Seattle Route 48 Electrification Study

Business Case

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EXECUTIVE SUMMARY

STUDY OVERVIEW

This study was conducted to establish (or refute) a positive business case for closing the overhead trolley wire gap on the southern portion of 23rd Avenue presently served by King County Metro Route 48. Closing this gap would allow the southern portion of Route 48 (Route 48S) to be served by electric trolley buses, while the northern portion of Route 48 (Route 48N) would remain a diesel bus route (hybrid bus assumed).

The study evaluated and compared the lifecycle costs and benefits of deploying diesel-hybrid (hybrid) or electric trolley buses (ETB or trolley bus) along the southern portion of Route 48 from NE 15th Avenue and NE 50th Street in the University District to Mount Baker Station, as shown in Figure ES-1. This portion of Route 48 currently has overhead wire infrastructure in place serving several other bus routes, with the exception of two gaps totaling approximately 1.7 corridor miles (shown in red). The analysis considered the incremental cost of installing and maintaining overhead wire on these new segments of wire.

Figure ES-1 Route 48 South Corridor and Overhead Wire Gaps

Source: Metro (LTK, Route 48 Electrification Project Conceptual Report, 2011)

POLICY CONTEXT

City of Seattle and King County Metro plans and policies support reducing GhG emissions, including actions to do so through vehicle technology that minimizes environmental impacts. These plans include the King County and King County Metro Strategic Plans, the King County Strategic Climate Action plan, and the City of Seattle Climate Action Plan. The latter plan includes an action to "collaborate with King County Metro to expand the electric trolley bus system to include more routes and more frequent service in areas identified in the Transit Master Plan by funding service, building infrastructure, and coordinating planning."[1]

LITERATURE REVIEW

The study included a review of the following reports or studies.

- TCRP Report 146: Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements, 2011.
- King County Metro Transit Hybrid Articulated Buses: Final Evaluation Results, 2006.
- King County Trolley Bus Evaluation, 2011.
- Final Report for Edmonton Transit System: Alternative Scenarios for Trolley Bus Replacement, 2008.
- Trolley Coaches and Diesel Hybrid Motor Coaches: Analysis of Existing Conditions and Future Operations at the SFMTA, 2011.
- Route 48 Electrification Project Conceptual Report (LTK), 2011.

OPERATING PLAN ASSUMPTIONS

The operating assumptions for the analysis included:

- About 45,100 annual service hours would be operated on Route 48S. Service hours for the hybrid bus scenario were assumed at 99.14% of trolley bus due to more efficient deadheading.
- Fourteen (14) peak vehicles would be required to operate Route 48S under either a hybrid or trolley bus mode.

The operating assumptions used to analyze Route 48S accounted for scheduling inefficiencies resulting from splitting the route, e.g., overlapping service on Route 48S and 48N in the University District. However, the Route 48S operating assumptions did not include any potential costs for increased inefficiency on Route 48N. A range of service scenarios are possible, ranging from a modest reduction in operating costs through more efficient interlining for Route 48N and increased reliability for both portions of the current route; no cost impact; or a potential increase of up to 15,000 annual service hours for Route 48N. Given the variety and complexity of rider needs and interlining scenarios that could be pursued for Route 48N, the financial implications (positive, neutral, or negative) are not included in the base analysis, but the least optimistic scenario of 15,000 additional service hours on Route 48N is framed in Appendix B of the study report as an upper bound case.

[1] Transportation Infrastructure and Service Action 4

LIFECYCLE COSTS AND BENEFITS

Figure ES-2 summarizes the lifecycle costs and benefits for the hybrid and trolley bus scenarios for Route 48S. The following sections itemize the costs and benefits considered.

Lifecycle Costs

The left portion of Figure ES-2 compares lifecycle costs for the hybrid and trolley bus scenarios. Lifecycle costs for trolley buses on Route 48S are about $363 million (2015 dollars), or about $18 million higher than for hybrid buses ($345 million) over a 30-year period, due to higher vehicle capital costs and trolley infrastructure costs. This is partially offset by lower fuel costs.

- **Operating and Maintenance Costs** are slightly lower for trolley buses (average annual costs of $7.0 million compared to $7.4 million) including:
  - **Direct operating costs** per service hour: slightly lower for hybrid buses (due to more efficient deadheading).
  - **Fleet maintenance costs**: slightly lower for trolley buses.
  - **Incremental trolley overhead wire maintenance costs** on a per-mile basis: applicable only to trolley buses.
  - **Fuel and energy consumption and costs:** lower for trolley buses. A medium level of diesel fuel costs was assumed, but sensitivity to diesel fuel costs was analyzed.
- **Vehicle Capital Costs** are about $578,000 higher per vehicle for a trolley bus, including soft costs such as Washington State sales tax. Despite a longer assumed trolley bus vehicle life of 20 years (compared to a hybrid bus life of 15 years) annualized vehicle costs are higher for trolley buses.
- **Non-Vehicle Capital Costs** include the addition of overhead wire, additional traction power substations, installing OCS poles on the I-90 lid, and overhead wire to expand layover facilities at each end of the line, although off-wire capabilities in new trolley bus vehicles may reduce layover-related infrastructure costs.

Lifecycle Benefits

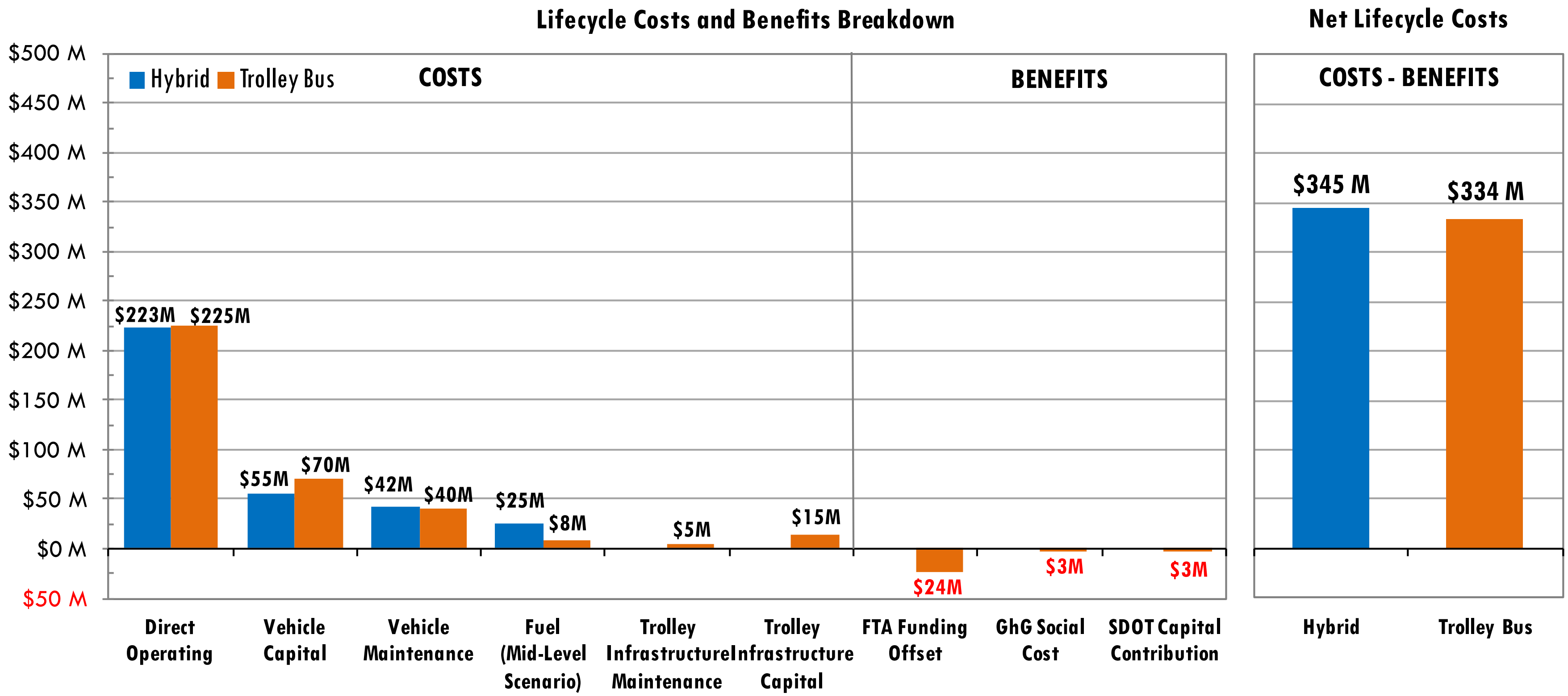
The middle portion of Figure ES-2 identifies cost offsets, or benefits, for the trolley bus scenario that are not captured in the lifecycle cost comparison. These include the availability of federal fixed guideway funding for trolley buses, the positive social cost of reducing GhG emissions, and the City of Seattle's $3.0 million commitment toward the capital cost of electrifying this corridor through the FY 2014 budget. Benefits total about $29 million.

Figure ES-3 compares the costs and benefits of electrifying Route 48S to operating the route using hybrid buses, including both tangible costs and benefits that can be quantified and others that are stated qualitatively. The most significant benefits positively affecting the trolley bus mode include FTA fixed-guideway funding and GhG emissions. Benefits of trolley buses also include air quality, reduced noise, and operation on hills.

Net Lifecycle Costs

Taking into account benefits, net lifecycle costs of implementing trolley buses on the southern portion of Route 48 are about $11 million lower than operating hybrid buses, as shown in the right portion of Figure ES-2.

Figure ES-2 Net Lifecycle Costs and Benefits Summary



Note: Costs are in 2015 dollars.

