Energy, Environmental and Economic Benefits Of Electric Rail and Dual Mode Transportation

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Abstract

In the search for alternatives to oil based transportation, there is growing interest in electric powered personal vehicle transportation. While providing electricity to the vehicles has been problematic, the use of an electric rail has considerable promise. Dual Mode vehicles, which drive similar to an automobile to reach individual destinations, but connect to an electric rail for longer distance travel, take advantage of this electric rail technology. But in addition to the usual benefits of electric transportation, dual mode vehicles also realize better fuel efficiency, driver productivity benefits from computer guidance, reduced congestion, improved safety and lower infrastructure costs.

This paper, starting with a brief discussion of the benefits of electric transportation, goes on to outline the benefits of electric rail transportation, specifically Dual Mode Personal Rapid Transit. It will also discuss Single Mode Freight transportation, the delivery of freight using automated driverless vehicles. This paper concludes with a cost/benefit analysis of a national Dual Mode PRT and Single Mode Freight system, which summarizes and gives perspective to this unique form of transportation.

INTRODUCTION

With concerns over rising oil prices and global warming there is increasing interest in using electricity to power our transportation systems. Responding to these concerns two of the largest automobile companies in the world, General Motors and Renault/Nissan, are planning large-scale introductions of electric automobiles in the United States in 2010. In addition, Project Better Place has raised $200 million for a comprehensive project to introduce electric automobiles to Israel. This venture is dependent on battery swap technology and a unique form of ownership of the batteries (monthly usage charges instead of ownership of the batteries). Even before Project Better Place has manufactured its first vehicle, they have announced expansion of the project to Denmark. According to Andy Grove, the ex-chairman of Intel Corporation and one of the most forward thinking business executives of the last thirty years, "Electricity in transportation has to be done. It is urgent. It is important that everything else is secondary….The drumbeat of electrical transportation is accelerating like nothing that I have ever seen in my life"*(1)*

This interest in electric transportation is being driven largely by the rising price of gasoline, but there are other important advantages, such as reductions in greenhouse gas emissions, improvements in air quality, and the geopolitical benefits of a reduction in foreign oil imports.

While there are many advantages to electric transportation, the problem becomes how to supply the electricity. The current choices are: fuel cells, small gasoline powered generators, batteries or electric rail. Fuel cells, unfortunately, continue to operate only in very controlled markets, awaiting better and less expensive methods of creating and providing hydrogen. The use of a small onboard gasoline powered generator to recharge batteries is an interesting idea being developed by General Motors for use in the Volt. The development of batteries continues at an accelerated pace but awaits a major breakthrough that will extend the driving range of the vehicle.

The fourth way to transfer electricity to transportation is an electric rail. While it has been around for decades in the form of subway systems and electric buses that rely on overhead electric wires, the idea of small vehicles attached to an electric rail has recently reemerged. It was extensively studied in the early 1970's but never gained momentum. (See TRB Special Report 170 "Dual Mode Transportation" May, 1974.) The Morgantown electric trams in West Virginia, which are still operating today, are a direct result of that interest. Spurred by the efforts of the Center for Environment, Energy and Transportation Institute (CEETI) at Texas A&M University; the efforts of some of the 1970's proponents; and a few entrepreneurs, the interest in electric rail technology has recently gained a strong following.*(2)*

An outgrowth of the Texas A&M University CEETI project is an expanded effort by some of the top government and institutional research groups in the United States. Oak Ridge National Laboratories, Argonne National Laboratories, National Renewable Energy Laboratories, Texas A&M University, Utah State University and others have formed a consortium called Automated Electric Transportation. Realizing the benefits of direct transfer of electricity from the grid to moving vehicles they are studying similar technology to dual mode.

Types of Electric Rail Transportation

The different types of electric rail transportation can be broken down into three different groups: single mode Personal Rapid Transit (PRT); dual mode PRT and single mode freight and public mass transit vehicles.

