Integrating Alternative Fuels into Long-term Air Quality Planning

Final Report

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Technical Report

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Prepared by
ICF International
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Metropolitan Energy Center, a 501(c)3 based in Kansas City, serves as the lead in this U.S. Department of Energy funded project. MEC provides staffing and administration for the Kansas City Regional Clean Cities Coalition.

The Mid-America Collaborative for Alternative Fuels is the Kansas City Regional Clean Cities Coalition, Nebraska Clean Cities Coalition, St. Louis Regional Clean Cities and the Iowa Clean Cities Coalition. The Collaborative endorses a multi-pronged approach where appropriate fuel diversity creates an energy secure future. We aim to eliminate obstacles to adoption of vehicles and infrastructure using natural gas, B20 biodiesel, E85 ethanol, propane autogas, electricity, and hybrid electric technologies. The project is funded by U.S. DOE Award DE-EE0006009. Visit www.metroenergy.org to learn more about the Collaborative.

Mid-America Collaborative for Alternative Fuels Implementation

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NOTICE

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Abbreviations and Acronyms

AC	Alternative current
AFV	Alternative Fuel Vehicle
B5	5% by volume blend of biodiesel with diesel
B20	20% by volume blend of biodiesel with diesel
B50	50% by volume blend of biodiesel with diesel
B100	100% by volume biodiesel
BEV	Battery Electric Vehicle
CAFE	Corporate average fuel economy
CARB	California Air Resources Board
CEC	California Energy Commission
CH4	Methane
CNG	Compressed Natural Gas
DC	Direct current
DGE	Diesel Gallon Equivalent
E85	85% by volume ethanol blend with gasoline
E100	100% by volume ethanol
EMFAC	Emission Factor
EPA	US Environmental Protection Agency
ERF	Emission reduction factor
EWGCOG	East-West Gateway Council of Government
FCV	Fuel cell vehicle
FFV	Flex-fuel vehicle
GGE	Gasoline Gallon Equivalent
H2	Hydrogen
H2O	Water
HD	Heavy-duty
HDV	Heavy-duty vehicle
ICE	Internal combustion engine
I/M	Inspections and maintenance
Il EPA	Illinois Environmental Protection Agency
kW	Kilowatt
kWh	Kilowatt-hour
LD	Light-duty
LDV	Light-duty vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MAC	Mid-America Collaborative for Alternative Fuels Implementation
MD	Medium-duty

Abbreviations and Acronyms (cont.)

MDV	Medium-duty vehicle
MEC	Metropolitan Energy Center
MO DNR	Missouri Department of Natural Resources
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organizations
NGV	Natural gas vehicle
NOx	Oxides of Nitrogen
OBVP	on-board refueling vapor recovery
PEV	Plug-In Electric Vehicles
PHEV	Plug-In Hybrid Electric Vehicles
PHEV10	PHEV with 10 miles equivalent all electric range
PHEV40	PHEV with 40 miles equivalent all electric range
PM	Particulate matter
SUV	Sport utility vehicle
UMN	University of Minnesota
US DOE	United States Department of Energy
V	Volt
VMT	Vehicle Miles Traveled
VOC	Volatile organic compound

Executive Summary

Metropolitan Energy Center (MEC) and the Clean Cities coalitions in the Mid-America Collaborative for Alternative Fuels Implementation (MAC), covering Missouri, Kansas, Nebraska and Iowa, expressed the need of a tool and methodology to better understand and incorporate alternative fuel vehicles (AFV) into air quality and transportation planning processes. The advantages of using alternative fuels can be substantial. Most alternative fuel vehicles produce lower tailpipe emissions of particulate matter (PM), nitrogen oxides (NOx), volatile organic compounds (VOCs), and other pollutants that cause air pollution and adverse public health effects. However, the emissions benefits of AFVs can vary widely, and it can be difficult for public agencies to estimate the magnitude of these benefits using current analysis tools.

