Alternative Fueled Transit Bus Fleets

Summary:
Transition 25% of Pennsylvania's existing transit buses to alternative fuels/hybrid technology by the year 2020. through an initiative that facilitates the replacement and/or conversion of the existing bus fleet to cleaner burning compressed natural gas (CNG) and/or more fuel efficient hybrid electric vehicle (HEV) technology for diesel-hybrid buses.

Discussion of Analysis:
The 2009-2010 fleet inventory lists 3,201 buses in fixed-route service. The inventory is split between 36 separate transit authorities. There are 22 urban transit systems accounting for 93% of the vehicles and 14 rural systems which comprise the remaining 7% of the vehicles. In 2009, the 2,979 urban buses traveled over 100 million miles with the urban systems accounting for 95% of the miles traveled, of which, 76% of these miles were traveled by SEPTA and PAAC. The rural systems accounted for 5% of the total miles traveled of which 42% of these miles were traveled by Area Transportation Authority (ATA) and New Castle Area Transit Authority (NCATA).

TABLE 1: Breakdown of PA Fleet's and Average Bus Miles Traveled:

TRANSIT SYSTEMS	FY 2009-10		
	Fixed Route Total Vehicle Miles	**Total Fixed Route Fleet Size**	**Average Annual Bus Miles**
SEPTA	45,027,501	1,392	32,347
PAAC	31,191,980	847	36,826
AMTRAN (Altoona)	536,238	30	17,875
BARTA (Berks)	1,726,679	53	32,579
BCTA (Beaver)	1,042,170	25	41,687
CAT (Dauphin/Cumberland)	1,951,040	78	25,013
CATA (Centre)	1,722,580	61	28,239
CCTA (Cambria)	1,163,744	47	24,761
COLT (Lebanon)	532,088	13	40,924
COLTS (Lackawanna)	1,172,356	33	35,526
EMTA (Erie)	2,037,199	73	27,907
FACT (Fayette)	544,895	10	54,490
LCTA-HPT (Hazleton)	1,463,906	50	59,175
LANTA (Lehigh/Northampton)	3,775,319	78	48,402
LCTA (Luzerne-Hazleton)	1,463,906	50	29,278
MMVTA (Mid Mon Valley)	889,897	25	35,596
POTTSTOWN	304,833	8	38,104
RRTA (Lancaster)	1,681,979	43	39,116
SVSS (Mercer)	151,387	6	25,231
WASHINGTON	192,643	5	38,529
WBT (Williamsport)	846,409	33	25,649

WCTA (Westmoreland)	939,810	33	28,479
YCTA (York)	1,566,498	36	43,514
ATA (North Central)	1,234,673	87	14,192
BTA (Butler)	231,966	6	38,661
CATA (Crawford)	232,346	7	33,192
CARBON	56,950	1	56,950
DUFAST (Clearfield)	119,819	6	23,964
EMTA (Endless Mtns)	719,095	19	34,847
ICTA (Indiana)	420,784	21	20,037
MCTA (Monroe)	508,231	15	33,882
MID-CO (Armstrong)	129,190	6	21,532
BMC (Mount Carmel)	52,275	3	17,425
NCATA (New Castle)	1,098,093	30	36,603
STS (Schuylkill)	371,415	14	26,530
TAWC (Warren)	204,656	5	40,931
VCTO (Venango)	162,888	3	54,296
TOTAL	**106,003,848**	**3,201**	**33,505**

The fleet inventory is further delineated by fuel type. For the purpose of this analysis however, we will only focus on gasoline, CNG, diesel-hybrid and diesel/biodiesel powered buses. The other fuel bus types, such as electric trackless-trolley employed by SEPTA, only account for 2.7% of SEPTA's transit fleet and are not considered in the transition scheme.

The urban transit systems make up 95% of the total transit vehicles in PA and a transition of their fleet will statistically have the largest impact. Currently, 33.9% of SEPTA's fleet is already made up of diesel-electric hybrid vehicles. SEPTA's replacement plan projects an 88.7% diesel-electric hybrid fleet by 2020. PAAC's fleet is made up of 32 diesel-electric hybrid vehicles, which is 4% of their current fleet. PAAC's replacement plan does not currently project the use of diesel-electric hybrids but rather clean diesel buses. PAAC is currently working on a CNG feasibility study that may impact future vehicle replacement decisions.

