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DATE February 22, 2012

TO Conrad Schneider, Clean Air Task Force

FROM Dana Lowell

RE: **Clean Diesel versus CNG Buses: Cost, Air Quality, & Climate Impacts**

This memo summarizes the results of an analysis which compares the economic, and the air quality and climate impacts, resulting from the use of compressed natural gas (CNG) transit buses to those from modern diesel buses. The purpose of the analysis was to evaluate the potential for life-cycle cost savings to transit agencies from the purchase of new CNG buses instead of new diesel buses, as well as the impact of CNG bus purchases on fleet-wide criteria pollutant and greenhouse gas (GHG) emissions. The analysis of GHG emissions includes both tail-pipe emissions and upstream emissions from production and transport of fuel. The analysis also includes the climate impact of the black carbon portion of tail-pipe PM emissions.

Inputs to the analysis include diesel fuel and natural gas cost projections from the U.S. Energy Information Administration (EIA); transit bus operating and cost data from the American Public Transportation Association (APTA); estimates of tail-pipe nitrogen oxide (NOx), particulate matter (PM), hydrocarbon (HC), carbon monoxide (CO), and methane (CH_4) emissions from EPA's MOVES emissions model; estimates of tail-pipe carbon dioxide (CO_2) emissions based on average in-use fuel use; and estimates of up-stream CO_2 and CH_4 emissions for diesel and natural gas fuel production, from the GREET model.

SUMMARY

CNG BUS COST SAVINGS

CNG transit buses currently cost, on average, approximately $70,000 more to purchase than equivalent diesel buses. When converting from diesel to natural gas operations, transit agencies must also invest in new CNG fueling stations, which can cost $25,800 or more per bus. On the other hand, natural gas currently costs approximately 35% less than diesel fuel per diesel gallon equivalent – which can result in over $11,000 per bus in annual fuel cost savings for CNG buses compared to diesel buses. EIA projects that for at least the next 20 years natural gas will continue to be priced significantly lower than diesel fuel, so that annual operating fuel cost savings from conversion to CNG buses will persist throughout the life of a transit bus purchased today.

This analysis indicates that the pay-back period on the incremental purchase cost of CNG buses and fueling infrastructure, compared to diesel buses, is between five and eight years. Life-time net savings to transit agencies that buy new CNG buses instead of new diesel buses could total $50,000 - $80,000 per bus over a transit bus' 12-15 year life, or an average of $4,200 - $5,300 per bus per year[1]. This is equivalent to about a 14% reduction in annual fuel costs compared to diesel buses.

AIR QUALITY IMPACTS

Both new diesel and new CNG buses have significantly lower emissions of NOx, PM, and HC than the older diesel buses that they replace[2]. According to EPA's MOVES emissions model a 2012 model year diesel bus emits 94% less NOx per mile, 98% less PM, and 89% less HC than a model year 2000 (12-year old) diesel bus. A model year 2012 CNG bus emits 80% less NOx, 99% less PM, and 100% less HC than a model year 2000 diesel bus.

Replacing 10 older diesel buses with new diesel buses will reduce annual NOx, PM, and HC emissions by 4,953 kg, 275 kg, and 421 kg respectively. Replacing 10 older diesel buses with new CNG buses will reduce annual NOx, PM, and HC emissions 4,197 kg, 279 kg, and 471 kg respectively. On a per-bus basis new CNG buses provide slightly greater PM and HC reductions, but lower NOx reductions, than new diesel buses.

Most transit agencies have limited funding available for purchase of new buses. In a capital-constrained environment, the higher purchase price of CNG buses may limit the number of new CNG buses that can be purchased compared to new diesel buses, thus reducing the number of older diesel buses that can be retired, despite the potential for life-cycle cost savings as discussed above. For every $10 million of capital funding, a transit agency could purchase approximately 26 new diesel buses or 21 new CNG buses (and associated fueling infrastructure), and retire an equivalent number of old buses. Given that a greater number of older, high emitting buses could be retired, fleet-wide emission reductions of NOx, PM, and HC per dollar of capital funding could be 47%, 23%, and 11% higher, respectively, if new diesel buses are purchased than if new CNG buses are purchased.

CLIMATE IMPACTS

To determine the climate impacts of replacing older diesel buses with new diesel or CNG buses, this analysis includes tail-pipe CO2, CH4, and black carbon (BC) emissions, as well as up-stream emissions of CO2 and CH4 from fuel production. Emissions of CH4 were converted to CO2-equivalent emissions using factors for global warming potential (GWP) produced by the Intergovernmental Panel on Climate Change (IPCC 2007). BC emissions were converted to CO2-

[1] These figures do not include the effects of any government subsidies or tax breaks potentially applicable to the purchase of CNG buses, which could reduce the pay-back period and increase net life-time savings.

[2] This analysis assumes that most newly purchased transit buses are used to replace buses which are at least 12 years old, which are retired. According to EPA's MOVES emissions model, new CNG buses have higher emissions of carbon monoxide (CO) than either old or new diesel buses.

equivalent emissions using GWP factors developed by Bond & Sun, consistent with other CATF analysis. As requested, the analysis includes both the long-term climate impact of CH4 and BC emissions, as calculated using factors for GWP over a 100-year time horizon (GWP_{100}), and the short-term climate impact, as calculated using factors for GWP over a 20-year time horizon (GWP_{20}).