Single Mode PRT:

With single mode PRT, driverless, computer guided vehicles are permanently connected to the rail. The vehicles are not privately owned. Typically the small, maximum four passenger vehicles are used by the occupants to go to the same destination. The major benefit of this system is that the vehicle goes directly the passengers' destination, without intermittent stops. Basically it has many of the same attributes as a driverless taxicab that is attached to an electric rail. There are several projects of single mode PRT either being constructed or planned. The ULTRA project at Heathrow Airport is now finished with construction and undergoing testing in preparation for an opening in 2009. In the United Arab Emirates, the $22 billion Masdar Project is a model city for environmental innovation. It is being promoted as the world's first zero carbon and zero waste city. Automobiles are banned from the City and all transportation will be via an underground PRT system.

Dual Mode PRT:

Dual mode PRT (usually just referred to as Dual Mode or DM), is a system involving the use of individual vehicles. It can operate in two modes, attached to the rail or disconnected from the rail. The benefit of disconnecting from the rail is that it has the convenience of the automobile to reach individual destinations on the driver's schedule. However for longer distance travel the DM vehicle can connect to the rail. While connected to the rail, electricity is supplied by the rail to provide power during rail transit, as well as to recharge the batteries that are onboard the vehicle. When the vehicle disconnects from the rail, the batteries are fully charged and capable of about fifty miles (80 km) of travel independent of the rail, similar to the range of other electric vehicles.

During travel on the rail the vehicles are controled by computers, GPS or the linear synchronous waves of the electric current. By eliminating the driver from control, spacing between vehicles is reduced, greatly increasing the capacity of the transportation systems. The goals of ITS proponents, to increase road capacities by reducing headway spacing could be achieved rather easily with a DM system, with vehicles captive to a track.

Because computers control the vehicles on the track, this allows for a high capacity system. The infrastructure cost per vehicle of capacity is much lower than the automobile and existing roadways. DM systems, consisting of four parallel tracks that are less than 40 feet wide (12.2 m), can have a capacity as high as 60,000 vehicles per hour, the same as a 20-lane highway (see appendix B).

Another potential benefit of computer control and vehicles captive to the track is that safety would be improved. Because the track is elevated, and even possibly partially enclosed, it would operate with little interference from weather and pedestrians. The precision of computers, capable of knowing traffic conditions many miles down the road, is substituted for driver judgment. The use of tracks makes collisions with other vehicles almost impossible.

Probably the most important benefit is high-energy efficiency. The combination of low rolling resistance from a hard surface track, lighter weight vehicles (generally 2,000 to 3,000 lbs. gross weight) (900 to 1400 kg) and the use of electric motors (in the range of 50 to 60 hp) that are inherently more fuel-efficient than the internal combustion engine results in much higher mileage per unit of energy. Based on BTU consumption DM vehicles are calculated to achieve a 70% to 80% reduction in fuel use (see appendix A)

Single Mode Freight Vehicles:

One important component of a national electric rail transportation system would be the ability to have driverless freight containers. They are called single mode freight (SMF) because they are permanently attached to the track and would be programmed to travel between depots along the rail system. Once a load arrived at a depot it would be transferred to a driver operated truck for local delivery.

This study will only discuss dual mode Personal Rapid Transit (DM) and single mode freight (SMF). This is because DM and SMF have the potential to replace a significant portion of traveling vehicles, becoming a national system, versus single mode PRT that will tend to involve smaller scale projects. DM and SMF can substantially reduce oil dependency and greenhouse gas emissions. The framework used for this study of DM and SMF is a cost/benefit analysis because it provides a sense of the magnitude of the project, as well as the benefits. A national project is an enormous task but the benefits are equally huge.

