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A Cost Comparison of Transportation Modes.

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Introduction

Figure 1. Skytrain, a system designed to move people rapidly from the edge of the region to the centre.

What is the optimal relationship between land use and transit, and what transit mode would best support this optimum state. On this there is no agreement - neither here in the Vancouver region nor in the rest of North America. Many transportation planners argue for transit services optimized to serve the long high speed commute trip at the expense of local service. In the Vancouver region this position has held sway, with billions of dollars borrowed to expand the Skytrain system and billions more on the table for future expansions. Others argue in favor of systems that perform better locally but have the slower traveling speeds more suited to shorter trips. Very few metropolitan transit agencies take this position, the City of Portland which invested in its own streetcar system is one of the very few. (see The Case for the Tram: Learning From Portland http://www.sxd.sala.ubc.ca/8_research/sxd_FRB06_tram.pdf). What is the more sustainable option? This bulletin attempts to clarify this question for our region, if not definitively answer it.

But there is a newer and burgeoning question of perhaps even greater significance. We are now entering a time of increasingly uncertain oil supply and rising concern over greenhouse gas emissions. It is therefore more important than ever to arrange our land uses, and the transit system that supports them, in a manner that reduces our greenhouse gas (GHG) emissions. What good does it do us if everyone rides the bus, if that bus still produces as much greenhouse gas per passenger mile as the car it replaces? This bulletin attempts to organize the energy and GHG consequences of land use and transit choices understandably.

Finally, there is the question of long term cost efficiency. Investment decisions made this decade for Vancouver and other North American cities will determine land use and transportation patterns that will last for the next hundred. How can we choose the system that helps create the kind of energy, cost and resource efficient region that the future demands.

We attempt to illuminate these three questions in the sections below. Our answers are organized around the three key sustainability principles drawn from related work in the Sustainability by Design initiative. (http://www.sxd.sala.ubc.ca/)

Sustainability Principles

We organize this information against three fairly well accepted sustainable transportation principles. First, whatever the mode, we know that *shorter trips are better than longer trips*. Transporting people requires energy, even in mass transit vehicles, and energy, even from 'green' sources, has its costs. Thus we ask what is the arrangement of transit and land uses that leads to the lowest average daily per capita demand for vehicle travel of any kind?

Second, we know that *low carbon is better than high carbon*. Therefore we must ask ourselves, what transportation mode has the least carbon emissions per trip, what mode has the lowest energy per mile? How does the energy source factor in? Here in BC most of the electricity used to power our Skytrain and trolley busses comes from hydro electric sources. But if it were from burning fossil fuels rather than hydro power, what would this mean for our carbon calculations?

Finally, *Choose what is most affordable over the long term***.** Long term capital, operating, maintenance and replacement costs need to be considered and evaluated to find the most efficient transportation mode. The public purse is only so full, and investments made in this generation must be intelligent and sustainable for a century or more.

Thus the limited purpose of this research bulletin is to provide the best available data to help answer these questions, and to organize that data against the framework of the three sustainability principles stated above. What this bulletin does not do is definitively lay to rest all of these questions. The resources available for this report were far too constrained for that, and, indeed, the issues impacting these decisions so multifold that no research study no matter how exhaustive could ever hope to answer these questions once and for all.

This notwithstanding we believe that the evidence shown here has never been organized this way. We also feel that given the transit initiatives currently under consideration for our region, and the many billions of dollars that are in play, framing the question this way is more than timely.

The following modes are compared throughout the report:

- Modern Tram: based on Siemens' Combino Plus featuring articulated, low floor, rail vehicles with regenerative braking technology, operating in existing street right of ways.
- Trolleybus: based on the Vancouver region's New Flyer electric rubber-wheeled trolley bus featuring low floor vehicles with regenerative braking technology.
- Skytrain: Vancouver's automated, mostly elevated, rapid rail transit system.
- LRT: Light Rail Transit differs from trams in that it generally operates in separate rights-of-way with less frequent stops and raised boarding platforms.
- Articulated Diesel Bus: 60' vehicles used in Vancouver's high-capacity, high-frequency B-line express routes (operates in traffic, no signal control)

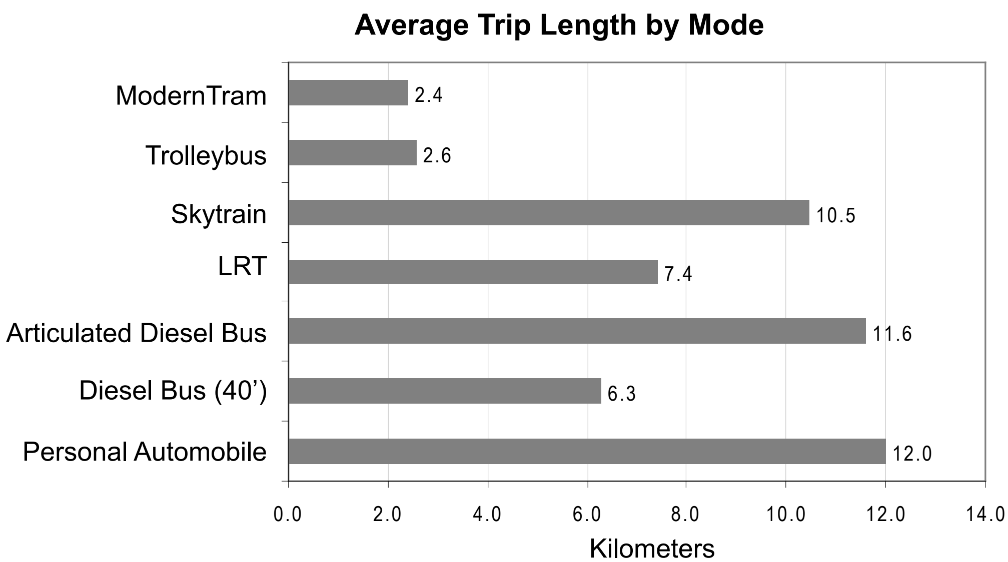
Figure 2. Shows the dense development and mixed use characteristic of "streetcar neighbourhoods"