Figure ES-3 Summary of Route 48S Costs and Benefits for Hybrid and Trolley Bus Modes

Benefit Category	Benefit	Favors Hybrid Bus	Favors Trolley Bus
Capital Costs	Initial Capital Cost	**X**	
	Lifecycle Cost	Dependent on sensitivity factors	
Operating Cost	Fuel Cost		**X**
	FTA Fixed Guideway Funding		**X**
Maintenance Costs	Vehicle		**X** (Slight benefit)
	Trolley Overhead Wire and Power	**X**	
Environmental	GhG Emissions		**X**
	Air Quality		**X**
	Noise		**X** (particularly on hills)
	Visual Quality	**X**	Most of Route 48S is already electrified
Operational	Operation on hills	May be partly mitigated by newer hybrid buses	**X**
	Flexibility (Route)	**X**	Partly mitigated by APUs allowing off-wire travel
	Flexibility (System)	**X** (Decreases scheduling/interlining flexibility)	Addition of wire may enable future restructuring/efficiency opportunities
	Regenerative Braking	**X**	**X**
	Road wear (weight)		**X** (Slight benefit)
	Vehicle Reliability	Undetermined	

KEY FINDINGS

Key conclusions of the analysis are:

- Purely from an operating cost perspective, not including any capital costs or benefit offsets, the cost of operating ETBs in the Route 48S corridor is lower than the operating costs of hybrid buses for all but the lowest projected future diesel fuel costs. In that instance the operating costs are approximately equivalent.
- Annualized lifecycle costs (operating and capital) for electrifying Route 48S are higher than for hybrid bus under the base assumptions used in this analysis, except the case of "high" level diesel fuel prices versus lower electricity consumption rates for ETBs; in this case, costs are equal when offsetting benefits are not included.
- When benefit offsets are included in the calculation, the lifecycle costs of electric trolleys are less than hybrid buses in most cases. The exception is if diesel fuel prices fall below the market trends of the past decade, but even then the lifecycle costs are very close.
- Under current federal funding formulas embedded in MAP-21, use of electric trolley buses is financially beneficial. This advantage has been in place for several re-authorizations of the Surface Transportation Act, but recent formulaic and programmatic changes have accentuated the financial benefit of this mode.
- From a public policy perspective the benefits of ETB support conversion of Route 48S to a full ETB route. GhG emissions are significantly reduced with a trolley bus mode, equivalent to eliminating daily per-capita VMT for 480 vehicles over a year. A range of intangible benefits also generally favor the trolley bus mode, including noise and air quality. The City of Seattle adopted policy is to encourage deployment of ETB. Consistent with that policy the City has budgeted $3.0 million toward the non-vehicle capital cost of electrifying this corridor. This action further tips the scale in favor of moving to ETB in the corridor as the appropriate financial decision.
- Lifecycle costs for trolley bus are higher than for hybrid buses under the low-cost and mid-cost diesel fuel price scenarios if MAP-21 fixed-guideway funding were to be eliminated as a consideration. While there are no guarantees on the precision of projecting future energy costs, two emerging factors offer some insight:
    1.) The cost of fossil fuels continues to be unstable and on an upward trend. Any disruption in the relatively finite production capacity results in significant price swings. Given that no new production facilities are likely to be available in the next decade, this is likely to continue as a trend affecting fossil fuel supply and, therefore, costs.
    2.) Alternative electricity generation costs have continued to decline. That decline, coupled with a trend of increasing alternative electricity production, is assisting to stabilize the costs of electric power.

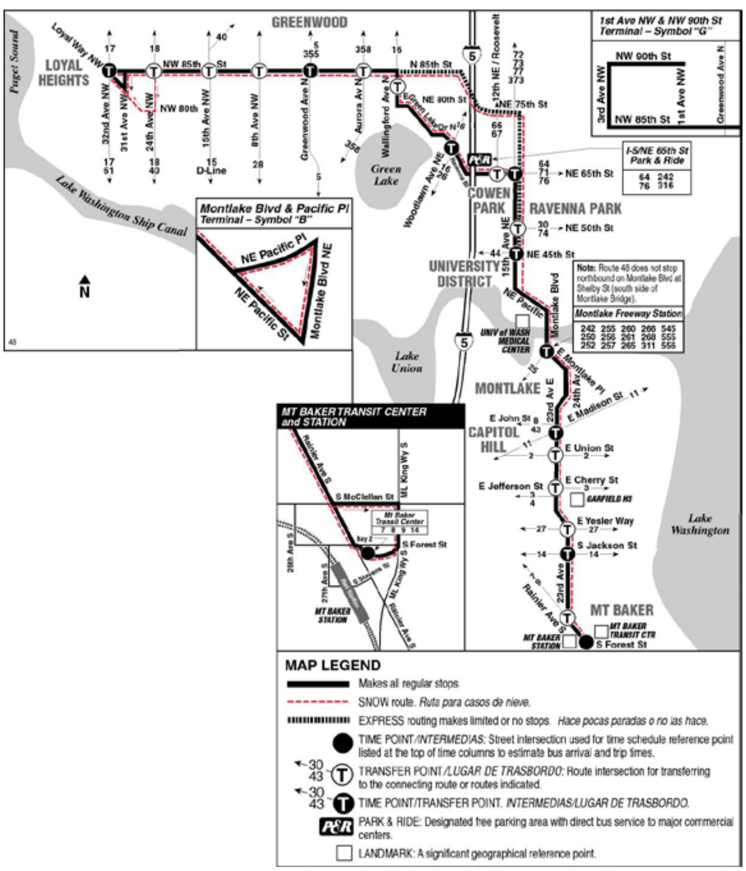
  From these trends it appears justified to consider the influences on the business case of higher future fuel costs.
- Given the tangible and intangible benefits, the increment of fleet necessary to accomplish this conversion, and the relative adjacency of the Mount Baker Station to Metro's operating base for ETB's, the business case for converting Route 48S takes on a positive perspective. Of many places where a route could be electrified, this particular corridor has, perhaps, the greatest opportunity given the relative simplicity and short length of the required infrastructure.
- SDOT is applying for grant funding from the Puget Sound Regional Council (PSRC) to complete the Route 48S electrification project. Initial feedback on this project has been favorable.

1 PROJECT OVERVIEW

The purpose of this project is to establish the veracity of a positive business case for closing the overhead trolley wire gap on the southern portion of 23rd Avenue presently served by King County Metro Route 48. This will be accomplished by evaluating and comparing the costs and benefits of deploying diesel-hybrid (hybrid) or electric trolley buses (ETB or trolley bus) along the portion of Route 48 from Mount Baker Station to NE 15th Avenue and NE 50th Street in the University District. The existing Route 48 is shown in Figure 1-1.

This analysis assesses the lifecycle impacts of operating the southern portion of Route 48 as a trolley bus route. The southern portion of Route 48 currently has overhead wire infrastructure in place serving several other bus routes, with the exception of two gaps totaling approximately 1.7 corridor miles. The analysis considers the incremental cost of installing and maintaining overhead wire on these new segments of wire. Figure 1-2 illustrates the two segments.

Figure 1-1 Existing Metro Route 48



Source: Metro

Figure 1-2 Overhead Wire Gaps along Route 48 Corridor

Source: Metro (LTK, Route 48 Electrification Project Conceptual Report, 2011)

2 RESEARCH

POLICY CONTEXT

City of Seattle and King County Metro plans and policies support reducing GhG emissions, including actions to do so through vehicle technology that minimizes environmental impacts. For example:

- The King County and King County Metro Strategic Plans include environmental sustainability as goal 4. Metro's Strategic Plan includes Strategy 4.2.1 to: "Operate vehicles and adopt technology that has the least impact on the environment and maximizes long-term sustainability." King County also has a Strategic Climate Action plan.[1]
- The City of Seattle's Climate Action Plan includes Transportation Infrastructure and Service Action 4 (by 2030) to: "Collaborate with King County Metro to expand the electric trolley bus system to include more routes and more frequent service in areas identified in the Transit Master Plan by funding service, building infrastructure, and coordinating planning."

LITERATURE REVIEW

Transit Research Board. TCRP Report 146: Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements. Washington, D.C., 2011

TCRP Report 146 is an evaluation of fuel choices for transit bus procurements made after 2010. The report includes numerous fuel choices including the electric trolley bus and hybrid diesel engine models. A model developed by in conjunction with this report, FuelCost2, may be valuable for calculating lifecycle costs for trolley and diesel hybrid bus models.

Electric Trolley Bus

Trolley buses have been in operation in the Seattle area since 1940 (12-2). These types of buses are ideal for hilly areas because they exhibit maximum torque at low engine speeds and lower noise relative to diesel buses when climbing hills (12-5). The capital costs for the average trolley bus is $875,000 (12-9). The trolley bus power trains have a long life as demonstrated by King County's retrofit of the 27-year old drive trains for new buses (12-7).

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[1] http://www.kingcounty.gov/exec/PSB/StrategicPlan/CountyStratPlan.aspx, http://metro.kingcounty.gov/planning/, and http://your.kingcounty.gov/dnrp/climate/documents/2012_King_County_Strategic_Climate_Action_Plan.pdf

The electric trolley bus is demonstrated to be more environmentally friendly with zero tailpipe emissions (2-3) and the potential to use renewable resources for electricity generation (12-1). Onboard fuel is not necessary for the trolley buses, except for a non-electric auxiliary power unit (APU) (12-1). The trolley bus traction motor uses DC power, which allows for regenerative breaking to feed into the overhead wire or APU (12-5).

The electric trolley bus does have concerns about fuel flammability, toxicity, and proper disposal in regards to the APU (12-3). Special training, protective equipment and diagnostic tools are necessary to work with the high voltage electric drive systems (12-3), although Seattle may already have these tools and training mechanisms because of its history with trolley buses. FTA funding may be difficult to obtain because of trolleybus classification as a "fixed guideway."

Hybrid Diesel Model

The hybrid diesel bus model initial purchase cost is close to $455,000 (14-15), although the average King County Metro Transit 60-foot articulated hybrid diesel bus costs $645,000 (14-14). Fuel economy per bus is about 4.01 mpg, with an associate maintenance cost of $0.19 for the propulsion system and $0.18 for the facility (14-15).

Many types of batteries are available for this bus model including which has various specific energies, specific power levels, life cycles and costs (14-3). Toxic chemicals within the batteries and risk of flammability and explosion can be a concern (14-5). There is a cost associated for maintenance and worker training for batteries (14-6). Battery recycling technology does exist, but is limited (14-6).

King County Metro Transit Hybrid Articulated Buses: Final Evaluation Results, 2006

This report is an evaluation and comparison of new diesel and diesel hybrid electric articulated buses operated over a 12-month period for the King County Metro Transit fleet in Seattle. The data in this document may be dated because of its publication in 2006.

The document includes a comprehensive list of operating costs for New Flyer articulated hybrid electric buses with the General Motor's Allison E^{P}50 System parallel hybrid propulsion system (v). These buses are powered through two operating modes: a diesel engine mechanical power train and an electric propulsion system powered through a catenary system. Electric power is employed for the buses while operating within downtown Seattle's tunnels and diesel power is utilized outside of the tunnels (4).

