Ultralight Rail and Energy Use

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GLOSSARY

Guideway The rail, support structure, power delivery conductors, and control sensors that make up the path on which ultralight vehicles move.
CONSIST An individual unit or multiple vehicles traveling in a linked set
HEADWAY The time period between trains or individual vehicles passing a particular point on the guideway.
GRADE The slope, or inclination, of the guideway
PPHPD (Passengers per hour per direction) The measure of capacity of a rail transit system, in terms of the maximum number of passengers the system can move in one direction.
kWhr (Kilowatt hour) Base energy unit – 1 kilowatt of power used for one hour

I. INTRODUCTION

In order to best describe the relationship between ultralight rail and energy, it is necessary to establish a basis of understanding. This basis is best defined in terms of the energy requirements of known and familiar modes of transportation, since there are so few examples of ultralight rail in operation at the moment. This article establishes this basis in terms of conventional rail systems, and where applicable, bus, automobile and truck systems. The reader is taken through the basic characteristics of both conventional and ultralight rail systems, followed by a comparison of the two systems, with an emphasis on the energy aspects of their direct operation. The energy aspects of ultralight rail in the overall transportation system of the United States is analyzed and discussed.

II. DEFINITION OF ULTRALIGHT RAIL

Ultralight rail (ULR) is at the low end of the spectra of weights of rail vehicles, generally considered as any vehicle with a loaded weight less than 10,000 pounds and with a more

personal type of operation (Irving, 1978). This compares with Light Rail Transit (LRT, www.travelportland.com/visitors/transportation.html) vehicles that can weigh over 100,000 pounds loaded and the locomotives that pull freight, commuter, and Amtrak trains and weigh over 300,000 pounds. The weight of a passenger vehicle on what is classified as a "Heavy Metro Rail", like BART in the San Francisco Bay area (www.bart.gov), the New York City subway, etc., can actually weigh less (around 60,000 pounds) than an LRT vehicle due to its construction and propulsion system ("Light" referring more to total passenger capacity than individual vehicle weight).

Figure 1 CyberTran Vehicle on Test Track in Alameda, California

In the ultralight range of steel wheeled rail vehicles, there are several technologies in development but none in operation. CyberTran (www.cybertran.com), shown in Figure 1, is an example at the top of the range (10,000 pounds, loaded) and an Australian technology, Austrans (www.Austrans.com), is somewhat lighter at approximately 6600 pounds, loaded. Futrex (www.futrexinc.com) is between the ultralight range and the LRT, or full size rail vehicles, weighing approximately 20,000 pounds loaded.

There are several systems with vehicles in the ultralight category that utilize rubber tired vehicles and channel type guideways, such as TAXI 2000 (www.taxi2000.com) and the ULTra system (www.atsltd.co.uk) at the University of Bristol in Cardiff, England. The Morgantown People Mover (www.wvu.edu/~facserv/prt.htm), shown in

Figure 2 Morgantown People Mover Vehicle

Figure 2 at the University of West Virginia, Morgantown, WV is just over the 10,000 pound loaded weight (9000 pounds empty with a passenger capacity of 21), but represents the best operating example of ultralight type systems. While these rubber-tired systems share many of the energy saving aspects of ultralight rail, they have a larger rolling friction than steel wheel on steel rail. The reader should keep these systems in mind regarding energy discussions that are functions of size, passenger load, small infrastructure costs due to vehicle size, and vehicle movement options generated by small vehicles. An excellent coverage of ultralight systems and innovative transportation concepts under development can be reviewed at the website of Professor Jerry Schneider, University of Washington. (http://faculty.washington.edu/jbs/itrans)

III. A BRIEF DISCUSSION OF CONVENTIONAL RAIL

Regardless of the weight of the vehicle – ultralight to heavy metro - a steel wheel on a steel rail is the most energy efficient way to

move a load over land. This efficient process was initiated by placing a iron rimmed wagon wheel on a iron plated beam, allowing draft animals to pull much heavier wagon loads. With the advent of steam engines to pull the wagons and flanges to keep the wagon wheels from slipping off the rails, the essence of the modern railway was born in the early 1800's in the coal mines of England, and quickly spread over the rest of the world. The energy efficiency of the basic steel wheel on steel rail system was further enhanced with the advent of roller bearings on the axles and propulsion systems with electric and diesel-electric power plants.