- Diesel Bus (40’): in local service in Vancouver, BC
- Toyota Prius: hybrid electric mid-sized car that won Green Engine of the Year 2008 from International Engine of the Year Awards
- Ford Explorer: mid sized sport utility vehicle (SUV) popular in North America

Principle 1: Shorter trips are better than longer trips

What is the best mode for short trips that act as an extension of the walk trip?

If shorter vehicle trips are the goal, what is the best transit option? Most experts agree that for short trips options to the car include the walk, the bike, the bus, or the tram. Certainly the walk and the bike trip have the least impact on the planet and the lowest cost. But to extend the walk trip the bus and the tram are the logical next mode shift. Traditional “streetcar neighbourhoods” of the type that characterize most Vancouver area districts built prior to 1950, generally encourage shorter trip length due to their close proximity of activities, their fine-grained mix of land uses, and their grid-like street networks. This hypothesis is born out by data that shows that North American districts still served by streetcar and their kindred rubber tired cousins the trolley bus exhibit shorter average trip lengths than other modes. The average trip length in a personal automobile in Vancouver, BC is around 12 km. Trip length averages across North America were found to be 6.3km for local bus, 11.6 for BRT, 7.4km for LRT, 2.6km for Trolleybus and 2.4km for Streetcar. These values are represented in the graph below.



Source: American Public Transportation Association, 2008; Translink, 2003; IBI Group, 2002; TSI Consultants, 2001; Savage, 1998

Figure 3. The modern Combino streetcar has an energy efficiency of 25 passenger-miles per kWh.

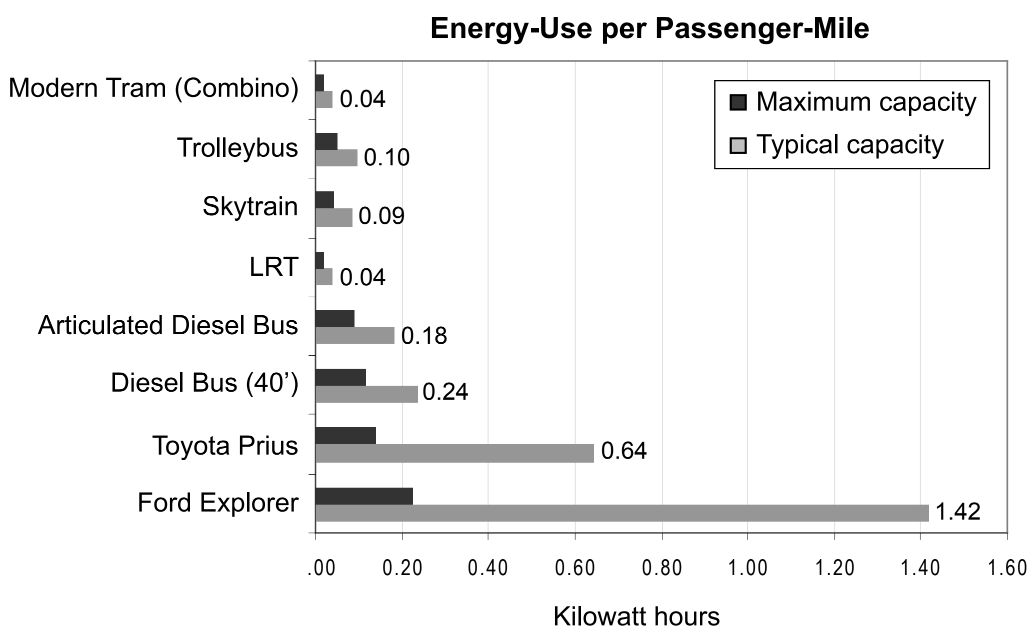
Figure 4. A trolley bus in Vancouver, BC is powered by overhead electrical wires therefore eliminating any tailpipe emissions. The energy efficiency for a trolleybus is approximately 10 passenger-miles per kWh.

Principle 2: Low carbon is better than high carbon

What transportation mode has the lowest energy use/cost per mile?