In addition to SEPTA and PAAC, other PA transit systems also have incorporated and plan to continue incorporating alternative fueled transit buses within their system. Specifically, Centre Area Transit Authority's entire fleet is operated on CNG. Some transit authorities, such as River Valley Transit of Williamsport, are progressing with plans to install CNG fueling infrastructure and to transition their bus fleet to operate on this alternative, domestically-produced fuel while some others are in the process of evaluating the costs of such a transition.

The current analysis indicates that the statewide fleet is responsible for 0.39 MMtCO2e emissions annually. Projected over 8 years (2013 through 2020), the current fleet composition would result in 3.05 MMTCO2e by 2020. These emissions were calculated using the emissions factors in Table 2, as provided by the US Department of Energy's Energy Information Administration (EIA) database and the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions and Energy Use in Transportation (GREET) model and the fuel economy factors presented in Table 3. The data in Tables 1, 2 and 3 were used to calculate the annual CO2e emissions for each fleet.

TABLE 2: Pounds of CO2 Emitted for Each Fleet Mode (GREET Model)

Bus Engine Type	**Pounds CO2/Gallon**
CNG	19.74
Diesel	25.02
Diesel-Hybrid	25.02
Gasoline	24.95

TABLE 3: Fuel Economy, MPG for Each Fleet Mode:

Data Source	**MPG**			
	Gasoline	**CNG**	**Diesel**	**Diesel - Hybrid**
U.S. Dept of Transportation Federal Transit Administration	5.5	3.27	3.86	4.58
U.S. Dept of Energy’s National Renewable Energy Laboratory New York City Transit Hybrid & Diesel Transit Buses	n/a	1.7	2.33	3.19
Environmental &Energy Study Institute	n/a	1.7	2.33	3.18
Argonne National Laboratory*	2.5	2.5	3	3.8
Centre Area Transit Authority (CATA)**	-	3.0	-	-
Southeaster PA Transit Authority (SEPTA)**	-	-	2.72	3.92

***Data selected for analysis**
****Date received from CATA and SEPTA**

Table 4 illustrates a simplified schedule for the transition of the statewide bus fleet to make a 25% transition to either CNG or HEV diesel (diesel-hybrid). Collectively, the data from each of the preceding tables was then used to estimate the projected annual CO2e emissions, through 2020, resulting from this transition, as illustrated in Tables 5A through 5C. In doing so the number of buses in the fleet was multiplied by the average annual bus miles, divided by the fuel economy (MPG) and then multiplied by the specific emissions factor for the specific fuel. The emissions reported in Tables 5A through 5C are in metric tons. The analysis shows the potential GHG emissions for different scenarios that would result if 25% of the 2010 bus fleet was operated on CNG (Scenario #1) or if 25% of the fleet was operated with diesel-hybrid technology (Scenario #2).

TABLE 4: 25% Fleet Transition Schedule:

	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total Additional Buses by Type**
CNG	77	77	77	78	78	78	78	78	621
Diesel-Hybrid	45	45	45	45	45	46	46	46	363

TABLE 5A: Baseline Annual Emissions Summary

Year	**Fixed**	**Total**	**Average**	**Bus Type**	**Emissions (MMtCO2e)**

	Route Total Vehicle Miles	Fixed Route Fleet Size	Annual Bus Miles	Gasoline	CNG	Diesel - Hybrid	Diesel	Gasoline	CNG	Diesel - Hybrid	Diesel	Total MMtCO2e
2010	106,003,848	3,201	33,116	57	90	542	2467	0.009	0.011	0.054	0.309	0.382
2011	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2012	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2013	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2014	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2015	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2016	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2017	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2018	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2019	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
2020	106,003,848	3,201	33,116	57	90	542	2,467	0.009	0.011	0.054	0.309	0.382
TOTALS	**106,003,848**	**3,201**	**33,116**	**57**	**90**	**542**	**2,467**	**0.068**	**0.085**	**0.429**	**2.472**	**3.054**

Note: Total bus type will not add "Total Fixed Route Fleet Size" because of other types of fleet vehicles, such as trackless trolley.