The analysis indicates that using GWP_{100} factors, wells-to-wheels GHG emissions from older diesel buses total 4,230 g CO2-e per mile. Wells-to-wheels GHG emissions from new diesel buses total 3,840 g CO2-e per mile, a 9% reduction compared to older buses; the entire reduction results from reduced PM and black carbon emissions.

Wells-to-wheels GHG emissions from new CNG buses total 3,655 g CO2-e per mile, 5% less than GHG emissions from new diesel buses. Tail-pipe CO2 emissions from CNG buses are approximately 22% lower per diesel-equivalent gallon than CO2 emissions from diesel buses. However, these lower per-gallon emissions are offset by greater fuel use per mile for CNG buses, as well as higher CH4 emissions, both from the tail pipe and up-stream.

In the analysis, upstream emissions of fugitive methane are particularly important. The latest version of GREET assumes significantly higher emissions of fugitive methane from natural gas production than previous versions of GREET, based on current EPA assumptions used to develop the national GHG emissions inventory. The issue of fugitive methane emissions continues to be reviewed by EPA and DOE; future versions of GREET may further adjust leakage rate assumptions (either up or down), which would affect this analysis. If leakage of fugitive methane from natural gas production was assumed to be zero, per-mile GHG emissions from CNG buses would be 16% lower than GHG emissions from new diesel buses (GWP_{100}).

Assessing short-term climate impact using GWP_{20} factors magnifies the importance of black carbon emissions from older diesel buses and fugitive methane emissions from natural gas production. The analysis indicates that using GWP_{20} factors, wells-to-wheels GHG emissions from older diesel buses total 5,241 g CO2-e per mile (+ 24% compared to GWP_{100}). Using GWP_{20} factors, wells-to-wheels GHG emissions from new diesel buses total 3,981 g CO2-e per mile (+ 4% compared to GWP_{100}). Using GWP_{20} factors, wells-to-wheels GHG emissions from new CNG buses are higher than per-mile GHG emissions from new diesel buses, at 4,643 g CO2-e per mile (+27% compared to GWP_{100}).

Most transit agencies have limited funding available for purchase of new buses. In a capital-constrained environment, the higher purchase price of CNG buses may limit the number of new CNG buses that can be purchased compared to new diesel buses, thus reducing the number of older diesel buses that can be retired. For every $10 million of capital funding, a transit agency could purchase approximately 26 new diesel buses or 21 new CNG buses (and associated fueling infrastructure), and retire an equivalent number of old buses.

Assuming GWP_{100} factors to assess the long-term climate impact of CH4 and BC, annual fleet-wide reductions in GHG emissions (MT CO2-e) would be 18% greater from purchasing 21 new CNG buses than from purchasing 26 new diesel buses. However, assuming GWP_{20} factors to assess the short-term climate impact of CH4 and BC, annual fleet-wide reductions in GHG emissions would be 62% *less* from purchasing 21 new CNG buses than from purchasing 26 new diesel buses with $10 million in capital funding.

ASSUMPTIONS AND DATA SOURCES

For this analysis, fuel costs for diesel fuel and natural gas were taken from the U.S. Energy Information Administration (EIA), Energy Outlook 2011, reference case (www.eia.gov/forecasts/aeo/). The assumed prices used are shown in Figure 1. As shown, in 2012 diesel fuel is assumed to cost $3.02 per gallon, and prices are assumed to increase approximately 5% per year, reaching $5.56 per gallon in 2030. The price of natural gas delivered for transportation is assumed to be $1.78 per diesel gallon equivalent (DGE)[3] in 2012; natural gas prices are assumed to increase approximately 3% per year, reaching $2.74 per DGE in 2030.