While both busses and trams are an effective way to extend the walk trip, trams are inherently more energy efficient than buses because they generally have higher passenger capacities and lose less energy to frictional resistance than rubber wheeled vehicles. Trams also more frequently capitalize on regenerative braking technology, which allows them to convert the kinetic energy of the vehicle in motion to electrical energy when it brakes. This energy is either returned to the overhead wires for use by other vehicles or used to power auxiliary equipment such as onboard heating/cooling systems (ExecDigital 2007). Modern trams like Siemens' Combino Plus, are able to recover 30% of the energy used to power the vehicle through this process (Blumenthal et al. 1998). A study of Combino's performance in the field found that at slower average speeds (19 km/hr) energy recovery from regenerative braking was more than 42% (Blumenthal et al. 1998).

Converting energy efficiency into kilowatt hours/mile we found that the energy efficiency of a modern streetcar was approximately 25 passenger-miles per kilowatt hour while trolleybus was 10.2, Skytrain was 11.6, articulated diesel bus was 5.5, diesel bus was 4.25, a Toyota Prius was 1.5, and a Ford Explorer was only 0.7 passenger-miles per kilowatt hour (all figures for typical capacity).



Source: Strickland, James. 2008. Energy Efficiency of different modes of transportation. Available online: http://strickland.ca/efficiency

Figure 5. The skytrain in Vancouver, BC has a typical energy efficiency of 11.6 passenger-miles per kWh.

Figure 6. Shows an articulated diesel bus in service in Vancouver, BC with an energy efficiency of 4.25 passenger-miles per kWh.

Figure 7. The Toyota Prius is an electric hybrid that provides substantial gains in fuel economy and major reductions in total tailpipe emissions. Reductions in CO2 emissions will vary depending on the source of the electricity that recharges the secondary battery. It has an energy efficienty of 1.5 passenger-miles per kWh.

Figure 8. This 2007 Ford Explorer has a fuel efficiency of only 0.7 passenger-miles per kWh.

Converting these fuel efficiencies to energy cost estimates (using US$ 3.99/ gallon[1] for gasoline and gasoline equivalent figures and US$ 0.11/ kWh for electricity[2]) yielded the following cost per passenger-mile figures. The cost per passenger ranges from 0.5 cents per passenger-mile for a modern streetcar to 16.8 cents for a Ford Explorer (given typical capacity).

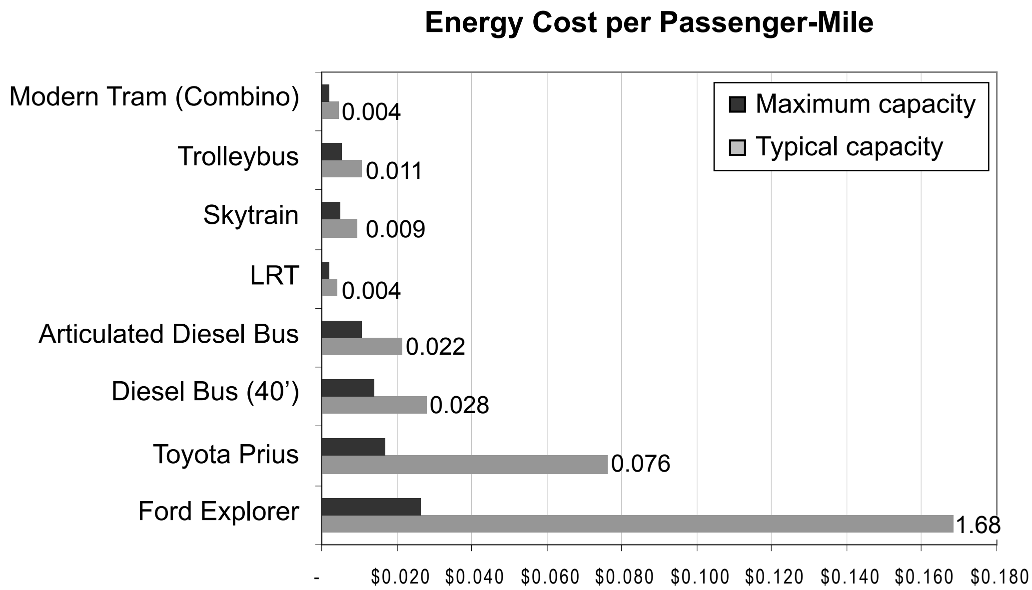


Figure 9. Internal combustion engines contribute significantly to street level pollution levels.

What transportation mode has the lowest carbon emissions[3] per passenger-mile?

Using electric energy to fuel transportation allows flexibility in an increasingly carbon conscious world. Power plants that supply energy can be retrofitted to produce energy from renewable sources and emissions can be more easily monitored and mitigated at point sources. From 2000 to 2006 the overall efficiency of U.S. electricity generation increased as a decline in energy losses helped to mitigate the sector's carbon dioxide emissions (EPA, 2007). Although electricity demand was essentially flat, this increased efficiency actually led to a decline in the carbon intensity of the electricity supply which spawned a drop in emissions from this sector. The transportation sector in contrast, which leads all US end-use sector emissions of carbon dioxide, showed an increase in emissions of 26.5%, or 407.5 million metric tons (this growth occurred between 1990 and 2006 and represents 46.4% of the growth in unadjusted energy-related carbon dioxide emission from all sectors) (EPA, 2007). Petroleum combustion is the largest source of carbon dioxide emissions in the transportation sector and carbon dioxide from the burning of fossil fuels is the single largest source of greenhouse gas emissions from all human activities.[4]

