FINAL REPORT for

Edmonton Transit System

Alternative Scenarios for Trolley Bus Replacement

Cost and Environmental Implications

Edmonton
March , 2008

DISCLAIMER

- **This Report was prepared by Booz Allen Hamilton to assist Edmonton Transit System (ETS) with evaluating the environmental and cost impacts associated with continued operation of it's trolley bus system. The information presented is developed to facilitate comparative analyses, and to help frame the long term consequences of alternative bus procurement decisions. In this context, the data is not developed to support detailed budgetary, operational, or financial planning.**
- **Further, the Report does not address issues associated with customer preferences for specific types of buses, perceived historical value of the trolley system, or other subjective preference measures.**
- **This Report is focused on analyzing alternative bus procurement strategies specifically for the City of Edmonton given the particular cost, environmental, operational, infrastructure, institutional, duty cycle and regulatory factors that are "in-play" in Edmonton. The observations and analyses therefore cannot, and should not, be generalized or applied to support decisions for other transit agencies operating in North America or internationally. The particular economic factors, service environments and regulations in other cities, (or in other parts of the world), may indeed support differing observations and conclusions related to bus technologies.**

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Study Background and Issues

Study background and issues….

- Edmonton Transit System (ETS) currently operates approximately 866 diesel buses and 41 electric trolley buses (ETBs)
- The trolley fleet is old (purchased in 1982) and is scheduled to be replaced with new trolleys in the 2010 timeframe.
- ETS has long recognized that overall costs for operating trolleys are somewhat higher than for diesels—but that trolleys have traditionally offered environmental advantages as well as reduced noise.
- Operating a trolley system presents special challenges for public transit agencies relative to service and route design, maintenance operations, as well as responding to various incidents that might temporarily disrupt trolley service. Historically, ETS has met these challenges and has provided reliably trolley service.
- ***In late 2003, Booz Allen Hamilton was retained to assist ETS with evaluating the costs and benefits of continuing to offer trolley service. Booz Allen's report was presented to City Council at that time, and although the Report suggested that from a strict cost/benefits perspective trolley buses did not fare well compared to other motorized bus options, the City Council recommended to continue trolley service…but to re-examine this issue periodically as both trolley and diesel technologies advanced.***
- ***This Report presents an update of the 2003 Booz Allen study using new information and data related to the costs and emissions from trolley and motorized bus alternatives.***

This Study compares the costs and emission implications for three alternative options related to replacing the existing trolley bus fleet…

Option	Description
Baseline (replace old trolleys with new trolleys)	The existing 41 trolley buses would be replaced in 2010 with 47 new trolley buses.
Scenario 1 (replace trolleys with diesel)	The existing 41 trolley buses would be replaced in 2010 with 47 new diesel buses. These buses would meet all prevailing emission standards set by Environment Canada. (Environment Canada's vehicle emission standards are, for the most part, harmonized with those of the US Environmental Protection Agency).
Scenario 2 (replace trolleys with hybrid-diesel)	The existing 41 trolley buses would be replaced in 2010 with 47 hybrid diesel buses.

It should be noted that if trolleys were replaced with diesel buses, it is unlikely that ETS would actually need to purchase as many new diesels as they would new trolleys. This is so because ETS already maintains some diesel spares to back up the trolley system. However, for purposes of this analyses, and to maintain an "apples to apples" comparison, we have assumed that the same number of diesel (or hybrid) buses would be needed as trolley buses.

The costs and emissions implicit with each scenario are projected from 2008 through 2027.

- For scenarios 1 and 2, it is assumed that the existing trolleys would continue to operate through the end of 2009:
  - further, the trolley catenary system would continue to be maintained to safe and efficient standards (normal annual catenary maintenance costs are assumed), but…
  - there would be no further capital investment in the trolley system beyond 2008, and,
  - the trolley system would be dismantled in 2010 at a cost of about $10.6M
- In projecting future costs (both capital and operating), and in summing total costs during the study period (2008 to 2027) we have assumed a 0% general inflation rate, and a 0% cost of capital for the following reasons:
  - For public agencies, the inflation rate and discount rate (or cost of capital) tend to cancel each other out, and,
  - The purpose of this analyses is to help make a decision between alternative bus procurement options rather than to support specific budget planning—and therefore the impacts of general inflation and discount rates would be applied to all options,
  - We have however allowed for unique escalation factors to be applied to specific cost elements (such as maintenance and fuel costs) for various bus and fuel types.
- Unless otherwise stated, all financial data shown (past and future) are expressed in 2007 dollars.

Data Sources...overview

Data Elements, Assumptions and other information used in developing costs and benefits for the three scenarios	Data Source	
	BAH	ETS
Current and future bus fleet inventory by make and model; year-by- year bus retirement and procurement plans through 2027		√
Operating costs data for current fleet including: bus maintenance; raw fuel costs, fuel economy (for both diesel and trolleys), and catenary system operations.		√
Future maintenance costs for the trolley overhead system		√
Capital costs for buses (trolleys, diesels, and hybrids)		√
Projected capital costs for the catenary system through 2027		√
Projected costs for dismantling the trolley system		√
Future bus fleet maintenance costs (trolleys, diesels, hybrids)	√	
Future diesel fuel and electricity costs	√	
Current & future emissions from diesel and hybrid buses (includes well-to-pump emissions)	√	
Current & future emissions from electricity generation: (electricity emission factors do not include well-to-pump emissions: see page 23 for explanation of "well-to-pump" and "well-to-wheel" emissions).		**Epcor**
Projected fuel economy from diesels (kilometers per liter) and from trolleys (kilometers per kWh)	√	

The bus fleet is expected to grow substantially through 2027… (baseline scenario shown)

Bus Type	Bus Fleet 1/1/2007	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Total Fleet																						
1. Community buses*	**29**	**42**	**44**	**46**	**46**	**50**	**52**	**52**	**52**	**52**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**
Community - Elf/Powerstroke		29	22	15	10	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0
Glaval		13	13	13	13	13	13	13	13	13	13	5	0	0	0	0	0	0	0	0	0	0
Future Community			*9*	*18*	*23*	*32*	*34*	*34*	*34*	*34*	*38*	*51*	*56*	*56*	*56*	*56*	*56*	*56*	*56*	*56*	*56*	*56*
2. 40 ft buses**	**755**	**807**	**807**	**864**	**866**	**883**	**905**	**937**	**969**	**1001**	**1033**	**1065**	**1097**	**1129**	**1161**	**1,193**	**1225**	**1257**	**1,289**	**1321**	**1353**	**1,385**
GMC/6v71		42	42	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flyer/6v92		57	57	57	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flyer/ISC8.3L		357	357	357	357	356	332	332	332	332	252	203	144	78	25	0	0	0	0	0	0	0
Flyer/ISL8.3L		122	122	122	122	122	122	122	122	122	122	122	122	122	122	97	62	0	0	0	0	0
Flyer/ISL8.9L		229	229	229	229	229	229	229	229	229	229	229	229	229	229	229	229	206	206	0	0	0
Future Diesel 40 Ft			*0*	*72*	*129*	*176*	*222*	*254*	*286*	*318*	*430*	*511*	*602*	*700*	*785*	*867*	*934*	*1,051*	*1,083*	*1,321*	*1,353*	*1,385*
3. Artics**	**13**	**13**	**13**	**13**	**21**	**21**	**21**	**21**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**	**35**
Artic - Flyer/Series 50		6	6	6	6	6	6	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0
Artic - Flyer/ISL8.8L		7	7	7	7	7	7	7	7	7	7	7	7	7	7	0	0	0	0	0	0	0
Future Arctics		*0*	*0*	*0*	*8*	*8*	*8*	*8*	*22*	*22*	*22*	*22*	*22*	*28*	*28*	*35*	*35*	*35*	*35*	*35*	*35*	*35*
4. Hybrids**	**2**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Hybrid/ISB260H		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	0	0	0
Future Hybrids			*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*2*	*4*	*4*	*4*
5. Trolleys**	**49**	**41**	**40**	**40**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**	**47**
Trolley		41	40	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Future Trolleys			*0*	*0*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*	*47*
Total	**848**	**907**	**908**	**967**	**984**	**1005**	**1029**	**1061**	**1107**	**1139**	**1175**	**1207**	**1239**	**1271**	**1303**	**1335**	**1367**	**1399**	**1431**	**1463**	**1495**	**1527**

Assumptions….average annual kilometers per bus by type of bus…

2007 Average Mileage (km) by type of bus per year	
1. Community buses*	**51,768**
Community - Elf/Powerstroke	51,768
Community - Glaval	51,768
New Community	*51,768*
2. 40 ft buses**	**40,219**
GMC/6v71	17,947
Flyer/6v92	26,043
Flyer/ISC8.3L	52,940
Flyer/ISL8.3L	59,983
Flyer/ISL8.9L	42,201
Future Diesel 40 ft	*42,201*
3. Artics**	**39,858**
Artic - Flyer/ISL8.8L	39,858
Artic - Flyer/Series 50	39,858
New Arctic	*39,858*
4. Hybrids	**37,432**
Hybrid/ISB260H	37,432
New Hybrid	*37,432*
5. Trolleys	**23,874**
Trolley	23,874
New Trolley	*23,874*

- Diesel buses average higher mileage than trolleys due to route assignments and other factors.
- Because hybrids are particularly advantaged in heavy stop & go traffic they will likely be assigned to routes with a slower average speed and reduced annual mileage.
- Note: for scenarios 1 and 2, the diesel and hybrid buses that would replace trolleys are assumed to accumulate the same kilometers per year as the trolleys.

Assumptions…direct bus maintenance costs…

# of buses (2005)	Year and Type of Bus	Labor & Parts Total Costs	Labor & Parts Cost per bus per year	Total fleet KMs per bus type	Average KMs per bus	Labor & Parts per Kilometer
6	1972 GM	$48,530	$8,088	92,292	15,382	$0.53
4	1973 GM	$31,213	$7,803	64,365	16,091	$0.48
9	1974 GM	$79,778	$8,864	141,622	15,736	$0.56
35	1975 GM	$356,589	$10,188	557,797	15,937	$0.64
70	1976 GM	$701,737	$10,025	1,130,628	16,152	$0.62
43	1977 GM	$662,831	$15,415	878,336	20,426	$0.75
26	1978 GM	$258,380	$9,938	469,210	18,047	$0.55
24	1980 GM	$342,120	$14,255	417,481	17,395	$0.82
35	1982 GM	$444,478	$12,699	655,664	18,733	$0.68
252	**GM Totals**	**$2,925,656**	**$11,610**	**4,407,395**	**17,490**	**$0.66**
51	1981 Trolley	$1,087,295	$21,320	865,286	16,966	$1.26
51	**Trolley Totals**	**$1,087,295**	**$21,320**	**865,286**	**16,966**	**$1.26**
43	1993 Flyer	$975,291	$22,681	1,008,510	23,454	$0.97
16	1994 Flyer	$434,902	$27,181	362,782	22,674	$1.20
80	1998 Flyer	$1,966,516	$24,581	3,795,038	47,438	$0.52
49	1999 Flyer	$1,190,617	$24,298	2,493,840	50,895	$0.48
59	2000 Flyer	$1,314,142	$22,274	3,176,320	53,836	$0.41
66	2001 Flyer	$839,602	$12,721	3,713,551	56,266	$0.23
53	2002 Flyer	$223,198	$4,211	3,067,415	57,876	$0.07
50	2003 Flyer	$220,806	$4,416	3,066,196	61,324	$0.07
35	2004 Flyer	$92,330	$2,638	2,218,985	63,400	$0.04
40	2005 Flyer	$448,891	$11,222	1,978,365	49,459	$0.23
491	**Flyer Totals**	**$7,706,295**	**$15,695**	**24,881,002**	**50,674**	**$0.31**
6	2001 Artic	$72,793	$12,132	169,490	28,248	$0.43
7	2003 Artic	$44,403	$6,343	242,029	34,576	$0.18
13	**Artic Totals**	**$117,196**	**$9,015**	**411,519**	**31,655**	**$0.28**
1	1994 ELF	$47,805	$47,805	43,300	43,300	$1.10
3	1995 ELF	$97,181	$32,394	130,669	43,556	$0.74
6	1997 ELF	$279,892	$46,649	386,710	64,452	$0.72
2	1998 ELF	$94,780	$47,390	123,717	61,859	$0.77
5	1999 ELF	$205,267	$41,053	283,068	56,614	$0.73
2	2000 ELF	$238,909	$119,455	98,562	49,281	$2.42
8	2001 ELF	$71,092	$8,887	399,687	49,961	$0.18
27	**ELF Totals**	**$1,034,926**	**$38,331**	**1,465,713**	**54,286**	**$0.71**
834	**Total Fleet**	**$12,871,368**	**$15,433**	**32,030,915**	**38,406**	**$0.40**
743	**Total 40 ft**	**$10,631,951**	**$14,309**	**29,288,397**	**39,419**	**$0.36**

- Direct bus maintenance costs (parts and labor for the buses themselves, and not including catenary system costs) vary substantially with age and type of bus,
- In 2005, (most recent year of audited data), 40-foot trolley and diesel buses averaged $1.26 and $0.36 per kilometer respectively for bus maintenance cost. (not including tire costs). Historically, the comparable bus maintenance costs have been much closer: from 2000 to 2003, the direct maintenance costs for trolleys was only about 6% higher than diesel. (ref BAH 2004 trolley Study).
- Most transit systems in North America that operate both diesel and trolley buses generally report that direct bus maintenance costs (i.e. not including catenary maintenance) are about equal, (based on anecdotal evidence from transit properties including San Francisco, Philadelphia and Vancouver).