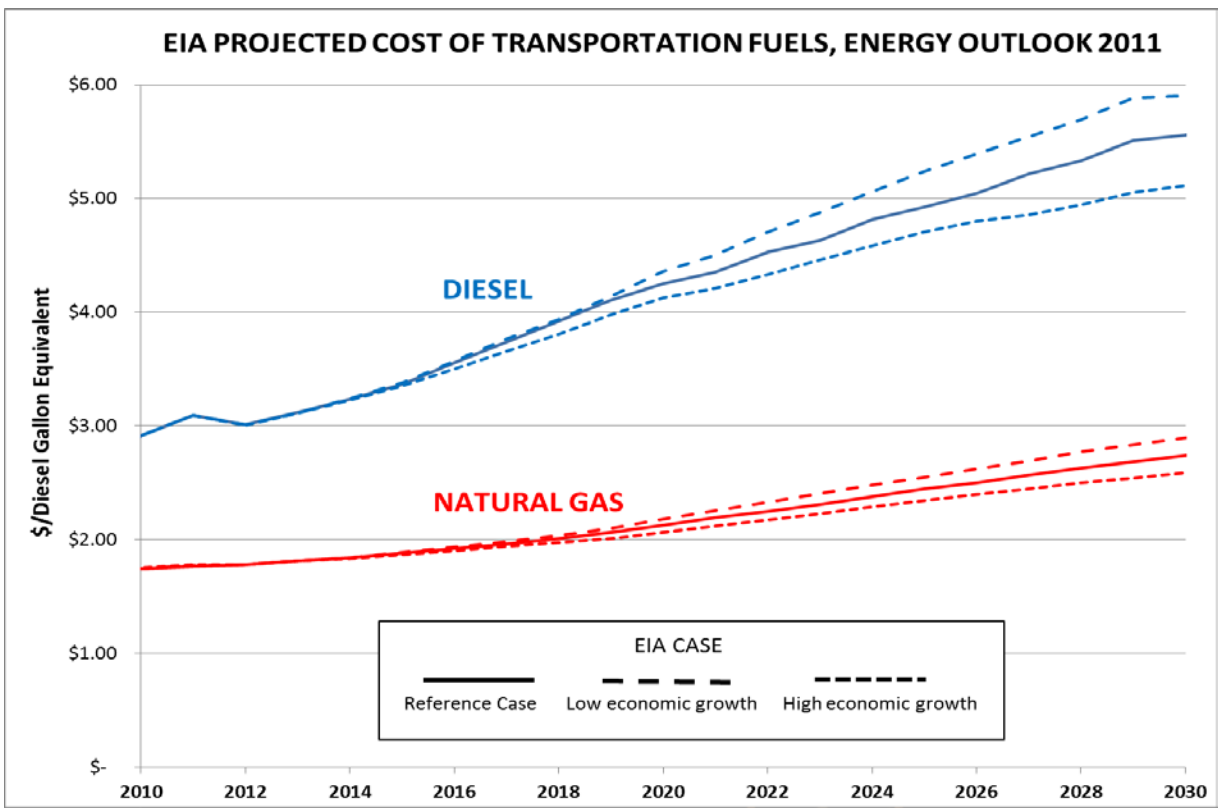

Figure 1 Diesel Fuel and Natural Gas Prices Used in the Analysis

[3] A diesel gallon equivalent is 140 standard cubic feet of natural gas, containing approximately 128,000 btu of energy.

Diesel and CNG transit buses are assumed to travel 35,966 miles per year; this represents the average annual mileage for transit buses reported by the American Public Transportation Association (APTA) for 2009[4]. Diesel buses are assumed to average 3.27 miles per gallon (MPG) and CNG buses are assumed to average 3.0 miles per diesel gallon equivalent (MPDGE)[5]. Based on the above annual mileage and fuel economy, diesel buses are assumed to use, on average, 10,999 gallons of fuel annually and CNG buses are assumed to use 11,989 DGE of fuel annually. To comply with EPA emission standards, new diesel buses are also assumed to use urea for selective catalytic reduction. Consistent with manufacturer marketing materials, urea use is assumed to be 2% of diesel fuel use. In 2012 urea is assumed to cost $4.00 per gallon, based on a web search of commercial retail pricing. Urea purchase costs are assumed to increase annually at the same rate as EIA's projections for increases to the wholesale price index.

New diesel buses are assumed to cost on average $390,000 each, and new CNG buses are assumed to cost on average $460,000 each, for an incremental cost of $70,000 per bus. This is the weighted average purchase price reported in the 2010 Transit Vehicle Database (www.apta.com/resources/statistics/Pages/OtherAPTAStatistics.aspx) maintained by the American Public Transportation Association (APTA), for fifty new 40-ft diesel buses delivered in 2011, and 154 new 40-ft CNG buses delivered between 2009 and 2011. Reported CNG bus prices ranged from $350,000 to $520,000. Reported diesel bus prices ranged from $366,000 to $439,000. Only 2011 data was used for diesel buses because it reflects buses fully compliant with more stringent EPA new engine emission standards that became effective in the 2010 model year. The weighted average price of 1,000 new diesel buses delivered in 2009 and 2010 was $370,000.

For this analysis, annual maintenance and operating costs (other than for fuel) are assumed to be the same for diesel and CNG buses.

The cost of CNG fuel station construction required for CNG buses is assumed to be $25,800 per bus, consistent with a cost calculator developed by Marathon Technical Services and used by the National Renewable Energy Laboratory to evaluate various scenarios for municipal fleet CNG fueling[6]. Consistent with the NREL analysis, this analysis also assumes that the incremental annual maintenance and operating cost of a CNG fuel station (compared to a diesel fuel station) is 5% of the up-front construction cost, or $1,290 per bus per year, which was added to the annual fuel cost for CNG buses.

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[4] American Public Transportation Association, 2011 Public Transportation Fact Book, Tables 8 and 9 (http://www.apta.com/resources/statistics/pages/transitstats.aspx)

[5] See: C. Johnson, National renewable Energy Laboratory, Technical Report NREL/TP-7A2-47919, June 2010, *Business Case for Compressed Natural Gas in Municipal Fleets*, page 4. These fuel economy assumptions are based on data reported by APTA in 2009.

[6] See: See: C. Johnson, National Renewable Energy Laboratory, Technical Report NREL/TP-7A2-47919, June 2010, *Business Case for Compressed Natural Gas in Municipal Fleets*, Figure 1. NREL's modeling shows that a transit CNG station costs approximately $1.25 million plus $17.50 per monthly DGE through-put. The average cost of $25,800 per bus used here assumes a fleet of 150 buses and monthly station through-put of 999 DGE per bus, consistent with the annual mileage and fuel use assumptions discussed above.

Tail-pipe NOx, PM, HC, CO, and CH_4 emissions factors (g/mi) for diesel and CNG buses were taken from the U.S. Environmental Protection Agency's MOVES emission model. Emission factors for new diesel and CNG buses are MOVES emission factors for model year 2012 Transit Buses in calendar year 2012. Emission factors for old diesel buses are MOVES emission factors for model year 2000 Transit Buses in calendar year 2012. All emission factors are U.S. averages for all roadway types.