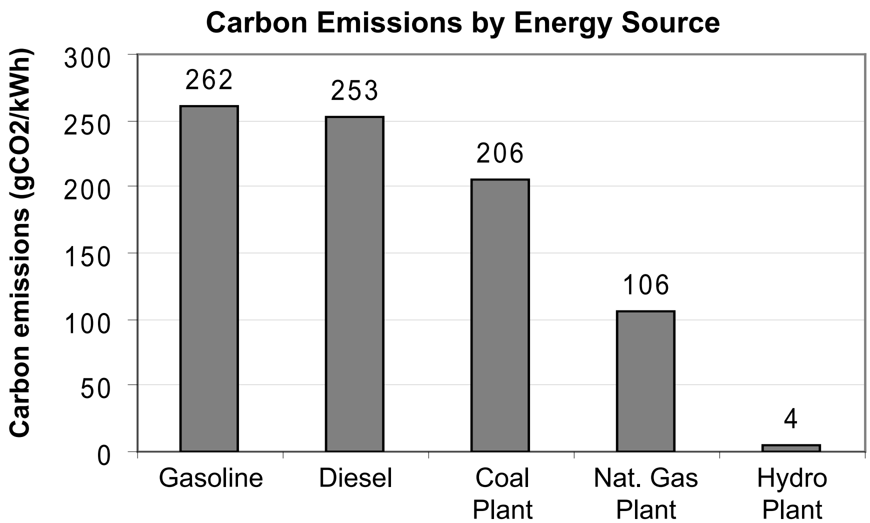
Carbon Equivalent Emissions by Energy Source

Gasoline	= 8,788 grams of CO_2 emissions/gallon (EPA 2005)
Diesel	= 10,084 grams of CO_2 emissions/gallon (EPA 2005)
Electricity (Coal)	= 206 grams of CO_2 emissions/ kWh (Spadaro et al. 2000)
Electricity (Nat. Gas)	= 106 grams of CO_2 emissions/ kWh (Spadaro et al. 2000)
Electricity (Hydro)	= 4.4 grams of CO2 emissions/kWh (Spadaro et al. 2000)

Given that one gallon of gasoline generates 33.6 kWh of energy and one gallon of diesel generates 39.9 kWh of energy[5], the carbon emissions per kWh by energy source are as follows:

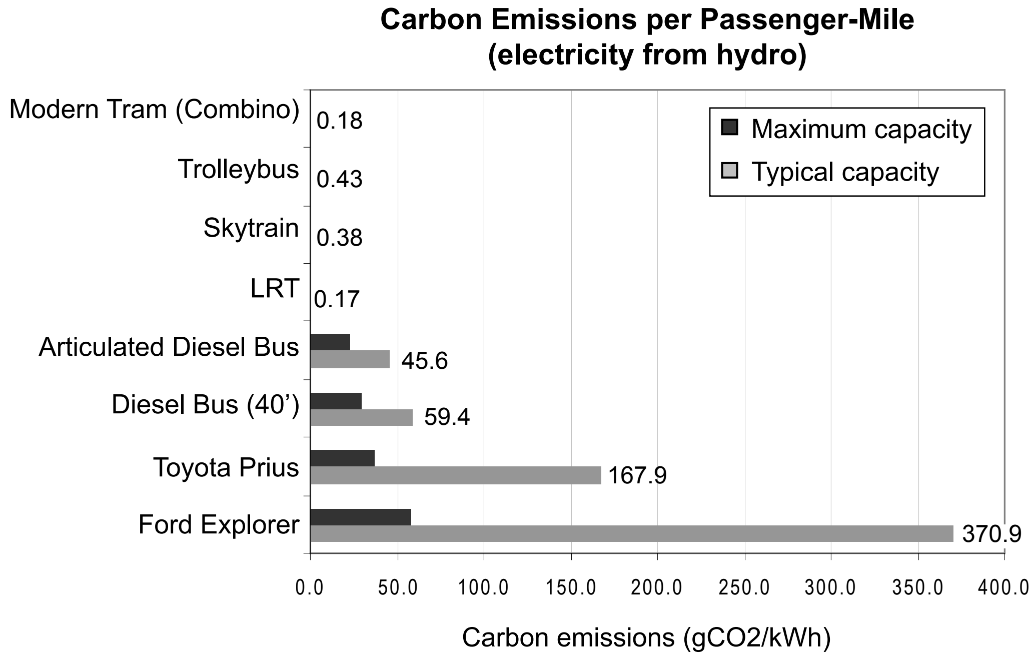
Carbon Equivalent Emissions by Energy Source

Gasoline	= 262	grams of CO_2 emissions/ kWh
Diesel	= 253	grams of CO_2 emissions/ kWh
Electricity (Coal)	= 206	grams of CO_2 emissions/ kWh
Electricity (Nat. Gas)	= 106	grams of CO_2 emissions/ kWh
Electricity (Hydro)	= 4.4	grams of CO_2 emissions/ kWh