TABLE 5B: Estimated Annual Emissions Summary for Fleet Transitioning Under Scenario #1 (CNG)

Year	Fixed Route Total Vehicle Miles	Total Fixed Route Fleet Size	Average Annual Bus Miles	Bus Type				Emission (MMtCO2e)				
				Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel-Hybrid	Diesel	Total MMtCO2e
2013	106,003,848	3,201	33,116	57	314	542	2252	0.009	0.037	0.054	0.282	0.38
2014	106,003,848	3,201	33,116	57	370	542	2196	0.009	0.044	0.054	0.275	0.38
2015	106,003,848	3,201	33,116	57	426	542	2140	0.009	0.051	0.054	0.268	0.38
2016	106,003,848	3,201	33,116	57	483	542	2083	0.009	0.057	0.054	0.261	0.38
2017	106,003,848	3,201	33,116	57	540	542	2026	0.009	0.064	0.054	0.254	0.38
2018	106,003,848	3,201	33,116	57	597	542	1969	0.009	0.071	0.054	0.247	0.38
2019	106,003,848	3,201	33,116	57	654	542	1912	0.009	0.078	0.054	0.240	0.38
2020	106,003,848	3,201	33,116	57	711	542	1855	0.009	0.084	0.054	0.232	0.38
TOTALS	**106,003,848**	**3,201**	**33,116**	**57**	**711**	**542**	**1855**	**0.068**	**0.486**	**0.429**	**2.058**	**3.04**

TABLE 5C: Estimated Annual Emissions Summary for Fleet Transitioning Under Scenario #2 (Diesel-Hybrid)

Year	Fixed Route Total Vehicle Miles	Total Fixed Route Fleet Size	Average Annual Bus Miles	Bus Type				Emissions (MMtCO2e)				
				Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel-Hybrid	Diesel	Total MMtCO2e
2013	106,003,848	3,201	33,116	57	90	674	2288	0.009	0.011	0.067	0.287	0.372
2014	106,003,848	3,201	33,116	57	90	707	2255	0.009	0.011	0.070	0.282	0.372
2015	106,003,848	3,201	33,116	57	90	740	2189	0.009	0.011	0.073	0.274	0.367
2016	106,003,848	3,201	33,116	57	90	773	2156	0.009	0.011	0.076	0.270	0.366

2017	106,003,848	3,201	33,116	57	90	806	2123	0.009	0.011	0.080	0.266	0.365
2018	106,003,848	3,201	33,116	57	90	839	2090	0.009	0.011	0.083	0.262	0.364
2019	106,003,848	3,201	33,116	57	90	872	2057	0.009	0.011	0.086	0.258	0.363
2020	106,003,848	3,201	33,116	57	90	905	2024	0.009	0.011	0.090	0.254	0.362
TOTALS	**106,003,848**	**3,201**	**33,116**	**57**	**90**	**905**	**2024**	**0.068**	**0.085**	**0.625**	**2.152**	**2.930**

CNG and Methane Losses:

Natural resources from within the U.S., particularly from deep shale formations such as the Marcellus, offer opportunity for economic prosperity and renewed optimism for greater energy independence and security. With adherence to environmental safeguards, natural gas can easily be the cleanest of the fossil fuel options for generating electricity, providing building heat and for use in transportation however, the climate change implications of utilizing these resource can be profound.

The climate effect that results from replacing other fossil fuels with natural gas depends largely on the sector and the type of fuel being replaced. These distinctions have been for the most part absent in policy discussions. When estimating the net climate change implications of fuel-switching strategies, outcomes must be based on the complete fuel cycle, a Life Cycle Analysis (LCA), and account for changes in the radiative forcing effects (warming) of the relevant GHGs.

The EPA's latest national GHG inventory, 2009, of the amount of methane (CH^4) released from leaks and venting in the U.S. natural gas network, from production through distribution to the ultimate consumer, is 570 billion cubic feet (Bcf). This corresponds to an emissions rate equal to 2.4% of gross U.S. natural production (1.9 – 3.1% at a 95% confidence level)[1]. There may be some disagreement as to the specific level of methane leakage but EPA's value of 2.4% is based on industry-reported data. This leakage rate is applicable in the analysis of any and all utilization of natural gas and is applied to the volume of natural gas estimated to be used for transportation under this initiative.

Methane, when considered on a 100-year time horizon, is 23 to 25 times more potent of a GHG than CO_2 but over a shorter, 20-year time horizon it is 72 times more potent than CO_2[2]. The shorter time frame is particularly relevant since many policy decisions are analyzed within such a window. With the addition of more wells and increased Marcellus Shale play activity, left unchecked, the amount of fugitive and vented CH_4 emissions will only increase, compounding any efforts to decrease emissions of GHGs.