ICF created a step-by-step methodology for developing AFV scenarios and analyzing the associated emissions benefits at the metropolitan area scale and completed a pilot study of the St. Louis metropolitan area using the methodology. A requirement of the methodology was that it could be replicated by other metropolitan planning organizations (MPOs). Baseline tailpipe emission factors from gasoline and diesel were derived from the current version of the U.S. Environmental Protection Agency's MOVES (Motor Vehicle Emission Simulator) model (version MOVES2010b) and supplemented with other research studies and agencies within the St. Louis metropolitan area. ICF performed a review of available and potential alternatives to gasoline and diesel in the various vehicle market segments and narrowed the list down to ethanol, biodiesel, natural gas, electricity, and propane. Emission reduction factors (ERF) were developed compared to gasoline and diesel to quantify the PM, NOx, and VOC emission reductions from converting to alternative fuels.

From the MOVES results and ERFs, ICF developed an Alternative Fuels for Air Quality (AFAQ) Tool. The Tool was then tested through the pilot study using the St. Louis metropolitan area using AFV scenarios for select vehicle market segments and fuels developed in consultation with MAC. The results of these scenarios were compared to show how various AFV penetration rates affect different vehicle class sectors and overall emission reductions. The pilot study for the St. Louis region was successful in demonstrating the tool can be used as part of an air quality and transportation planning process and that the methodology can be replicated by other MPOs for regional-specific analysis.

1 Introduction

1.1 Purpose of Study

The purpose of this study is to provide Metropolitan Energy Center (MEC) and the Clean Cities coalitions in the Mid-America Collaborative for Alternative Fuels Implementation (MAC), covering Missouri, Kansas, Nebraska and Iowa, with information and tools to better incorporate alternative fuel vehicles (AFV) into air quality and transportation planning processes.

The advantages of using alternative fuels can be substantial. For many, the most compelling reason to switch to alternative fuels is the environmental benefits. Most alternative fuel vehicles produce lower emissions of particulate matter, nitrogen oxides, and other pollutants that cause air pollution and adverse public health effects. Most alternative fuel vehicles also produce fewer greenhouse gas (GHG) emissions that contribute to global climate change. While many state and local governments recognize the promise of alternative fuels, the path forward is often unclear because the emissions benefits of AFVs can vary widely and it can be difficult for public agencies to estimate the magnitude of these benefits using current analysis tools.

Transportation and air quality agencies have expressed the need for a methodology and corresponding analysis that could assign air quality outcomes to alternative fuel implementation strategies included in their long term planning efforts. To address this need, ICF created a step-by-step methodology for developing AFV scenarios and analyzing the associated emissions benefits at the metropolitan area scale. A pilot study of the St. Louis metropolitan area was conducted using the methodology, which serves as an example that can be replicated by other planning organizations. From this, ICF developed the Alternative Fuels for Air Quality (AFAQ) Tool for MAC to help encourage the use of cleaner burning alternative fuel vehicles and equipment.

1.2 Description of Alternative Fuels

The major alternatives to gasoline and diesel include biofuels (ethanol and biodiesel), fossil fuel alternatives (natural gas and propane), and electricity. These fuels differ widely in terms of their sources and applications. This section provides an overview of the five major transportation alternative fuels.

Ethanol

Description

Ethanol is a renewable fuel made from various plant materials collectively referred to as biomass. Also known as ethyl alcohol, it is a clear, colorless liquid. Ethanol can be made from corn grain (typical in the United States), sugar cane (mainly in Brazil), or cellulosic feedstocks (non-food-based feedstocks such as crop residues). Currently, the United States produces almost all of its ethanol from corn feedstocks, with small niche markets using other materials. Ethanol is produced largely in the Midwest, corresponding with the bulk of the nation's corn production. The U.S. ethanol industry includes more than 200 operational production facilities and a number of facilities currently under construction.