Diesel and Trolley Bus maintenance assumptions…continued

- The quality and reliability of diesel transit buses has generally increased over the past several decades (in a similar way that cars have become more reliable). However, future diesel buses will have additional emission control equipment (including particulate traps and selective catalytic (NOx) reduction units that some experts have argued could jeopardize reliability.

- For purposes of this analysis, the bus maintenance cost for an average 40-foot diesel of average age is assumed to be $0.38/km (which is the $0.36/km current ETS average cost from 2005 inflated to 2007). Essentially we assume that future diesel bus maintenance costs will stay essentially the same as they are today.

- The future quality and reliability of new trolley buses is also unclear. In general new trolley buses will be far more reliable than current trolleys as the electronic controls and electric drivetrains have improved greatly. At the same time however, new trolleys will also be more complicated (e.g., the addition of auxilary power units), and are heavier, which could increase maintenance requirements.

- For purposes of this analyses, we assume that new trolley buses (exclusive of overhead maintenance systems costs) will be 10% *less* costly to maintain than diesels on a per kilometer basis. This is a very “pro-trolley” assumption given the historical trend at ETS.

Hybrid vehicle maintenance costs…

- Over the past 5 years, several transit properties in North American have been purchasing and gaining experience with hybrid transit buses; for example:
  - Washington DC: 50 New Flyer Allison Hybrid buses in operation and recently purchased 500 more,
  - San Francisco: 200 Orion/BAE hybrid buses,
  - Toronto: 150 Orion/BAE Hybrid Buses,
  - Seattle: New Flyer/Allison, approximately 250 buses,
  - New York: Orion/BAE, approximately400 buses
  - Ann Arbor: New Flyer/Allison, 70 buses

- Many of these properties are trying to closely track and compare operating costs of hybrids, diesels (and even CNG) buses to determine net life cycle costs. There appears to be mixed results. A Study by Connecticut showed that hybrid buses had significantly lower bus maintenance costs (by about 30%) than equivalent diesel buses due to reduced brake wear, extended oil change intervals, and reduced maintenance on the diesel particulate trap[1]. Other studies (USDOT) suggest that diesel and hybrid bus maintenance costs will be quite similar.[2]

- For purpose of this analyses, we assume that future hybrid bus maintenance costs will be 10% less than an equivalent diesel bus.

1) Connecticut Academy of Science and Engineering: Demonstration and Evaluation of Hybrid Diesel Electric Transit Fuses; 2005

2) US Dept of Transportation: Transit Bus Life Cycle Cost and Emissions Estimation, July, 2007

Fuel economy and fuel cost assumptions.

- The current average fuel economy for the 40 foot ETS diesel buses (in 2005) was 1.678 kilometers per liter based on data supplied by ETS. It is likely there will be modest, evolutionary improvements in engine and transmission efficiency…but these could be offset by emission control equipment and calibration changes needed to meet prevailing emission standards. Future diesels are therefore assumed to achieve the same fuel economy as current diesels.

- Fuel economy of articulated buses is 20% worse (lower) than that of 40-foot buses…and for community buses is 25% better (higher) than 40-foot buses.

- Hybrid buses achieve 20% better fuel economy than an equivalent non-hybrid diesel.

- Current trolley buses achieve a "fuel economy " of 2.89 kWh per kilometer based on data supplied by ETS. Future trolleys, for purposes of this analyses, are estimated to be 10% more efficient than current trolleys.

Catenary System maintenance and capital costs (for Baseline Scenario)…

- Annual Maintenance Costs:
  - Annual maintenance costs for the substations and overhead were supplied by ETS as shown at right,
  - Beyond 2012, maintenance costs were assumed to be flat (projected at 2012 levels going forward).

Year	$ (000)
2007	$1,964
2008	$2,046
2009	$2,200
2010	$2,442
2011	$2,539
2012	$2,818

- Capital Cost:
  - Capital costs were also supplied by ETS and are shown below
  - These costs are for various substation upgrades as well as new feeder wire, SCADA system, poles, contact wire and other special hardware.

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Total Substations	$1,590	$1,325	$1,220	$750	$990	$1,090	$5,605	$500	$500	$895	$663	$663	$663	$663	$663	$663	$1,074	$1,074	$1,074
Poles																			
D/F Rated	$4,108	$4,108																	
C rated			$2,314	$2,314	$2,314	$2,314	$2,314	$2,314	$2,314										
A/B rated										$1,300									
Contact Wire	$320	$320	$320	$320	$320	$320	$320	$320	$320	$32									
Special Hardware																			
	$450																		
	$50	$50	$50	$50	$50	$50	$50	$50	$50	$50									
	$2,100																		
Lightning Arresters (16	$120	$100	$100																
Total Overhead	$7,148	$4,578	$2,784	$2,684	$2,684	$2,684	$2,684	$2,684	$2,684	$1,382	$2,152	$2,152	$2,152	$2,152	$2,152	$2,152	$2,152	$2,152	$2,152
Total Budget	$8,738	$5,903	$4,004	$3,434	$3,674	$3,774	$8,289	$3,184	$3,184	$2,277	$2,815	$2,815	$2,815	$2,815	$2,815	$2,815	$3,226	$3,226	$3,226

Catenary System dismantling cost assumptions (for Scenarios 1 and 2)

- For Scenarios 1 and 2, it is assumed that trolley system capital upgrades scheduled for 2008 would still take place, but no new capital investment thereafter.
- Further, a one-time cost of $10.6 million would be incurred in 2010 to dismantle the trolley system,
- It is assumed that “normal” catenary system maintenance costs would be incurred in 2008 and 2009..but no maintenance costs would be incurred in 2010.

New bus purchase costs assumptions….

- Unit replacement cost assumptions for new diesel, hybrid and trolley buses are shown at right.
- Cost of new diesel buses is expected to be slightly higher than most recent bus order due to additional emission control equipment needed to meet 2010 standards.
- Many industry observers believe that costs of hybrid vehicles will come down as demand increases.
- Prices quoted at right were obtained directly from New Flyer and reflect pricing for equivalent 40 foot buses.

Bus Type	Unit Replacement Cost
Hybrid	$587,420
Diesel	$381,800
Trolley	$895,850

Diesel fuel and electricity cost assumptions

- Diesel fuel price is assumed to be $0.758 per liter (data supplied by ETS)
- Electricity costs are assumed to be $0.055 per kWh:
  - This is the electricity cost supplied by EPCOR for power sold to the City of Edmonton.
  - Actual trolley system power consumption and cost data supplied by ETS (based on invoices from EPCOR) show electricity costs to be much higher at about $0.115 per kWh. For purposes of this analyses, we have assumed the lower electricity prices supplied by EPCOR.
- The future cost of both of diesel fuel and electricity is highly speculative:
  - About 95% of electric power in the Alberta area is generated using natural gas and/or coal fired plants…and this is not expected to change significantly in the future.[1]
  - Electricity pricing generally tracks closely with the cost of fossil fuels.
  - For purposes of this analyses, we assume that both electricity and diesel fuel will track with general inflation.

1) Based on CASA 2002 Report of current and future emissions in Alberta

2) US Dept of Transportation: Transit Bus Life Cycle Cost and Emissions Estimation, July, 2007

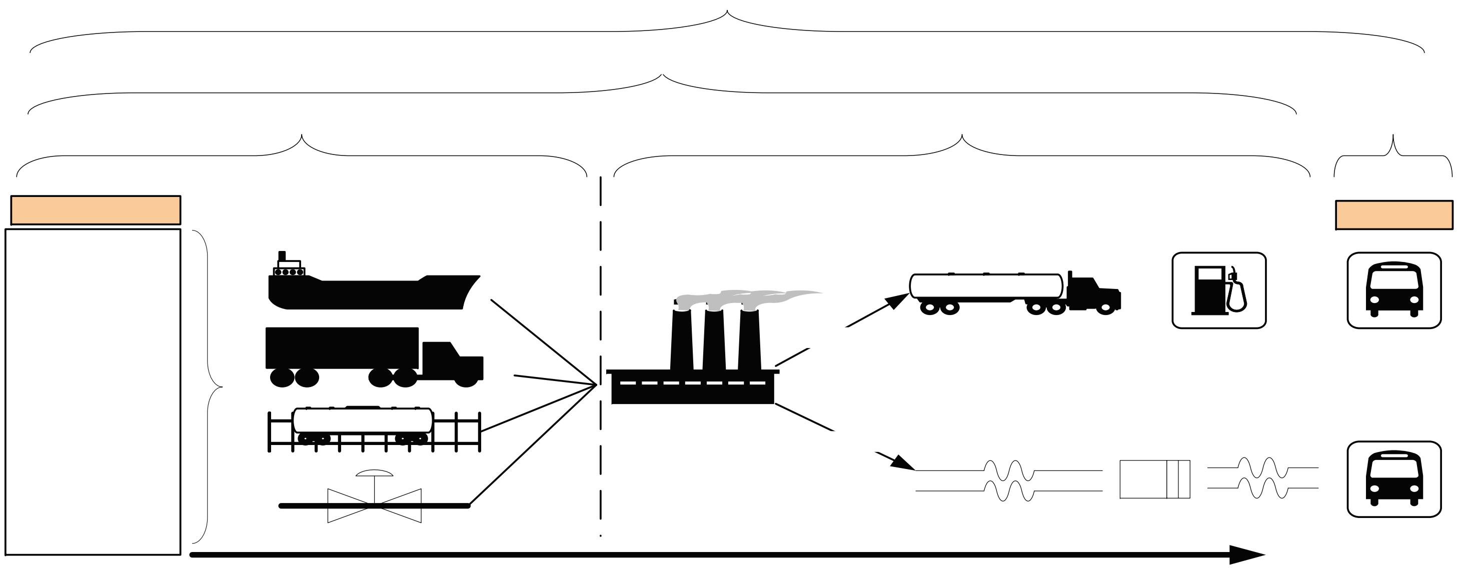
Emission Inventories for each Scenario..

- Emission inventories for each Scenario were calculated based on:
  - Obtaining the fuel economy and annual mileage for various sub-segments within the fleet…including diesel sub-segments as well as trolley buses. (note: fuel economy is expressed in kilometers-per-liter for diesels and kWh-per-kilometer for trolleys).
  - Estimating the emission factors (grams per kilometer) for each sub-segment,
  - Calculating the number of buses within each sub-segment for future years (through 2027) in order to obtain a year-by-year fleet profile,
  - For each sub-segment, multiplying the annual mileage estimates by corresponding emission factors to obtain total emissions from the sub-segment, and,
  - Adding together total emissions from all sub-segments.
- The emissions of most concern from diesel buses are NOx and Particulate Emissions (specifically PM10), *(note: VOC and CO emissions from diesels are inherently extremely low and are generally not reported or discussed when evaluating new heavy-duty propulsion technologies.)* The health and environmental issues associated with NOx and PM10 emissions can be found in numerous sources from the US EPA and Environment Canada—and are discussed in the 2003 BAH Report.
- Greenhouse Gas Emissions, (principally CO2), is also an effluent of concern as evidence continues to point to its impacts on global warming.
- The focus of the emissions inventory analyses is therefore on NOx, PM10 and CO2 (although other regulated emissions are also reported as a matter of convenience)

Estimating Emission Inventories from bus operations

Emission factors (in terms of grams per kilometer) from buses are based on total “well-to-wheel” (WTW) emissions…

- Well-to-wheel emissions consist of the sum of:
  - **Vehicle Emissions**; attributable to the vehicle operation itself (i.e., tailpipe exhaust emissions),
  - **“Fuel” Emissions:** in the case of petroleum (diesel) this would include emissions associated with the refining of crude oil and transportation of the final product to the end-user. For electricity, this would include the emissions associated with the power-plants themselves, (i.e. for trolleys, it is the equivalent emissions produced by the power plants for electricity needed to drive the trolleys).
  - **“Feedstock” Emissions**: For petroleum, it is the emission associated with the supply of feedstock (crude oil) to the refinery. It would include crude oil extraction, processing and transportation. For electricity, it is the emissions associated with the mining, processing and transportation of coal, natural gas and/or other feedstocks to the generating facilities.



The emissions data for each portion of the fuel supply chain were derived from a variety of sources..

Emissions Component (within total well-to-wheel emissions)	Source of Emission Factor Data	
	Diesel and Hybrid Buses	Trolley
Vehicle (emissions from the vehicle itself, or "tailpipe" emissions)	EPA Mobile 6.2 Model	There are zero emissions at the vehicle level
Fuel (emissions associated with refining of crude and transportation of final product to the "pump"; or, for electricity, emissions associated with generating plants)	Argonne National Labs "GREET" Model	Data Supplied by EPCOR
Feedstock (emissions associated with extraction of raw feedstocks and distribution to refining and/or generating facilities).	Argonne National Labs "GREET" Model	Argonne National Labs "GREET" Model

Each of these data sources, as well as various assumptions used in the estimates are reviewed in the following pages.