Given the 2.4% above-referenced leakage and loss rate for natural gas, along with the associated CH_4 emissions from the transportation sector itself, CNG vehicles do not currently represent a viable mitigation strategy for climate change.[3] Applying the current leakage rate for the conversion of a fleet of heavy-duty diesel vehicles to CNG would actually increase radiative forcing and only provide a net climate benefit after about 300 years .[3] Stated differently, converting a diesel fleet to CNG would result in many decades of increased greenhouse gas emissions, facilitating more rapid climate change because of the greater radiative forcing effect of methane. However, if the natural gas system leakage rate was reduced from the current estimate of 2.4% down to below 1%, CNG-powered heavy-duty vehicles would provide immediate greenhouse gas reductions[3]. In this analysis, it is assumed that the leakage rate will be reduced to 1% or less by 2016. This work plan makes the assumption that the leakage rate will be

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[1] National Academy of Science: 2012, February 2012, *Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure*

[2] Argonne National Laboratory, 2011, November 2011, *Life-Cycle Analysis of Shale Gas and Natural Gas*

[3] IBID

reduced such that additional GHG benefits can be realized, as estimated in this document. The assumption is based on the fact that implementing the measures to reduce these losses is highly cost-effective and already being deployed., In addition to the cost effectiveness, beginning in 2015, US EPA regulations will require natural gas operators to employ green completion technology to prevent gas from escaping into the atmosphere after the well has been hydraulically fractured, typically when the most methane is released. This technology captures gas and condensate that is released during the flowback period after hydraulic fracturing. By implementing green completions, emissions are expected to be reduced by up to 95%. The new Federal regulation also includes requirements for other sources of emissions in the oil and gas industry, including storage vessels. The US EPA has also encouraged operators to join the Natural Gas STAR Program. This program was first developed in 1993 and provides operators with information on cost-effective methane emission reduction technologies and practices and requires participating operators to submit annual reports describing the actions they've taken to reduce their emissions. As more and more shale wells are drilled and hydraulically fractured each year, programs like this will become more important at controlling methane leakage from natural gas production and distribution.

Emissions Reductions:

As noted in Table 5B, the 25% fleet transition to CNG buses (Scenario 1), coupled with a leak reduction rate below 1%, is estimated to result in total emissions of 0.38 MMTCO2e in 2020. The 25% increase in fleet CNG buses is the result of the addition of 621 CNG buses to the existing fleet, as suggested in Table 4. Commensurately, the number of diesel buses in the fleet is reduced by 621 units. This difference leads to an overall calculated GHG reduction of 0.003 MMtCO2e in 2020 (Table 6A) and a cumulative reduction from 2013 through 2020 of 0.01 MMtCO2e (Table 6B).

As noted in Table 5C, the 25% fleet transition to diesel-hybrid buses (Scenario 2), results in total emissions of 0.362 MMTCO2e in 2020. This fleet transition is accomplished by the addition of 363 diesel-hybrid buses to the existing fleet, as suggested in Table 4. Commensurately, the number of diesel buses in the fleet is reduced by 363 units. The net effect leads to an overall calculated GHG reduction of 0.02 MMtCO2e in 2020 (Table 6A) and a cumulative reduction from 2013 through 2020 of 0.12 MMtCO2e (Table 6B).

As noted in Tables 6A and 6B, both scenarios (CNG and diesel-hybrid) provide GHG emissions reductions however, the difference is significant, with 92% greater GHG reductions by utilizing diesel-hybrid technology. This difference is in part, due to the differences in energy density (Btu per unit of fuel) and increased fuel efficiency of diesel (includes diesel-hybrid) buses. Based on Btu values and the fuel economy data, a CNG-powered bus requires more fuel to travel an equal distance as compared to a diesel or diesel-hybrid powered bus. Diesel-hybrid buses are capable of reducing greenhouse gas emissions by as much as 75% when compared to conventional diesel buses. These reductions are a function of the electric drive system which facilitates utilization of a smaller than normal conventional internal combustion engine.

Table 6A: 2020 Annual Emissions Summary (MMtCO2e) Comparison of Baseline, CNG and HEV Scenarios

	Gasoline	CNG	Diesel-Hybrid	Diesel	Total	Reduction*
2010 Baseline	0.009	0.011	0.054	0.309	0.382	0
25% transition to CNG	0.009	0.084	0.054	0.232	0.379	0.003
25% transition to HEV	0.009	0.011	0.089	0.254	0.362	0.020

**CNG emissions reduction possible only if upstream CH4 leakage rate dips below 1%*

Table 6B: Cumulative (2013 -2020) Emissions Summary (MMtCO2e) Comparison of Baseline, CNG and HEV Scenarios

	Gasoline	CNG	Diesel-Hybrid	Diesel	Total	Reduction*
2010 Baseline	0.068	0.085	0.429	2.472	3.054	0
25% transition to CNG	0.068	0.486	0.429	2.058	3.041	0.01
25% transition to HEV	0.068	0.085	0.625	2.152	2.930	0.12