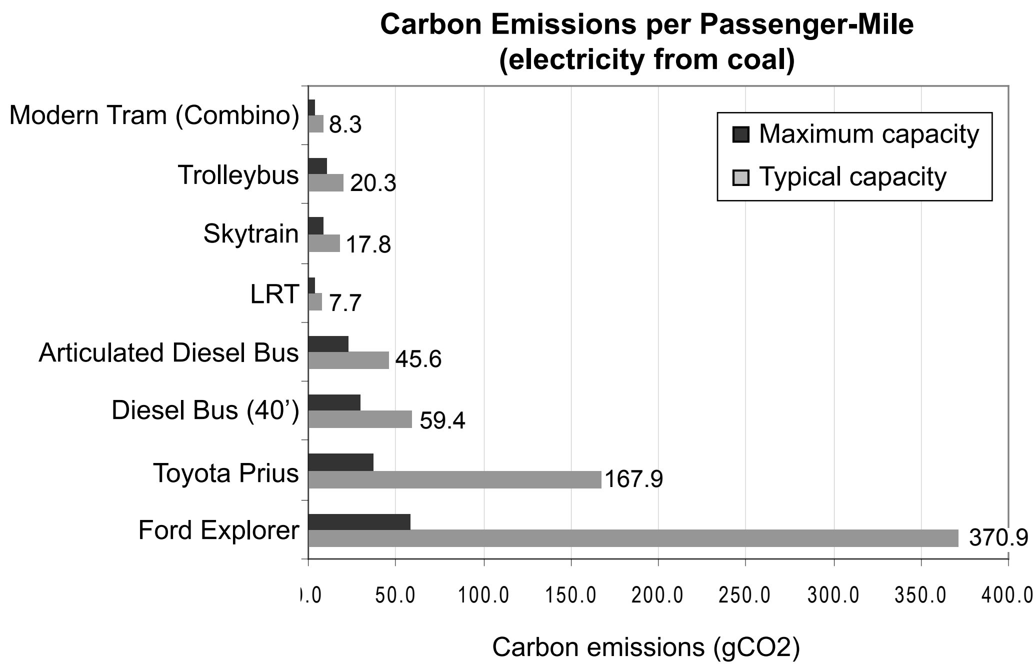


Source: EPA, 2005; Spadaro et al. 2000

Applying these emissions to our transportation modes based on their source of energy we can calculate their carbon emissions per passenger-mile. Even using electricity generated from a coal burning power plant (the bottom graph), the carbon emissions for electric powered trolleybuses and rail is so low as to be almost negligible. To better understand why electrically powered vehicles are so much cleaner than gasoline or diesel powered vehicles (even when carbon emissions produced by gasoline, diesel and coal differ by only 56 grams of CO_2 emissions/ kWh) we must look at the energy efficiency of the electric motor versus the internal combustion motor. According to Strickland (2008) internal combustion engines typically convert, at best, 1/3 of their energy into useful work while electric motors generally have energy efficiencies of 80-90%. This means that electrically powered vehicles perform significantly better from the perspective of carbon mitigation and energy efficiency in comparison with the relatively inefficient internal combustion engine.



Source: Strickland, 2008; EPA, 2005; Spadaro et al. 2000



Source: Strickland, 2008; EPA, 2005; Spadaro et al. 2000

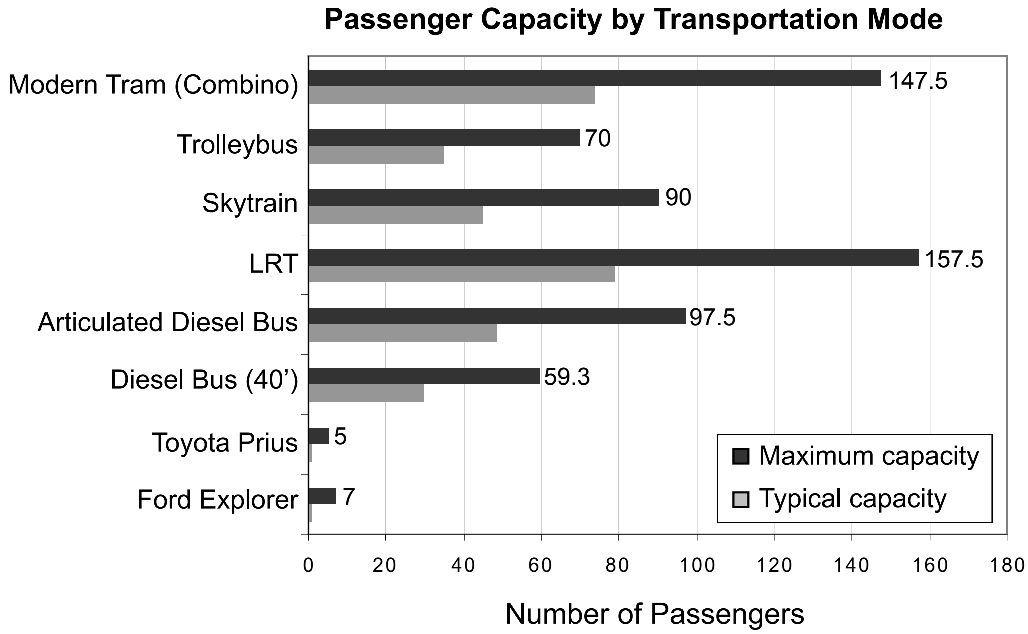
Figure 12. The crush capacity for articulated diesel buses in Vancouver, BC (above) is approximately 100 passengers. Demery & Higgins (2003) found that peak occupancy for buses is less than 3 passengers per meter compared to 4-5 passengers per meter for rail. Below is a picture of a modern streetcar at peak capacity.