For both diesel and CNG buses, 75% of PM is assumed to be black carbon, per EPA particulate matter speciation profiles[7].

Tail-pipe CO_2 emission factors (g/mi) for diesel and CNG buses are based on the fuel economy (MPDGE) assumptions noted above, assuming that burning diesel fuel produces 10,084 grams CO_2 per gallon, and that burning natural gas produces 7,905 grams CO_2 per DGE (EPA 420-F-05-001).

Upstream emissions (well-to-tank) of CO_2 and CH_4 for production of diesel fuel and natural gas were taken from the latest version of the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET 1 2011) produced by Argonne National Laboratory. U.S. average default values from GREET were used to determine emission factors (g/MJ) for CNG and diesel fuel production and transport. Based on the assumed bus fuel consumption (DGE/mi), and standard values for energy content (MJ/DGE) of natural gas and diesel fuel, these values were converted to g/mi emission factors for CNG and diesel buses.

To convert emissions of CH_4 (both upstream and tailpipe) to CO_2-equivalent emissions this analysis uses factors for global warming potential (GWP) published by the Intergovernmental Panel on Climate Change (IPCC 2007). The GWP_{100} for CH_4 is assumed to be 23, while the GWP_{20} for CH_4 is assumed to be 72.

To convert tail pipe black carbon emissions (75% of PM) to CO_2-equivalent emissions this analysis uses GWP values developed by Bond and Sun[8], consistent with other CATF analyses[9]. The GWP_{100} for black carbon is assumed to be 680, while the GWP_{20} for black carbon is assumed to be 2200.

A 6% discount rate was used to calculate the net present value of out-year annual fuel cost savings, in 2012 dollars.

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[7] U.S. Environmental Protection Agency, Technology Transfer Network Clearinghouse for Inventories and Emissions Factors, Speciation. April 26, 2005. Titles and Documentation for PM Profiles. <www.epa.gov//ttn/chief/emch/speciation>

[8] Bond, T. C. and Sun, H. (2005). *Can reducing black carbon emissions counteract global warming?* Environmental Science and Technology, v. 39, p. 5921-5926

[9] See: Hill, Bruce, Clean Air task Force, *The Carbon Dioxide-Equivalent Reduction Benefits from Reducing Black Carbon Particle Emissions in Long Haul Trucks Using Diesel Particulate Filters: A Preliminary Analysis,* May 20, 2009

DISCUSSION

CNG BUS COST SAVINGS

This analysis shows that based on current and projected fuel costs for diesel fuel, the annual fuel cost of the average new diesel transit bus will be $34,014 in 2012, rising to $47,915 in 2020. These figures include costs for purchase of both diesel fuel and urea. Based on current and projected costs for natural gas, the annual fuel cost of the average new CNG transit bus will be $22,664 in 2012, rising to $27,208 in 2020. These figures include both the cost of natural gas purchased from a utility, and the differential operation and maintenance cost of a CNG fuel station compared to a diesel fuel station.

