibility as well as emergency off-wire capability.

3. Battery/Diesel Hybrids

This hybrid vehicle, which has been deployed in Germany and Japan, is a battery bus to which a small diesel engine and fuel tank have been added. The batteries alone are used to propel the bus in congested areas, where noise and pollution are especially undesirable, while the diesel engine is used on other portions of the route (residential areas, freeways, etc.). Since batteries are recharged over a major portion of the route, the vehicle range is much greater than that of a conventional battery bus. The disadvantages of these hybrids lie in the complexity and life-cycle costs of their propulsion systems. Battery charging or battery changing facilities are still necessary. Also, since much of their power comes ultimately from a diesel engine, the systems do little to reduce petroleum consumption. Because the existing systems may yield useful data, however, UMTA will evaluate this hybrid as part of its battery bus assessment update.

4. Other Combinations

Applications of flywheels to either a diesel or a battery bus are feasible, but not as attractive as the trolley coach combination. For this reason, UMTA does not have active development programs for these configurations at this time. Several European manufacturers are developing prototypes of smaller flywheels which can contribute to fuel economies in diesel buses, and these will be reviewed periodically for potential application in the United States.

II. ALTERNATIVE FUELS

Until recently, most U.S. Department of Energy and Department of Transportation studies of alternative fuels have addressed the needs of the automotive industry. The fuel-related problems of the transit industry, which is dominated by the diesel bus, received little attention. Under a cooperative agreement with UMTA, the Port Authority of Allegheny County (PA Transit) is investigating the possibility of running buses on nonpetroleum-based fuels. These fuels include alcohols (methanol and ethanol), gases (propane and methane), and synthetic fuels. In evaluating fuel alternatives, UMTA and PA Transit are considering several factors, including:

- fuel availability and costs,
- cost and complexity of vehicle and facility modifications, and
- vehicle performance and maintenance.

In response to a Congressional directive, UMTA has also instituted a companion project to develop and test the technologies associated with the use of a specific alternative fuel, methanol. At present, methanol is considered the most logical long-term replacement for petroleum fuel because of the abundance of American coal from which it can be produced. Conducted by the Florida Department of Transportation, the project will begin with a study of the feasibility of converting a diesel bus engine for methanol use. The most efficient retrofit alternative will then be selected for an engineering evaluation, which will include the actual modification of an engine. Successful completion of road tests may lead to the commercial manufacture of retrofit kits which may be purchased by transit operators.

Longer-range alternatives for transit are possible through engines which are designed to use multiple fuels. A gas turbine is one such approach, and UMTA has contributed to a Department of Energy project in order to test the application of a gas turbine engine to transit coaches. Since transit buses, however, are a miniscule portion of the automotive industry, development of an engine specifically for transit would not be practical. The current UMTA strategy is to monitor progress in the field of propulsion and look for opportunities where a modest investment would provide substantial benefits for transit.

III. DIESEL FUEL ECONOMIES

Several new or improved bus components related to the exhaust system are being developed and tested for their potential to minimize energy waste. Other components or modifications are being evaluated for their effect on overall fuel economy. Fuel economy testing is performed by a variety of public agencies, as well as by manufacturers.

In order to facilitate and improve such evaluations, UMTA has sponsored a Transit Bus Fuel Economy Test Program. Under this program, a procedure proposed by the Society of Automotive Engineers (SAE) was applied to turbo-charged diesel engines, air conditioning systems, axles with different ratios, different diesel fuels and oil additives, and buses of different weights. Wide-scale application of the SAE testing procedure (which has been positively verified) is expected to give the transit industry a more accurate picture of which products or modifications will contribute to energy efficiency and lower costs.

UMTA is also monitoring the development of different approaches to storing and recovering braking power in order to conserve fuels in stop-and-go traffic. In addition to flywheels, three types of hydraulic accumulators are being developed in Europe. These devices aroused little interest in the United States until recently. However, tests in Copenhagen, Denmark, and an assessment study by the Tri-County Metropolitan District (TRIMET) of Portland, Oregon, indicate that accumulators could produce significant savings and merit testing by U.S. operators. UMTA has invited interested transit operators to contact the manager of the Energy Conservation and Propulsion Technology Program.

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