Cellulosic ethanol is produced from dedicated energy crops, such as wood chips or crop residues. While it is more difficult to release the sugars in these feedstocks for ethanol production, they offer several advantages over starch and sugar crops. Cellulosic feedstocks are more abundant and can include waste products or feedstocks that can be grown on land not appropriate for other crops. In addition, less energy is required to grow, collect, and convert these feedstocks to ethanol. Researchers are currently addressing challenges associated with cellulosic ethanol production. For example, enzymes and microbes are currently under development that can accelerate deconstruction of cellulosic biomass into the sugars used for ethanol production.[1]

Ethanol's octane number is greater than gasoline, making it ideal for blending with gasoline (octane increases vehicle power and performance). The energy content of ethanol is less than that of gasoline; 1 gallon of pure ethanol (E100) contains approximately 34% less energy than 1 gallon of gasoline.

More than 95% of gasoline used for transportation in the United States contains up to 10% ethanol to boost octane levels, meet air quality requirements, or satisfy mandates such as the U.S. Environmental Protection Agency's (EPA's) Renewable Fuel Standard. E10 (gasoline mixed with 10% ethanol) can be used in any gasoline-powered vehicle. Other low-level blends of ethanol are also available, and E15 was recently approved by EPA for use in conventional gasoline vehicles that are model years 2001 and newer.

Uses and Applications

Ethanol is used as a substitute for conventional gasoline in light-duty vehicle (LDV) applications. While low-level blends can be used in gasoline-powered vehicles without alterations, E85 has different properties than gasoline. Consequently, only automobiles with compatible fuel systems and powertrain calibration can operate using the fuel. These vehicles are referred to as flexible fuel vehicles (FFVs). FFVs have an internal combustion engine (ICE) and are capable of operating on gasoline, E85, or a mixture of the two. From the driver's perspective, the only difference between FFVs and conventional gasoline-powered vehicles is the reduced fuel economy when using E85 or other mid-level blends. Gasoline-powered vehicles can be converted to FFVs, although it requires extensive modifications to the original vehicle.

FFVs are widely available from nearly every major auto manufacturer, in part because manufacturers are able to earn credits toward the federal corporate average fuel economy (CAFE) standards by selling FFVs. Ford, Chrysler, and General Motors offer the widest variety of FFVs. Most models of pick-up

[1] Renewable Fuels Association, 2012, "Statistics," http://www.ethanolrfa.org/pages/statistics#C

trucks, sport utility vehicles (SUVs), and vans, as well as many sedans, are available with an FFV option. The price of a new FFV is typically similar or identical to its gasoline counterpart.

Presently, E85 FFVs account for two of every three alternative fuel vehicles in use nationwide. It is important to note, however, that many (perhaps most) FFVs are fueled primarily with gasoline.

Biodiesel

Description

Biodiesel is a renewable fuel made by reacting animal or vegetable fats with alcohol. Approximately 70% of the nation's biodiesel is produced in the Midwest, where soybean oil is the dominant biodiesel feedstock.[2]

Most biodiesel is used in low-level blends, usually as 5% or 20% biodiesel blended with conventional diesel (referred to as B5 or B20, respectively). B20 is the highest blend of biodiesel commonly used in the United States as it provides good cold-weather performance, is generally cost effective, and can be used in most engines without modification. Fifty percent (B50) and pure biodiesel (B100) are available in the marketplace and can be used in some engines without modification, although equipment changes may be necessary in other engines.

Uses and Applications

In contrast to most other alternative fuels, biodiesel does not require a specific alternative fuel vehicle. Depending on the blend level, biodiesel can be used in most conventional diesel vehicles. High-level blends tend to have a solvent effect that cleans a vehicle's fuel system and releases deposits accumulated from previous petroleum diesel use. Once released, these deposits may initially clog filters and require filter replacement in the first few tanks of high-level biodiesel blends. As such, vehicle operators should consult their vehicle and engine warranty statements before using biodiesel, particularly before using biodiesel blends higher than B5.