Principle 3: Choose what is most affordable over the long term.

Given the long term capital, operating, maintenance and replacement costs what mode is the most efficient/cheapest?

Although trams have higher initial capital costs than buses, these costs are eventually offset through increased capacity, increased operating efficiencies and longer vehicle life. Trams can carry between 70% and 150% more people than an average low floor bus. Thus one tram driver is more than twice as productive per hour than is a diesel bus driver.

Notes on Methodology:
The typical capacity for transit service was estimated based on ridership statistics from the Toronto Transit Commission. The typical capacity for private automobiles is based on the average vehicle occupancy for trips to or from work (from the Hu & Reuscher 2004: NHTS Summary of Travel Trends).



Source: URS Corporation, 2008; Strickland, 2008; Transit Toronto, 2007; City of Vancouver, 2006; The Urban Transportation Monitor, 2001

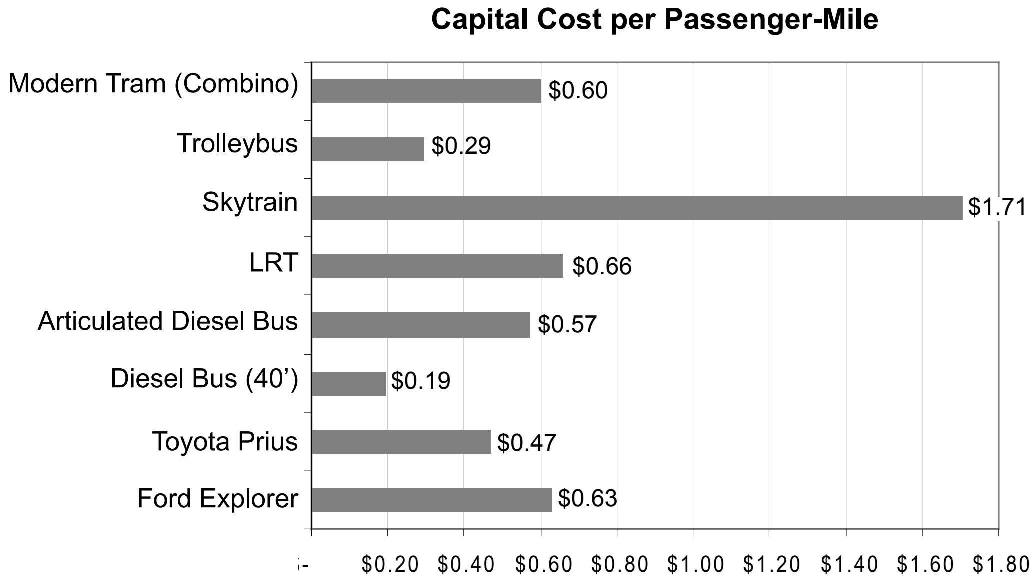
Tram vehicles while more expensive to purchase tend to last longer, with an average lifespan of 25 years compared to 12 to 17 for busses. (City of Vancouver, 2006; Litman, 2004).

The energy cost for electrically powered transportation is dramatically cheaper and cleaner than gasoline or diesel powered automobiles per passenger mile. Of the electrically powered transportation, rail is more energy efficient and therefore cheaper than rubber wheeled transportation per vehicle mile and significantly cheaper per passenger mile when the higher capacity of rail vehicles increases the efficiency of the entire system.

To make a sound comparison of the long term aggregate costs per passenger-mile associated with each transportation mode we incorporated initial capital and construction costs, amortization costs, on-going operation and maintenance expenses, energy use and carbon offsets to come up with a final cost comparison. Parking costs for both the Ford Explorer and the Toyota Prius contributed significantly to the total operating costs for both of these modes (62 and 68 percent respectively). Carbon offsets were calculated using the market price of carbon traded in the European Emissions Trading scheme in December 2008 ($49 per ton). The latest analysis by New Carbon Finance predicts that prices will increase to more than $72 per ton by 2012 (New Carbon Finance, 2008).