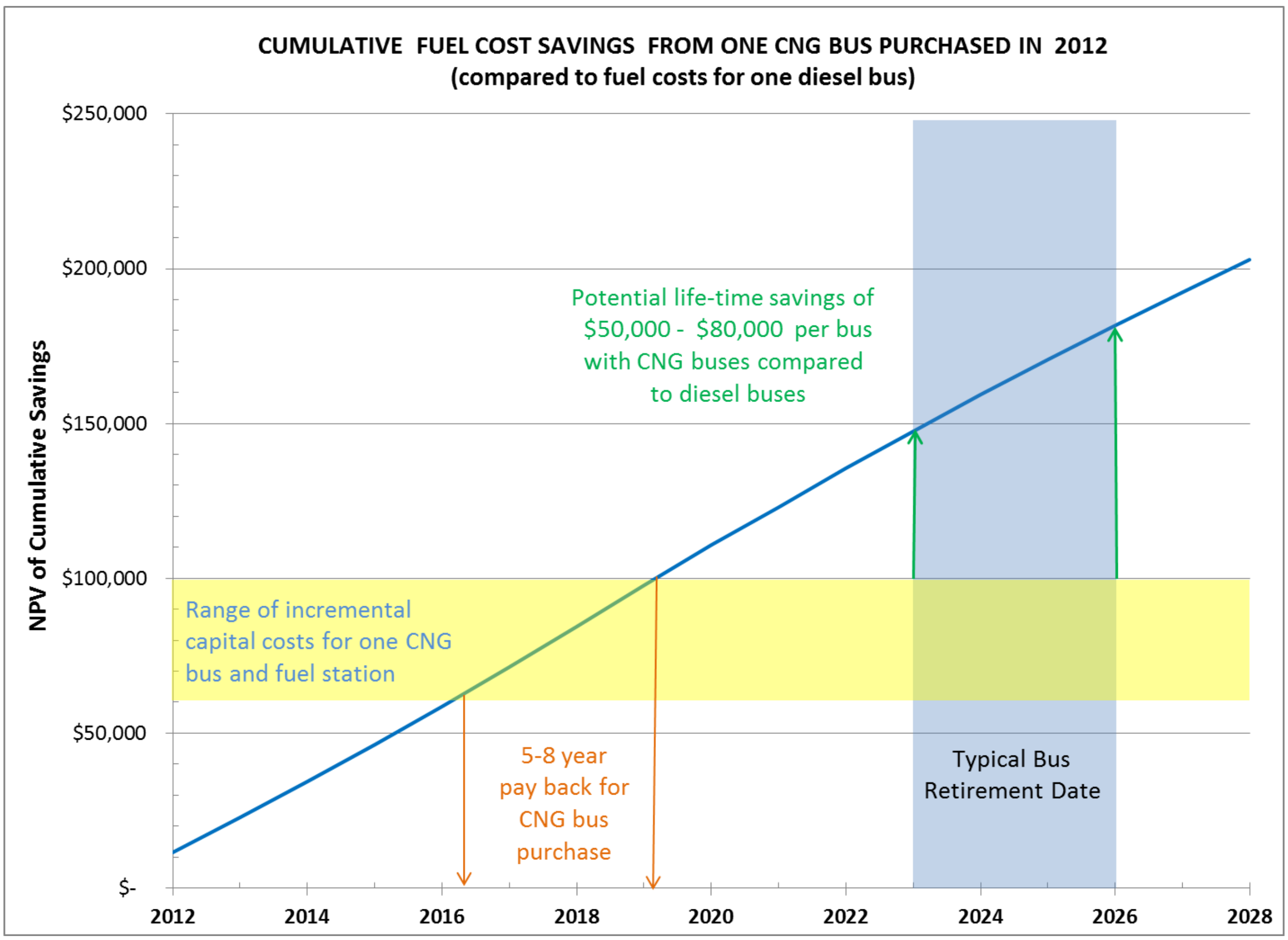

Figure 2 Cumulative fuel cost savings from purchase of CNG buses instead of diesel buses

Projected annul fuel cost savings for a new CNG bus compared to a new diesel bus total $11,377 in 2012, rising to $20,707 in 2020. The net present value (2012 dollars, using 6% discount rate) of cumulative annual fuel cost savings is projected to be $147,521 over 12 years. See Figure 2 for a plot of the cumulative fuel cost savings that can be achieved each year, for a CNG bus purchased in 2012.

Also shown in Figure 2 is the range of expected incremental per-bus purchase costs for CNG buses and fueling infrastructure, compared to diesel buses (the yellow horizontal band). As shown, while a CNG bus will typically cost $60,000 - $100,000 more to purchase than a diesel bus (including the cost of the CNG fuel station), this incremental cost will be paid back in 5-8 years through annual fuel cost savings. Despite higher up-front capital costs, over the typical 12 – 15 year life of a transit bus, net savings will equal $50,000 - $80,000 per bus for agencies that purchase new CNG buses instead of new diesel buses. This net savings equates to an average of $4,200 - $5,300 per bus per year, which is equivalent to about a 14% reduction in annual fuel costs compared to diesel buses.

The above calculation of net life-time savings includes bus and infrastructure purchase, and annual fuel costs, only – it explicitly assumes that annual maintenance and overhaul costs for diesel and CNG buses will be the same. It also assumes "average values" for annual mileage accumulation (35,996 mi/yr/bus) and fuel economy (3.27 MPG for diesel, reflecting approximately 12 MPH average in-service speed). Greater annual usage and/or a slower-speed duty cycle will increase annual fuel use per bus, which will increase net life-time savings for CNG buses compared to diesel buses. This calculation also does not include the effect of any government subsidies or tax breaks that might be applicable for the purchase of CNG buses or fueling infrastructure, which would reduce purchase costs and increase net life-time savings.

AIR QUALITY & CLIMATE IMPACTS

See Table 1 for a calculation of annual air emissions from older diesel (model year 2000), new diesel (model year 2012) and new CNG (model year 2012) transit buses. As shown, the calculation of annual emissions for each bus type is based on assumed annual mileage and fuel use, and either gram per mile or gram per gallon emission factors, depending on the pollutant in question. Calculated wells-to-wheels GHG emissions include well-to-tank CO2 emissions from energy use during fuel production and transport, upstream fugitive CH4 emissions from fuel production, and tail-pipe emissions of CO2, CH4, and BC. Criteria pollutant emissions include tail-pipe emissions of NOx, PM, VOC, and CO.

The annual emissions data in Table 1 was used to calculate annual emission reductions that would be achieved by retiring older diesel buses and replacing them with new diesel or new CNG buses; this is shown in Table 2. Table 2 includes total annual mass reductions (kg or metric tons [MT]) of NOx, PM, CO, HC, and CO2-e that could be achieved for every older bus retired, as well as for every $10 million spent on new buses and, for CNG buses, associated fueling infrastructure . The calculation of total annual wells-to-wheels CO2-e reductions includes both the short-term climate impact of CH4 and BC (using GWP_{20}) and the longer-term climate impact (using GWP_{100}) of these reductions.