Biodiesel can have a limited shelf life due to factors such as contamination and exposure to air, extreme temperatures, and additives. Shelf life issues are a greater concern with higher blends. Proper fuel management can dramatically extend biodiesel's shelf-life to a year or more, which is on par with conventional diesel.

2 U.S. Energy Information Administration, 2012, "Monthly Biodiesel Production Report: May 2012," http://www.eia.gov/biofuels/biodiesel/production/

A majority of the biodiesel used in the United States is consumed by commercial fleets and government entities, including transit agencies, waste haulers, and school districts. As of 2009, 6% of transit buses nationwide were using biodiesel in some blend. More recent information from the American Public Transportation Association suggests that this fraction is now closer to 8%.[3]

Most heavy-duty diesel engine manufacturers state that using up to B20 will not void engine warranties. Many fleets have successfully used B50 to B99 blends for several years or more.[4] In 2008, the American Society for Testing and Materials adopted biodiesel standards for blends up to B20 and for B99.

Natural Gas

Description

Natural gas is an odorless, gaseous mixture of hydrocarbons, predominantly composed of methane (CH4). One-quarter of the energy used in the United States is produced by natural gas. With plentiful reserves bolstered by newly accessible gas in shale formations, natural gas is a reliable, primarily domestic source of clean-burning fuel. Natural gas is typically extracted from gas and oil wells, as well as from supplemental sources such as biomass and coal. Gas trapped in reservoirs is extracted through drilling. Advances in hydraulic fracturing technologies have provided access to large volumes of natural gas from shale formations. In addition, natural gas can be derived from biogas, which is produced through anaerobic digestion of organic matter in biomass waste materials.

Natural gas in compressed (CNG) or liquefied (LNG) form is used as a transportation fuel. The high octane number of natural gas makes it suitable for spark ignition (gasoline) engines with some modifications. Heavy-duty natural gas vehicles are also available. Some use spark ignition natural gas systems, while others use high-pressure direct injection in a compression ignition (diesel) cycle.

CNG is stored onboard a vehicle in cylinders pressurized at 3,000–3,600 pounds per square inch (psi). A CNG-powered vehicle has a similar fuel economy to a gasoline vehicle on a gasoline gallon equivalent (GGE) basis, with a GGE equal to approximately 5.66 pounds of CNG. CNG is used in light-, medium-, and heavy-duty vehicles.

Purifying natural gas and super-cooling it to -260°F creates LNG. Because it must be kept at cold temperatures, LNG is stored in double-walled, vacuum-insulated pressure vessels. Liquid is more dense than gas (CNG), so LNG is beneficial for vehicles that require a longer driving range—as more energy can be stored by volume in an LNG tank. As such, LNG is typically used in medium- and heavy-duty vehicles. A gallon of LNG has approximately 66% of the energy in a gallon of diesel; consequently, a diesel gallon equivalent (DGE) equals approximately 1.5 gallons of LNG.

3 American Public Transportation Association, "Transit on the Cutting Edge of Clean Technology," September 2012

4 California Energy Commission, 2009, "Investment Plan for the Alternative and Renewable Fuel and Vehicle Technology Program," http://www.energy.ca.gov/2009publications/CEC-600-2009-008/CEC-600-2009-008-CMF.PDF

Uses and Applications

Natural gas can be used in virtually all types of on-road vehicles. There are actually three different types of natural gas vehicles (NGVs):

- Dedicated, which run only on natural gas
- Bi-fuel, which can use either natural gas or gasoline
- Dual-fuel, which run on natural gas and use diesel for ignition assistance

Dual-fuel vehicles are traditionally limited to heavy-duty vehicles (HDVs). Dedicated NGVs tend to demonstrate better performance and produce lower emissions than bi-fuel vehicles. Because dedicated NGVs have only one fuel tank, they weigh less than bi-fuel NGVs and offer more cargo capacity.