A. Energy Efficiency of Steel Wheel on Steel Rail

The primary reason for the energy efficiency of steel wheel on steel rail vehicles is the extremely low rolling resistance of the wheel, even under very high loads and/or stresses. A typical loaded freight car can weigh as much as 280,000 pounds, being supported by 8 wheels, with each wheel supporting over 35,000 pounds. This wheel load is supported through a "contact patch" approximately the size of a dime, resulting in a contact stress between the wheel and the rail of around 100,000 pounds per square inch (psi). While this stress actually deforms the steel wheel and the steel rail, the energy lost in this process is small compared to the energy it takes to deform and roll a rubber tire under heavy load. The force required to roll a standard railroad vehicle on level ground is approximately 2 – 4 pounds per ton of vehicle weight. (Armstrong, 1994)

B. Conventional Systems - Vehicle Weights and Capacities

Conventional transit vehicles typically weigh much less than loaded freight cars, but still represent a heavy load to place on wheels and rails. A BART car weighing 80,000 pounds loaded, and supported by 8 wheels, has a per wheel load of 10,000 pounds. Articulated LRT vehicles generally have 3 sets of 4 wheel trucks, and with loaded weights up to 120,000 pounds, results in a load of 10,000 pounds per wheel. These vehicles roll even more efficiently than heavily loaded freight cars, but still represent a sizable load, with energy absorbing deformation of the wheel/rail contact area. Rolling friction of typical transit vehicles are on the order of 3 pounds per ton. Figure 3 shows a typical LRT vehicle, operating at ground level in Portland, Oregon.

Figure 3 LRT Vehicle in Portland, Oregon

Figure 4 shows an example of a Heavy Metro Rail system, BART, operating on elevated track in the San Francisco Bay area. LRT vehicles can transport over 100 passengers per vehicle and a 10 car BART train can carry over 1000.

Figure 4 BART Train on Elevated Track

C, Operation of Conventional Rail Transit Systems

The operational process of picking up passengers and moving vehicles around the system is an area where ultralight systems differ significantly from conventional rail transit systems, resulting in opportunities for energy and operational cost savings.

Conventional rail transit systems generally operate as a "linear" system, i.e., vehicles or trains proceed down the track in sequence, with each train stopping at each station and loading/unloading passengers. The NYC subway system is a rare exception to this process, having express trains that bypass certain stations in favor of decreasing the travel time to just a few stations. The NYC system requires an additional set of tracks in order to operate in this fashion. For most conventional systems in the world, however, the trains run in single file along the system, with the average speed of the system governed by the rate at which the trains can be cycled through each station. For an average station, it takes about 30 seconds for a train to approach a station and come to a complete stop, another 30 – 45 seconds to open the doors, unload/load passengers, then close the doors, and another 30 seconds or so to clear the station with enough margin for the next train to come in. The smallest delay in any of these functions slows the entire line of traffic, with subsequent negative impact on the average speed of the system. Minimum headways of 1.5 – 3 minutes are the norm when safety margins are included. Ultralight systems use a different operational process (explained in Section V) that minimizes the effect of local delays, resulting in a positive effect on average system speed.