A note about reliability and relevance of each emissions component…

Emissions Component (within total well-to-wheel emissions)	Reliability of Estimates	Relevance
Vehicle (emissions from the vehicle itself, or "tailpipe" emissions)	Vehicle emission factors are deemed highly reliable as they are derived from empirical test data.	Very relevant since these emissions occur at "street" level.
Fuel (emissions associated with refining of crude and transportation of final product to the "pump"; or, for electricity, emissions associated with generating plants)	Deemed reasonably reliable as data was supplied by EPCOR (for generating facilities); and, emissions from refinery operations are fairly well known and characterized.	Relevant since refineries and generating facilities are within the Edmonton region.
Feedstock (emissions associated with extraction of raw feedstocks and distribution to refining and/or generating facilities).	These estimates are the least reliable. They have been developed based on nationwide estimates and are not tailored to reflect the Edmonton energy supply scenario.	Less relevant since these emissions will be generated outside the Edmonton region. (although CO2 emissions are of global concern and therefore proximity of the source to Edmonton is not particularly relevant.

- The analyses presented in this report calculates emissions from all three components. However, because "feedstock" emissions will generally occur outside the Edmonton area, and because "feedstock" emission estimates are less reliable, we would recommend that "Vehicle plus Fuel" emission factors are the most appropriate metric for comparing the environmental impact from trolleys and diesel buses, and that "feedstock" related emissions be wieghted less heavily.

The vehicle emission factors for diesel buses are based on the US Environmental Protection Agency (EPA) Mobile 6.2 Emission Inventory model

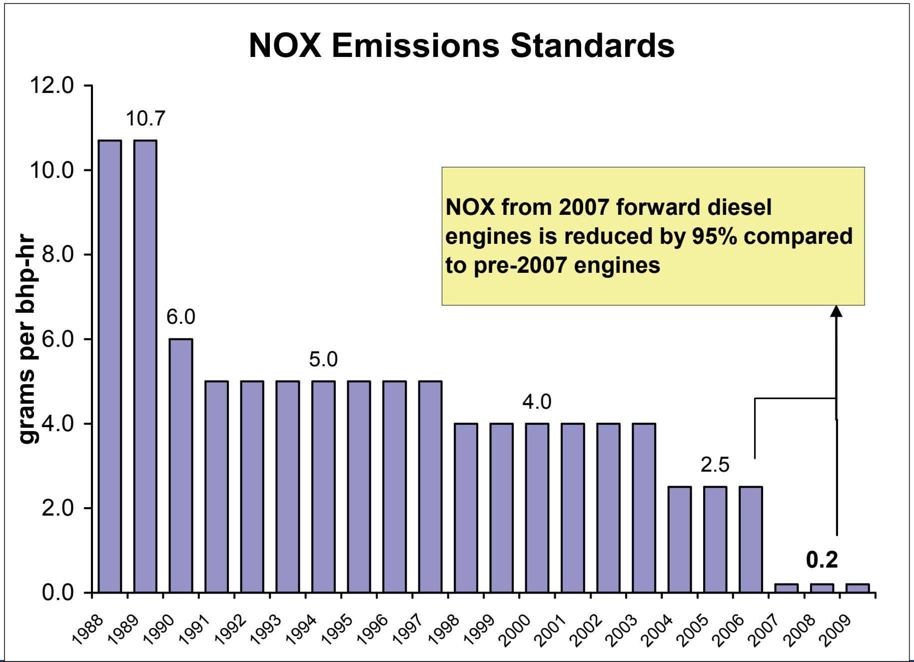
- MOBILE6.2 is the latest release of the software developed by the EPA to estimate current and future emissions from motor vehicle fleets. The model calculates in-use fleet emission rates of criteria (i.e., regulated) pollutants such as CO, HC, NOx, SO2, and PM as well as CO2.

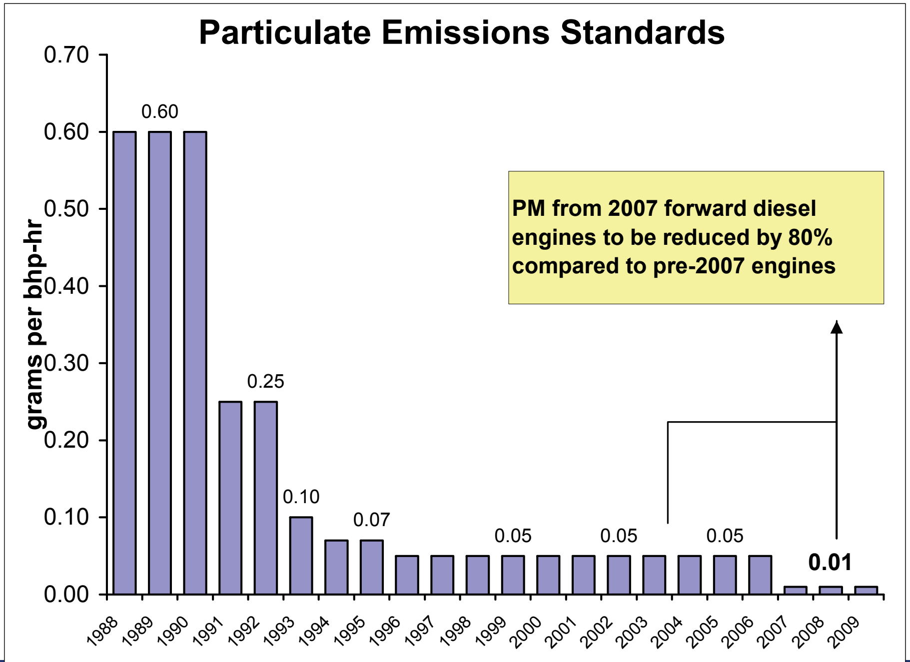
- The emission rates generated by the model are based on emission factors derived from test data collected from a variety of vehicles operating under wide-ranging conditions. The model allows users to specify vehicle type, age (or model year), fuel economy and other parameters. The software also incorporates historical, current, and future emission standards, as well as factors to account for the degradation of emission controls and engine performance, in order to generate emission factors on a grams per mile basis.

- The MOBILE6.2 model was used to develop emission factors for heavy-duty transit buses operating on ultra low sulfur fuel, and in a typical urban environment. Emission factors were developed for model year buses between 1980 and 2010, thus representing the age distribution of the current fleet, as well as providing estimates for future diesel transit buses.

Estimates of future emissions from diesel buses are based only on currently enacted emission regulations…and are therefore conservatively estimated

- It is important to note that the MOBILE 6.2 model only estimates future emissions (from diesel buses) based on currently enacted emission regulations. It does not attempt to forecast new (more stringent) regulations. To this extent, the future emissions from diesel buses are very conservatively estimated since it is highly likely that over the next 20 years there will be new, even more stringent regulations enacted for heavy-duty diesel buses by both EPA and Environment Canada. Simply put, the emission factors for diesel buses (used in this analysis) hold steady from 2010 forward—when in reality, they will likely decline as new emission control technologies are developed and new regulations are promulgated. While the rate of decline will likely not be as dramatic as the previous 20 years, (see below), some degree of improvement is anticipated.





“Fuel” and “Feedstock” emissions were developed using Argonne National Labs GREET model

- To fully evaluate energy and emission impacts of advanced vehicle technologies and new transportation fuels, the fuel cycle from well to wheels needs to be considered. Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne has developed a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle basis.

- GREET was developed as a multidimensional spreadsheet model in Microsoft Excel. The first version of GREET was released in 1996. Since then, Argonne has continued to update and expand the model. The most recent GREET versions are GREET 1.8a version for fuel-cycle analysis and GREET 2.8a version for vehicle-cycle analysis.

The GREET model ….continued

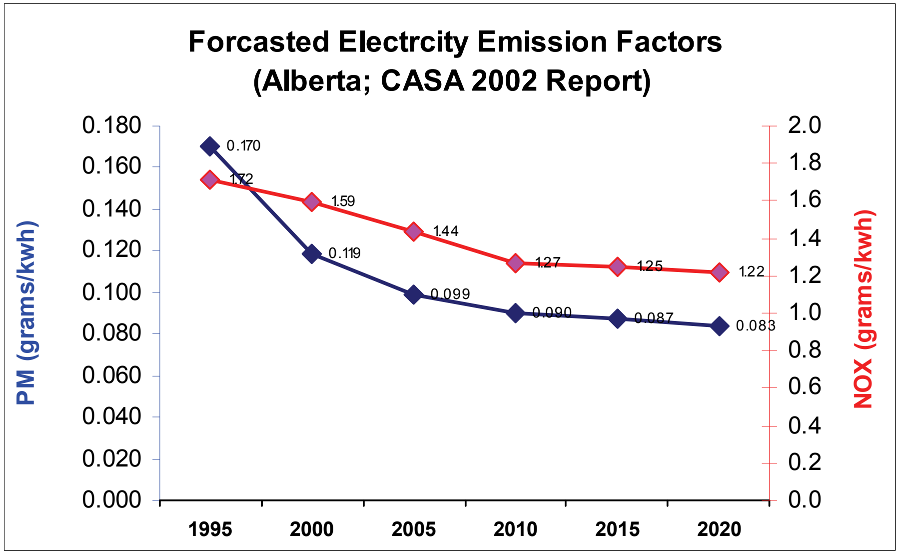
- The GREET model contains hundreds of default assumptions (or national averages) related to the emissions associated with production and transportation of a fuel. For example:
  - Emissions associated with importing crude oil…
  - Emissions associated with drilling and pumping of crude oil,
  - Mix of imported versus domestic crude oil production, as well as the mix of various grades being produced and/or imported,
  - Emissions associated with refining crude oil into various gasoline and diesel grades,
  - Assumptions about the age and processes from various types of refineries….as well as future regulations that will impact emissions from these facilities;
  - Emissions factors for the transportation of fuel by truck, rail, and pipeline;
  - The mix of transportation modes used to distribute the fuels,
  - The location of end-user facilities relative to various supply points,
  - And numerous other assumptions that have been researched and documented by Argonne National Laboratories over the last 10 years.
- The GREET model also allows users to change any of the default values to account for local conditions and assumptions regarding fuel supply chain logistics. For this project for ETS, the default assumptions in GREET were utilized. A tailored analyses of diesel fuel supply logistics to the Edmonton area was not within the scope of this Study. However, we suspect that such an analyses would not appreciably change the results from the average emissions for diesel fuel.
- More information on the GREET model can be found at: http://www.transportation.anl.gov/software/GREET

Emission factors for Trolley buses…

- There are no vehicle-based emissions associated with trolley buses,
- However, there are emissions associated with the generating plants that supply the trolley buses with electricity,
- The emission factors for electricity generation (for 2005) were obtained directly from EPCOR (expressed in terms of grams per kWh)
- Future electricity generation emission factors were calculated based on forecasts presented in the 2002 CASA emissions inventory report for Alberta. (note: EPCOR specifically recommended and referenced this document for calculation of future electricity generation emission rates).
- Emission factors for trolleys are calculated based on the electricity emission factors supplied by EPCOR, and on the trolley bus efficiency rates (or fuel economy, expressed in kWh per kilometer) obtained from ETS.
- Just as there are emissions associated with the production and transportation of diesel fuel, there are also emissions associated with the mining, production and distribution of both coal and natural gas that supply the electricity generating plants in Alberta. Total “well to wheel” emissions for the trolleys should therefore include the so-called “feedstock” emissions. These emissions have been estimated using the GREET model.

Future emission factors for electricity generation in Alberta…

- NOx and PM10 emission rates are expected to drop by 15% by 2020,
- CO_2 emissions were not forecast by CASA, and EPCOR suggests "moderate" reductions. For planning purposes we have assumed a 10% reduction in CO_2 emission rates by 2020, (even though there are no specific plans in place that would result in such efficiency improvements for electricity generation).



All Data From CASA 2002 Final Report on Emissions in Alberta

Estimated Electric Power Generation in Alberta (trillion watt hours)						
	1995	2000	2005	2010	2015	2020
Coal	46	45	49	65	64	64
Gas	5	11	18	21	24	28
Hydro	2	2	2	2	2	2
Wind, Biomass, Solar,	1	1	2	2	2	2
Total Generation	53	59	71	89	92	96

Estimated Electric Power Generation in Alberta (percent contribution by energy source)						
	1995	2000	2005	2010	2015	2020
Coal	87%	76%	69%	73%	70%	67%
Gas	9%	19%	25%	24%	26%	29%
Hydro	4%	3%	3%	2%	2%	2%
Wind, Biomass, Solar,	2%	2%	3%	2%	2%	2%
Total Generation	100%	100%	100%	100%	100%	100%

Forecasted Emissions from Electric Generation in Alberta (kilotonnes)						
	1995	2000	2005	2010	2015	2020
PM 10	9	7	7.00	8.00	8.00	8.00
NOX	91	94	102	113	115	117
SO2	130	125	129	131	131	131
CO	8	9	11	12	13	13
VOC	1	1	1	1	1	1

Emission Rates from Electric Generation in Alberata (grams per kwh)						
	1995	2000	2005	2010	2015	2020
PM 10	0.170	0.119	0.099	0.090	0.087	0.083
NOX	1.72	1.59	1.44	1.27	1.25	1.22
SO2	2.45	2.12	1.82	1.47	1.42	1.36
CO	0.151	0.153	0.155	0.135	0.141	0.135
VOC	0.019	0.017	0.014	0.011	0.011	0.010

Electic Power Generation Emission Rates as a Percent of 2005 Baseline						
	1995	2000	2005	2010	2015	2020
PM 10	172%	120%	100%	91%	88%	85%
NOX	120%	111%	100%	88%	87%	85%
SO2	135%	117%	100%	81%	78%	75%
CO	97%	98%	100%	87%	91%	87%
VOC	134%	120%	100%	80%	77%	74%

Trolley Bus Emission factor calculations ("Fuel" Emissions)…

Emissions Intensity (grams per kWh) from Electricity Generation in Alberta

Year	PM10	SOx	NOx	VOCs	CO	CO2 (2004)	Data Source
2005	0.081	1.97	1.282	0.009	0.172	861	From EPCOR
2015	0.071	1.54	1.115	0.007	0.157	818	Future Reductions in PM, NOx, VOC, and CO estimated based on data presented in CASA 2002 Emissions Inventory Report for the Alberta region. Future reductions in CO2 emissions are not listed in CASA but improvements in overall electricity generation of 5% in 2015 and 10% in 2020 are assumed for planning purposes.
2020	0.068	1.48	1.088	0.007	0.150	736	

Trolley Bus Emissions (Grams per Kilometer)

		PM10	SOx	NOx	VOCs	CO	CO2 (2004)	Data Source
Current Trolley: 2005 Electricity	@ 2.89 kWh per km	0.234	5.693	3.705	0.026	0.497	2,488	Calculation
Future Trolleys: 2015 Electricity	@ 2.6 kWh per km	0.186	4.014	2.900	0.018	0.408	2,127	Calculation
Future Trolleys: 2020 Electricity	@ 2.6 kWh per km	0.178	3.847	2.828	0.017	0.391	1,914	Calculation

Note: Emission factors for electricity supplied directly by EPCOR to ETS in a letter dated October 18th, 2007.