Although extra storage tanks can increase the range of an NGV, the additional weight may decrease the amount of cargo the vehicle can carry.

For light-duty uses, the only NGV currently available from an original equipment manufacturer (OEM) is the CNG Honda Civic. More models are available for medium-duty truck and van applications. For example, a 2013 GMC Savana cargo van is available in a CNG version.[5] Many of the other on-road NGVs in use today are conversions.

For medium- and heavy-duty trucks, natural gas options are widely available. For example, medium-duty natural gas trucks are available from Ford, Freightliner, Kenworth, and Peterbilt, among others. Natural gas street sweepers and refuse trucks are produced by several manufacturers. Scranton Manufacturing produces CNG New Way Trucks for refuse hauling and is headquartered in Iowa.

Among transit buses, natural gas has been the dominant alternative fuel. Approximately 12,000 natural gas transit buses are in operation nationwide, or 19% of the national bus fleet.[6]

[5] http://www.gmc.com/savana-cargo-van.html

[6] National Transit Database 2012, Table 17 – Energy Consumption. http://www.ntdprogram.gov/ntdprogram/pubs/dt/2012/excel/DataTables.htm

Propane

Description

Liquefied petroleum gas (LPG) is commonly referred to as propane. *Autogas* is another term specific to propane used in transportation. Propane turns into a colorless, odorless liquid when stored under pressure inside a tank. As pressure is released, the liquid propane vaporizes and turns into a gas, which is used for combustion. Propane presents no threat to soil, surface water, or groundwater. Additionally, propane has a high octane rating, which allows for increased vehicle power and performance.

Nearly all U.S. propane supply is produced in North America either as a by-product of natural gas processing or by crude oil refining. Pipelines, railroads, barges, trucks, and tanker ships are used to ship propane from its points of production to bulk distribution terminals. Trucks are filled at the terminals, and propane dealers then distribute propane to end users, which include retail fuel sites.

Uses and Applications

Propane is mainly used in light-duty pick-up trucks, taxis, medium-duty vans, and heavy-duty school buses. Propane is well suited for spark ignition engines, and gasoline engines can be converted relatively easily to use propane. The high octane rating of propane (104–112 compared to 87–92 for gasoline), combined with low carbon and oil contamination characteristics, results in engine life that can last up to two times longer than a gasoline engine. Propane can be stored onboard a vehicle as a liquid at a low pressure—between 100 and 200 psi, allowing for refueling times comparable to gasoline refueling.

The cruising speed, power, and acceleration of propane vehicles are similar to those of gasoline-powered vehicles. Propane has approximately 73% the energy content of gasoline per gallon; therefore, the typical range of an LDV equipped with a 20-gallon tank is approximately 250 miles. Driving range can be increased by adding additional storage tanks; however, the added weight displaces payload capacity.

Because few propane vehicles are offered by OEMs, propane normally requires conversion of a gasoline vehicle. Companies providing propane conversions include Bi-Phase Technologies, CleanFuel USA, Icom North America, IMPCO Technologies, and Roush CleanTech.

In addition to the applications noted above, propane has a niche among transit fleets and can also be well suited to off-road applications such as fork lifts, commercial mowers and other grounds maintenance equipment, and airport ground support equipment.

Electricity

Description

Electricity can be used to power all plug-in electric vehicles (PEVs), which include battery electric vehicles (BEVs, which run exclusively on electricity) and plug-in hybrid electric vehicles (PHEVs, which