**CNG emissions reduction possible only if upstream CH4 leakage rate dips below 1%*

Table 7: Estimated Economic Costs 2013-2020

Net present value (2013-2020) at 25% transition CNG*	525.3	$million
Net present value (2013-2020) at 25% transition HEV	590.5	$million
Cost-effectiveness CNG (2013-2020)*	52,532	$/t$CO_2$e
Cost-effectiveness HEV (2013-2020)	4,921	$/t$CO_2$e

$/Mt$CO_2$e = dollars per metric ton of carbon dioxide equivalent.
*CNG emissions reduction possible only if upstream CH4 leakage rate dips below 1%

Economic Cost:

The primary cost of the transition to a CNG or diesel-hybrid fleet is the incremental purchase cost of the vehicles or the costs to retrofit or convert the few existing gasoline-powered buses to operate on CNG. CNG vehicles require a spark-ignited engine but as diesel buses are compression-ignition engines, lacking spark plugs, it is not feasible to convert a diesel bus to operate on CNG. In 2011 the MSRP of a diesel-powered, standard options Orion VII 40' low-floor transit bus was $380,000. The MSRP for the same model and optioned bus powered by CNG was $425,000 (incremental cost of $45,000), while the same bus powered by hybrid electric diesel technology was $545,000 (incremental cost of $165,000). In addition to the incremental purchase price of the vehicles other factors must be taken into consideration to determine the cost effectiveness of a transition to either CNG or diesel-hybrid transit buses. In this analysis the cost of the bus, the annual cost of fuel, the cost of compression electricity for CNG, the cost of operation and maintenance (O&M), the cost of HEV battery replacement and the cost of additional infrastructure for CNG buses (not required for diesel-hybrids) was considered. Fuel costs were based on the price at the pump at the end of March 2012 (diesel fuel at $4.17 per gallon and CNG at $2.40 per diesel gallon equivalent (DGE)). Compression electricity costs of $3,000 per month were based on publicly available data from WAVE Transit in Wilmington, Delaware. O&M costs of $1.04 for both CNG and diesel-hybrid buses were calculated using a formula provided in the NYCT study and the available data provided for the current PA transit bus fleet. CNG fueling station costs of $1.7 million per station are from WAVE Transit. Battery replacement costs were based on an average HEV bus traction battery replacement ranging from $35,000 - $45,000 per unit. The analysis for this initiative assumes an average battery cost of $40,000. Recent information provided by SEPTA indicated that they experience lower diesel fuel costs ($2.41/gal.), lower O&M costs ($0.46/mile, depot maintenance not included) and lower battery replacement costs ($31,450/battery) for their diesel-hybrid fleet than the formulated and national laboratory data utilized in this work plan.

Along with the option to purchase original equipment manufacturer (OEM) CNG buses is the option to retrofit/convert existing fleet vehicles to CNG. CNG retrofit kits also present a sizable investment of $20,000 and more depending on size. These kits are not always the best economical route to take. A comprehensive evaluation of the existing fleet must be conducted to ascertain the merit of converting existing transit buses. In the case of older buses the age and condition of the unit must be taken into consideration in order to determine if this type of investment is warranted. A retrofit to an existing vehicle that is near the end of its useful life may experience a catastrophic failure before the investment payback period has been reached. For this reason, replacement of the bus with a new CNG bus may be the best option.

The infrastructure costs associated with the transition to a CNG-powered fleet are significant. An engineering analysis should be conducted to determine if a fleet depot has access to CNG and also has the physical capability to house CNG-related infrastructure. Major facility reconfiguration and/or the purchase of additional real estate could be required to house and maintain a CNG fleet which would result in increased capital costs over and beyond the incremental cost of the vehicles. In a report to the DEP, SEPTA conducted an evaluation of converting its fleet to CNG. They conducted an engineering study involving eight SEPTA depots and found that only two of their eight depots, (Midvale and Frontier) had the physical capability to accommodate new CNG- related infrastructure. Construction costs to retrofit these two facilities would have to include a new fueling station and existing building modifications to satisfy minimum code requirements. The cost of the retrofit to these two depots was estimated to be $34.4 M and $12.2 M respectively. Replacement costs of the other six depots ran from $35 M to $53 M.

With such a significant capital investment, SEPTA chose to transition a large portion of their fleet to diesel-hybrid buses and utilize existing infrastructure, even though the incremental cost of the new buses was higher than that of a comparable CNG unit. The use of HEV transit buses does present advantages over CNG units in that the technology does not require any reconfiguration of an existing depot as with the addition of CNG infrastructure.