The ten buses studied averaged the following per month: 3,096 miles, 3.17 mpg, a fuel cost of $0.62 per mile, a maintenance cost of $1.06, and 4,954 miles between all road calls (viii). The purchase cost of each bus was $645,000 (9).

Parametrix and LTK Engineering Services. King County Trolley Bus Evaluation, 2011

This document is an evaluation of vehicle options for the replacement of the King County Metro's electric trolley bus fleet scheduled to begin in September 2014. The evaluation includes data on relative costs, limitations, environmental impacts, and benefits. Electric trolley buses were recommended out of the six technologies evaluated, although diesel hybrid bus technology was also explored in detail.

Electric Trolley Buses

Fourteen trolley bus routes carry 20% of Metro's weekday riders on 159 trolley buses over 70 miles of two-way overhead wires (1-5). These buses accrue a total of 3.7 million service miles (62.8% on 40-ft buses, 37.2 % on 60-ft buses) (4-4) and carry over 20 million riders annually. They are the cleanest and quietest buses in the transit system (2-3).

A new electric trolley bus is estimated to last 15 years (4-3). In 2010, total service substitutions (route dieselization) accounted for approximately 16.6 % of all electric trolley bus route service miles. Battery APUs should reduce dieselization to 1.7% of total electric trolley bus route miles (4-4). Forty-foot buses average 5.175 kWh/mile and sixty-foot buses average 6.919 kWh/mile. Energy consumption is known to fluctuate seasonally with heating, venting, and air conditioning (4-8).

Metro projected their 2011 effective electric trolley bus electricity service rate to be $0.0658/kWh (4-8). Metro was eligible for offsetting grants of up to 83% of the total capital costs of electric trolley buses and diesel hybrid buses in 2011 (4-5).

The electric trolley bus is the preferred technology because is it more cost effective with current federal funding expectations, it generates significantly lower GHG emissions (Seattle City Light generates 98% of Seattle's electricity from non-GHG gas emitting sources), and other factors including traffic (performances on slopes), noise, air quality/climate change factors, energy and environmental justice (no emissions in EJ neighborhoods along routes) (1-5). Annualized cost of an electric trolley bus is $11.8 million, which is $3.7 million less per year than diesel hybrid buses ($15.5 million). The level of fixed guideway funding would have to drop to 31% of current funding levels before the diesel hybrid bus technology would have a cost advantage (1-4).

APUs installed to date have limitations such as reduced vehicle speeds, shortened expected battery life, and the need for operators or other staff to reattach poles to wires after APU use (2-5). A replacement trolley bus should be equipped with an Auxiliary Power Unit (APU) to increase flexibility by permitting off-wire travel. The study recommended a battery APU based on performance and cost (1-2). APUs used for the San Francisco MTA buses have a range of 2 miles flat at 5 mph, while those used for Coast Mountain Bus Company buses (Vancouver, B.C.)have a range of 4 km (2.5 mi) on 6% grade (2-5).

Diesel Hybrid Buses

A new diesel hybrid bus is estimated to last 12 years (4-3). Diesel hybrid buses are common and currently comprise a growing portion of Metro's fleet. Bus maintenance facilities exist to perform maintenance on the buses, although additional fueling capacity would be needed to accommodate increased fleet size (1-2). The 40-ft diesel hybrid bus is expected to average 4.16 mpg, while the 60-ft bus is expected to achieve 2.81 mpg (4-8). Diesel fuel prices were estimated for the near term with three price projections: low prices at $2.642/gallon, medium prices at $3.482/gallon and high prices at $4.460/gallon in 2011 (4.8-9).

Diesel hybrid buses have a better visual quality than electric trolley buses because there is no need for catenary lines (1-3). Diesel hybrid buses may require modification to the drive train system for travel on steep hills, which would limit the bus' top speed on level grades. Bus maintenance facilities exist to perform maintenance on diesel hybrid electric in King County, although additional fueling capacity would be needed to accommodate increased fleet size (3-4).

Electric Trolley Bus and Diesel Hybrid Bus Comparison

The electric trolley bus service is economically favorable only with partial "fixed guideway funding" from the FTA. Diesel fuel price forecasts have the greatest influence on life-cycle cost results. A change in vehicle life span for one or both technologies can significantly alter the magnitude of the cost difference between the two technologies. Electricity rates, stabilized by public utility commission oversight, have little influence on the life-cycle cost results. Lowering the real discount rate can change the total cost of the program, but not the preferred technology (4-16).

Rolling stock operating costs typically account for bus operator labor, central dispatch staff and equipment, field supervisors, relief stations and fuel or energy. However, in a differential cost life-cycle model comparing two technologies following the same nominal route profile and operating schedule, the only significant contributor becomes the fuel or energy (4-7). Since electricity prices are essentially fixed by Seattle City Light, diesel fuel prices have the greatest effect on operating costs comparisons between electric trolleys and diesel hybrid buses.

According to Metro estimates, new electric trolley buses equipped with APUs would be capable of providing off-wire power for at least a mile. Based on this coverage area, approximately 90% of detours could be accommodated by trolley buses; however, the remaining 10% would still need to be served by diesel hybrid buses (5-4).

For VOC, PM10, NOx, and CO2, the emissions from a diesel hybrid fleet would be several orders of magnitude higher when compared to a fleet of electric trolley buses. This is because 98% of the electricity used by the trolley bus is from renewable resources. Seattle City Light would need to increase coal and natural gas usage by 50% to result in emissions comparable to diesel hybrid bus fleets. Moreover, the trolley bus fleet emissions account for generation and tail pipe emissions, while the diesel fleet emissions are only accounting for tail pipe emissions (5-6).

The weight of the two types of buses is roughly the same for the 40-foot bus, although the articulated 60ft diesel hybrid bus is approximately 1,700 pounds heavier than the trolley bus at 47,980 pounds. Noise test results from 2003 and 2011 are available for each type of bus (5-4, 5).

Base Rolling Stock Unit Capital Costs		
Unit Cost ($ in millions, 2010)		
Size	Elect. Trolley Bus	Hybrid
40 ft	1.031	0.495
60 ft	1.285	0.785
Total Rolling Stock Unit Capital Costs		
Unit Cost ($ in millions, 2010)		
Size	Elect. Trolley Bus	Hybrid
40 ft	1.255	0.629
60 ft	1.557	0.972

Source: KC Metro Trolley Bus Eval. Study, p. 4-5

The base rolling stock unit capital costs were adjusted for the following factors (4-5):

- Additional Equipment ($8,000 for 40-foot, $12,000 for 60-foot, Fixed)
- Sales Tax (8.9 percent)
- Project Management ($8,100, Fixed)
- Service Preparation and Inspection (2 percent)
- Aftermarket Equipment ($25,700, Fixed)
- Contract Spares (zero percent)
- Training and Manuals ($6,700, Fixed)
- Special Tools and Diagnostic Equipment (0.3 percent)
- Contingency (5 percent)

Booz Allen Hamilton, Final Report for Edmonton Transit System: Alternative Scenarios for Trolley Bus Replacement. Edmonton, 2008

This report is an evaluation of the environmental and cost impacts associated with the operation of the Edmonton Transit System trolley buses. The document was published in 2006 with the assumption that electricity generated for trolley buses would use mostly non-renewable resources. For these reasons, the information within the document should be used only as a reference.

Capital costs for a hybrid bus and trolley bus were listed as $587,420 and $895,850 respectively. A list of direct bus maintenance, labor and parts costs is provided for the electric trolley and diesel bus fleet, but the costs are variable depending on the age and type of bus (10). Maintenance and capital costs for the catenary system are also provided including costs for poles, contact wire, and other special hardware (14).

San Francisco MTA, Trolley Coaches and Diesel Hybrid Motor Coaches: Analysis of Existing Conditions and Future Operations at the SFMTA, 2011

Overall, SFMTA's analysis was concluded that maintaining trolley bus service was warranted, with continued receipt of FTA Fixed Guideway Funding a key element in the cost equation. Key findings from the analysis include:

- Trolley vehicles were found to be less expensive to operate, but gave up their cost advantages when the greater capital infrastructure costs were added into the equation. The cost equation shifted back to trolley vehicles when FTA Fixed Guideway Funds for trolley service were added to the equation.
- Given that TC vehicles are competitive or less expensive than DHMC service, and have the additional benefits of quiet operation, zero emissions, and generally hold higher

public support, the report recommended that SFMTA should retain trolley service in as many corridors as possible unless unique circumstances argue otherwise.

LTK, Route 48 Electrification Project Conceptual Report, 2011

This is a planning-level study to determine the basic requirements and capital costs estimates for infrastructure to allow trolleybus operation on all of Route 48 South, including new sections of trolleybus overhead contact system (OCS) and substations.

3 OPERATING AND CAPITAL COSTS

This chapter first describes the operating assumptions and scenarios for the analysis of electrifying the southern portion Route 48. It then provides key assumptions and cost estimates for annual operating and maintenance costs, capital costs, and total lifecycle costs.

OPERATING ASSUMPTIONS AND SCENARIOS

This section describes the operating assumptions and scenarios that are assumed for this analysis.

Route 48 South Operating Assumptions

Figure 3-1 provides the assumed operating assumptions for Route 48, provided by Metro. It is assumed that Route 48 South (48S) would operate between Mount Baker Transit Center and NE 50th Street in the University District. It assumed that 14 peak vehicles would be required to operate the southern portion of the route under either a hybrid or trolley bus mode. Hybrid scenario hours were assumed at 99.14% of trolley due to more efficient deadheading.