COST/BENEFIT ANALYSIS

This analysis is based on building an elevated electric rail system consisting of four parallel tracks either in the middle or alongside every United States Interstate road, 46,835 miles (75,400 km*)(3)*. The decision to use this criterion, installing a national DM/SMF system where the existing Interstate system is today, was based on three reasons: it represents a minimum system, it would provide for a national network, and data is readily available for an accurate analysis. Although this paper only discusses a national Interstate DM/SMF System it is likely that there would be a rapid expansion of the DM/SMF System to important state operated highways and other major arterial roadways.

There are a number of assumptions and statistics that are used extensively in this analysis. In 2005 the vehicle miles traveled (VMT) by passenger cars, vans, SUV's, pick-up/passenger trucks and freight trucks on United States Interstate System was 722 billion miles (1,162 billion km), 24.2% of all VMT on all roads in 2005 *(3)*. These are the types of vehicles that would use the electric rail track system and thus would be removed from the current road system.

We are assuming that if a national rail system was installed along the nation's Interstate System, that eventually 60% of those vehicles would use the electric rail versus the Interstates. Vehicles that would not use the track would be vehicles not capable of running on the tracks as well as short distance vehicles that may choose not to run on the track.

The existence of an electric track system that solves the number one problem with electric cars, lack of travel range, will make the ownership of electric vehicles more widespread. Therefore there will be an added benefit beyond the vehicles using the track. At any given time, while only 20% of the all vehicles will actually be running on the DM/SMF System, the availability of the track means that 40% of all vehicles in the United States are electric. In other words, without the electric rail system the total electric car market might be only 5% of all vehicles. We are assuming that for every vehicle using the DM/SMF System, there will be another electric vehicle using the local roads and highways.

As discussed in the preceding Introduction and Description of Electric Rail Transportation sections of this study, the benefits of a DM/SMF system are summarized in Table 1.

TABLE 1

Benefits of Electric Transportation

- Oil independence
- Reduced greenhouse gas emissions
- Improved air quality

Benefits of DM and SMF

- Improved energy efficiency
- Driver productivity
- Computer control with higher speeds
- Congestion relief
- Improved safety
- Reduced infrastructure costs

Benefits of Electric Transportation

Benefit of Oil Independence

If foreign oil imports disappeared, the United States would realize a reduction in the military expenses incurred to protect shipments of oil and compromises in foreign policy as a result of the need for allies and overseas military bases to protect that oil. Because it is difficult to estimate the cost of foreign policy compromises, this analysis will only estimate the reduction in military costs.

Estimates of the cost to protect the importing of foreign oil vary widely. At the high end are experts that include estimates of the rise in oil prices attributable to speculation over foreign policy events and inclusion of the entire funding for the Iraq War. In testimony before the Senate Foreign Relations Committee in March 2005 the President of the National Defense Council Foundation estimated the hidden cost of gasoline consumption at $780 billion in military costs, terrorism/speculation premium in gasoline prices and foreign policy costs. *(4)*

Many other estimates are much lower, with most estimates in the range of $33 billion to $113 billion per year.*(5)* For our analysis the International Center for Technology

Assessment estimates of $47.6 billion to $113.1 billion appears to be the most useful because it includes military expenses around the world versus just in the Persian Gulf. About 80% of the ICTA estimate is based on current Department of Defense budget numbers, with the remaining 20% attributable to a small portion of the Iraq War expenditures. The number that we will use is $80.35 billion (midpoint of the ICTA estimate) for total military costs associated with protecting the worldwide supply of oil.

The analysis of the benefit of constructing a national DM/SMF system will include two calculations: the direct benefit from vehicles traveling on the electric rail system and another calculation for the fact that there is a substantial electric vehicle market, that is traveling independent of the rail.