can run both on electricity and other fuels, typically gasoline). All PEVs draw electricity from off-board electrical power sources (i.e., the electrical grid) and store the electricity as chemical energy in onboard batteries. In a BEV, the battery powers an electric motor. PHEVs also have an electric motor that uses energy stored in a battery, as well as an internal combustion engine (ICE) that can run on petroleum or alternative fuel depending on the vehicle design. All PHEVs commercialized at scale today use electricity and gasoline. An important distinction between PHEVs is the equivalent all-electric miles, which is directly proportional to the size of the battery. PHEV10 and PHEV40 are PHEVs that have 10 and 40 mile equivalent all-electric range, respectively, on a full charge. While PHEV40s have battery capacities to travel 40 miles in all-electric range, due to insufficient recharging and a subset of the population with daily commutes greater than 40 miles in day, data from the EV Project shows that GM Volt owners (PHEV40) drive an average of 30 miles per day in all-electric mode.[7] Increased use and availability of opportunity charging during the day and fully charging the battery during the night can increase the amount of electric vehicle miles traveled from PHEVs.

PEVs are charged by plugging into charging equipment, often known as electric vehicle supply equipment (EVSE). Electric vehicle supply equipment is generally categorized in terms of its level, a term that refers to the range of current or voltage at which the equipment is designed to support the charging of the vehicle. Charging times vary and can range from 15 minutes to 20 hours or more, depending on factors such as battery size and type, and the type of charging equipment used. AC level 1 EVSE supports conductive charging at current levels up to 16 amperes (A), at voltage levels of 120 alternating current volts (VAC), common in standard outlets. AC level 2 EVSE supports conductive charging at current levels between 12 and 80 A, using 208 to 240 VAC circuits. There is a third type or level of equipment, known as DC fast charge (sometimes referred to as DC level 3), which uses direct current. This type of equipment enables charging at much higher current, and has a rated power in the order of 50kW. DC fast charging equipment uses a charger included in the equipment, while level 1 and 2 use the charger in the vehicle. DC fast chargers require a different connector, for which a standard is currently being developed in the United States. In addition, inductive charging uses an electromagnetic field to transfer electricity. Charging equipment using inductive charging has been used since the 1990s, but conductive charging has been the dominant mode in the current large-scale commercialization of PEVs. It is possible to use inductive charging in wireless charging systems. This technology has not been deployed yet, but it is seen as one with potential and that car manufacturers are investigating.

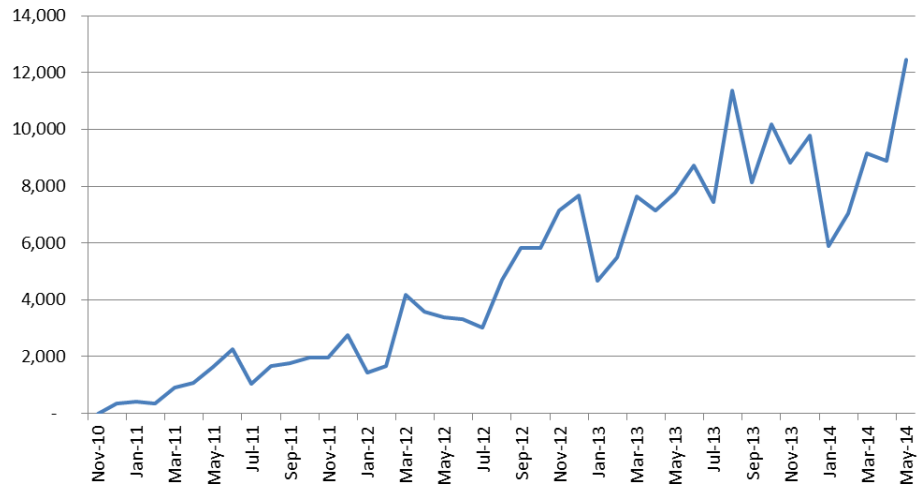
As of the date of this writing, there were 8,250 EV charging stations installed and reported across the country, with a total of over 20,000 outlets.

Uses and Applications

The cumulative sales of PEV in the United States grew to over 211,000 by the time of this writing. PEV sales in May 2014 alone amounted to 12,453, with 6,651 PHEV and 5,802 BEV; record sales in both categories. Figure 1 shows the monthly sales of PEVS from November 2010 to May 2014.