D. Passenger Flow Rates of Conventional Rail Systems

Capacities of conventional rail systems vary substantially, depending on the capacity of each vehicle or train, the headway between trains, and the speed of the trains. The LRT system in Portland, Oregon (Transportation Research Board, SR# 221, 1989) is made up of two-car consists with a total capacity of approximately 320 passengers (seated and standing). At their average headway of 5 minutes during peak flows, or 12 vehicles per hour, this constitutes a maximum flow rate of 3,840 passengers per hour per direction (pphpd). BART, utilizing 10 car consists capable of carrying over 1,000 passengers and operating at less than 3 minute headways, has a capacity approaching 26,000 pphpd. The Paris Metro, using 5 car consists capable of carrying 1,000 people and operating at 90 second headways, has a capacity approaching 40,000 pphpd.

III. Capacity and Energy Consumption of Highways

Highways can also be rated with respect to their maximum capacity and energy consumption, thus making it easier to compare them with rail as a related transportation mode, relative to cost and energy usage. A great deal of research and observation has resulted in the understanding that a multi-lane highway has a maximum capacity on the order of 2,400 vehicles per hour per lane (Transportation Research Board, SR #209, 1994). Considering the fact that approximately 95% of freeway traffic consists of single occupancy vehicles, a highway lane has a passenger capacity of approximately 2,500 pphpd. One can see instances, especially on Los Angeles freeways, of groups of vehicles moving at densities of 50% or more in excess of this number, but not on a sustained basis or over an extended distance.

Considering only those vehicles that meet the CAFÉ (Corporate Average Fuel Economy) standards of 27.5 mpg, an average vehicle capacity of four seats, and an energy equivalent of 40 kWhr/gallon, the energy efficiency of an automobile is approximately 0.37 kWhr/seat-mile. New technology vehicles such as the

hybrid powered automobiles by Honda and Nissan have decreased fuel consumption by a factor of two or more, for an energy efficiency of approximately 0.18 kWhr/seat-mile. The ultra-car technology by Dr. Amory Lovins of the Rocky Mountain Institute (www.rmi.org) promises to increase this efficiency by another 50%, or 0.1 kWhr/seat-mile, by achieving a fuel efficiency of approximately 80 miles per gallon.

V. Ultralight Rail – Operational Characteristics

Figure 5 Taxi 2000 Vehicle

The most dramatic and obvious characteristic of ultralight systems is the size of the individual vehicles relative to conventional rail vehicles. Figure 1 shows the CyberTran #2 Test Vehicle, a 38 foot long vehicle, weighing 10,000 pounds loaded, and designed to carry 15 – 20 passengers. Figure 5 shows the Taxi 2000 vehicle, designed to carry 3 passengers at a loaded weight estimated to be less than one ton..

A. Computer Controlled Systems

An important characteristic of ultralight rail system vehicles is that they are computer controlled. While this characteristic is not unique to ultralight systems (the Vancouver, B.C. SkyTrain Metro system [Tayler, 1992] and the Paris Metro Meteor line are driverless), in the ultralight systems it is almost a necessity for any reasonable operating economics. If a driver were required in each small vehicle, the overhead costs would be intolerable, requiring trip costs typical of taxicabs without the route flexibility of taxis. It is this characteristic, however, that offers the opportunity for significant energy and cost savings due to the different operating modes possible.

B. Ultralight Rail Station Configuration

Two important characteristics of ultralight rail systems are the rapidity in which passengers can be dispatched toward their destination and the speed with which the passengers arrive at their destination. Both of these characteristics are due to a passenger loading/unloading process known as "off-line loading" and "direct to destination" routing. Off-line loading means that the loading and unloading process takes place off the main line, in a station that is reached by going through a rail switch and proceeding to a loading platform well away from the high speed traffic of the main line. This accomplishes two important functions, the first being that delays in the loading/unloading process at one station do not slow vehicles on the main line, and secondly, by being able to maintain a high speed between origin and destination, a vehicle has a high average speed over its route. Direct to destination routing means that the vehicles do not stop at intermediate stations between their origin and their destination. The ability of a system to send vehicles directly between origin and destination requires that all passengers in that vehicle are going to the same destination, a situation that can only be realized by using small vehicles in conjunction with high speed and computer controlled direction of passengers to their proper vehicles. Computer control over the operation of each vehicle, and between individual vehicles, results in headways between vehicles of 15 seconds or less. Managers of the Morgantown People Mover are suggesting going to 7.5 seconds between vehicles on the main line, and Dr. Edward Anderson, with Taxi

2000, is proposing running at even smaller time increments (Anderson, www.taxi2000.com). The effect of these short headways is to get more people to their destination quicker, with less energy consuming starts and stops along the way.