Our analysis is based on the following assumptions: Interstate vehicle travel by passenger vehicles, vans, pickup trucks and freight trucks (the types of vehicles that would use the DM/SMF system) accounts for (722,196 million VMT) of all travel during 2005 (2,989,807 million VMT) *(3)*; that 60% of those miles would be used by vehicles capable of attaching to the rail versus traveling on local roads; that because of the availability of that rail for convenient long-distance travel, for every vehicle using the rail that there would be an equal number of electric cars driving on the local roads and highways. Based on these assumptions 60% of 722,196 million VMT would be on the rail or 433,318 million miles. An additional 433,318 million VMT would be driven by electric cars off the rail on local roads and highways. Therefore the total number of VMT as a direct result of having a DM/SMF system would be 866,636 million miles (1,395,284 million km) out of a total of 2,989,807 million miles (4,813,589 million km) by all motorized road vehicles or 29%.

The conclusion is that a national DM/SMF system built where the existing Interstate currently runs would reduce direct United States military expenditures of $80.35 billion by 29% or <u>$23.3 billion annually saved in military expenses to protect the oil supply</u>.

Air Quality Improvements

Similar to estimates of military spending to protect the oil supply, the cost to society in terms of damage to air quality from automobile emissions vary widely. Using the low estimate from a major study by Mark A. Delucchi, James J. Murphy and Donald R. McCubbins at University of California-Davis *(6)*, the total annual costs to society from air pollution from motor vehicles is: $24 billion for health costs; $5 billion per year for visibility costs; $0.4 billion for material damage costs and $2 billion for crop and forest damage for a total of $31.4 billion (the total of the high-end of the estimates is $347 billion per year).*(6)*

As shown in Appendix A the energy used by DM/SMF vehicles when attached to the rail is 21% of the automobile. The energy use by regular electric vehicles when operating off the rail is 30%. With less energy use there is less damage to air quality. (Electric vehicles are not pollution free because pollution is created in the production of the electricity).

Assuming that DM/SMF use the rail for 433,318 VMT per year (14.5% of total VMT) and that those vehicle reduce air quality problems by 79% the benefit of that rail travel would be an 11.45% reduction in total air quality damage.

For those electric vehicles that would be driving on roads (not attached to the rail) the benefit would be calculated: 433,318 VMT per year (14.5% of total VMT) with an average reduction of 70%. The reduction in air quality damage by electric cars not on the rail would therefore be 10.15% of total air quality damage.

Combining the travel of DM/SMF both while on the rail with electric vehicle travel on regular roadways results in an estimate of a reduction in air quality damage by 21.6% (11.45% plus 10.15%) of the total caused by all motorized vehicles. Applying this percentage to $31.4 billion results in a figure of $6.78 billion for the reduction in air quality damage.

Reduced Greenhouse Gas Emissions

In addition to improvements in air quality there would be a reduction in the greenhouse gas emissions. To calculate the benefit of a reduction it is convenient to use the value of CO2 emissions credits that are currently traded as part of the European Union Emission Trading System in countries that ratified the Kyoto Protocol. The price of these emissions credits is probably on the low side because they were over allocated to some countries, but in the absence of a better measurement we will use the current price of $25 per one-ton CO2 emission credit.*(7)*

A passenger vehicle weighing 12,000 lbs (5,450 kg), carrying 1.2 passengers and getting 20 mpg (8.5 km/L) averages emissions of 6 tons of CO2 per year (conveniently this works out to 1 lb of CO2 per passenger mile). *(8)*. As shown in Appendix A the CO2 emissions of DM/SMF when operating on the track would be .27 lbs (.123 kg) per passenger mile and an electric vehicle operating on regular roads would be at .53 lbs (.85 kg) per passenger mile.

Assuming that 14.5% of all VMT would be done on a national DM/SMF system and that there would be a reduction of 73% in CO2 emissions this would be a reduction of 10.6% in total CO2 emissions. For those electric vehicles traveling off the rail the reduction would be 6.8% (47% of 14.5%) of total VMT travel by all motorized vehicles. Therefore the reduction in CO2 emissions due to a DM/SMF system would be 17.4% (10.6% plus 6.8%) of the total CO2 emissions in the United States.