Table 1 Annual emissions from old diesel, new diesel, and new CNG transit buses

BUS TYPE	Fuel Economy	Annual Usage	Annual Fuel	DEF Use		Annual Emissions										
						GHG [1]							Other Pollutants [2]			
						Upstream CO2 (Energy Use)	Upstream Fugitive CH4	Tail Pipe CO2	Tail Pipe BC	Tail Pipe CH4	TOTAL CO2-e CH4 & BC GWP_{100}	TOTAL CO2-e CH4 & BC GWP_{20}	NOx	PM	CO	HC
	[MPDGE]	[mi]	[DGE]	[% of fuel]	[Annual gal]	[MT]	[g]	[MT]	[g]	[g]	[MT]	[MT]	[kg]	[kg]	[kg]	[kg]
2000 Diesel	3.27	35,966	10,999	NA	NA	24.9	90,419	110.9	21,013	71.9	152.1	188.5	527.6	28.0	299.6	47.1
2012 Diesel	3.27	35,966	10,999	2.0%	220	24.9	90,419	110.9	405	71.9	138.1	143.2	32.4	0.5	26.6	5.0
2012 CNG	3.00	35,966	11,989	NA	NA	20.0	683,735	94.8	81	38,843	131.5	167.0	107.9	0.1	360.4	0.0

NOTE 1

	Upstream CO2	Fugitive CH4	Tailpipe CO2	Tail Pipe CH4	CH4 GWP		BC GWP		% PM BC
	[g/gal]	[g/gal]	[g/gal]	[g/mi]	GWP_{100}	GWP_{20}	GWP_{100}	GWP_{20}	
2012 Diesel	2,260	8.2	10,084	0.002	23	72	680	2200	75%
2012 CNG	1,669	57.0	7,905	1.080					75%
2000 Diesel	2,260	8.2	10,084	0.002					75%
Source	*GREET 1 2011*		*EPA 420-F-05-001*	*EPA MOVES*	IPCC 2007		Bond and Sun 2005		*EPA*

NOTE 2

	NOx	PM	CO	VOC
	[g/mi]	[g/mi]	[g/mi]	[g/mi]
2012 Diesel	0.90	0.015	0.74	0.14
2012 CNG	3.00	0.003	10.02	0.00
2000 Diesel	14.67	0.779	8.33	1.31
Source	*EPA MOVES, CY 2012, National Average*			

Table 2 Emission reductions from retirement of old diesel transit buses and replacement with new diesel or new CNG buses

ANNUAL REDUCTIONS FROM REPLACING OLDER DIESEL BUSES WITH NEW BUSES		Number of Buses	Reduction in Annual Fuel Use [DGE]	Reduction in Annual Emissions NOx [kg]	PM [kg]	CO [kg]	HC [kg]	TOTAL CO2-e CH4 & BC GWP_{100} [MT]	TOTAL CO2-e CH4 & BC GWP_{20} [MT]
ANNUAL REDUCTION Per BUS	New Diesel	1	0	495.3	27.5	273.0	42.1	14.0	45.3
	New CNG	1	(990)	419.7	27.9	(60.8)	47.1	20.7	21.5
ANNUAL REDUCTION per $10 mill CAPITAL[1]	New Diesel	25.6	0	12,698.8	704.6	6,999.5	1,079.0	359.3	1,162.5
	New CNG	20.6	(20,376)	8,639.8	574.5	(1,251.2)	969.9	425.8	443.2

Note 1 Capital cost per bus, including cost of fueling infrastructure.

	Bus	Fuel Infra	TOTAL
Diesel =	$390,000	$0	$390,000
CNG =	$460,000	$25,800	$485,800
Source	*2010 APTA Database*	*NREL/TP-7A2-47919*	

As shown, replacing older diesel buses with new diesel buses will reduce annual PM, NOx, HC, CO, and CO2-e emissions. Replacing older diesel buses with new CNG buses will reduce annual PM, NOx, HC, and CO2-e emissions, but will increase CO emissions. On a per-bus basis replacement of older buses with new CNG buses yields marginally higher annual reductions in PM, HC, and CO2-e (GWP_{100}) than replacing them with new diesel buses. However, replacement with new diesel buses yields higher annual reductions in NOx and CO. Replacement with new diesel buses also yields higher reductions in CO2-e if GWP_{20} is used to evaluate the short-term climate impact of CH4 and BC emissions (wells-to-wheels).

As discussed above, new CNG buses typically cost significantly more to purchase than new diesel buses. Most transit agencies have limited funding available for purchase of new buses. In a capital-constrained environment, the higher purchase price of CNG buses may limit the number of new CNG buses that can be purchased compared to new diesel buses, thus reducing the number of older diesel buses that can be retired, despite the potential for life-cycle cost savings as discussed above. As shown in Table 2, $10 million in capital funding will purchase almost 26 new diesel buses, but only about 21 new CNG buses (as associated fueling infrastructure). Given that a greater number of older, high emitting buses could be retired, fleet-wide emission reductions of NOx, PM, and HC per dollar of capital funding would be 47%, 23%, and 11% higher, respectively, if new diesel buses are purchased than if new CNG buses are purchased.

Assuming GWP_{100} factors to assess long-term climate impact, annual fleet-wide reductions in GHG emissions (MT CO2-e) would be 18% greater from purchasing 21 new CNG buses than from purchasing 26 new diesel buses. However, assuming GWP_{20} factors to assess short-term climate impact, annual fleet-wide reductions in GHG emissions (MT CO2-e) would be 62% *less* from purchasing 21 new CNG buses than from purchasing 26 new diesel buses with $10 million in capital funding.

As shown in Table 3 and Figure 3, this analysis indicates that using GWP_{100} factors for CH4 and BC, wells-to-wheels GHG emissions from older diesel buses total 4,230 g CO2-e per mile. Wells-to-wheels GHG emissions from new diesel buses total 3,840 g CO2-e per mile, a 9% reduction compared to older buses; the entire reduction results from reduced PM and black carbon emissions.