Emissions Modeling Results

Vehicle-only emission factors….

"Raw" Emission Factors: (diesel tailpipe emissions)					grams per kilometer (vehicle only)					Data source
Length	Sub Fleet	Year	Engine	THC	CO	NOX	PM10	PM2.5	CO2	
40	HF GMC	1975 to 1982	6v-71	2.890	12.990	17.190	2.130	1.704	1,614	Based on EPA Mobile 6.2 and BAH analyses
40	Flyer	1993-1994	6v-92	1.730	6.870	14.500	1.230	1.107	1,559	Based on EPA Mobile 6.2 and BAH analyses
40	Flyer	1998 to 2003	ISC 8.3L	0.265	4.030	11.690	0.117	0.105	1,459	Based on EPA Mobile 6.2 and BAH analyses
40	Flyer	2004 to 2005	ISL 8.3L	0.277	4.030	8.100	0.101	0.091	1,459	Based on EPA Mobile 6.2 and BAH analyses
40	Flyer	2007	ISL 8.9	0.277	0.418	3.600	0.015	0.014	1,459	Data Provided by Cummins
40	Hybrid	2006 to 2007	ISB 260H	0.222	0.334	2.880	0.012	0.011	1,167	Assumes 20% lower emissions than comparable (2007) diesel due to fuel economy benefits
40	Future Diesel	2008 Forward	Diesel	0.277	0.418	0.540	0.015	0.014	1,459	Based on EPA Mobile 6.2 and BAH analyses
40	Future Hybrid	2008 Forward	Hybrids	0.222	0.334	0.432	0.012	0.011	1,167	Assumes 20% lower emissions than comparable (2010) diesel due to fuel economy benefits
40	Trolley	1981	Electric	0.000	0.000	0.000	0.000	0.000	0.000	There are no emissions from the trolley at the "street level"
40	Trolley	Future (2015 +)	Electric	0.000	0.000	0.000	0.000	0.000	0.000	There are no emissions from the trolley at the "street level"
60	Artic Flyers	2001 to 2003	ISL 8.3L & S50	0.318	4.836	14.028	0.140	0.126	1,751	Assumes 20% higher emissions than comparable 40-foot diesel due to 20% worse fuel economy
60	Future Artics	2008 Forward	Diesel	0.332	0.502	0.648	0.018	0.017	1,751	
27	Elf	1994 to 2001		0.199	3.023	8.768	0.088	0.079	1,094	Assumes 25% lower emissions than comparable 40-foot diesel due to 25% better fuel economy
27	Community	2007		0.21	0.31	2.70	0.011	0.010	1,094	
27	Community	2008 Forward		0.21	0.31	0.41	0.011	0.010	1,094	

"Vehicle + Fuel" Emission Factors. In other words, emission factors "corrected" to include emissions from refining and transportation (diesel), and equivalent power-plant emissions for trolleys.

Vehicle + Fuel Emission Factors.
Diesel emission factors corrected to include emissions from refining and transportation of fuel to end-user:
Trolley emission factors based on powerplant emissions that would be generated to power the trolleys

Sub Fleets				Grams per kilometer						
Length	**Sub Fleet**	**Year**	**Engine**	**THC**	**CO**	**NOX**	**PM10**	**PM2.5**	**CO2**	
40	HF GMC	1975 to 1982	6v-71	2.983	13.139	17.638	2.312	1.77	1,891	
40	Flyer	1993-1994	6v-92	1.823	7.019	14.948	1.412	1.17	1,836	
40	Flyer	1998 to 2003	ISC 8.3L	0.358	4.179	12.138	0.299	0.17	1,736	
40	Flyer	2004 to 2005	ISL 8.3L	0.370	4.179	8.548	0.283	0.16	1,736	
40	Flyer	2007	ISL 8.9	0.370	0.567	4.048	0.197	0.08	1,736	
40	Hybrid	2006 to 2007	ISB 260H	0.300	0.459	3.256	0.164	0.07	1,399	
40	Future	2008 Forward	Diesel	0.370	0.567	0.988	0.197	0.081	1,736	
40	Future	2008 Forward	Hybrids	0.300	0.459	0.808	0.164	0.067	1,399	
40	Trolley	1981	Electric	0.026	0.497	3.705	0.234	0.116	2488	Base on emission factors supplied by EPCOR, and on efficiency data from ETS
40	Trolley	Future (2010+)	Electric	0.018	0.408	2.900	0.186	0.092	2127	Base on emission factors supplied by EPCOR future efficiency improvements from CASA Report; and on efficiency data from ETS
60	Artic Flyers	2001 to 2003	ISL 8.3L & S 50	0.434	5.022	14.589	0.368	0.21	2,097	
60	Future Artics	2008 Forward	Diesel	0.449	0.688	1.209	0.246	0.10	2,097	
27	Elf	1994 to 2001		0.277	3.147	9.144	0.240	0.14	1,326	
27	Community	2007		0.286	0.438	3.076	0.164	0.07	1,326	
27	Community	2008 Forward		0.286	0.438	0.781	0.164	0.07	1,326	

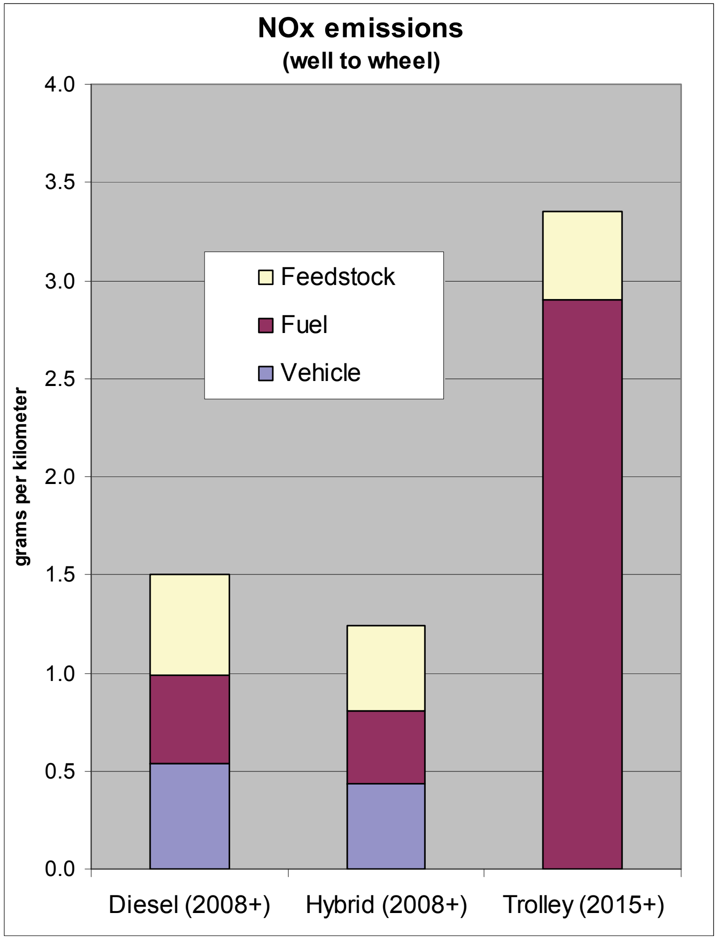
Total well-to-wheel emission factors…(includes emissions from supplying the feedstock fuel to the refinery and/or the power-plant)

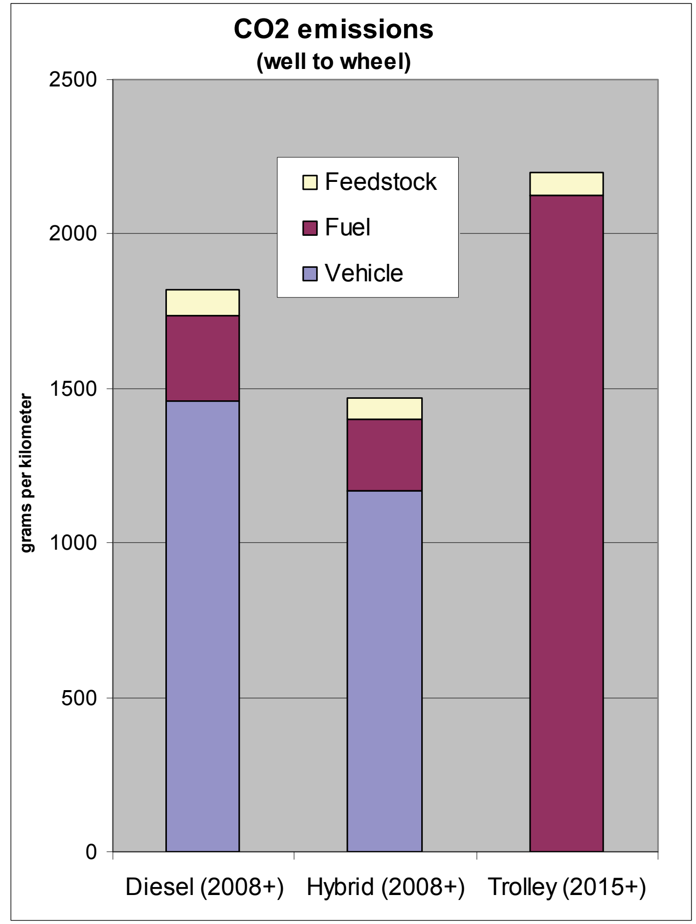
Vehicle + Fuel + Feedstock Emission Factors (Well to Wheel) Diesel and electric emission factors corrected to include emissions associated with supplying feedstock to processing facilities (whether (Well to Wheel)									
Subfleet				grams per kilometer (Vehicle +Fuel + Feedstock: Well to Wheel)					
Length	**Sub Fleet**	**Year**	**Engine**	**THC**	**CO**	**NOX**	**PM10**	**PM2.5**	**CO2**
40	HF GMC	D 1975 to 1982	6v-71	3.055	13.276	18.154	2.360	1.79	1,977
40	Flyer	D 1993-1994	6v-92	1.895	7.156	15.464	1.460	1.19	1,922
40	Flyer	D 1998 to 2003	ISC 8.3L	0.430	4.316	12.654	0.347	0.19	1,822
40	Flyer	D 2004 to 2005	ISL 8.3L	0.442	4.316	9.064	0.331	0.18	1,822
40	Flyer	D 2007	ISL 8.9	0.442	0.704	4.564	0.245	0.10	1,822
40	Hybrid	Hybrid 2006 / 2007	ISB 260H	0.360	0.574	3.689	0.205	0.08	1,472
40	Future	Future 40 ft Diesel	Diesel	0.442	0.704	1.504	0.245	0.10	1,822
40	Future	Future 40ft Hybrid	Hybrids	0.360	0.574	1.241	0.205	0.08	1,472
40	Trolley	Old Trolleys	Electric	0.236	0.621	4.209	3.874	1.02	2,568
40	Trolley	New Trolleys (2010+)	Electric	0.207	0.519	*3.354*	3.460	0.91	2,198
60	Artic Flyers	Artic 2001 to 2003	ISL 8.3L & S50	0.525	5.194	15.235	0.428	0.24	2,205
60	Future Artics	Future Artic diesel	Diesel	0.539	0.860	1.855	0.306	0.13	2,205
27	Elf	Comm1994 to 2001		0.337	3.262	9.576	0.281	0.15	1,399
27	Community	Comm2007		0.346	0.553	3.509	0.204	0.08	1,399
27	Community	Future Comm.		0.346	0.553	1.214	0.204	0.08	1,399

Estimated total well-to-wheel emissions (grams per kilometer) for future diesel, hybrids and trolleys…

Bus length	Type	Year	Emissions Segment	THC	CO	NOX	PM10	PM2.5	CO2
40 foot	Diesel	Future (2008+)	Vehicle	0.277	0.418	0.540	0.015	0.014	1,459
			Fuel	0.093	0.149	0.448	0.182	0.067	277
			Feedstock	0.072	0.137	0.516	0.048	0.020	86
			Total	**0.442**	**0.704**	**1.504**	**0.245**	**0.101**	**1,822**
40 foot	Hybrid	Future (2008+)	Vehicle	0.222	0.334	0.432	0.012	0.011	1,167
			Fuel	0.078	0.125	0.376	0.152	0.056	232
			Feedstock	0.061	0.115	0.433	0.041	0.017	72
			Total	**0.360**	**0.574**	**1.241**	**0.205**	**0.084**	**1,472**
40 foot	Trolley	Future (2015+)	Vehicle	-	-	-	-	-	-
			Fuel	0.018	0.408	2.900	0.186	0.092	2,127
			Feedstock	0.189	0.111	0.453	3.275	0.818	72
			Total	**0.207**	**0.519**	**3.354**	**3.460**	**0.910**	**2,198**