Based on the 247 million passenger vehicles, vans, pick-up trucks and freight trucks in the United States and assuming that each emits 6 tons of CO2 per year at a cost to society of $25 per ton, the total cost to the United States from CO2 emissions each year from these vehicles would be $37 billion. Since a national DM/SMF system would reduce that by 17.4% the total benefit would be $6.44 billion from reduced CO2 emissions as the result of a national DM/SMF system.

Benefits of DM and SMF Transportation

These are savings that are uniquely available to the DM and SMF transportation system. They are: fuel savings from improved energy efficiency, increased driver productivity due to computer guidance of vehicles, less travel time due to higher speeds, congestion relief, improved safety and reduced infrastructure costs.

Fuel Savings Calculation

As a result of low rolling resistance, a lightweight vehicle and the high efficiency of electric motors, the DM vehicles consume approximately 37 KWh (126,244 BTU per hour) to go 100 miles (161 km). By comparison an automobile operating at an average of 20 miles per gallon of gasoline consumes 575,000 BTU's to go 100 miles (161 km) (see appendix A). Therefore the consumption of fuel for DM is 22% of existing automobiles. While similar numbers for freight vehicles are not available, it will be assumed that freight vehicles operating on the electric rail would realize similar savings.

Calculations by General Motors for their Volt project and Tesla Motors for their electric vehicles have similar indications of the energy efficiency of electric transportation. The Tesla claims that their vehicle, a small lightweight coupe, gets the equivalent of 200 miles per gallon, or energy use of approximately 10% of automobiles[i]. This estimate appears to be based on the best driving circumstances and the recharging of the batteries at nighttime electric rates that are 30% of regular rates. A more realistic assessment of mileage for electric cars versus the automobile is an estimate of 30% of energy use (70% reduction from the automobile).

During 2005 total consumption of gasoline for vehicle travel on all roads was 174.3 billion gallons (660 billion L). *(3)* At $4.00 per gallon ($1.06 per L) this would be $697 billion for fuel costs. DM/SMF running on the rail would account for 14.5% of the total VMT by all motorized vehicles. Because they realize a reduction of 78% in fuel costs the total reduction as a percentage of all fuel costs for motorized vehicles would be 11.3%. For those electric cars operating on roads the total fuel reduction would be 10.1%. Combining 10.1% and 11.3% results in a reduction of 21.4% in fuel costs. Based on total fuel costs of $697 billion this results in $149.16 billion in fuel cost reduction per year.

Driver Productivity Benefit

Because vehicles are guided by computers while traveling on the track, drivers can relax, sleep or use their time productively. In the case of truck drivers, they would no longer be needed, as all freight loads would be handled by driverless vehicles.

Based on 722 billion VMT by passenger cars, vans, SUV's, pickup trucks and freight trucks on Interstates in 2005 and assuming an average speed of 60 mph (97 km/hour), the number of hours spent driving was 12 billion hours. Assuming $12 per hour as the opportunity cost for that time, the annual cost in lost driver productivity is $144 billion. Assuming that 60% of that travel would switch to the DM/SMF System the benefit to society of the self-guiding travel would be $86.4 billion

Benefit of Increasing Speed to 100 mph (161 km/h)

The benefit of traveling at 100 mph (161 km/h) versus 60 mph (97 km/h) is that the travel time is reduced for both the driver and the passenger by 33%. Based on 722 billion VMT on Interstates and assuming 60 mph, the driver is non-productive for 12 billion hours. Multiplying that by the driver's time value of $12 per hour equals $144 billion. Assuming that 60% will use the electric rail system, that the driver is traveling at 100 mph and therefore reducing his travel time by 33%, the value of the faster travel speed for all drivers is $28.8 billion.