Figure 3-1 Route 48 South Operating Assumptions

	Weekday	Saturday	Sunday	Annual Total	Notes
Trolley Scenario					
Annualized Hours	36,189	5,522	3,393	45,103	
Annualized Miles	312,273	48,776	31,192	392,241	
Daily Service Trips	162	126	74	-	
One-Way Service Mileage	7.1	7.1	7.1	-	
Daily Service Mileage	1,150	895	525		
Daily Deadhead Trips	24	14	4	-	
Deadhead Mileage	3.1	3.1	3.1	-	
Daily Deadhead Mileage	74	43	12		
Total Daily Miles	1,225	938	538	-	
Hybrid Scenario					
Annualized Hours	35,878	5,474	3,364	44,715	1
Annualized Miles	309,587	48,357	30,924	388,868	1
Daily Service Trips	162	126	74		2
One-Way Service Mileage	7.1	7.1	7.1		2
Daily Service Mileage	1150	895	525		2
Daily Deadhead Trips	24	14	4		2
Deadhead Mileage	2.7	3.0	2.8		3
Daily Deadhead Mileage	64	42	11		3
Daily Miles	1,214	936	537		

Notes: (1) Hybrid scenario hours and total miles assume 99.14% of Trolley due to more efficient deadheading. (2) Assumed to be the same as Trolley Bus. (3) Assumes that increased efficiency is solely due to deadheading.

Source: Trolley bus scenario characteristics and 99.14% assumption for Hybrid from Metro.

Route 48 Split

Converting Route 48 to a trolley bus route will require splitting the route, with Route 48S electrified and served by an ETB mode, and Route 48 North (48N) remaining a diesel bus route (hybrid bus assumed). The split would add some scheduling inefficiencies to the route assuming no other route alignments were explored. While these inefficiencies are inherent in the split, the offsetting consideration is an increase in reliability. The scheduling inefficiency related to the 48S are already assumed in the operating assumptions developed by Metro.

The 48N is a different case. Metro identified an annual increase of up to 15,000 hours for 48N as one potential scenario for Route 48N. This assumption is based on what could be called the least optimistic scenario, i.e., that no other reasonable options are available to leverage the inefficiency and that the two routes, 48S and 48N, would overlap one another throughout the University District. The analysis presented in this report does not attribute any potential costs for this inefficiency to the costs for electrifying Route 48S, instead assuming that any such inefficiencies would most likely be addressed by restructuring Route 48N, e.g., interlining it with other bus routes.

However, to be complete, Appendix B provides a summary of the analysis assuming the additional costs for the route split. It should be emphasized that the Appendix assumes what would be an upper bound for any additional costs that simply cannot be quantified for this study. Splitting Route 48 into two routes at the University of Washington has been a point of discussion for several years. Many concepts have been created and tested and it is believed that there are viable concepts than can be implemented that fall between this analysis and what is presented in the Appendix. In nearly any configuration one of the very significant advantages strictly from a rider perspective is that the split offers a more reliable service overall compared to the current situation.

OPERATING AND MAINTENANCE COSTS

This section describes estimated annual costs for vehicle and non-vehicle maintenance and operations. It first describes key assumptions in each cost area, leading to an estimate for annual operating and maintenance costs.

Key Assumptions

Operating Costs

Figure 3-2 identifies basic operating cost assumptions.

Figure 3-2 Operating Cost Assumptions

Assumption	Value (2015$)	Source/Notes
Direct Operating Costs	$115.99	Metro. 2014 direct operating cost of $112.07; escalated at 3% annually.

Fleet Maintenance

Figure 3-3 identifies per-mile unit costs for fleet maintenance. The methodology and costs are based on the King County Metro Trolley Bus Evaluation Study, adjusted to 2015 based on assumed 3% annual escalation. The per-mile costs were multiplied by the estimated annual service costs for each scenario.

Figure 3-3 Fleet Maintenance Cost Assumptions

Mode	Assumption	Value (2015$)	Source/Notes
Hybrid or Trolley Bus	Tire Maintenance per Tire per Mile x 10 tires per vehicle	$0.10	See Note 1. Escalated from $0.09 in 2010 at 3% annually.
Hybrid	General Maintenance Cost per Mile	$1.68	See Note 1. Escalated from $1.45 in 2010 at 3% annually.
	Year-to-Year Increase	$0.06	See Note 1. Additional year-to-year increase based on vehicle life, reset upon vehicle replacement.
Trolley Bus	General Maintenance Cost per Mile	$1.60	See Note 1. Escalated from $1.38 in 2010 at 3% annually.
	Year-to-Year Increase	$0.05	See Note 1. Additional year-to-year increase based on vehicle life, reset upon vehicle replacement.

Notes: (1) Adapted from King County Metro Trolley Bus Evaluation Study, 2011.

Trolley Overhead Maintenance

The analysis assumed an incremental maintenance cost for the additional nearly 3.4 route-miles of overhead wire that would be required to fill-in the OCS gaps in the Route 48 corridor. A maintenance cost per one-way overhead-wire mile was calculated for the current trolley system based on the cost identified in the Trolley Bus Evaluation report, escalated to 2015 and subsequent years at a rate of 3%, and applied to the additional OCS distance.

No additional capital system costs were attributed to the incremental cost of electrifying Route 48; new total and annualized infrastructure costs are discussed in the Capital Costs section below.

Figure 3-4 Trolley Overhead Maintenance Cost Assumptions

Assumption	Value (2015$)	Source/Notes
Annual Maintenance Cost per OCS Mile	$30,497	Based on 2011 overhead costs divided by one-way trolley system miles (138). Overhead costs of include maintenance and repair, cleaning and landscape, and utilities and taxes categories, but exclude trolley power. Escalated to 2015 and subsequent years at 3%.

Notes: (1) Adapted from King County Metro Trolley Bus Evaluation Study, 2011.

Fuel and Energy

Figure 3-5 identifies the fuel and energy cost assumptions used in the analysis. These influence annual operating and maintenance costs that are part of the lifecycle cost described in this chapter, as well as estimates of greenhouse gas emissions, described in Chapter 4. The fuel efficiency assumed for a hybrid bus was consistent with the King County Metro Trolley Bus study, which scaled typical hybrid bus fuel efficiency to the Seattle trolley bus system. It is assumed that the characteristics of Route 48S that affect fuel efficiency (such as grade) are similar to the average for the trolley bus system.

Figure 3-5 Fuel and Energy Cost Assumptions

Mode	Assumption	Value	Source/Notes
Hybrid	Fuel Efficiency, 60-foot bus	2.81 mpg	See Note 1. Hybrid bus fuel efficiency was scaled to typical trolley bus duty based on LTK analysis (consistent with Trolley Bus Evaluation Study; Assumes that the overall ETB assumption applies reasonably well to Route 48.
	Fuel Cost	$3.75/gallon	See Note 1. The middle-end estimate from the 2011 study was used in the analysis, inflated from $3.48 in 2011 to $3.75 in 2015 based on the EIA annual energy outlook used in the 2011 study. The 2015 projection is consistent with the current 2015 projection of $3.73 (as of February 14, 2014).[2] A sensitivity analysis will be conducted using low and high end values (see Chapter 4).
Trolley Bus	Energy consumption, 60-foot bus	6.919 kWh/mile	See Note 1. Average annual rate.
	Energy cost	$0.0658/kW	See Note 1. 2011 projected Seattle City Light rate, increased by projected CPI.

Notes: (1) King County Metro Trolley Bus Evaluation Study, 2011. (2) http://www.eia.gov/tools/faqs/faq.cfm?id=31&t=9

Annual Operating and Maintenance Costs

Figure 3-6 summarizes operating and maintenance costs for each scenario, which overall are slightly lower for trolley bus relative to hybrid.

- **Direct operating costs.** Total direct operating costs are slightly lower for the hybrid bus scenario since the number of total service hours is lower (due to more efficient deadheading).
- **Fleet/Vehicle Maintenance**. Fleet maintenance costs are slightly lower for the trolley bus scenario.
- **Trolley Overhead Maintenance**. This category applies only to the trolley bus scenario.
- **Fuel/Energy Costs**. Energy costs are lower for the trolley bus scenario.

Figure 3-6 Average Annual Operating and Maintenance Costs (Over 30 Year Period)

Annual O&M Costs	1 - Hybrid	2 – Trolley Bus
Direct Operating	$5,186,600	$5,231,600
Annual Fleet/Vehicle Maintenance	$1,388,700	$1,332,700
Annual Trolley Overhead Maintenance	-	$163,000
Annual Fuel/Energy	$848,900	$279,600
Total Annual Operating and Maintenance	$7,424,000	$7,007,000

VEHICLE CAPITAL COSTS

King County Metro provided current bus capital costs, which were inflated (if necessary) to the assumed implementation year (2015) at a rate of 3.5%. These were assumed to be equivalent to the base capital costs identified in Trolley Bus System Evaluation report (2011) and are about $530,000 higher per vehicle for a trolley bus. A subset of the soft costs[2] identified in that report were also inflated to the assumed 2015 implementation year; sales tax adds about $47,000 to the cost differential between a hybrid bus and a trolley bus. Figure 3-7 provides these costs for the hybrid and trolley bus scenarios. Vehicle costs were annualized assuming a hybrid bus life of 15 years and a trolley bus life of 20 years, and a discount rate of 3.5%. Given these assumptions, annualized hybrid bus capital costs are lower than for trolley buses.

Although a 30-year analysis period is used for this study, hybrid and trolley bus capital costs are most comparable using a 60-year period, where five hybrid bus procurements would be required compared to four with trolley buses. Figure 3-8 illustrates total vehicle capital costs for the hybrid and trolley bus scenarios for Route 48S over 60 years. The actual costs used in the lifecycle cost

[2] Other than Washington State sales tax, the costs considered to be applicable to this incremental fleet expansion were fixed costs per vehicle and were assumed to be the same for Hybrid and Trolley Bus vehicles. These included additional equipment, project management, and aftermarket equipment. Other costs assumed on a percentage basis in the original analysis were not included, e.g., service preparation and inspection, contract spares, training and manuals, special tools and equipment, and contingency.

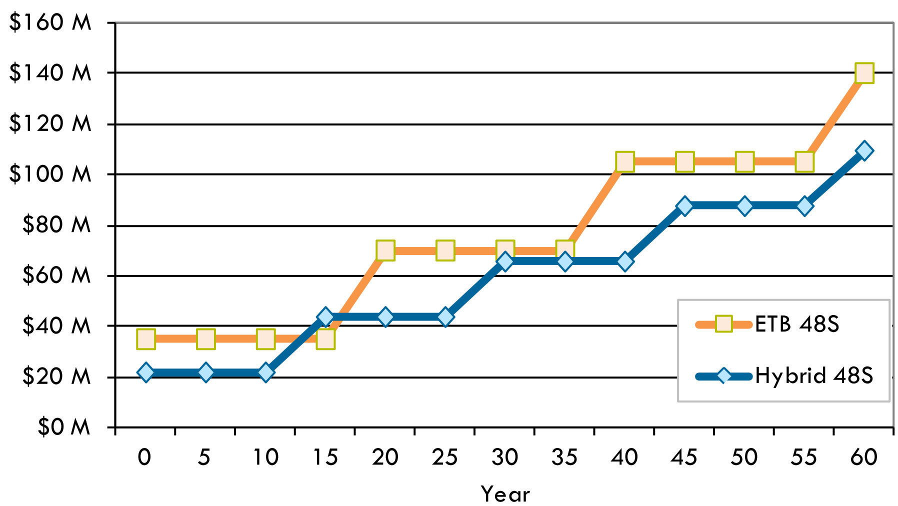
analysis are averaged over a 60-year replacement cycle: hybrid bus cost of $1.8 M compared with $2.3 M for trolley buses.