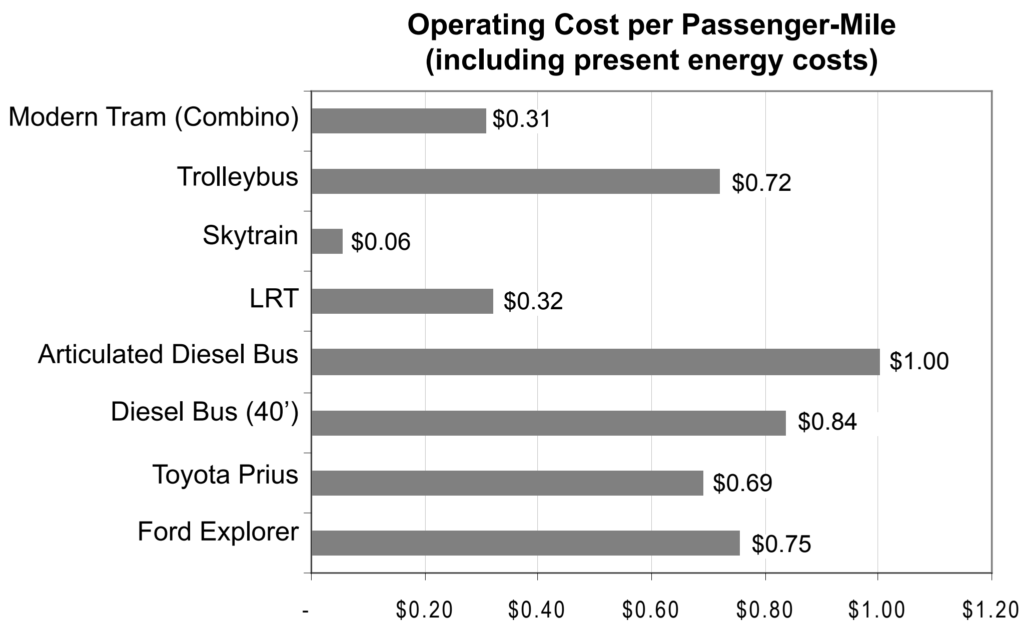
Figure 13. *Capital costs were calculated using construction costs and/or vehicle costs ammortised over the expected life of the system and/or vehicles. This annualized cost was then divided by the annual passenger-miles of each mode.*

Note: Modern tram ridership is based on actual ridership numbers recorded by the Toronto Transit Commission (TCC, 2007). Toronto was chosen as a benchmark for tram ridership because it is the largest system in North America and serves districts that typify the land use characteristics of traditional "trolly car suburbs."



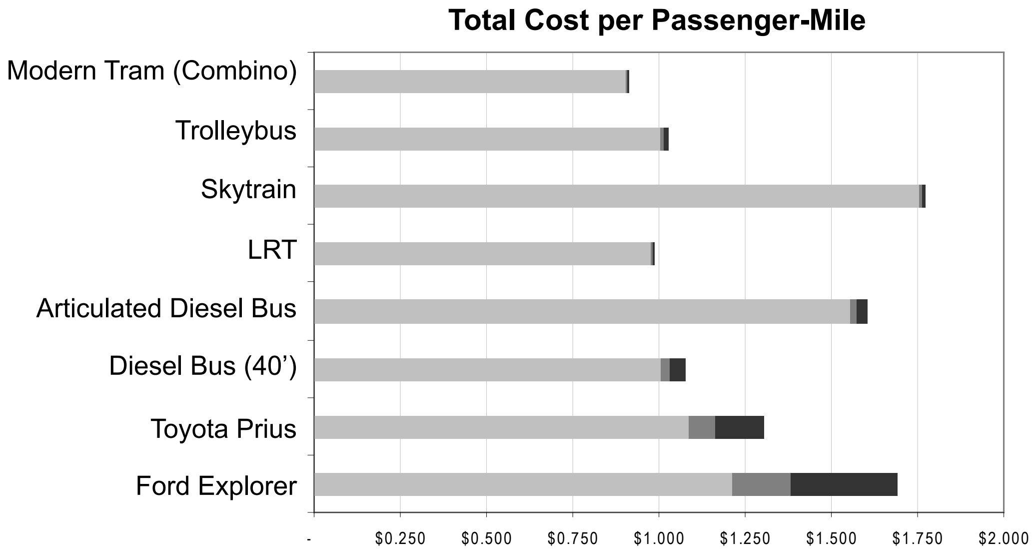
Source: Canadian Automobile Association, 2008; Translink, 2008; TTC, 2007; Translink, 2003; National Transit Database 1996-2006; Translink, 2005; Brown, 2001

Figure 14. Operating costs for private automobiles include parking, insurance, maintenance and fuel. These fuel costs are highlighted separately in the Total Cost chart. Operating costs for transit modes also include employee salaries.



Source: Canadian Automobile Association, 2008; National Transit Database 1996-2006; Vincent & Callaghan, 2007; FTA, 2005 & 2007; LightRailNow, 2001; Brown, 2001 and Rafter, 1995

While there is still much debate about how to accurately compare the long term life cycle costs of the various options, the general relationships between each mode in each category are relatively sound and well supported in the literature.[6]