Along with the cost of CNG fueling stations there is another major consideration with CNG fueling infrastructure is the operational reliability of the CNG station. A transit agency transitioning to CNG buses in areas where CNG refueling infrastructure is limited or non-existent must rely entirely on their own depot fueling infrastructure. Unlike an event where one or two buses have mechanical problems that impacts only those vehicles, a CNG compressor failure or other serious problem with the CNG fueling station could ground the entire fleet. Because of this, redundancy of station components is a necessity for some locations adding to fleet conversion costs. Redundancy, over sizing and a back-up station provide operational reliability.

HEV technology, on the other hand, can be introduced into a transit fleet and use the existing conventional refueling infrastructure at the depot or at readily available public or private diesel fueling stations. HEV buses are also expected to have lower maintenance costs due to reduced stress and maintenance on mechanical components such as brake linings. In addition the electric drive has fewer moving parts than conventional drive units, thus requiring less maintenance than a traditional transmission. More efficient operation and higher average fuel economy of the HEV technology significantly reduce annual fuel costs over both conventional fuel and CNG transit buses. Studies indicate that on average HEV buses experience a 37 % improvement in fuel economy compared to a standard diesel bus. In comparison with CNG buses, the improved fuel economy of HEV technology increased by an average of 88% [1] with expected decreases in the summer months due to increased energy demand by vehicle accessories.[4] Maintenance costs are reported to be slightly lower for CNG buses when compared to the maintenance costs of a diesel unit. Diesel-hybrid bus maintenance costs are reported to be lower than both CNG and non-HEV diesel powered buses,[5] however our analysis indicates that they are the same.

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[4] *NREL, 2006: New York City Transit (NYCT) Hybrid (125 Order) and CNG transit Buses, Final Evaluation Results, November, 2006.*

[5] *Environmental and Energy Study Institute (EESI) "Hybrid Buses Costs and Benefits" March, 2007*

Table 7 and the following tables within the Appendix provide additional details on costs and cost-effectiveness. The cost effectiveness dollar amounts were derived by taking the numbers of CNG and diesel-hybrid buses needed to complete a 25% fleet transition of each fuel mode. For CNG buses this amounted to 621 buses and for the transition to diesel-hybrid, 363 additional buses are needed. The total cost for each scenario ($656.1 M for CNG, $776.2 M for diesel-hybrid) is divided by the total emissions reduction to determine the cost-effectiveness of each scenario, expressed as dollars per metric ton of CO2e reduced. A more detailed analysis of the data and calculations can be found in the appendix at the end of this work plan.

Key Assertions:

- HEV diesel transit buses are superior in fuel economy, emissions and have lower maintenance costs.
- GHG emissions could be further reduced if a more comprehensive public transit system were in place throughout Pennsylvania.
- The use of mandated percentages of biodiesel in the Commonwealth will further add to GHG reductions associated with the operation of HEV diesel buses. The associated incremental reductions have not been accounted for in this work plan but will be addressed separately in the Biofuel Development and In-state Production Incentive Act work plan.

Key Uncertainties:

- The largest uncertainty with this assessment involves the life cycle greenhouse gas impacts of unconventional natural gas. A number of studies have been published on the subject of GHG emissions from natural gas, e.g., the impacts of using natural gas for electricity generation and of natural gas substituted as transportation fuel.[6] While these studies are comprehensive in scope they do not present a rigorous treatment of the uncertainty and variability in estimating life cycle environmental impacts. The lifecycle GHG emissions factors applied in this assessment do not take into account unconventional natural gas which many have reported to have a greater impact on GHG emissions.
- Availability of state and federal grant dollars for AFV and infrastructure
- Cost of alternative fuels and AF technology
  - With increased manufacturing, incremental costs of AFV technology are reasonably expected to decline over time
- Increased utilization of public transit

Additional Benefits and Costs:

- Direct reduction of diesel fuel and therefore imported petroleum
- Criteria pollutants are reduced. A Northeast advanced vehicle study, conducted by the U.S. Department of Energy, demonstrated that nitrogen oxide (NOx) emissions from diesel-hybrid buses were 30% to 40% lower than conventional diesel vehicles.[7] In addition diesel-hybrid buses exhibited the lowest carbon monoxide (CO) emissions of any of the buses tested including CNG powered units.
- Criteria pollutants are reduced. A Dept. of Energy study indicated that nitrogen oxide (NOx) emissions from CNG buses were up to 59% lower than conventional diesel buses.