Figure 3-7 Hybrid and Trolley Bus Scenarios, 2015$

Scenario #	1 - Hybrid	2 – Trolley Bus
# Vehicles for 48S - Hybrid or Trolley Bus	14	14
Base Cost / Vehicle [1]	$1,053,800	$1,584,000
Soft Costs / Vehicle [2]	$148,200	$195,400
48S Base+Soft Capital Costs / Vehicle [3]	$1,202,000	$1,779,400
Total Initial 48S Vehicle Capital Costs	$16,828,000	$24,912,000
Total Annualized 48S Vehicle Costs (Vehicle Life) [3]	$1,461,000	$1,753,000
Annualized 48S Vehicle Costs (60 Year Cycle)	$1,800,000	$2,300,000

Notes (1): From Metro procurements; 2012 cost for hybrid ($950,470), inflated to 2015 at 3.5%; 2015 cost for trolley bus. (2) Adapted from King County Metro Trolley Bus Evaluation Study, 2011. Include WA State sales tax of 8.9% and fixed costs per vehicle, e.g., after-market equipment. (3) Annualized over vehicle lifetime, assuming hybrid vehicle life of 15 years, trolley vehicle life of 20 years, and a discount rate of 3.5%.

Figure 3-8 Total Vehicle Capital Costs over 60 Years, 2015$



FTA Grants

Consistent with the 2011 Metro Trolley Bus Evaluation Study methodology, it is assumed that the higher cost of trolley buses would not increase the overall amount of regional grant capital funding and offsetting capital grants are not included in the analysis.

NON-VEHICLE CAPITAL COSTS

Non-vehicle capital costs include the addition of overhead wire (OCS) along NW 23rd Street and two additional traction power substations (TPSS), corresponding to the "most likely" scenario from the LTK Route 48 Electrification Report. In addition, allowances were added for additional costs of installing OCS poles on the I-90 lid (between S. Judkins and S. Massachusetts Streets) and overhead wire to expand layover facilities at each end of the line (Mt. Baker and in the University District).

An allowance for layover facilities at Mt. Baker and in the University District was assumed based on prior discussions between SDOT and Metro. Off-wire capabilities in new trolley bus vehicles may reduce layover-related infrastructure costs for Route 48S, but the costs of improving the layover/circulation needs at route terminal points were included, nevertheless.

While not directly included as a benefit or cost offset, it must be noted that the City of Seattle has already committed, through the FY 2014 budget, $3.0 million toward the capital cost of electrifying this corridor.

Figure 3-9 provides the assumed non-vehicle capital costs. Non-vehicle infrastructure costs were annualized assuming a lifetime of 60 years. A discount rate of 3.5% was assumed.

Figure 3-9 Non-Vehicle Capital Costs

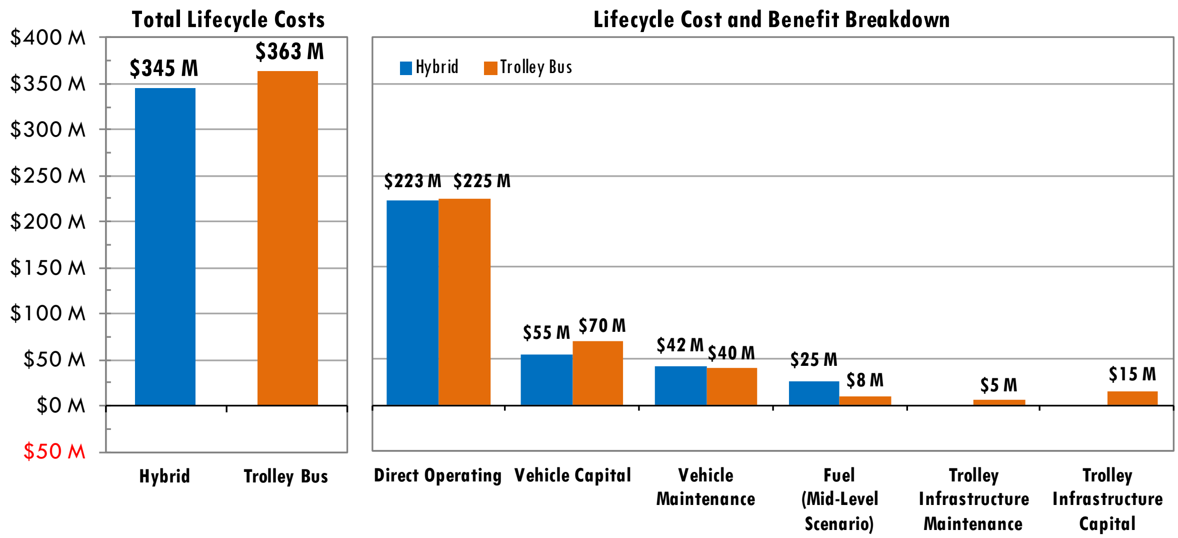
Cost Item	Location	Description	Estimated Cost	Source
New Trolley Bus OCS	John-Jefferson, Dearborn-Hill	17,800 route-feet wire, 116 steel and 19 new wood poles (including 10 joint-use with street lighting)	$11,548,838	Note 1; see p. 30. Includes contingency, design, etc.
Traction Power System ("Likely Estimate" case)	Pacific & Yesler	2 New Substations		
Additional cost for I-90 pole support allowance @ $1,500 each	I-90 Lid	20 poles assumed	$61,800	Note 2; includes contingency, design, etc.
Additional layover allowance	Mt. Baker		$250,000	Rough estimate
Additional layover allowance	University District		$250,000	
Total Non-Vehicle Capital Costs			$12,111,000	
Annualized Non-Vehicle Capital Costs [3]			$486,000	

Notes: (1) LTK Route 48 Electrification Project Conceptual Engineering Report. (2) Perteet (Email Communication). (3) Annualized over 60-years.

LIFECYCLE COSTS

Figure 3-10 compares lifecycle costs for hybrid and trolley bus over a 30-year period, showing trolley bus to be about $18M higher due to higher vehicle capital costs and initial and ongoing trolley overhead costs, partially offset by lower fuel costs and slightly lower vehicle maintenance costs. Costs include all of the operating and maintenance and capital costs described in this chapter, but do not include the availability of federal fixed guideway funding for trolley bus, which is addressed in the next chapter along with a discussion of other benefits. A medium level of diesel fuel costs is assumed; sensitivity to diesel fuel costs is provided in the next chapter.

Figure 3-10 Total Lifecycle Costs



4 BENEFITS

Figure 4-1, from the Metro Trolley Bus Evaluation Study, identifies a range of environmental benefits and impacts of hybrid and trolley bus modes. Figure 4-2 compares costs and benefits of electrifying Route 48S compared to operating the route using hybrid buses. Benefits include both tangible costs and benefits that can be quantified, and others that are stated qualitatively. The most significant benefits positively affecting the trolley bus mode include FTA fixed-guideway funding and GhG emissions; these are quantified below. Fuel costs along with hybrid bus fuel efficiency also have the potential to influence the cost-competitiveness of hybrid buses with trolley buses.

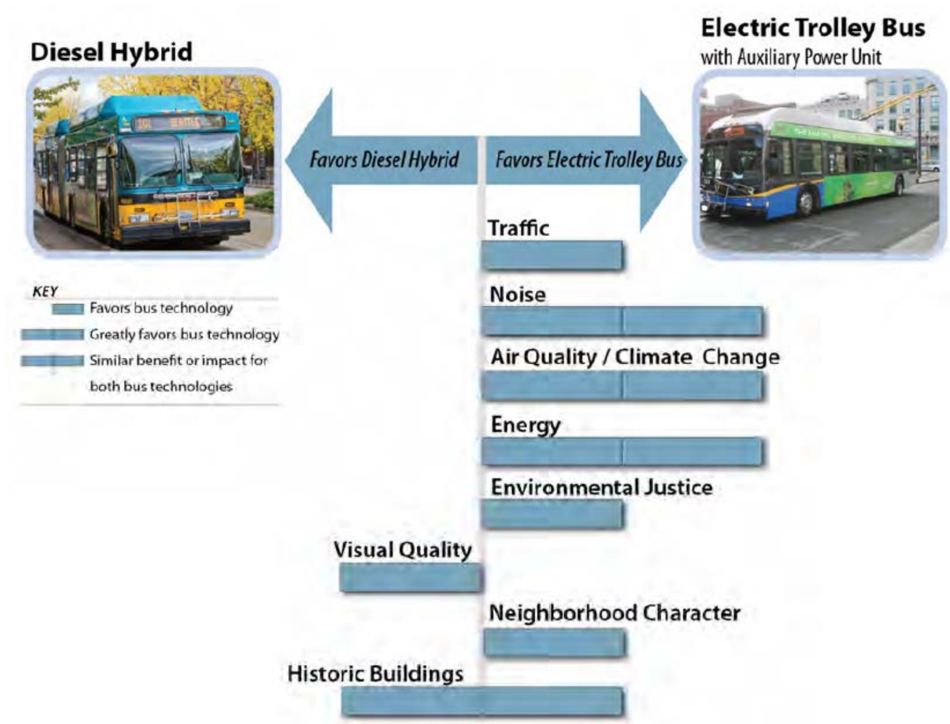
Benefits of trolley buses also include air quality, reduced noise, and operation on hills. The Trolley Bus Study provides a more comprehensive comparison, however several key points are highlighted below as specifically related to Route 48S or where there have been changes since publication of the study.