The evaluation of the passenger's travel time is slightly different since the passenger can use his time while driving in the car or truck and the time value for passengers would tend to be slightly lower than drivers. Since a passenger is only in the vehicle 25% of the time, the time spent by passengers in vehicles traveling on interstates in 2005 is about 3 billion hours. If assume a time value of $6 per hour for passengers, this would be $18 billion of non-productive time. Assuming that 60% of vehicles connect to the track, traveling at 100 mph (161 km/h) versus 60 mph (97 km/h) results in a savings of 33% or $3.6 billion.

The total benefit to the driver is $28.8 billion and for the passenger it is $3.6 billion for a total benefit of $32.4 billion benefit by increasing the speed of passenger and freight from 60 mph to 100 mph.

Congestion Relief

The DM/SMF System, which is four parallel tracks (under 40 feet or 12 meters wide) has the capacity of a 20-lane highway (capacity approximately 60,000 vehicles). As a result there will be no congestion on the System (see appendix B)

Based on Texas A&M University/ Texas Transportation Institute Study *(9)* traffic congestion on all roadways was $64 billion in 2004. The miles driven by passenger vehicles, vans, SUV's, pickup trucks and freight trucks (vehicles that would travel on the DM/SMF system) on the Interstate system represents 24.2% of all highways VMT. If 60% of those vehicles connect to the track the value of congestion relief from a DM/SMF system is $9.3 billion.

Safety (reduction in death, injury and property damage)

United States Department of Transportation estimates that the annual economic impact of all motor vehicle crashes is $231 billion. *(10)* This consists of loss of productivity due to death and disability, property damage and medical expenses.

The DM/SMF System should greatly improve safety because computer guidance is substituted for driver judgment and driver impairment, tracks that are elevated and therefore separated from weather and pedestrians and vehicles that are captive to the rail. Interstate VMT represents 24.2% of all highways VMT. If 60% of those vehicles attach to the track then the estimated improvements in safety from a national DM/SMF system would be $33.5 billion per year.

Infrastructure Cost Reduction

The DM/SMF System is estimated to cost less than 1/10th the cost of current highways based on VMT (see appendix B). This is the result of several factors: computer control of vehicles eliminates some spacing between vehicles, the higher speed of vehicles and the low-cost of construction with pre-fabrication, minimal grading and durability of the system. Because the DM/SMF has excess capacity beyond the existing Interstate System it would be inaccurate to use this as a comparison of the costs (i.e.: the government would never build a 20 lane highway through rural Nebraska). A fairer comparison is the cost to build and maintain 46,835 miles of DM/SMF for fifty years (with the equivalent capacity of 936,700 lane miles) and the cost to maintain the existing Interstate System with 212,029 lane miles for fifty years.

The DM/SMF System is estimated to cost $10 million per mile ($6.2 million/km). *(11)* Based on 46,835 miles (75,400 km) *(3)* the cost of a national MonoMobile System is $468 billion during the initial 20 year construction period. Repair/replacement costs will add an additional $2 million per mile ($1.24 million/ km) over the remaining thirty years of the track system. Based on 46,835 miles this is a total cost of $93.7 billion for repair and replacements at an average of $3.12 billion per year during years twenty-one to fifty. The schedule of payments would be 23.4 billion each year for the first 20 years and 3.12 billion each year for the remaining 30 years. Using an inflation rate of 2.25% the present value of those payments is $417 billion.

Based on 212,029 lane miles (341,370 km of lanes) of Interstate in the US and an estimated cost of $5 million per lane mile ($3.1 million/km), the cost to replace the existing Interstate system would be $1.06 trillion. The repairs over that 50-year period are estimated to cost an additional $5 million per lane mile ($3.1 million/km) *(12)* for a total cost of $10 million per lane mile ($6.2 million/km) or $2.12 trillion for the entire Interstate System for fifty years. If we assume that this $2.12 trillion will be paid with a $300 billion initial investment (the amount indicated by FHWA in their latest budget as necessary for important repairs and improvements over the next six years) and the balance paid with equal payments of $41.36 billion per year for the years seven to fifty. The present value of those payments is $1,282 billion.