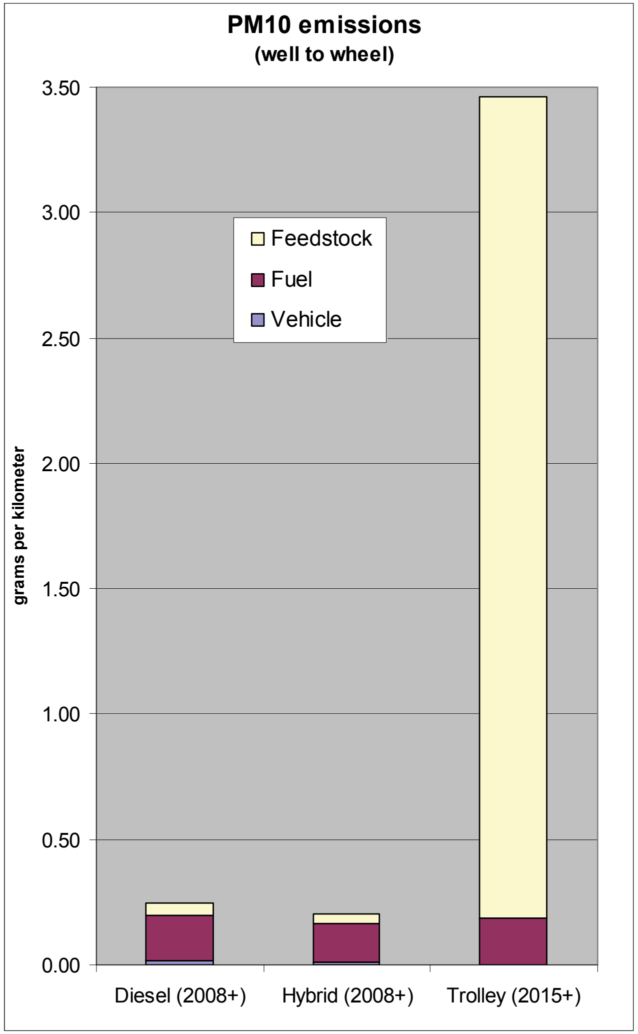
Trolleys will yield higher well-to-wheel NOx and Greenhouse Gas emissions (CO2) than diesels or hybrids

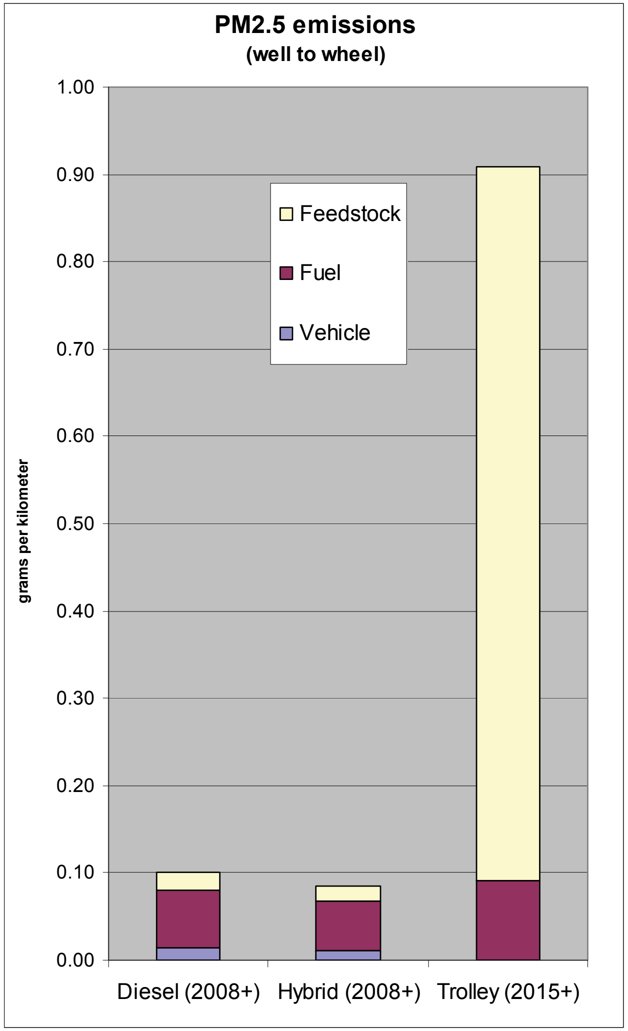




Well to wheel PM10 and PM2.5 emissions…

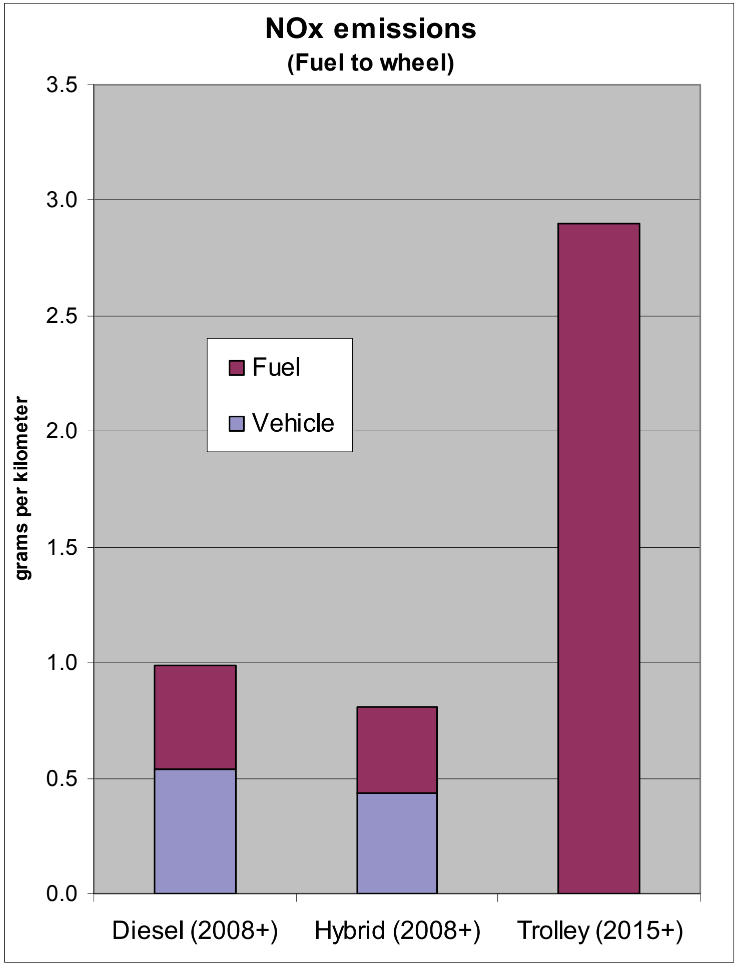
- Trolley operation will result in much higher PM emissions due primarily to emissions associated with mining, extraction and supply of coal (feedstock) to the power-plant facilities.
- However, it should be noted that PM emissions associated mining of coal (i.e., feedstock related PM emissions) are suspected to quickly precipitate out of the atmosphere.
- For the above reason, and because “feedstock” emissions generally occur outside the immediate Edmonton area, and because such estimates are less reliable than “vehicle” and “fuel” estimates, we would recommend focusing on “vehicle + fuel” emissions in considering the environmental impacts of trolleys and diesel buses.

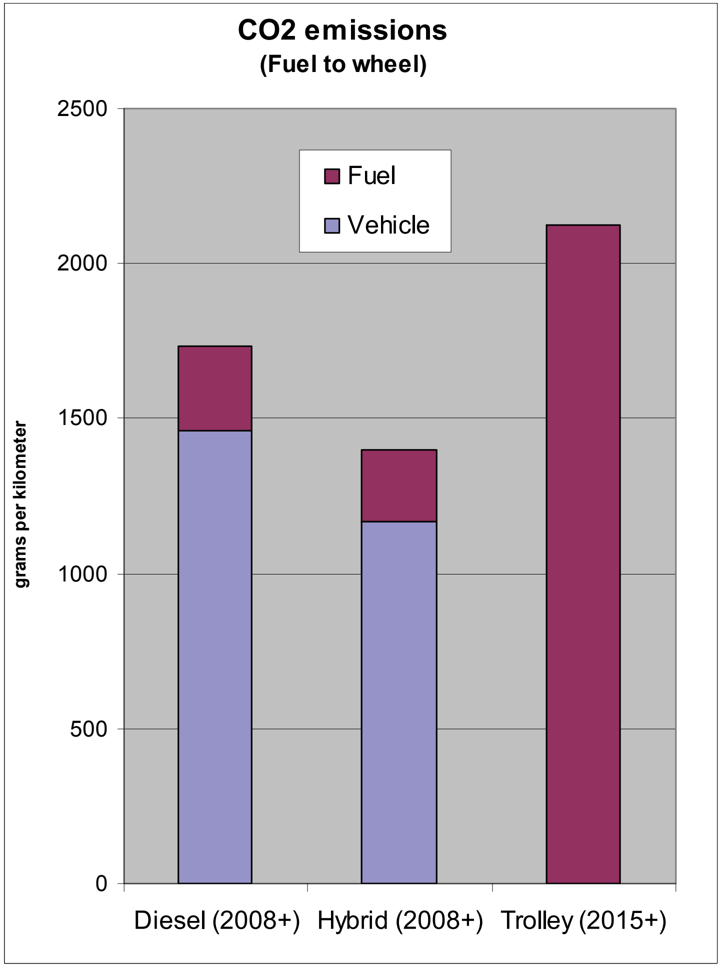




If we exclude emissions associated with the “feedstock”, the NOx and CO2 emissions from trolleys (or actually the powerplants supplying trolleys with electricity) are higher than for the diesel and hybrid buses

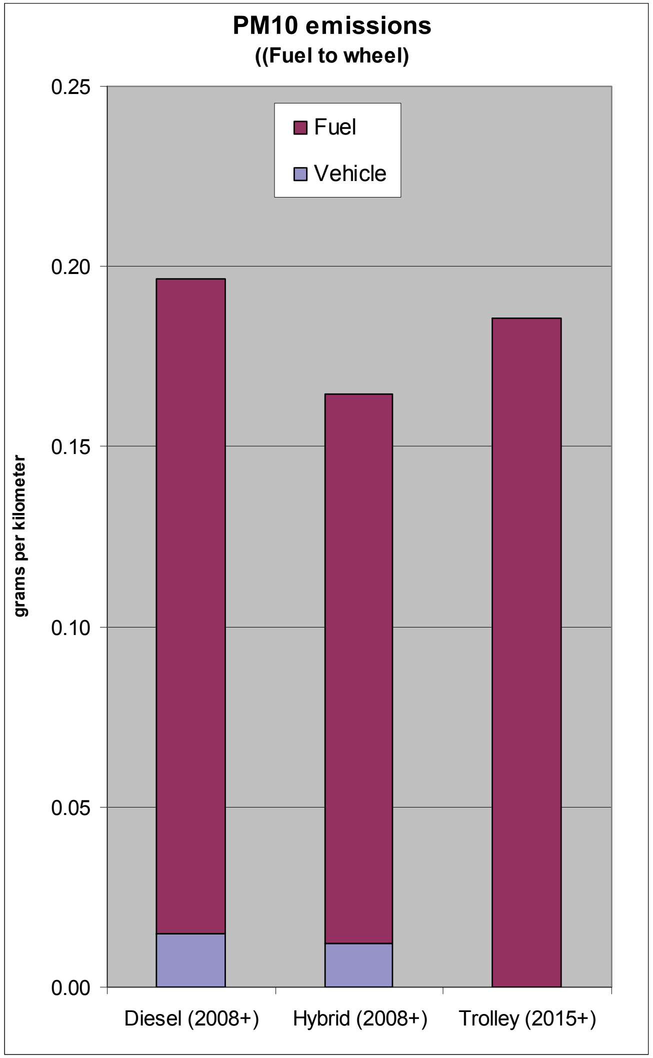
- These emission factors include emissions associated with refining and transportation of diesel to the end-user, (diesel), and,
- For trolleys, include the emissions from power-plants supplying electricity to the trolleys.