- **Visual Impact**. Hybrid buses have a lower visual impact, although much of the Route 48S corridor is already electrified.
- **Operation on Grades**. The Trolley Bus Evaluation Study notes that hybrid buses partly mitigate past advantages of the trolley bus mode in operation on steep grades. However, SFMTA's analysis highlighted that this would require gearing changes that could negatively impact hybrid vehicles' maximum speed and fuel efficiency.
- **Regenerative Braking.** The 2011 Trolley Bus Evaluation Study considered regenerative braking as a benefit only for hybrid buses; regenerative braking has, and may continue to improve, hybrid fuel efficiency. However, more recent trolley buses, such as those implemented in Vancouver B.C. and announced by Metro for implementation in Seattle, also include regenerative braking capabilities that would decrease the energy requirements for operating trolley buses, potentially reducing the substation investments needed to electrify Route 48S. As noted in Metro's press release,[3] the new buses would use an "estimated 25-30 percent less energy than the current electric trolley buses, and use regenerative braking that puts power back into the energy system."
- **Operational Flexibility:**
  - **Off-Wire Operation.** Auxiliary power units (APUs) have improved the operational flexibility of trolley buses, allowing operation around temporary obstacles or detours. Increased battery capacity may increase the range of off-wire operation for trolley buses in the future.
  - **System Flexibility:** Electrification of the Route 48S may decrease scheduling flexibility and interlining opportunities although filling in the wire gaps on the Route

[3] http://kingcounty.gov/transportation/kcdot/NewsCenter/NewsReleases/2013/June/nr06172013_trolleycontract.aspx

48S corridor may allow Metro to restructure other Metro trolley bus routes in the future to achieve greater efficiency/productivity.

Figure 4-1 Summary of Environmental Benefits and Impacts



Source: Metro Trolley Bus Evaluation Study, 2011

Figure 4-2 Summary of Route 48S Costs and Benefits for Hybrid and Trolley Bus Modes

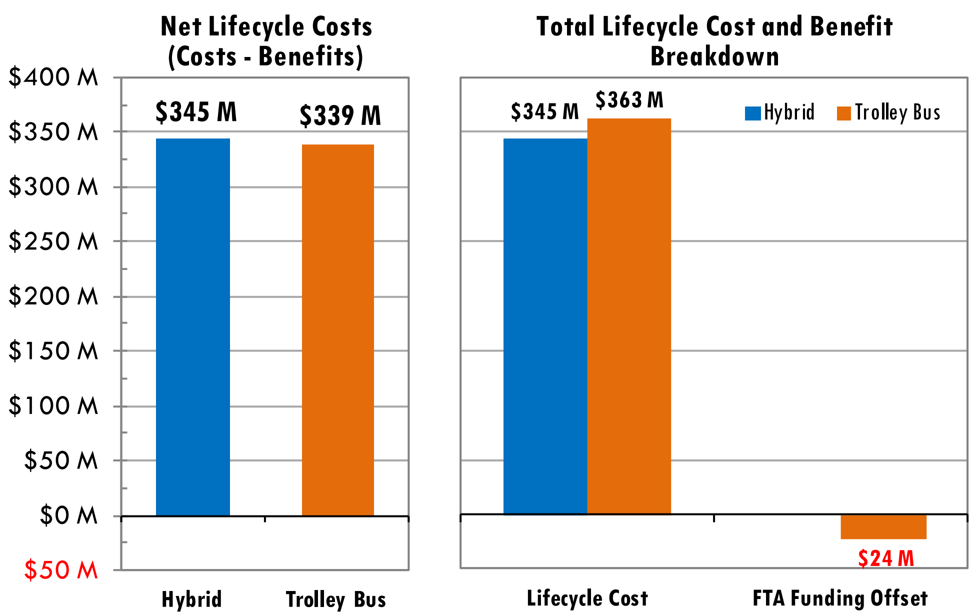
Benefit Category	Benefit	Favors Hybrid Bus	Favors Trolley Bus	Quantified?
Capital Costs	Initial Capital Cost	X		Yes
	Lifecycle Cost	Dependent on sensitivity factors		Yes
Operating Cost	Fuel Cost		X	Yes
	FTA Fixed Guideway Funding		X	Yes
Maintenance Costs	Vehicle		X (Slight benefit)	Yes
	Trolley Overhead Wire and Power	X		Yes
Environmental	GhG Emissions		X	Yes
	Air Quality		X	No
	Noise		X (particularly on hills)	No
	Visual Quality	X	Most of Route 48S is already electrified	No
Operational	Operation on hills	May be partly mitigated by newer hybrid buses, but required gearing may limit speed and efficiency for operation on flat grades	X (maximum torque at low engine speeds)	No
	Flexibility (Route)	X	Partly mitigated by APUs allowing off-wire travel	No
	Flexibility (System)	X (Decreases scheduling/interlining flexibility)	Addition of wire may enable future restructuring/efficiency opportunities	No
	Regenerative Braking	X	X	No
	Road wear (weight)		X (Slight benefit)	No
	Vehicle Reliability	Undetermined		No

FTA FIXED GUIDEWAY FUNDING

The Federal Transit Administration (FTA) includes fixed-guideway vehicle miles in the funding formulas for 5307, 5337, and 5339 programs. Metro calculated that increasing fixed-guideway vehicle revenue miles by converting Route 48S to trolley bus would increase net federal funding from these programs by over $784,000 annually, given current federal funding under MAP-21 as allocated by the Puget Sound Regional Council (PSRC). Although funding levels have remained relatively stable in recent years, these funds are treated as a benefit because there is no guarantee of future federal funding levels, nor of the specific allocation to Metro by PSRC.

Accounting for federal funding, and assuming this level of funding remains constant, the cost of trolley buses is reduced to approximately $6 M lower than the cost of hybrid buses over a 30-year period as shown in Figure 4-3.

Figure 4-3 Effects of FTA Fixed-Guideway Funding on Net Lifecycle Costs



GHG EMISSIONS

Figure 4-4 compares CO_2 emissions for the hybrid and trolley bus scenarios for Route 48S. A hybrid bus would emit over 1,400 metric tons (MT) of CO2 annually while a trolley bus would emit approximately 40 MT of CO2 per year, given Seattle City Light's nearly 100% renewable energy mix.

The City of Seattle's 2008 GhG Inventory estimated emissions of 64,379 MT from buses. The annual reductions from electrifying Route 48S represent about 2.1% of this total. To put these emissions in context:

- Assuming 2013 fleet fuel efficiency of 20.9 miles per gallon and average Seattle-area VMT per capita of 18.6 miles per day, there are 2.5 MT of CO2 emissions per capita annually. GhG emissions savings from electrifying Route 48S is equivalent to eliminating daily auto emissions from approximately 480 vehicles over the course of a year (or over 175,000 daily auto trips).

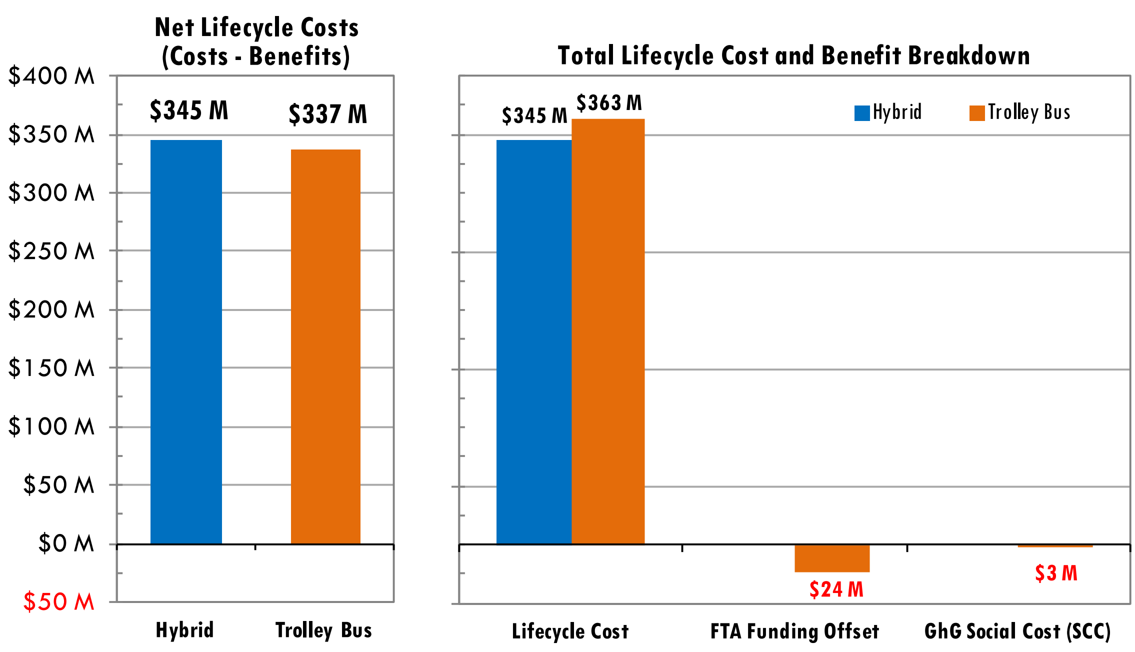
Figure 4-4 Summary of CO_2 Emissions

Scenario	Annual Service Miles	Annual Energy Consumption	Annual CO_2 Emissions		Notes
1 - Hybrid	388,868	138,363 gallons	1,410 MT	3,114,450 lbs	1
2 - ETB	392,241	2,713,977 kWh	40 MT	86,360 lbs	2
Net Emissions Reduced			1,370 MT	3,028,093 lbs	

Notes: (1) Based on hybrid bus fuel efficiency from the King County Metro Trolley Bus Evaluation Study (2011) and emissions factor of 10.21 kg CO_2 per gallon of diesel fuel, from US EPA, (2) Based on an emissions rate of 0.0999 kg CO_2 per mile, calculated from overall trolley bus kWh and service miles from NTD, and Seattle City Light CO_2 emissions factor per kWh from 2008 Seattle GhG inventory.

The U.S. EPA and other federal agencies have developed a social cost of carbon (SCC)[4] to estimate the monetary benefits of climate policies. The SCC represents an estimate of the economic damages associated with each metric ton of CO2 emissions in a given year, or the benefit of this amount of CO2 reduction. Over a 30-year period, the CO2 reduction from electrifying Route 48S is equivalent to over $2.6M, or an average of nearly $88,000 annually. As shown in Figure 4-5, incorporating both the current projection for FTA fixed-guideway funding and the SCC benefit reduces the net lifecycle cost of electrifying Route 48S to approximately $8M lower than the lifecycle cost of the hybrid scenario.