The difference in present value cost between a national DM/SMF System, $417 billion, and maintaining the current Interstate, $1,282 billion, is $865 billion. Over the fifty-year period DM/SMF infrastructure costs will be $17.3 billion less per year.

Conclusion

The cost of building a DM/SMF system along the nation's 46,835 miles (75,400 km) of the existing Interstate system is estimated at $12 million per mile ($7.45 million/km) for a total cost of $562 billion. As explained above the benefits of a DM/SMF are as follows:

TABLE 2

Benefits of Electric Transportation	
• Oil independence	$ 23.30 billion
• Improved air quality	6.78
• Reduced greenhouse gas emissions	6.44
Benefits of DM and SMF	
• Improved energy efficiency	149.16
• Driver productivity	86.40
• Computer control with higher speeds	32.40
• Congestion relief	9.30
• Improved safety	33.50
• Reduced Infrastructure costs	17.30
	364.58

The total benefit of a DM/SMF System is $364.58 billion per year for an annual return of 65% on the investment of $562 billion. It is interesting to note that very few of the benefits were derived by switching to just electric transportation (only $36.52 billion out of the total of

$364.58 billion). The largest benefits resulted from building the electric rail system that resulted in large fuel savings and increases in driver productively.

While this analysis was done based on a national DM/SMF System in The United States, similar levels of benefits would be available on a regional basis in the United States and in other countries. In some urban regions of the United States, where the time value of passenger travel is higher than $12 per hour and congestion is a constant problem, the advantages of a DM/SMF System would exceed the 65% annual rate of return. In other countries, where gasoline prices are much higher and where expensive vehicle permit fees are imposed the benefits of a DM/SMF System would be higher than disclosed by this paper, although the tax policies of the government could mitigate some of the advantages.

Appendix A

Energy and CO2 per passenger mile
for 400 mile trip

	Travel Time (1)	Energy/ passenger mile	CO2 /pass. Mile
Automobile (2)	6 hours 40 min.	4600 BTU	1.0 lbs.
Train (2)	7 hours 35 min.	2709 BTU	0.46 lbs.
Airplane (2)	2 hours 20 min	3264 BTU	1.06 lbs.
Dual Mode (4)	4 hours	960 BTU (5)(7)	0.27 lbs.(5)(4)
Tesla Electric Automobile (3)	9 hours 30 min.	1400 BTU (5)(6)(8)	0.53 lbs.(5)
LRT	local transit only(20mph)	1800 BTU(9)	

(1)1 hour check-in time airplane & 1/2 hour train
(2) Source: Popular Science 12/2007
(3) assumes 150 mile range and 2 hour recharge
(4) based on national average of 1.341 lbs. CO2 Per KWh
(5) assumes 1.2 passengers
(6) based on 35 KWh per 100 miles (no AC included)
(7) based on 25 KWh per 100 miles (with AC)
(8)adjusted- Tesla claims 110 MPGe based on only 4.9 cents/Kwh
(9)Calgary LRT actual use:
Average number of boarding passengers per day: (2006) 248,200
Average annual power costs: $4.8M (2006)
http://www.calgarytransit.com/html/technical_information.html

Appendix B

Comparison of DM/SMF Track and Interstate Highway Costs

Calculation of Number of DM/SMF Vehicles per hour: cars run in groups of 5 vehicles with 100 feet of space between each group. Therefore each group of 5 vehicles takes up 165 feet. Dividing 5280 feet (a mile) by 165 means that there are 32 groups of vehicles or 160 vehicles per mile. At 100 mph it takes a vehicle 40 seconds to travel a mile. Therefore the track has a capacity of 267 vehicles per minute. Therefore the capacity of the track is 16,000 cars per hour. With a three-track system the capacity is 48,000 vehicles. Four tracks would have a capacity of 64,000 vehicles per hour.