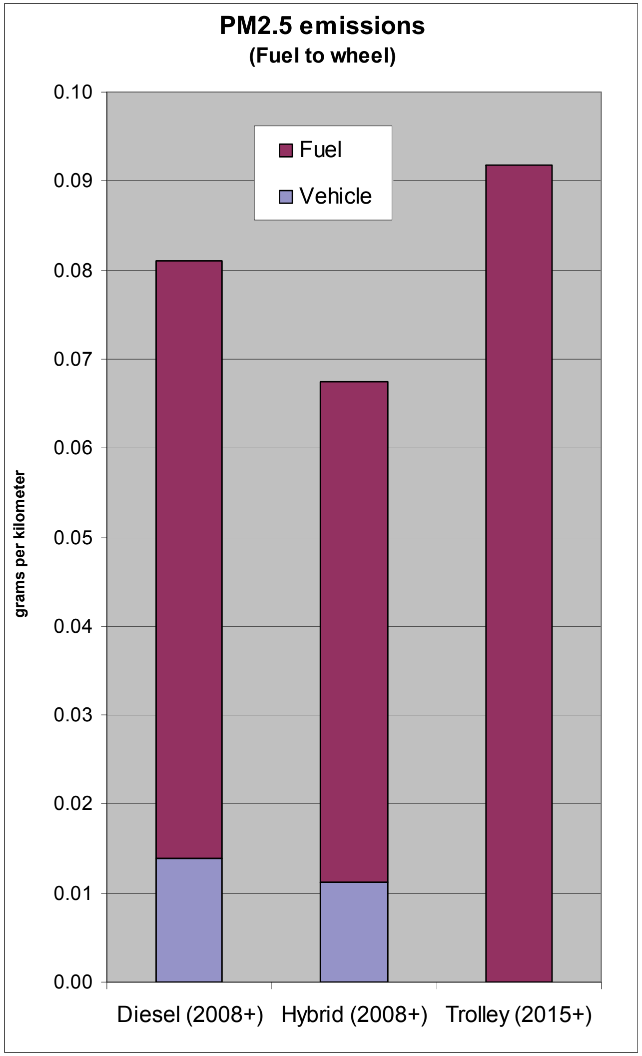




Excluding the emissions associated with feedstock supply, the PM emissions are roughly equivalent for diesels and trolleys

- These emission factors include emissions associated with refining and transportation of diesel to the end-user, (diesel), and,
- For trolleys, include the emissions from power-plants supplying electricity to the trolleys.





There is very little difference in overall fleet emissions among the three scenarios evaluated.

- There are only 47 buses "in play" among the three scenarios compared to an overall fleet size of approximately 900 buses (in 2007)….therefore, the impact on total fleet emissions is quite small no matter what bus technology is selected
- Scenario 2 (replace trolleys with hybrids) yields the lowest overall fleet emissions with NOx reduced by about 4% by 2027

Forecasted Annual Emissions from Bus Fleet Operations (tonnes)

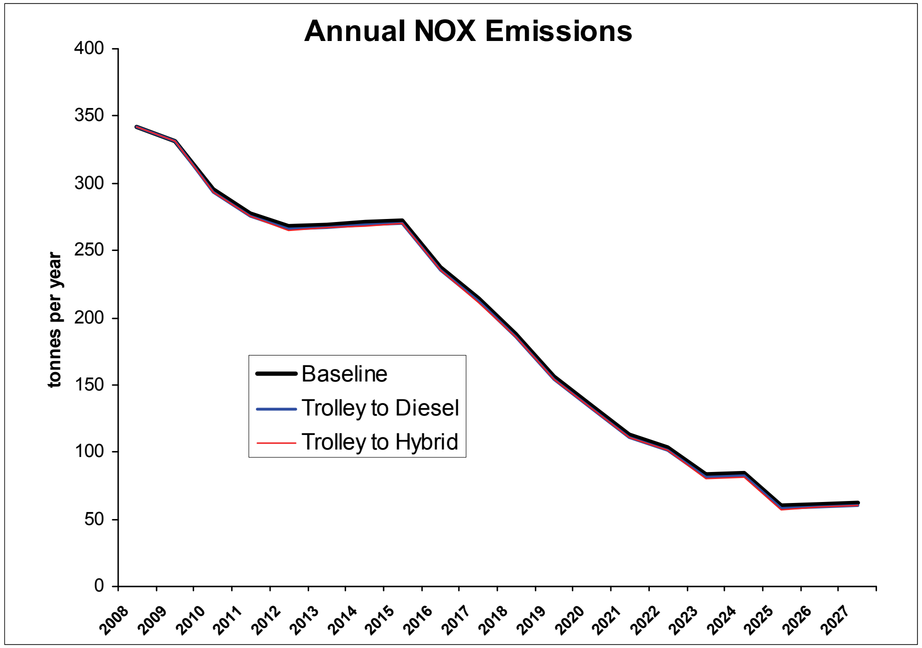
Scenario Description	NOX			PM			CO2		
	2007	2017	2027	2007	2017	2027	2007	2017	2027
Renew Trolley Fleet in 2010 (Baseline)	345.05	213.87	62.38	15.54	10.79	12.01	63,440	83,709	106,047
Scenario 1: Trolley to Diesel	345.05	211.72	60.24	15.54	10.81	12.02	63,440	83,271	105,608
Scenario 2: Trolley to Hybrid	345.05	211.52	60.03	15.54	10.77	11.98	63,440	82,893	105,231

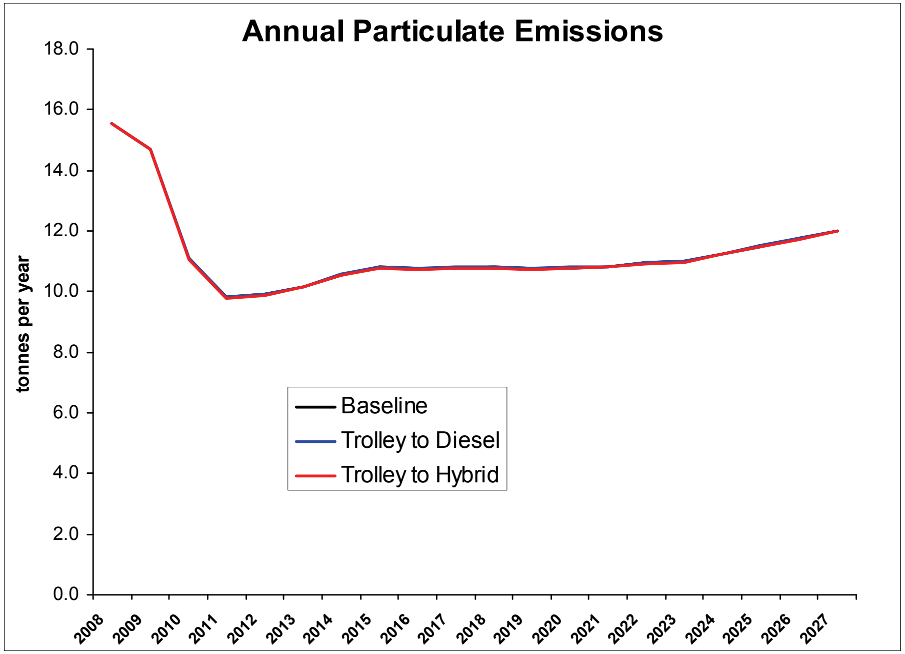
Forecasted Percentage Change in Bus Fleet Emissions

Scenario Description	NOX			PM			CO2		
	2007	2017	2027	2007	2017	2027	2007	2017	2027
Renew Trolley Fleet in 2010 (Baseline)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 1: Trolley to Diesel	0.0%	-1.0%	-3.4%	0.0%	0.1%	0.1%	0.0%	-0.5%	-0.4%
Scenario 2: Trolley to Hybrid	0.0%	-1.1%	-3.8%	0.0%	-0.2%	-0.2%	0.0%	-1.0%	-0.8%

The good news from an environmental perspective is that in spite of substantial fleet growth, regulated emissions from the fleet will decline during the study period (2007 to 2027)

- The ETS fleet is forecast to grow from approximately 900 buses in 2007 to 1,500 buses in 2027.
- However, because older (higher polluting) buses will be retired over the next decade—and replaced with new “clean diesel” technology, the emissions from the fleet decline.

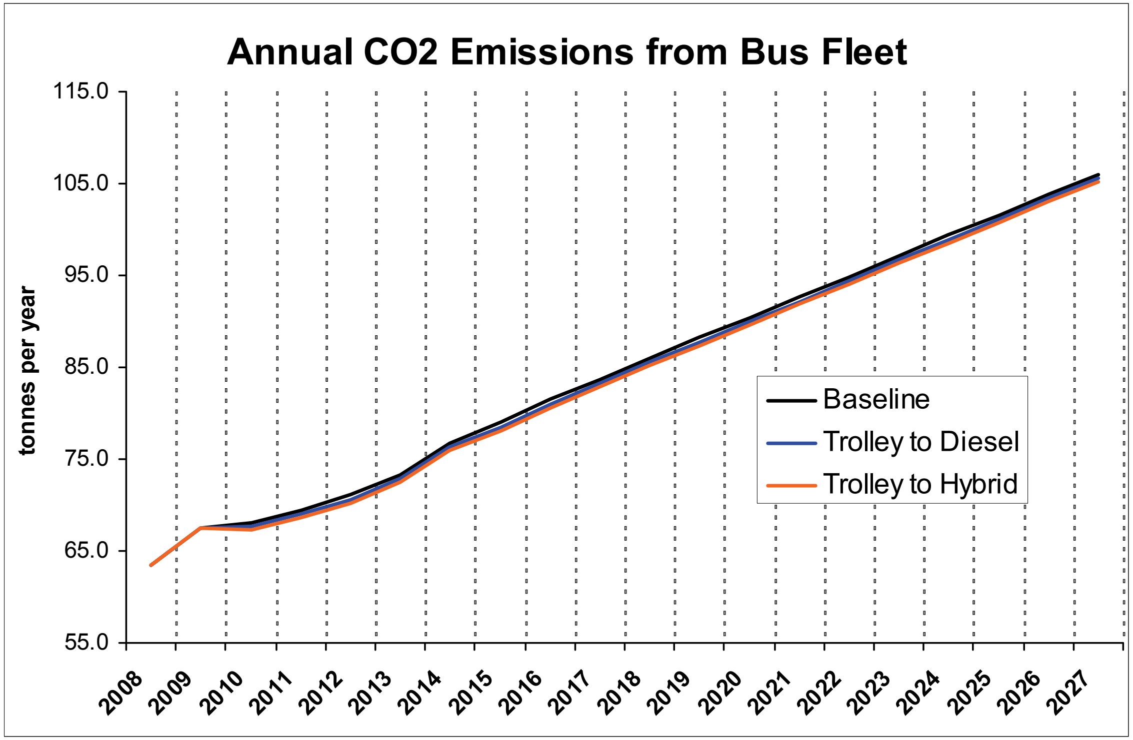




This same story does not hold true for Greenhouse Gas emissions…

- Future diesel (and trolley) buses are forecasted to have only minor improvements in vehicle efficiency (kilometers-per-liter or kWh-per-kilometer), and therefore the CO_2 emissions from the fleet will roughly be proportional to total fleet size (or to total fleet mileage accumulation).

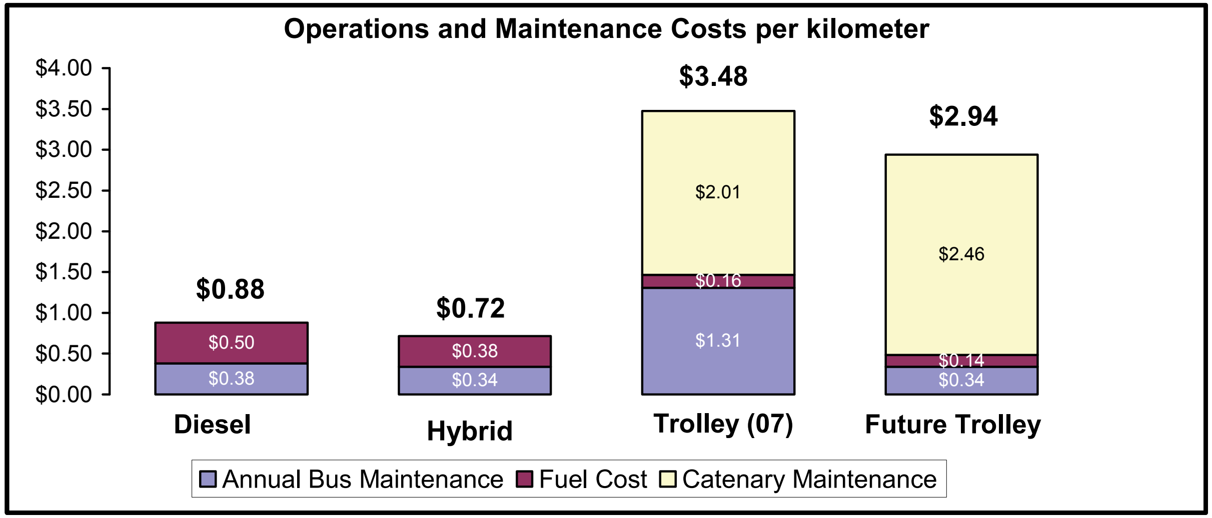
- It should also be noted that there are no significant improvements forecasted either by CASA or EPCOR in the efficiency of new or existing coal or natural gas generating facilities. Also, there are no significant increases forecasted in the supply of nuclear, hydro, or other renewable electricity power sources in Alberta which might otherwise lower CO_2 emissions associated with electricity production.