Figure 4-5 Social Cost of CO2 Emissions



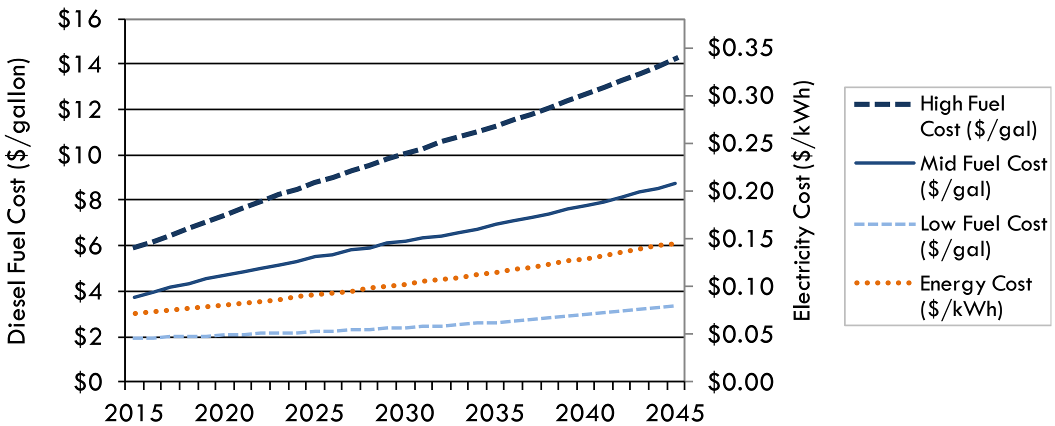
[4] http://www.epa.gov/climatechange/EPAactivities/economics/scc.html

SENSITIVITY TO FUEL COSTS

Figure 4-6 illustrates the energy and fuel cost projections used in the analysis. These costs are based on the Metro Trolley Bus Evaluation study (inflated to 2015$), which combined short-term projections from Linwood Capital with U.S. Energy Information Administration (EIA) Annual Energy Outlook long-term projections. The middle-end cost, which Metro typically uses for budgeting, is targeted at 65% below probability (65% chance of prices being lower than projected), the low-end is set to one standard deviation below the projected average price, and the high-end is set to two standard deviations above the average price.

As noted in the previous chapter, the current price trajectory for diesel fuel appears to be tracking close to the middle-end cost curve. The current 2015 EIA projection of $3.73 is consistent with the inflated 2015 cost of $3.75 per gallon. Diesel fuel prices have trended higher than gasoline prices since 2004. Factors driving this trend include high worldwide demand for diesel and other distillate fuel oils, limited global refining capacity to meet high demand, and a transition to cleaner, lower-sulfur diesel fuels in the U.S.[5]

Figure 4-6 Diesel Cost Curves

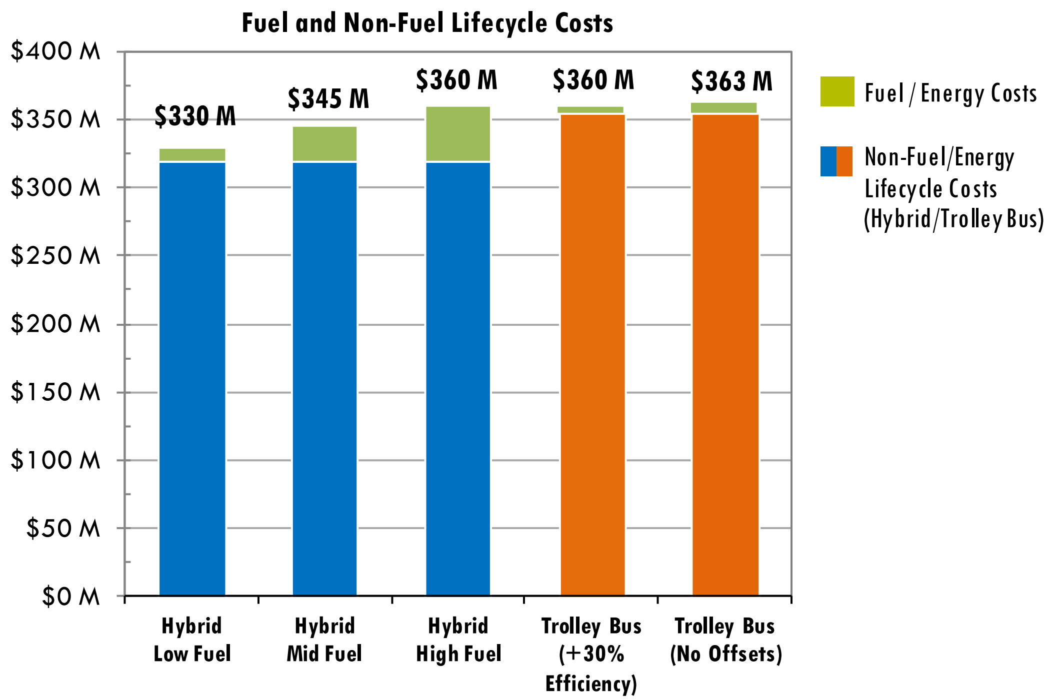


Source: Based on Metro Trolley Bus Evaluation Study

[5] Energy Information Administration

Figure 4-7 identifies the hybrid scenario's cost under both low and high fuel cost scenarios, in relation to trolley bus (not including offsets from federal fixed-guideway funding and SCC costs). Fuel costs are shown separately from other lifecycle costs. Without federal fixed-guideway funding, the total lifecycle costs of trolley bus exceed those of hybrid bus under each fuel cost scenario, although the difference is reduced to $3M comparing the high hybrid fuel cost scenario and the base trolley bus scenario without offsets (far right column). If trolley bus energy efficiency improves by 30% (2nd bar from right) (see page 4-1), costs are approximately equalized with the high hybrid fuel cost scenario. If the cost offsets including federal funding and social costs of carbon are considered then the lifecycle costs of trolley bus are lower than all but the hybrid low fuel cost scenarios.

Figure 4-7 Sensitivity to Fuel Costs, 30-Year Total Costs, with and without Federal Fixed Guideway Funding and Social Cost of Carbon Offset



Note: Does not include FTA capital funding.

5 SUMMARY OF KEY FINDINGS

Figure 5-1 summarizes the lifecycle costs and benefits for the hybrid and trolley bus scenarios, and the net costs after benefits are taken into account. Benefits include an additional $3.0 million in budgeted/committed SDOT capital cost contribution.

Key conclusions of this analysis are:

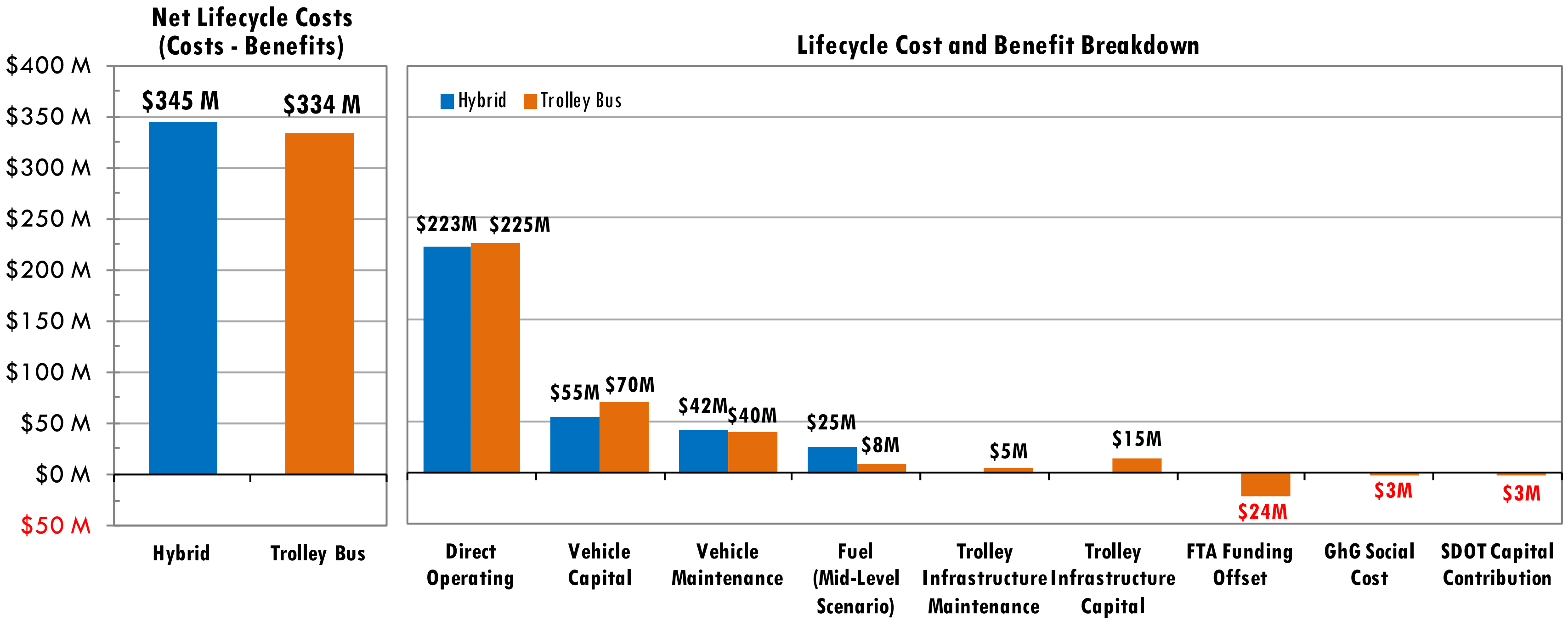
- Purely from an operating cost perspective, not including any capital costs or benefit offsets, the cost of operating ETBs in the Route 48S corridor is lower than the operating costs of hybrid buses for all but the lowest future projected fuel costs. In that instance the operating costs are approximately equivalent.
- Annualized lifecycle costs for electrifying Route 48S are higher than for hybrid bus under the base assumptions used in this analysis, except the case of "high" level diesel fuel prices versus lower electricity consumption rates for ETBs; in this case, costs are equal when offsetting benefits are not included. The costs considered include the capital costs of purchasing vehicles, analyzed over a 60-year period to normalize total costs (this does not affect annualized vehicle costs); filling the 3.4 one-way mile gap in Route 48S corridor trolley overhead wire and power and the incremental ongoing cost of maintaining the new trolley infrastructure; and other ongoing vehicle maintenance costs. Figure 4-7 (above) compares costs along with various sensitivity factors.
- When benefit offsets are included in the calculation, the lifecycle costs of electric trolleys are less than hybrid buses in most cases. The exception is if diesel fuel prices fall below the market trends of the past decade, but even then the lifecycle costs are very close.
- As described in Chapter 3, this analysis assumes no increase in service hours for Route 48N, the portion of current Route 48 that would not be converted to a trolley bus route north of the new Route 48S terminus in the University District. A range of service scenarios are possible, ranging from a modest reduction in operating costs through more efficient interlining for Route 48N and increased reliability for both portions of the current route; no cost impact; or a potential increase of up to 15,000 annual service hours for Route 48N. Given the variety and complexity of rider needs and interlining scenarios that could be pursued for Route 48N, the financial implications (positive, neutral, or negative) are not included in this analysis, but are framed in Appendix B.
- Under current federal funding formulas embedded in MAP-21, use of electric trolley buses is financially beneficial. This advantage has been in place for several re-authorizations of the Surface Transportation Act, but recent formulaic and programmatic changes have accentuated the financial benefit of this mode.
- From a public policy perspective the benefits of ETB support conversion of Route 48S to a full ETB route. GhG emissions are significantly reduced with a trolley bus mode, equivalent to eliminating daily per-capita VMT for 480 vehicles over a year. A range of intangible benefits also generally favor the trolley bus mode, including noise and air