Wells-to-wheels GHG emissions from new CNG buses total 3,655 g CO2-e per mile, 5% less than GHG emissions from new diesel buses. Tail-pipe CO2 emissions from CNG buses are approximately 22% lower per diesel-equivalent gallon than CO2 emissions from diesel buses. However, these lower per-gallon emissions are offset by greater fuel use per mile for CNG buses, as well as higher CH4 emissions, both from the tail pipe and up-stream.

In the analysis, upstream emissions of fugitive methane are particularly important. The latest version of GREET assumes significantly higher emissions of fugitive methane from natural gas production than previous versions of GREET, based on current EPA assumptions used to develop the national GHG emissions inventory. The issue of fugitive methane emissions continues to be reviewed by EPA and DOE; future versions of GREET may further adjust leakage rate assumptions (either up or down), which would affect this analysis. If leakage of fugitive methane from natural gas production was assumed to be zero, per-mile GHG emissions from CNG buses would be 16% lower than GHG emissions from new diesel buses (GWP_{100}).

As shown in Table 4 and Figure 4, assessing the short-term climate impact of CH4 and BC using GWP_{20} factors magnifies the importance of black carbon emissions from older diesel buses and fugitive methane emissions from natural gas production. The analysis indicates that using GWP_{20} factors, wells-to-wheels GHG emissions from older diesel buses total 5,241 g CO2-e per mile (+ 24% compared to GWP_{100}). Using GWP_{20} factors, wells-to-wheels GHG emissions from new diesel buses total 3,981 g CO2-e per mile (+ 4% compared to GWP_{100}). Using GWP_{20} factors, wells-to-wheels GHG emissions from new CNG buses are higher than per-mile emissions from new diesel buses, at 4,643 g CO2-e per mile (+27% compared to GWP_{100}).

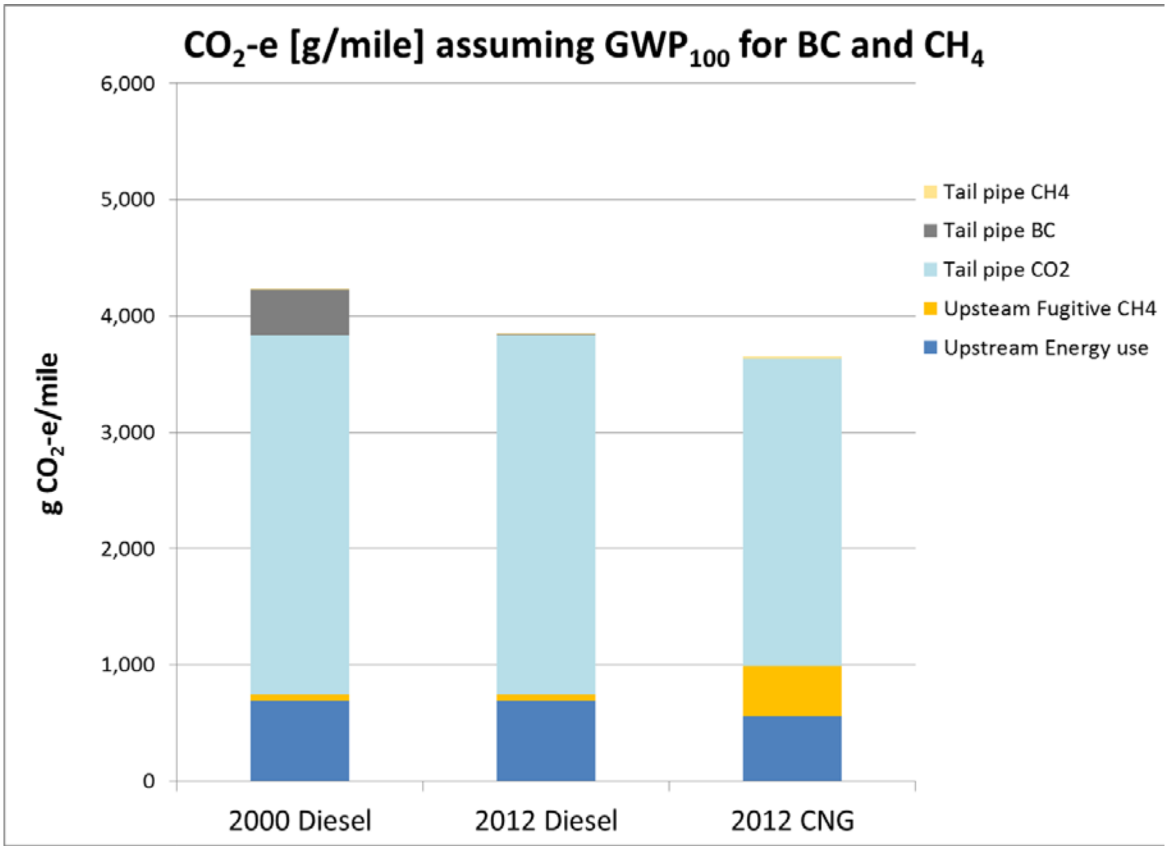

Figure 3 Wells-to-wheels GHG emissions (g/mile CO_2-e) from old diesel, new diesel and new CNG buses (assuming GWP_{100} for methane and black carbon)