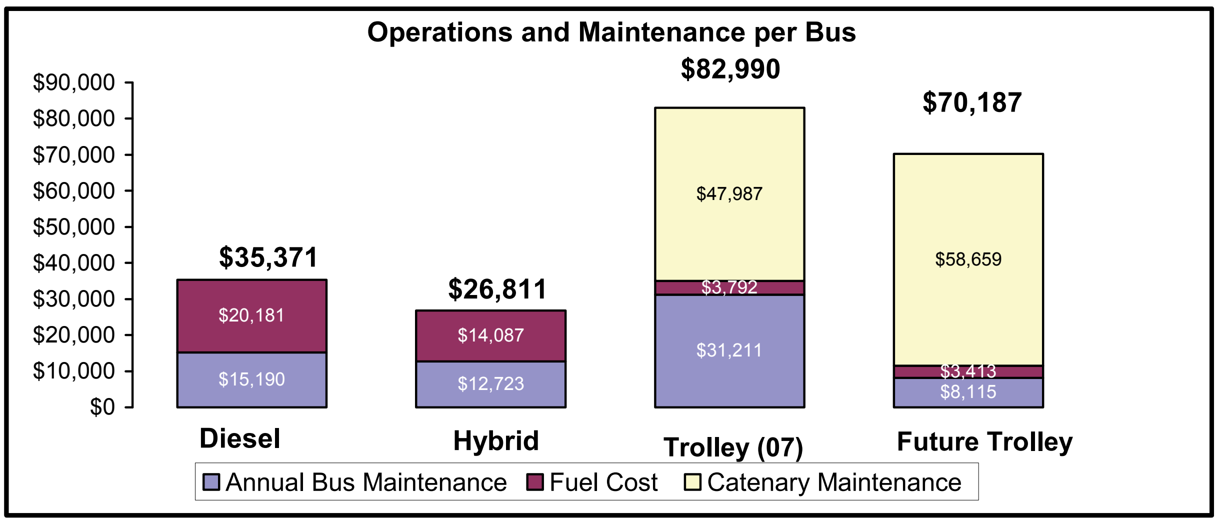


Financial Results

Overall maintenance costs for trolleys are significantly higher than for diesel buses…

- Direct bus maintenance and fuel costs are similar between diesels and trolleys, however,
- The cost of maintaining the overhead catenary system must be added to the cost of trolleys.
- Even after adjusting for annual differences in utilization, (diesel buses accumulate higher annual kilometers due to route assignments), the diesel buses are still far less expensive to operate and maintain than trolley buses.





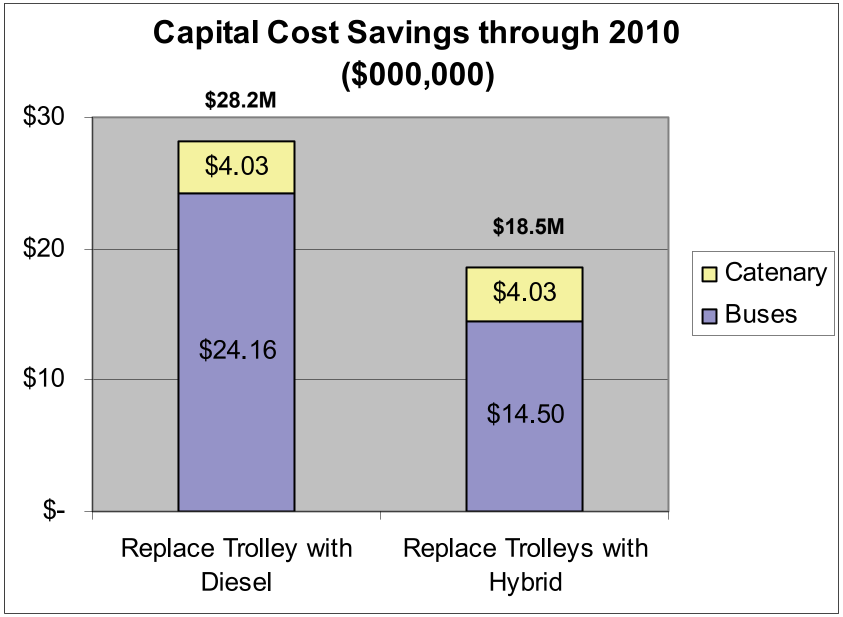
Total capital and operating cost summary for all three scenarios…

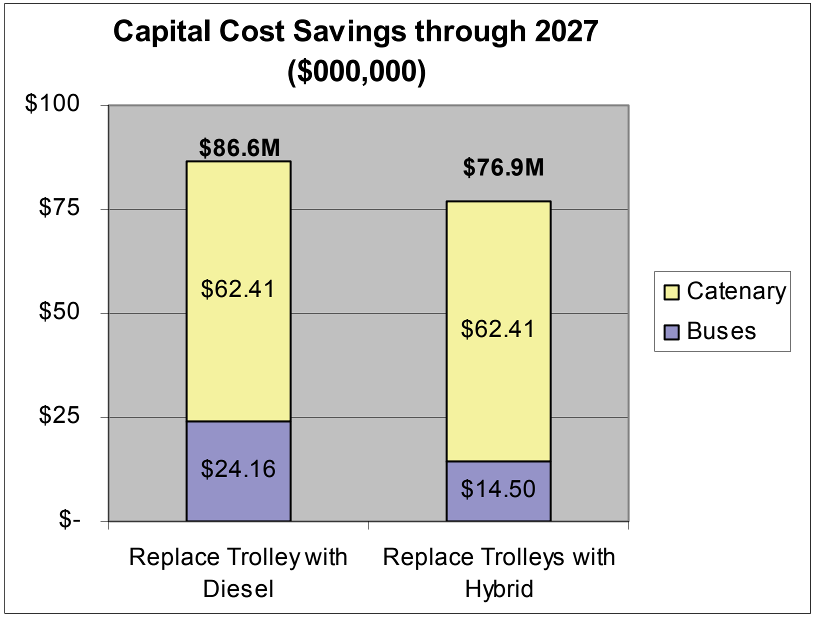
	Lifecycle Cost Summary 2008 - 2027 ($, 000)					
	Baseline Renew Trolleys		Scenario 1 Trolley to Diesel		Scenario 2 Trolley to Hybrid	
Description	**Units**	**Cost**	**Units**	**Cost**	**Units**	**Cost**
Capital Costs						
Bus Procurements						
Trolleys	47	$42,105	**0**	$0	**0**	$0
40 Ft	1,425	$544,065	1,472	$562,010	1,425	$544,065
Hybrids	6	$3,525	6	$3,525	53	$31,133
Community	88	$15,766	88	$15,766	88	$15,766
Artics	35	$24,500	35	$24,500	35	$24,500
Total Bus Procurements	**1,601**	**$629,961**	**1,601**	**$605,801**	**1,601**	**$615,465**
Catenary System						
Overhead capital through 2010		$18,484				
Overhead capital 2011 - 2027		$58,385				
Minimum capital investment through 2010				$3,843		$3,843
Dismantling of Overhead				$10,612		$10,612
Total Catenary System		**$76,869**		**$14,456**		**$14,456**
Total Capital Costs through 2010		**$ 119,562**		**$ 91,373**		**$ 101,037**
Total Capital Costs through 2027		**$ 706,830**		**$ 620,256**		**$ 629,920**
Total Capital Savings through 2010				**$ 28,189**		**$ 18,525**
Total Capital Savings through 2027				**$ 86,574**		**$ 76,910**
Operating Costs						
Total Operating Costs through 2010		**$102,686**		**$100,609**		**$100,506**
Total Operating Costs through 2027		**$854,809**		**$811,299**		**$809,451**
Total Operating Savings through 2010				**$ 2,077**		**$ 2,180**
Total Operating Savings through 2027				**$ 43,510**		**$ 45,358**
Lifecycle Cost Summary						
Total Lifecycle Costs through 2010		**$222,249**		**$191,982**		**$201,544**
Total Lifecycle Costs through 2027		**$1,561,640**		**$1,431,555**		**$1,439,371**
Total Savings through 2010				**$ 30,266**		**$ 20,705**
Total Savings through 2027				**$ 130,084**		**$ 122,269**

Capital cost Savings…

- Replacing the trolley buses with diesel buses would save $28M in capital costs through year 2010…and is due largely to reduced bus costs ($24M) as well as reduced catenary capital expenditures ($4M). Replacing trolleys with hybrids also results in a savings, but is reduced to $18M due to the higher cost of the hybrid buses.

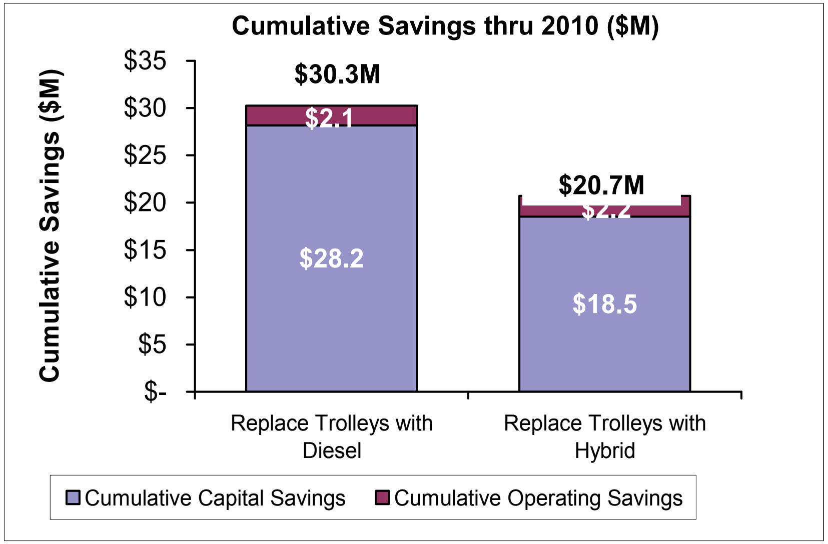
- Over the next 20 years, replacing trolley buses with diesel buses would result in $87M capital savings due largely to elimination of catenary system capital costs.

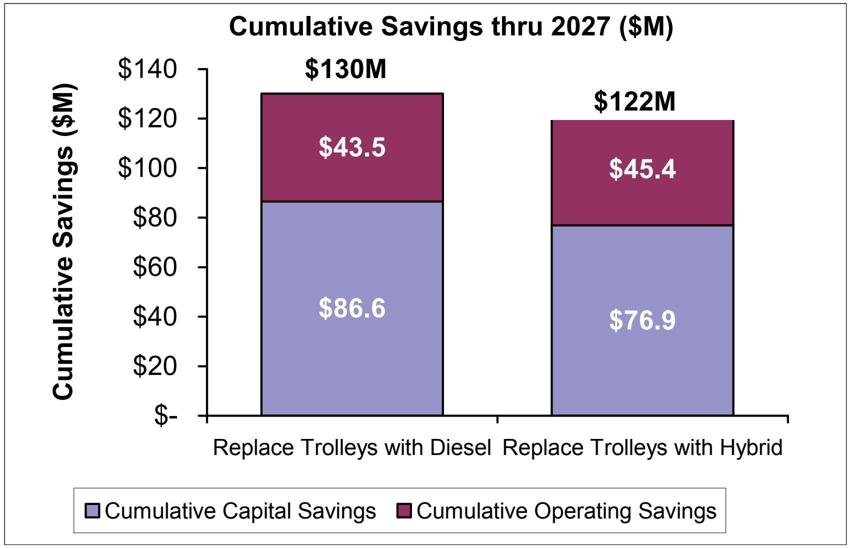




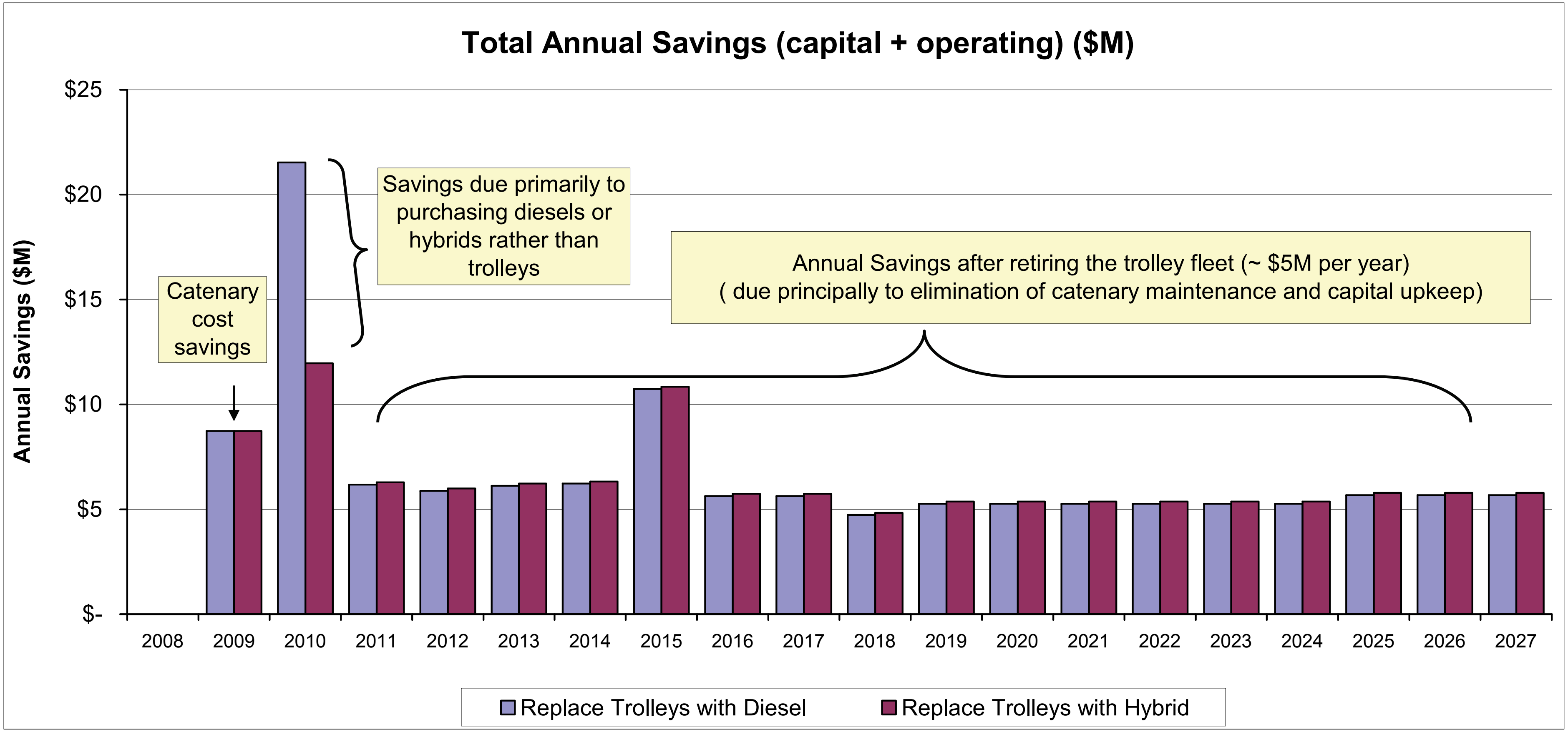
Cumulative capital plus operating savings…

- Replacing trolley buses with diesel buses results in a total savings of $30M through 2010, and $130M through 2027
- There is little operating savings through 2010 since it is presumed that trolleys would continue to operate through 2009 in both scenarios 1 and 2.
- Scenario 2 (replace trolleys with Hybrids) would result in slightly more operating cost savings (compared to replacing trolleys with diesels) as a result of the improved fuel economy of hybrids.