C. Ultralight Rail Structures

An important characteristic of ultralight rail is that the structures carrying the vehicles are much smaller that the bridges, columns, foundations, etc., normally associated with conventional rail transit systems, or even highway bridges. This characteristic is the one having the most impact on relative costs between conventional and ultralight rail systems. The size of structures required to support a 100,000 pound vehicle 15 feet in the air vs. elevating a 10,000 pound vehicle not only has a dramatic cost effect on the construction effort, but also in the amount of system energy it takes to produce the extra material and hardware.

D. Power Requirements of Ultralight systems

A hidden, yet important characteristic of ultralight systems is the low power of the electric propulsion motors required to move the vehicles around. While rolling friction is low for all rail vehicles, the energy required to accelerate or elevate a vehicle is in direct proportion to its weight. This characteristic of having low power propulsion motors is of most importance relative to the movement of empty or low ridership vehicles. Conventional large, high capacity rail systems must move 10's of 1000's of pounds of hardware around the system even if they are empty or lightly loaded. Ultralight rail systems move much smaller vehicles around, and then only the number of vehicles that are required to meet the passenger load demands. The advantages of this aspect of ultralight rail systems are discussed further in Energy Requirements of Ultralight Rail and Conventional Rail.

E. Passenger Flow Rates

Capacities of ultralight systems cannot approach the capacities of heavy metro rail like BART, NYC, or the Paris Metro, but can provide the carrying capacity normally provided by the various LRT systems around the United States. The capacity of a system like the Morgantown People Mover or CyberTran, both having a capacity of around 20 passengers and operating at 15 second headways, would be 240 vehicles per hour, for a capacity of 4800 pphpd. Morgantown operators are suggesting that the next upgrade to their system will provide for operation using 7.5 second headways, a headway also evaluated for use with CyberTran. Should these headways be implemented, these two systems would provide a line capacity of 9600 pphpd.

These headways are based on the requirement to allow enough time and distance between adjacent vehicles so that should the leading vehicle come to a sudden stop, the trailing vehicle has the time and distance to stop before hitting the leading vehicle. With this requirement in mind, during high passenger flow conditions, it is possible to slow vehicles down and operate under headways even shorter than the proposed 7.5 seconds. If one reduces the headway to 5 seconds, a speed of 40 MPH represents a separation the length of a football field and the safe emergency stopping distance is less than 1/2 of that distance. An operational scenario like this results in a passenger flow rate of 14,400 pphpd, which rivals the advertised capacity of almost any LRT system, and is far greater than any actual flow being carried by an existing LRT system. The Taxi 2000 system is proposed to operate 3 passenger vehicles at a headway of 0.5 –1 seconds for a passenger flow rate of 7200 pphpd.

VI. Energy Requirements of Ultralight Rail and Conventional Rail

This section looks at the major factors affecting the energy requirements of ultralight

and conventional rail systems and the factors that differentiate the energy requirements of the two systems.

A. Basic Energy Requirements of Rail Systems

There are four primary energy requirements in the operation of both ultralight rail and conventional rail. These are acceleration, rolling friction, elevation in grade, and aerodynamic drag. Energy requirements for acceleration, rolling, and grade changes are all a direct function of the weight of the vehicle and its occupants. Aerodynamic drag is a function of size, shape, length, etc., and although a small force relative to conventional system acceleration and grade climbing forces, can be a significant energy consumer in ultralight systems where vehicle weight is a tenth of conventional rail vehicles.