Table 3 Wells-to-wheels GHG emissions (g/mile CO_2-e) from old diesel, new diesel and new CNG buses (assuming GWP_{100} for methane and black carbon)

	g CO_2-e/mile (BC & CH_4 GWP_{100})					
	Upstream Energy use	Upstream Fugitive CH4	Tail Pipe CO2	Tail Pipe BC	Tail Pipe CH4	TOTAL
2000 Diesel	691	58	3,084	397	0	4,230
2012 Diesel	691	58	3,084	8	0	3,840
2012 CNG	556	437	2,635	2	25	3,655

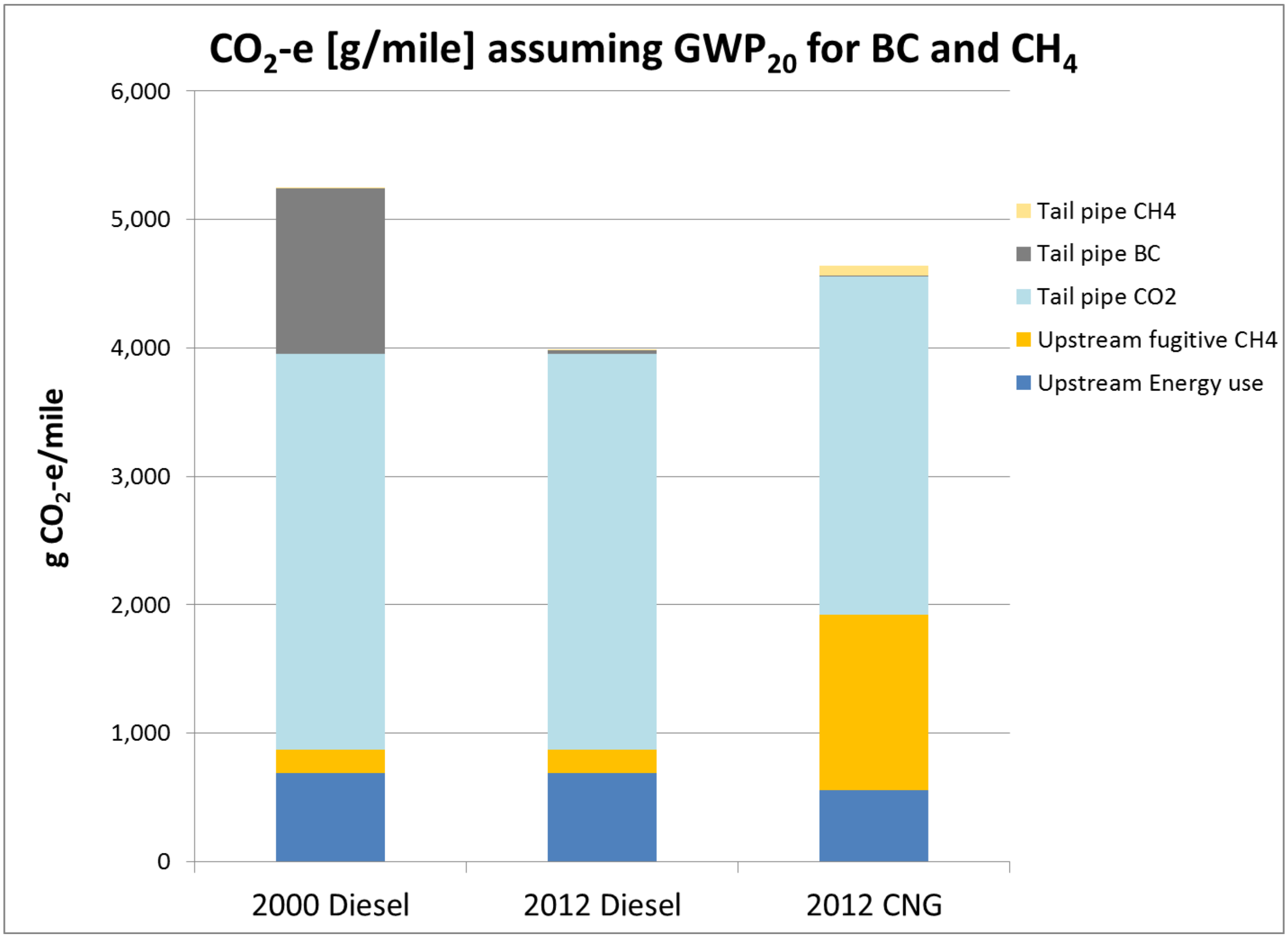

Figure 4 Wells-to-wheels GHG emissions (g/mile CO_2-e) from old diesel, new diesel and new CNG buses (assuming GWP_{20} for methane and black carbon)

	g CO_2-e/mile (BC & CH_4 GWP_{20})					
	Upstream Energy use	**Upstream Fugitive CH4**	**Tail Pipe CO2**	**Tail Pipe BC**	**Tail Pipe CH4**	**TOTAL**
2000 Diesel	691	181	3,084	1,285	0	5,241
2012 Diesel	691	181	3,084	25	0	3,981
2012 CNG	556	1,369	2,635	5	78	4,643

Table 4 Wells-to-wheels GHG emissions (g/mile CO_2-e) from old diesel, new diesel and new CNG buses (assuming GWP_{20} for methane and black carbon)