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6 Advanced Resources International Inc. Life-Cycle Emissions Study: Fuel Life-Cycle of U.S. Natural Gas Supplies and International LNG; 2008

[7] *Department of Energy "Early results from National Renewable Energy Laboratory Transit Bus Evaluations" May, 2005*

[8] *Department of Energy "Heavy Duty Vehilce Emissions Testing" June, 2003*

- Utilization of CNG is expected to result in increased job opportunities, at least for short-term jobs

Implementation Steps:

- Encourage transit authorities to utilize AF vehicles and AF technology buses especially HEV diesel buses when replacing transit buses that are scheduled for normal replacement.
- Keep transit authorities updated on available financial state and federal alternative fuel vehicle incentives.
- Offer special state grant solicitations for transit authorities to install AF infrastructure.
- Offer special state grant solicitations to assist transit authorities with the incremental cost associated with the purchase of HEV diesel and dedicated CNG buses.

Potential Overlap:

- The use of mandated percentages of biodiesel in the Commonwealth will further add to GHG reductions associated with the operation of HEV diesel buses. The associated incremental reductions have not been accounted for in this work plan but will be addressed separately in the Biofuel Development and In-state Production Incentive Act work plan.

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Appendix

Fleet Base Year	FY 2009-10		Number of Buses by Type				Emissions Tons CO2e				
	Total Fixed Route Fleet Size	Average Annual Bus Miles	Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel / Hybrid	Diesel	Total Tons CO2e
2013-2020	3,201	33,116	57	90	542	2467	9,419.2	11,766.8	59,089.6	340,677.2	420,952.7

CNG Scenario: Fleet Stats

Year			Number of Buses by Type			
	Total Fixed Route Fleet Size	Average Annual Bus Miles	Gasoline	CNG	Diesel-Hybrid	Diesel
2013	3,201	33,116	57	314	542	2243
2014	3,201	33,116	57	370	542	2187
2015	3,201	33,116	57	426	542	2131
2016	3,201	33,116	57	483	542	2075
2017	3,201	33,116	57	540	542	2018
2018	3,201	33,116	57	597	542	1961
2019	3,201	33,116	57	654	542	1904
2020	3,201	33,116	57	711	542	1847
TOTAL	**3,201**	**33,116**	**57**	**711**	**542**	**1847**

CNG Scenario: Vehicle and Fuel Costs

Year	Vehicle Cost $				Fuel Cost $			
	Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline @ $3.85	CNG @ $2.71	Diesel Hybrid @ $4.09	Diesel @ $4.09
2013	0.0	$23,800,000	0.0	0.0	$2,906,922	$11,271,892	$19,318,654	$101,267,293
2014	0.0	$23,800,000	0.0	0.0	$2,906,922	$13,282,165	$19,318,654	$98,738,997
2015	0.0	$23,800,000	0.0	0.0	$2,906,922	$15,292,439	$19,318,654	$96,210,701
2016	0.0	$24,225,000	0.0	0.0	$2,906,922	$17,338,610	$19,318,654	$93,682,404
2017	0.0	$24,225,000	0.0	0.0	$2,906,922	$19,384,782	$19,318,654	$91,108,960
2018	0.0	$24,225,000	0.0	0.0	$2,906,922	$21,430,953	$19,318,654	$88,535,516
2019	0.0	$24,225,000	0.0	0.0	$2,906,922	$23,477,125	$19,318,654	$85,962,071
2020	0.0	$24,225,000	0.0	0.0	$2,906,922	$25,523,296	$19,318,654	$83,388,627
TOTAL	**0.0**	**$192,525,000**	**0.0**	**0.0**	**$31,976,147**	**$168,755,295**	**$212,505,198**	**$1,057,866,225**

CNG Scenario: O&M Costs

Year	O&M Cost $ (Facility & Propulsion Maintenance)				O&M Cost $ (Compression Electricity)				O&M Cost $ (Battery Replacement)			
	Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel Hybrid	Diesel	Gasoline	CNG	Diesel Hybrid	Diesel
2013	0	$10,814,361	$18,666,827	0	0	$36,000	0	0	0	0	0	0
2014	0	$12,743,037	$18,666,827	0	0	$36,000	0	0	0	0	0	0
2015	0	$14,671,713	$18,666,827	0	0	$36,000	0	0	0	0	$21,680,000	0
2016	0	$16,634,829	$18,666,827	0	0	$36,000	0	0	0	0	0	0
2017	0	$18,597,946	$18,666,827	0	0	$36,000	0	0	0	0	0	0
2018	0	$20,561,062	$18,666,827	0	0	$36,000	0	0	0	0	0	0
2019	0	$22,524,179	$18,666,827	0	0	$36,000	0	0	0	0	0	0
2020	0	$24,487,295	$18,666,827	0	0	$36,000	0	0	0	0	0	0
TOTAL	**0**	**$161,905,449**	**$205,335,096**	**0**	**0**	**$396,000**	**0**	**0**	**0**	**0**	**$21,680,000**	**0**