Calculation of Number of Automobiles on a highway per hour: applying similar reasoning to the automobile ...each car with spacing takes up approximately 110 feet, which results in 47 vehicles per mile. At an average speed of 60 mph it takes each vehicle one minute to travel 1 mile, thus there are 47 vehicles per mile. During an hour period this would be 2,880 automobiles. This calculation is consistent with published information of lane capacity of 2,500 to 3,000 automobiles per lane per hour. Based on the higher figure of 3,000 vehicles per lane per hour, a twenty-lane highway has a capacity of 60,000 automobiles per hour, slightly less than a four track Monomobile System.

Calculation of cost of Monomobile Track: Based on <u>MonoMobile Structure Supporting System,</u> a six month study conducted in 1998 at the University of Cincinnati Graduate Engineering School, that analyzed span spacing, various construction methods and highway construction standards established by the Federal Highway Administration (including earthquake standards) the cost to build the track is $1.95 million for the structure. Adding $3.0 million per mile for increases in material costs, electric contact rails and control systems; $2 million per mile for adding the fourth track; and $3 million for switches and other expenses the track is calculated to cost $10.0 million per mile.

Calculation of cost of Highway: The cost to build a highway is calculated at $5 to $6 million per lane mile. Based on the lower estimate of $5 million, the cost to build a 20-lane highway is $100 million per mile. Considering that it would be virtually impossible to purchase the land for a 20-lane highway, this is probably a low estimate. The cost to build a bridge over rivers and other depressed areas would be dramatically different between DM and existing roadways. For example recent estimates to replace the I-75 Bridge across the Ohio River with a total of six lanes is estimated at $1.2 billion for entry ramps and a ¾ mile span. The cost for a DM bridge would be under $50 million.

Conclusion: The cost of the DM track, which carries 64,000 vehicles per hour, is $10.0 million per mile. The cost of a 20 lane highway that carries the same capacity is $100 million ...10 times the expense of the DM/SMF Track based on vehicle capacity.

(1) Andy Grove *Our Electric Future*, American Enterprise Institute Press volume 2,number 4 July/August 2008

(2) For complete and up-to-date list of dual mode systems: http://faculty/washington.edu/jbs/itrans accessed 8/1/08

(3) United States Department of Transportation, Federal Highway Administration-Highway Statistics 2005 http://www.fhwa.dot.gov/policy/ohim/hs05/htm/vm1.htm accessed 8/1/08

(4) Senate Foreign Relations Committee testimony March 5,2005 as reported in the New York Times January 7,2007

(5) International Center for Technology Assessment January 25,2005; Mark A. Delucchi and James J. Murphy *US military Expenditures to Protect the Use of Persian Gulf Oil for Motor Vehicles* April, 2008 University of California-Davis-ITS-RP-08-05; Koplow, D. and Martin, A. Fueling *Global Warming: Federal Subsidies to Oil in the United States*, Industrial Economics Inc. June,1998 p.64

(6) *The Health and Visibility Cost of Air Pollution: a Comparison of Estimation Methods* by Mark A. Delucchi, James J. Murphy and Donald R. McCubbins Journal of Environmental Management (2002) pp. 139-152

(7) see www.eueuropa.eu/environment/climat/emissions.htm accessed 8/1/08

(8) Calculated based on www.epa.gov/climatechange/emissions/ind_calculator.html accessed 8/1/08

(9) Ehlig-Economides, C. and Longbottom, J. Dual Mode Vehicle and Infrastructure Alternative Analysis Texas A&M University and Texas Transportation Institute April, 2008

(10) National Highway Traffic Safety Administration http://www.nhsta.dot.gov/people/economic accessed 8/1/08

(11) Weisgerber, F. *MonoMobile Structure Supporting System*, University of Cincinnati April,1998

(12) Source: FHWA 2005 Budget Request for repairs and replacements was $356 billion. The actual allocation was $289 billion for a six-year period or an annual average of $48.2 billion