A major expenditure of energy is required for elevation change (upward) of conventional rail vehicles and their loads, and it is in this area that one of the major differences in system energy consumption can be seen between conventional systems and ultralight rail systems. It is also the reason that conventional rail systems, especially locomotive powered systems, are limited to rather flat grades throughout their routing. A conventional, 100,000 pound LRT traveling up a 2% grade at 60 MPH requires 240 kW of power just for energy associated with the grade change, plus the energy required to overcome the rolling friction and aerodynamic drag at this speed. An ultralight vehicle loaded to 10,000 pounds would require only 24 kW to handle the same grade. In transit systems where a series of "trailer" cars are pulled by a locomotive, such as with Amtrak, all of the "grade" drag must be supplied by the traction of the locomotive. In the case of a train of ten cars, each weighing 100,000 pounds, the locomotive pulling this train must exert a pulling force of 10,000 pounds for each degree of slope of the roadbed (.01grade * 10 cars * 100,000 pounds), plus the adhesion required to move the locomotive (2,500 pounds for a typical 250,000 pound locomotive). BART has four 110 kW electric motors per car, for a total of 4400 kW for a 10 car train. LRT vehicles typically have electric motors in the range of 400 kW per vehicle. Ultralight vehicles require motors of less than 50 kW to meet rolling, acceleration, grade, and aerodynamic energy needs.

B. Vehicle Weight per Passenger

For rail vehicles not pulled by a locomotive (BART, NYC, Paris Metro, LRT, ultralight systems), the vehicle weight per passenger is remarkably similar. LRT vehicles have an advertised capacity in the neighborhood of 160 passengers and an empty weight of around 80,000 - 90,000 pounds (depending on manufacturer and configuration), for a per passenger capacity weight of approximately 500 - 560 pounds. BART has a vehicle weight of approximately 60,000 pounds and a capacity of around 120 per vehicle, or 500 pounds per passenger. CyberTran has an empty weight of approximately 7500 pounds and a seated capacity of 15 – 20, or a maximum per passenger weight of 375 - 500 pounds per passenger. The Morgantown People Mover vehicle is approximately 9000 pounds with a 21 passenger capacity, or 428 pounds per passenger.

C. Vehicle Weight per Passenger vs. Load Factor

In addition to the similarity of weights per passengers, all of the rail systems described use very efficient electric motors in their propulsion systems, albeit of greatly different power between the heavy and the ultralight systems. Therefore, on a per passenger basis, one should not expect much difference in the energy efficiency of a heavy system and a light system when both systems are operating at or near their capacity. It is when the systems are required to operate at less than their maximum

loads (which is the case for most systems having a morning and evening rush hour), that significant differences can be seen between the operation of conventional rail systems and ultralight systems.

To illustrate the effects of weight, passenger capacity, and operating process on the energy consumption of a rail transit system, assume an LRT with an empty weight of 75,000 pounds and a passenger capacity of 150 (@ 166 pounds per passenger), comparing its operation with an ultralight system of 7500 pound vehicles and a capacity of 15 (to make the math easy). Table I shows the effective system weight and the weight per passenger of a conventional and ultralight system as the ridership drops (assuming constant frequency for the LRT and sufficient ultralight vehicles to carry the ridership.

Table I Effects of Load Factor on Vehicle Efficiency

Riders/cycle	Effective System Weight		Vehicle Weight per Passenger	
Riders	LRT	ULR	LRT	ULR
150	100,000	100,000*	500	500
75	87,500	50,000**	1000	500
37	81,166	28,642***	2027	608
20	78,333	18,320	3750	750
10	76,666	9,166	7500	750
1	75,166	7,666	75,000	7500

* assumes 10 fully loaded vehicles to carry load at 10,000 pounds per loaded vehicle
** 5 vehicles @ 7500 pounds each plus 12,500 pounds of passengers
*** requires 3 vehicles to carry 37 passengers

Table I shows the dramatic effect of operating a system with small vehicles, and one which allows the system control to use only the number of vehicles/capacity required to carry the load at any one time. The LRT system is forced to provide an entire, high capacity vehicle even when there are only a few riders, whereas the ultralight system merely provides enough vehicles to carry the riders. From Table I, it can be seen that the primary energy requirements of an ultralight system that are based on vehicle and passenger load weights go from equal at full load to only 10% as the passenger load approaches zero.