Year-by-year savings resulting from replacing trolleys with diesels (scenario 1) or with hybrids (scenario 2)…



Year-by-year cost data (for the record)…

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Baseline Lifecycle Costs																				
Operating $	$ 33.0	$ 35.0	$ 34.7	$ 35.5	$ 36.5	$ 37.6	$ 39.2	$ 40.2	$ 41.4	$ 42.4	$ 43.4	$ 44.3	$ 45.3	$ 46.3	$ 47.4	$ 48.4	$ 49.5	$ 50.5	$ 51.5	$ 52.6
Capital $	$ 5.46	$ 38.50	$ 91.09	$ 23.99	$ 21.78	$ 16.19	$ 26.09	$ 20.80	$ 47.69	$ 37.18	$ 39.11	$ 46.59	$ 36.95	$ 40.67	$ 29.01	$ 48.56	$ 16.75	$ 108.90	$ 15.74	$ 23.93
Buses	$ 1.61	$ 29.76	$ 85.18	$ 19.99	$ 18.34	$ 12.51	$ 22.31	$ 12.51	$ 44.51	$ 34.00	$ 36.84	$ 43.77	$ 34.13	$ 37.86	$ 26.20	$ 45.75	$ 13.93	$ 105.68	$ 12.51	$ 20.71
Overhead	$ 3.84	$ 8.74	$ 5.90	$ 4.00	$ 3.43	$ 3.67	$ 3.77	$ 8.29	$ 3.18	$ 3.18	$ 2.28	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 3.23	$ 3.23	$ 3.23
Total $	**$ 38.4**	**$ 73.5**	**$ 125.8**	**$ 59.5**	**$ 58.3**	**$ 53.8**	**$ 65.3**	**$ 61.0**	**$ 89.1**	**$ 79.6**	**$ 82.5**	**$ 90.9**	**$ 82.3**	**$ 87.0**	**$ 76.4**	**$ 97.0**	**$ 66.2**	**$ 159.4**	**$ 67.3**	**$ 76.5**

Scenario 1 Lifecycle Costs	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operating $	$ 33.0	$ 35.0	$ 32.6	$ 33.3	$ 34.1	$ 35.1	$ 36.7	$ 37.8	$ 38.9	$ 39.9	$ 40.9	$ 41.9	$ 42.9	$ 43.9	$ 44.9	$ 46.0	$ 47.0	$ 48.1	$ 49.1	$ 50.1
Capital $	$ 5.46	$ 29.76	$ 57.77	$ 19.99	$ 18.34	$ 12.51	$ 22.31	$ 12.51	$ 44.51	$ 34.00	$ 36.84	$ 43.77	$ 34.13	$ 37.86	$ 26.20	$ 45.75	$ 13.93	$ 105.68	$ 12.51	$ 20.71
Buses	$ 1.61	$ 29.76	$ 47.16	$ 19.99	$ 18.34	$ 12.51	$ 22.31	$ 12.51	$ 44.51	$ 34.00	$ 36.84	$ 43.77	$ 34.13	$ 37.86	$ 26.20	$ 45.75	$ 13.93	$ 105.68	$ 12.51	$ 20.71
Overhead	$ 3.84	$ -	$ 10.61	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total $	**$ 38.4**	**$ 64.8**	**$ 90.4**	**$ 53.3**	**$ 52.4**	**$ 47.6**	**$ 59.1**	**$ 50.3**	**$ 83.5**	**$ 73.9**	**$ 77.8**	**$ 85.7**	**$ 77.0**	**$ 81.8**	**$ 71.1**	**$ 91.7**	**$ 60.9**	**$ 153.7**	**$ 61.6**	**$ 70.8**
Scenario 1 Savings Analysis																				
Operating Savings	**$ -**	**$ -**	**$ 2.08**	**$ 2.17**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**	**$ 2.45**
Capital Savings	**$ -**	**$ 8.74**	**$ 33.31**	**$ 4.00**	**$ 3.43**	**$ 3.67**	**$ 3.77**	**$ 8.29**	**$ 3.18**	**$ 3.18**	**$ 2.28**	**$ 2.81**	**$ 2.81**	**$ 2.81**	**$ 2.81**	**$ 2.81**	**$ 2.81**	**$ 3.23**	**$ 3.23**	**$ 3.23**
Buses	$ -	$ -	$ 38.02	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Overhead	$ -	$ 8.74	$ (4.71)	$ 4.00	$ 3.43	$ 3.67	$ 3.77	$ 8.29	$ 3.18	$ 3.18	$ 2.28	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 3.23	$ 3.23	$ 3.23
Cumulative Operating Savings	**$ -**	**$ -**	**$ 2.08**	**$ 4.25**	**$ 6.71**	**$ 9.16**	**$ 11.61**	**$ 14.07**	**$ 16.52**	**$ 18.97**	**$ 21.43**	**$ 23.88**	**$ 26.33**	**$ 28.79**	**$ 31.24**	**$ 33.70**	**$ 36.15**	**$ 38.60**	**$ 41.06**	**$ 43.5**
Cumulative Capital Savings	**$ -**	**$ 8.74**	**$ 42.05**	**$ 46.06**	**$ 49.49**	**$ 53.16**	**$ 56.94**	**$ 65.23**	**$ 68.41**	**$ 71.59**	**$ 73.87**	**$ 76.69**	**$ 79.50**	**$ 82.32**	**$ 85.13**	**$ 87.94**	**$ 90.76**	**$ 93.98**	**$ 97.21**	**$ 100.4**
Buses	$ -	$ -	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02	$ 38.02
Overhead	$ -	$ 8.74	$ 4.03	$ 8.03	$ 11.47	$ 15.14	$ 18.91	$ 27.20	$ 30.39	$ 33.57	$ 35.85	$ 38.66	$ 41.48	$ 44.29	$ 47.11	$ 49.92	$ 52.74	$ 55.96	$ 59.19	$ 62.41
Replace Trolleys with Diesel	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Total Annual Savings	$ -	$ 8.74	$ 35.39	$ 6.18	$ 5.89	$ 6.13	$ 6.23	$ 10.74	$ 5.64	$ 5.64	$ 4.73	$ 5.27	$ 5.27	$ 5.27	$ 5.27	$ 5.27	$ 5.27	$ 5.68	$ 5.68	$ 5.68
Cumulative Savings	**$ -**	**$ 8.7**	**$ 44.1**	**$ 50.3**	**$ 56.2**	**$ 62.3**	**$ 68.6**	**$ 79.3**	**$ 84.9**	**$ 90.6**	**$ 95.3**	**$ 100.6**	**$ 105.8**	**$ 111.1**	**$ 116.4**	**$ 121.6**	**$ 126.9**	**$ 132.6**	**$ 138.3**	**$ 143.9**

Scenario 2 Lifecycle Costs	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operating $	$ 33.0	$ 35.0	$ 32.5	$ 33.2	$ 34.0	$ 35.0	$ 36.6	$ 37.7	$ 38.8	$ 39.8	$ 40.8	$ 41.8	$ 42.8	$ 43.8	$ 44.8	$ 45.9	$ 46.9	$ 48.0	$ 49.0	$ 50.0
Capital $	$ 5.46	$ 29.76	$ 72.82	$ 19.99	$ 18.34	$ 12.51	$ 22.31	$ 12.51	$ 44.51	$ 34.00	$ 36.84	$ 43.77	$ 34.13	$ 37.86	$ 26.20	$ 45.75	$ 13.93	$ 105.68	$ 12.51	$ 20.71
Buses	$ 1.61	$ 29.76	$ 62.20	$ 19.99	$ 18.34	$ 12.51	$ 22.31	$ 12.51	$ 44.51	$ 34.00	$ 36.84	$ 43.77	$ 34.13	$ 37.86	$ 26.20	$ 45.75	$ 13.93	$ 105.68	$ 12.51	$ 20.71
Overhead	$ 3.84	$ -	$ 10.61	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total $	**$ 38.4**	**$ 64.8**	**$ 105.3**	**$ 53.2**	**$ 52.3**	**$ 47.5**	**$ 59.0**	**$ 50.2**	**$ 83.4**	**$ 73.8**	**$ 77.7**	**$ 85.6**	**$ 76.9**	**$ 81.7**	**$ 71.0**	**$ 91.6**	**$ 60.8**	**$ 153.6**	**$ 61.5**	**$ 70.7**
Scenario 2 Savings Analysis																				
Operating Savings	$ -	$ -	$ 2.18	$ 2.28	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56	$ 2.56
Capital Savings	$ -	$ 8.74	$ 18.27	$ 4.00	$ 3.43	$ 3.67	$ 3.77	$ 8.29	$ 3.18	$ 3.18	$ 2.28	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 3.23	$ 3.23	$ 3.23
Buses	$ -	$ -	$ 22.98	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Overhead	$ -	$ 8.74	$ (4.71)	$ 4.00	$ 3.43	$ 3.67	$ 3.77	$ 8.29	$ 3.18	$ 3.18	$ 2.28	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 2.81	$ 3.23	$ 3.23	$ 3.23
Cumulative Operating Savings	$ -	**$ -**	**$ 2.18**	**$ 4.46**	**$ 7.01**	**$ 9.57**	**$ 12.13**	**$ 14.68**	**$ 17.24**	**$ 19.80**	**$ 22.35**	**$ 24.91**	**$ 27.46**	**$ 30.02**	**$ 32.58**	**$ 35.13**	**$ 37.69**	**$ 40.25**	**$ 42.80**	**$ 45.4**
Cumulative Capital Savings	**$ -**	**$ 8.74**	**$ 27.01**	**$ 31.01**	**$ 34.45**	**$ 38.12**	**$ 41.89**	**$ 50.18**	**$ 53.37**	**$ 56.55**	**$ 58.83**	**$ 61.64**	**$ 64.46**	**$ 67.27**	**$ 70.09**	**$ 72.90**	**$ 75.72**	**$ 78.94**	**$ 82.17**	**$ 85.39**
Buses	$ -	$ -	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98	$ 22.98
Overhead	$ -	$ 8.74	$ 4.03	$ 8.03	$ 11.47	$ 15.14	$ 18.91	$ 27.20	$ 30.39	$ 33.57	$ 35.85	$ 38.66	$ 41.48	$ 44.29	$ 47.11	$ 49.92	$ 52.74	$ 55.96	$ 59.19	$ 62.41
Replace Trolleys with Hybrid	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Total Annual Savings	$ -	$ 8.74	$ 20.45	$ 6.28	$ 5.99	$ 6.23	$ 6.33	$ 10.85	$ 5.74	$ 5.74	$ 4.83	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.37	$ 5.78	$ 5.78	$ 5.78
Cumulative Savings	**$ -**	**$ 8.7**	**$ 29.2**	**$ 35.5**	**$ 41.5**	**$ 47.7**	**$ 54.0**	**$ 64.9**	**$ 70.6**	**$ 76.3**	**$ 81.2**	**$ 86.6**	**$ 91.9**	**$ 97.3**	**$ 102.7**	**$ 108.0**	**$ 113.4**	**$ 119.2**	**$ 125.0**	**$ 130.8**

Observations and Conclusions

Summary observations..

- Trolley buses have no emissions at the "street level", but the area-wide emissions from electricity generation to power the trolley buses results in higher levels of pollution than would be produced by diesel or hybrid buses. This is true for both regulated emissions (NOx and PM10) as well as for Greenhouse Gases (CO_2)

- The "street level" exhaust emissions from new (model year 2010+) diesel buses are exceedingly low. Further, new emission control system warranty requirements will mandate the use on automatic On-Board Diagnostics (OBD) systems to monitor the emission performance of in-service diesel vehicles. This new generation of clean diesels can easily be monitored and audited to ensure compliance with emission regulations.

- Trolley buses will continue to be more costly to operate and maintain than diesel buses.

- Hybrid buses offer even lower emissions and reduced Greenhouse gases than "pure" diesels. The operating cost for hybrids also promises to be lower than diesels due to improved fuel economy, reduced brake wear and extended oil change intervals. However, initial purchase price of hybrids is still exceedingly high—and the operating savings cannot offset this high purchase price.