quality. The City of Seattle adopted policy is to encourage deployment of ETB. Consistent with that policy the City has budgeted $3.0 million toward the non-vehicle capital cost of electrifying this corridor. This action further tips the scale in favor of moving to ETB in the corridor as the appropriate financial decision.

- Lifecycle costs for trolley bus are higher than for hybrid buses under the low-cost and mid-cost diesel fuel price scenarios if MAP-21 fixed-guideway funding were to be eliminated as a consideration. While there are no guarantees on the precision of projecting future energy costs, two emerging factors offer some insight:
    1.) The cost of fossil fuels continues to be unstable and on an upward trend. Any disruption in the relatively finite production capacity results in significant price swings. Given that no new production facilities are likely to be available in the next decade, this is likely to continue as a trend affecting fossil fuel supply and, therefore, costs.
    2.) Alternative electricity generation costs have continued to decline. That decline, coupled with a trend of increasing alternative electricity production, is assisting to stabilize the costs of electric power.

  From these trends it appears justified to consider the influences on the business case of higher future fuel costs.
- Given the tangible and intangible benefits, the increment of fleet necessary to accomplish this conversion, and the relative adjacency of the Mount Baker Station to Metro's operating base for ETB's, the business case for converting Route 48S takes on a positive perspective. Of many places where a route could be electrified, this particular corridor has, perhaps, the greatest opportunity given the relative simplicity and short length of the required infrastructure.
- SDOT is applying for grant funding from the Puget Sound Regional Council (PSRC) to complete the Route 48S electrification project. Initial feedback on this project has been favorable.

Figure 5-1 Net Lifecycle Costs and Benefits Summary



APPENDICES

Appendix A Methodology Comparison

The table below compares the methodology between this analysis and the 2011 Metro Trolley Bus Evaluation Study.

Methodology Area	Route 48 Business Case	2011 Trolley Bus Evaluation
Annualization	▪ Hybrid annualized at 15 years, Trolley Bus at 20 years. For the purposes of comparing totals (does not affect annualized costs), vehicle replacement calculated over 60 years, where five hybrid bus purchases are required compared to four for trolley bus ▪ Trolley infrastructure assumed to have a 60-year life time. ▪ Inflation rate of 3.5% assumed	▪ Hybrid annualized at 12 years, Trolley Bus at 15 years. ▪ Inflation rate of 7.5%
Operating Costs	▪ Applied direct operating cost provided by Metro (to differential service hours for Route 48S)	
Vehicle Maintenance	▪ Assumed same tire and tire maintenance costs as in the 2011 study; costs inflated at 3% annually. ▪ Assumed both 3% annual inflation in vehicle maintenance costs as well as a 4.5 cent per mile increase per year of vehicle age (latter reset upon purchase of new vehicle).	▪ 2011 study held costs constant in 2010$
Trolley Overhead Maintenance	▪ Applied cost per incremental route-mile of new trolley overhead wire based on average cost from 2011 study, inflated at 3.0% from 2011 to 2015.	▪ 2011 study held costs constant in 2010$
Fuel and Energy Costs	▪ Applied same assumptions for hybrid and trolley bus fuel/energy efficiency as 2011 study; one question is whether hybrid bus efficiency scaled to trolley service is as applicable to Route 48 as to the overall trolley system; our judgment is that Route 48 is likely comparable to the average of the trolley system. ▪ Applied same assumptions from 2011 study as they appeared to be consistent with updated energy price forecasts.	
Vehicle Capital Costs	▪ Costs as supplied by Metro, inflated as necessary at a rate of 3.5%Modified soft cost assumptions; equalized for each vehicle. Base cost and sales tax are primary differentiators.	▪ Did not assume capital grants for either hybrid or trolley bus; followed same assumption. ▪ Several assumed soft costs calculated on a percentage basis were not considered relevant to the incremental fleet expansion applicable to this analysis as opposed to the full fleet replacement contemplated in the 2011 Metro Study.
Non-Vehicle Capital Costs	▪ Based on LTK “likely” cost estimate, with exception of I-90 poles (based on unit cost from Perteet), and allowance for layover locations.	▪ 2011 assumed system infrastructure replacement/improvements over time; Route 48 business case did not assume additional improvements would be necessary

Appendix B Route 48N Cost Increase Scenario

This appendix presents a scenario for potentially increased operating costs on Route 48N, resulting from a split in Route 48. These costs cannot be quantified for this study, however, Metro identified an annual increase of up to 15,000 hours for 48N as the likely upper bound for a potential cost increase. As described in Chapter 3, this scenario assumes that no reasonable options are available to leverage the inefficiency introduced in Route 48N as a result of the split; Route 48S and 48N would, therefore, overlap in the University District. This inefficiency is already included in the operating assumptions developed by Metro for Route 48S and the results presented elsewhere in this report assume that such inefficiencies would most likely be addressed by restructuring Route 48N, e.g., interlining it with other bus routes.

Figure B-1 identifies the assumptions used to analyze the incremental cost of splitting Route 48 that is attributed to Route 48N in this scenario.

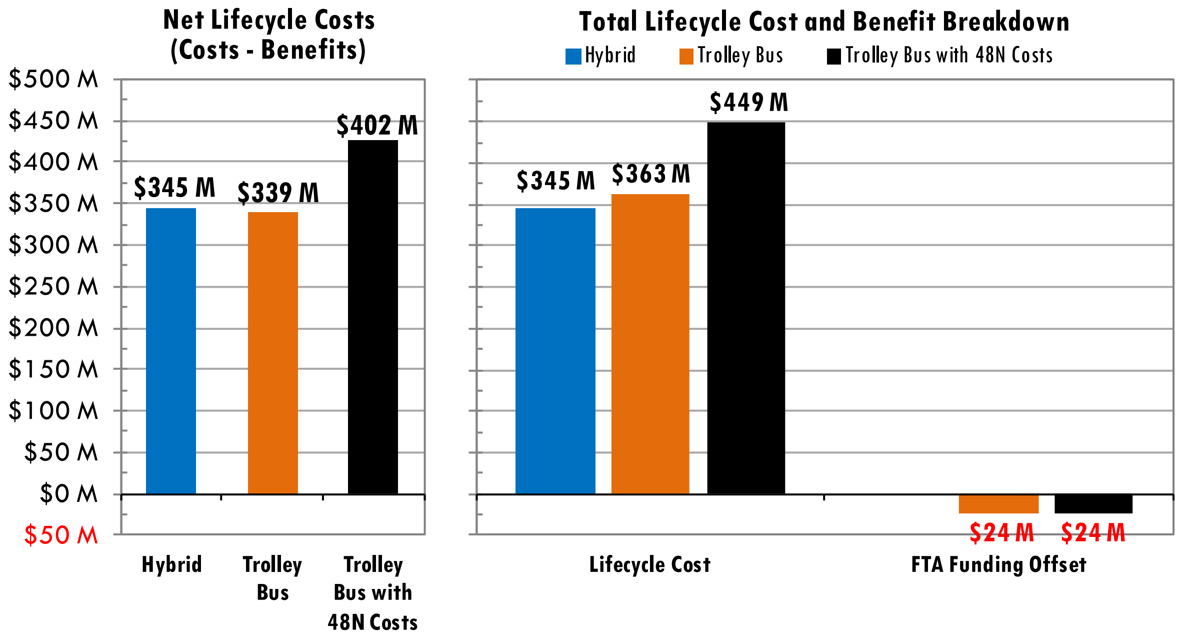
Figure B-1 Incremental Operating and Vehicle Requirements Assumed for Route 48N Cost Increase Scenario

Annual Service Hours	Additional Peak Vehicles
15,000	3 Hybrid

Figure B-2 compares lifecycle costs for the "upper bound" scenario with the base hybrid and trolley bus scenarios for Route 48S described elsewhere in this report. The left portion of the chart shows lifecycle costs including offsetting FTA fixed-guideway funds. The right portion of the chart shows total lifecycle costs and the assumed FTA funding offset. In either case this scenario increases 30-year lifecycle costs by about $86.5 million relative to the base 48S Trolley Bus scenario. These lifecycle costs reflect:

- An additional approximately $1.7 M in annual direct labor costs (Year 1) based on the assumption of up to 15,000 additional service hours to operate Route 48N; additional fuel or vehicle maintenance costs are not included given the range of potential operating options. These costs are based on Metro's projected direct hourly labor cost of about $116 in 2015 dollars (see Figure 3-2).
- An additional approximately $400,000 in annualized vehicle capital costs based on the assumptions of 3 additional hybrid peak vehicles to operate Route 48N.

Figure B-2 Route 48N Cost Increase Scenario (Upper Bound) – Lifecycle Costs



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