D. Energy Efficiency of Off-Line Loading and Direct-To-Destination Routing

Another aspect of operational differences between conventional and ultralight systems that can have effects on energy consumption is the ability of ultralight systems to operate in a full time express mode, i.e., direct to destination, as opposed to the linear operating mode of conventional rail, i.e., stopping at every station. The standard operating mode of ultralight systems is with off-line loading/unloading, as described in the previous section. With an appropriately designed station, an ultralight vehicle can leave any station and go directly to any other station, in either direction. A conventional linear system, however, must start at one end of the line with all of the capacity it will require to handle the heaviest traffic between any two stations on the line.

Table II illustrates the effect of this necessity for "carrying your capacity" through the entire line versus the option available with ultralight systems to only place in service that capacity needed to carry the load.

Table II Conventional vs Capacity Dictated Vehicle Dispatch

Station	Passengers Flow Entry	Exit	Net	Required Capacity LRT	ULR*
1	20	0	20	150	30(2 veh)
2	50	10	60	150	60(4 veh)
3	50	20	90	150	95(7 veh)
4	70	10	150	150	150(10 veh)
5	20	80	90	150	95 (7 veh)
6	10	50	50	150	60 (4 veh)
7	5	30	25	150	30 (2 veh)
8	0	25	0		
Total Capacity Required				485 passenger segments**	
Total Capacity Delivered (passenger segments) -				1050	520

* Assumes vehicles carry multi-destination passengers, stop only at stations to which passengers are going, and can reverse direction at any station

** One passenger segment is one passenger transported between adjacent stations

The operational efficiency of each system for this example, defined as the passenger segments required/passenger segments provided, is 46.2% for the conventional system and 93.2% for the ultralight system.

Each unit of capacity delivered carries a cost in energy as well as wear and tear on the system. With each system having a vehicle weight of approximately 500 pounds per unit of capacity, accelerating each of these extra units of capacity, and carrying them through any change in elevation, plus the small amount of rolling energy indicates that, for this example, the ultralight system is over twice as energy efficient in carrying the required passenger load. This increased efficiency is due entirely to the operating options available with the ultralight system, since the basic weight per passenger capacity, motor efficiency, and effects that are a function of weight, such as acceleration, elevation change, and rolling are essentially the same.

An additional effect that is not illustrated in Table II, but can be readily seen as a source of additional energy savings, is the saving associated with not having to stop at intermediate stations. When traffic becomes sufficiently large, the small vehicles can be filled at one station with passengers destined for a single other station, as opposed to conventional linear rail systems where all passengers to all stations are in the same vehicle and stop at all stops. This single destination vehicle then proceeds directly from its originating station to its destination station, not having to expend the energy of stopping and starting at each intermediate station, and traveling between the stations at a much higher average speed. Computer simulations between direct to destination routing and linear system routing indicate an increase in average system speed of a factor of 3 (from 15.7 MPH in the Portland MAX system to 51 MPH in a simulated system with ultralight vehicles).

E. Energy Efficiency Potential from Intermodal Operations

As illustrated in Table I, high capacity, heavy metro and LRT systems can be very efficient, energy-wise, when operated at high passenger loads, and conversely, can be extremely inefficient during periods of low passenger flow.