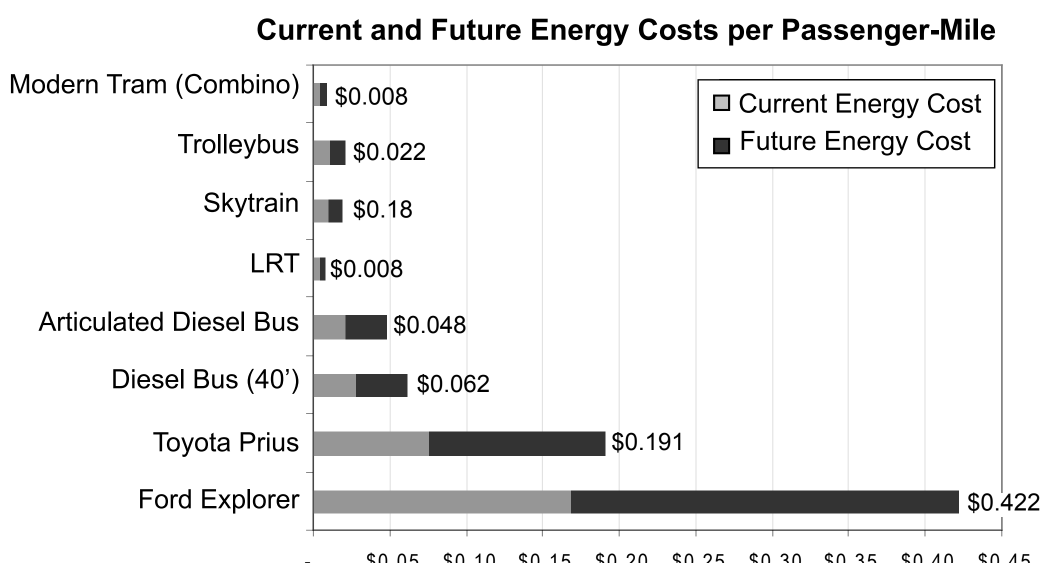


	Ford Explorer	Toyota Prius	Diesel Bus (40')	BRT (Articulated Diesel	LRT	Skytrain	Trolleybus	Streetcar
Future Increase in Fuel Costs	$0.309	$0.142	$0.046	$0.030	$0.007	$0.010	$0.012	$0.006
Present Fuel Costs	$0.168	$0.076	$0.028	$0.022	$0.004	$0.009	$0.011	$0.004
Capital & Operating Costs	$1.215	$1.089	$1.005	$1.553	$0.976	$1.755	$1.005	$0.905

Figure 15. The total cost per passenger-mile was calucalated by adding the capital and operating and energy costs for each mode. Parking was a significant component of the private automobile costs.

How does the rising cost of fuel factor into these calculations?

The vast majority of projections for the next 50 years predict rising fuel prices as global economies expand and competition for finite oil reserves increases. Assuming that future gasoline and diesel prices rise to $10.00 per gallon and the price of electricity doubles, the difference in energy cost per passenger-mile between a tram and a Ford Explorer skyrockets from 16 to 41 cents. The difference between a tram and an articulated diesel bus increases from 2 cent to 5 cents.



Electrically powered transportation modes will show greater flexibility in the coming years and will be in a better position to benefit from the advances and expansion of alternative energy technologies.

Conclusion

Based on the three sustainability criteria, reducing trip length, greenhouse gas reduction, and lifecycle cost, trams represent the best investment. This investment is entirely dependent, however, on a long term commitment to balancing jobs and housing and a gradual reduction in the per capita demand for daily transportation of any kind. If most trips in the region are short then the rationale for investment in trams is overwhelming. If all trips are long then the rationale for the very expensive Skytrain system may still hold sway. Currently our region is at a tipping point between the two. Decisions made now about which mode to invest in could precipitate very different land use consequences, consequences lasting for decades. These arguments apply to every North American metropolitan area. All are struggling with these same questions. This bulletin does not provide a definitive answer to which path to take, but attempts to illuminate the significance of the choice. This generation of citizens and decision makers will determine, by its choices, what the Vancouver region, presently home for two million residents, will be like when it contains four million. Hopefully it will be much more sustainable than it is now. How we spend the billions proposed for investment in transit this decade will likely be decisive.

Figure 16. A busy transit stop along a modern Tram line.

Notes

1. Based on the Lundberg Survey which tallied prices at thousands of gas stations across the country between May 16 and June 6, 2008. The national average was $3.99 a gallon for self-serve regular with the highest average price in California at $4.41 per gallon and the lowest average price in Kansas at $3.65 per gallon. According to AAA figures diesel prices in early June 2008 were $4.762 per gallon.

2. Based on data released by the Energy Information Administration: Official Energy Statistics from the US Government on the 'Average Retail Price of Electricity to Ultimate Consumers by End-Use Sector, by State, March 2008' (EIA 2008). The US total for the transportation sector in March 2008 was 10.96 cents per kilowatt hour.

3. Carbon dioxide equivalents are calculated by estimating the weight of carbon dioxide having the same estimated global warming potential as a given weight of another gas. For example, methane is a much more potent greenhouse gas then carbon and therefore has a global warming potential of 21. The carbon dioxide equivalent for methane is 21 times the actual weight of methane. Carbon equivalents are useful because they allow us to conceptually evaluate the global warming effects of a given activity much more intuitively. For the purposes of this paper 'carbon emissions' refers to 'carbon dioxide equivalent emissions.'

4. For more information see the Climate Change Information Kit on the UNFCC's Internet site at www.unfcc.de unequivocal

5. Unfortunately there is a lot of variation in quoted energy density among different sources. Here we are using Strickland's number of 32 MJ/L (33.6 kWh/gallon) for gasoline and 38 MJ/gallon (39.9 kWh/gallon). Strickland (2008) found a range of 29 MJ/L (30.4 kWh/gallon) to 32 MJ/L (33.5 kWh/gallon) for gasoline and a range of 34 MJ/L (35.6 kWh/gallon) to 40 MJ/L (41.9 kWh/gallon) for diesel.

   Conversions are as follows: 1 kWh = 3.6 MJ; 1 gallon = 3.78 L
   Therefore: 1 MJ/L = 3.6/3.78 = 0.95 kWh/gallon

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