CNG Scenario: Costs Associated with Refueling Infrastructure

Year	Total Fixed Route Fleet Size	Average Annual Bus Miles	Number of Buses by Type				Additional Infrastructure (CNG Stations)			
			Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel Hybrid	Diesel
2013	3,201	33,116	57	314	542	2243	0	$5,559,000	0	0
2014	3,201	33,116	57	370	542	2187	0	$5,559,000	0	0
2015	3,201	33,116	57	426	542	2131	0	$5,559,000	0	0
2016	3,201	33,116	57	483	542	2075	0	$5,559,000	0	0
2017	3,201	33,116	57	540	542	2018	0	$5,559,000	0	0
2018	3,201	33,116	57	597	542	1961	0	$5,559,000	0	0
2019	3,201	33,116	57	654	542	1904	0	$5,559,000	0	0
2020	3,201	33,116	57	711	542	1847	0	$5,559,000	0	0
TOTAL	**3,201**	**33,116**	**57**	**711**	**542**	**1847**	**0**	**$61,149,000**	**0**	**0**

Diesel – Hybrid Scenario: Fleet Stats

Year			Number of Buses by Type			
	Total Fixed Route Fleet Size	Average Annual Bus Miles	Gasoline	CNG	Diesel-Hybrid	Diesel
2013	3,201	33,116	57	90	674	2335
2014	3,201	33,116	57	90	707	2302
2015	3,201	33,116	57	90	740	2269
2016	3,201	33,116	57	90	773	2236
2017	3,201	33,116	57	90	806	2203
2018	3,201	33,116	57	90	839	2170
2019	3,201	33,116	57	90	872	2137
2020	3,201	33,116	57	90	905	2104
TOTAL			**57**	**90**	**905**	**2104**

Diesel – Hybrid Scenario: Vehicle and Fuel Costs

Year	Vehicle Cost $				Fuel Cost $			
	Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline @ $3.85	CNG @ $2.71	Diesel Hybrid @ $4.09	Diesel @ $4.09
2013	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$24,023,566	$105,420,922
2014	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$25,199,794	$103,931,034
2015	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$26,376,023	$102,441,145
2016	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$27,552,251	$100,951,256
2017	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$28,728,479	$99,461,367
2018	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$29,904,707	$97,971,478
2019	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$31,080,935	$96,481,589
2020	$0	$0	$17,985,000.0	$0	$2,906,922	$3,230,797	$32,257,163	$94,991,701
TOTAL	$0	$0	**$197,835,000.0**	$0	**$31,976,147**	**$35,538,767**	**$290,136,248**	**$1,126,852,593**

Diesel – Hybrid Scenario: O&M Costs

Year	O&M Cost $ (Facility & Propulsion Maintenance)				O&M Cost $ (Compression Electricity)				O&M Cost $ (Battery Replacement)			
	Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel-Hybrid	Diesel	Gasoline	CNG	Diesel Hybrid	Diesel
2013	0	3,099,658	23,212,991	0	0	$36,000	0	0	0	0	0	0
2014	0	3,099,658	24,349,532	0	0	$36,000	0	0	0	0	0	0
2015	0	3,099,658	25,486,074	0	0	$36,000	0	0	0	0	$1,320,000	0
2016	0	3,099,658	26,622,615	0	0	$36,000	0	0	0	0	$1,320,000	0
2017	0	3,099,658	27,759,156	0	0	$36,000	0	0	0	0	$1,320,000	0
2018	0	3,099,658	28,895,697	0	0	$36,000	0	0	0	0	$1,320,000	0

2019	0	3,099,658	30,032,238	0	0	$36,000	0	0	0	0	$1,320,000	0
2020	0	3,099,658	31,168,779	0	0	$36,000	0	0	0	0	$1,320,000	0
TOTAL	**0**	**34,096,234**	**280,346,810**	**0**	**0**	**$396,000**	**0**	**0**	**0**	**0**	**$7,920,000**	**0**