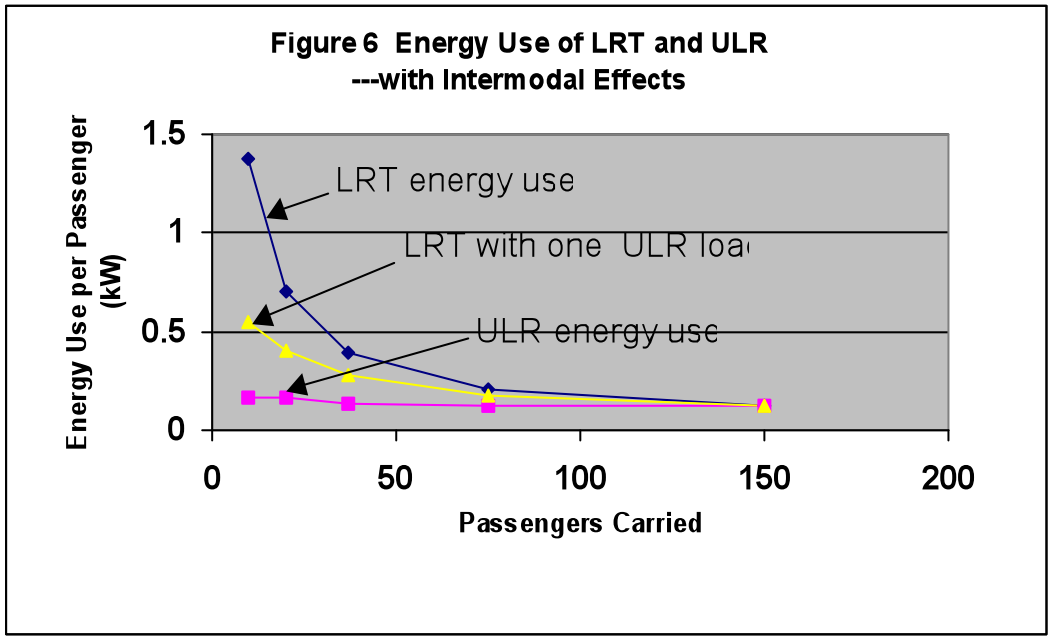

Figure 6 illustrates the effect of load on energy efficiency as the passenger load decreases in (1) a 150 passenger LRT vehicle and (2) ten ULR vehicles, with the ultralight vehicles being removed from service as the load decreases.

Ultralight rail systems have the potential to increase the energy efficiency of high speed and heavy rail systems (Transportation Research Board, SR 233, 1991) by feeding extra passengers into existing stations from outlying areas off the sides and ends of the high capacity systems. Figure 6 provides an example of the increase in energy efficiency possible by the intermodal connection of conventional rail systems and ultralight rail, where a single ultralight passenger load is brought in from the side or end and added to the passenger load of a conventional LRT size vehicle.

Additional passengers brought in from the side or ends of conventional systems by small ultralight vehicles not only increase the energy efficiency of the conventional systems, but reduce the need to provide additional parking in the immediate station area. Parking for the ultralight systems can be placed far from the conventional system stations in less expensive and more accessible real estate.

Conventional heavy metro and LRT systems are expensive ($50,000,000 to $100,000,000 per mile) and have a large ground footprint, two characteristics that detract from extending the systems into lower density sources of passengers. Additionally, it is not only expensive to provide parking around stations, where the land is at a premium, but 5 acres of expensive parking can only hold about 750 vehicles, approximately the passenger capacity of one heavy metro train. Therefore, the first train through the system can take all of the parking lot patrons, leaving the station isolated to many potential passengers and lowering the efficiency of the large transit system. Ultralight systems that cost $10,000,000 to $20,000,000 per mile and have a much smaller ground footprint can be extended far beyond the walking limits of conventional rail stations, bringing additional passengers to the conventional system in an energy efficient process, making the operation of the conventional system even more efficient, since the marginal energy cost of additional passengers on a conventional system is extremely low.

F. Ultralight Rail and Cargo Transport

A final point in the spectra of possibilities with ultralight rail is transportation of cargo. Ultralight vehicles with a maximum gross vehicle weight of up to 10,000 pounds have a cargo carrying potential of over 5,000 pounds. With a rolling resistance and an aerodynamic drag of an ultralight vehicle requiring an average power requirement of approximately 12 kW, the energy consumption of an ultralight cargo vehicle can be on the order of 0.08 kWhr/ton-mile. This value compares with a Class 8 truck that can carry 25 tons at an average diesel consumption of 6 miles per gallon (Charles River Associates, 2000), or for an energy equivalent of 40 kWhr/ diesel-gallon, an energy consumption of .266 kWhr/ton-mile. While the energy consumption of highway trucks is approximately a factor of 3 times that of a ultralight rail vehicle, the monetary economics of the process is not as disparate. For an electricity cost of $0.10 per kWhr, the direct energy cost of an ultralight rail vehicle is $0.008 per ton-mile. For a diesel price of $1.50 per gallon, the direct energy cost of truck cargo is $0.01 per ton-mile, only 25% more that the ultralight vehicle cost. This cost comparison is more a reflection of the energy policy of the United States than of the energy consumption rates of the two modes of cargo transport. However, when one adds in the cost of the truck driver, approximately $0.02 per ton-mile, the monetary cost difference between the two modes of transport are comparable with the differences in energy consumption between ultralight rail and heavy trucks.

Obviously, ultralight rail systems would be best utilized in certain types of high value cargo such as the U. S. Mail, electronics, or any item with a high time value.

VII. Energy Saving Opportunities with Ultralight Rail

The above data and comparisons indicate that significant energy savings are possible with the implementation of ultralight rail systems. The energy savings of ultralight rail systems relative to conventional rail systems is due primarily to the ability of ultralight systems to quickly adjust the number of vehicles, thus capacity, to the ridership requirements. These savings are possible not only with stand-alone ultralight rail systems, but with their use as support and passenger feed systems to high passenger volume conventional rail systems, such as BART, NYC, and certain LRT systems.

The energy savings of ultralight rail relative to automobiles is due not only to the basic increased energy efficiency of a steel wheeled vehicle over a rubber tired vehicle, but also due to the highly inefficient utilization of automobiles in congested commuting situations.

Table III illustrates the potential effect of ultralight rail on energy consumption in the human transportation sector of the United States economy. Table III shows the energy consumption of 4 transportation modes, in terms of their potential (kWhr/available place mile) and in terms of their actual (or best estimated) usage (kWhr/passenger mile).

TABLE III ENERGY USAGE OF VARIOUS TRANSPORTATION MODES

	LRT*	ULR	Bus*	Auto**
Potential (kWhr/place mile)	0.04	0.04***	0.14	0.37
Actual (kWhr/ pass-mile)	1.14	0.106****	4.06	1.4*****

* Data from Portland MAX (Transportation Research Board, SR #221, 1989)

** 4 passenger auto, 27 mpg

*** Estimated based on weight and seats compared to LRT

**** Based on dispatching out at 60% occupancy and deadheading back empty

***** Based on 1.05 passenger average occupancy – units of kWhr/passenger mile

Table III shows that conventional rail and ultralight rail are essentially the same in energy efficiency when operated at their maximum potential, but that the capability of ultralight rail to leave unneeded capacity in the station has a dramatic effect on energy efficiency at less than maximum loads. Table III indicates that in situations where ultralight rail can augment or be substituted for other transportation modes, significant energy savings can result, such as with LRT (91%), bus (97%), and personal auto (92%). While there will always be a necessity for buses and automobiles, the energy consumption numbers indicate that rail in general, and ultralight rail in particular, should be implemented as widespread as possible for the energy saving potential the technology offers.

Not only are significant energy savings possible with the implementation of ultralight rail systems, but the energy source for these systems, electricity, can be generated from resources under domestic control (coal, hydroelectric, nuclear, natural gas) as opposed to the foreign oil base of the majority of the United States transportation infrastructure.

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