[7] http://www.theevproject.com/documents.php

Figure 1. Monthly Electric Vehicle Sales in the United States (November 2010 – May 2014)



Source: www.hybridcars.com, Hybrid Market Dashboard

There currently are 19 different models of PEVs offered in the market. The focus of large auto manufacturers is heavily on the light-duty vehicle market. Table 1 lists plug-in vehicles currently commercially available. This table excludes concept models, such as the Audi e-tron or limited production models, such as the McLaren P1. The Toyota Prius Plug-In is representative of a PHEV10 and the Chevrolet Volt is representative of a PHEV40. As manufacturers increase their model year offerings, sales are expected to increase. EVs currently make up 0.8% of all U.S. LDV sales.[8]

[8] http://www.hybridcars.com/may-2014-dashboard/

Table 1. Plug-in Light-Duty Vehicles Offered in the United States

Make	Model	Platform	Type	Battery Size (kWh)
BMW	I3	BEV	Compact/Subcompact	21
BMW	I3 with range extender	PHEV	Compact/Subcompact	
BMW	I8	PHEV	Sport	-
Cadillac	ELR	PHEV	Large	16.5
Chevrolet	Spark	BEV	Minicompact	20
Chevrolet	Volt	PHEV	Compact/Subcompact	16.5
Fiat	500e	BEV	Minicompact	24
Ford	C-Max Energi	PHEV	Midsize	7.6
Ford	Focus	BEV	Compact/Subcompact	23
Ford	Fusion Energi	PHEV	Midsize	7.6
Honda	Accord	PHEV	Midsize	6.7
Honda	Fit	BEV	Small station wagon	20
Kia	Soul	BEV	Compact	16.4
Mercedes Benz	B-Class Electric	BEV	Midsize	28
Mitsubishi	i-MiEV	BEV	Compact/Subcompact	16
Nissan	Leaf	BEV	Midsize	24
Porsche	Panamera SE	PHEV	Sport	9.4
Scion	iQ EV	BEV	Minicompact	12
Smart	fortwo	BEV	Two Seater	17.6
Tesla	Model S	BEV	Large	60
Toyota	Prius plug-in	PHEV	Midsize	5.2
Toyota	RAV 4 EV	BEV	SUV	41.8
Volkswagen	E-Golf	BEV	Midsize	24.2
Wheego	LiFe	BEV	Two Seater	30

There are some medium-vehicles (MDV) and heavy-duty vehicles (HDV) plug-in models commercially available. One of the key companies focusing in this market segment, Smith Electric Vehicles, is headquartered in the state of Missouri. Table 2 summarizes the HDV models currently available indicating the application.

Table 2. Medium and Heavy-Duty Electric Vehicles Currently Commercialized

Manufacturer	Model/Chassis	Application	Platform
Trans Tech	SST-e	School bus	All electric
DesignLine Corp.	Eco Smart 1	Transit bus	All electric
New Flyer	Xcelsior	Transit bus	All electric
Proterra	EcoRide BE35	Transit bus	All electric
Balgon	Nautilus XRE 20	Tractor	All electric
Balgon	Nautilus MX-30	Tractor	All electric
Balgon	Mule M100	Truck	All electric
Boulder Electric Vehicle	500 Series	Truck, van	All electric
Boulder Electric Vehicle	1000 Series	Truck, van	All electric
Electric Vehicles International	EVI-MD	Truck, van	All electric
Smith Electric Vehicles	Newton	Truck, school bus	All electric
Electric Vehicles International	EVI Walk-in Van	Van	All electric
Enova Systems	Enova Ze	Van	All electric
Freightliner Custom Chassis	MT E-Cell	Van	All electric
Orange EV	T-Series	Yard Truck	All electric

1.3 Layout/Progression of Report

The remainder of this report is organized into five main sections:

- Section 2 – Methodology of Determining Baseline Emission Factors
  - Describes how the baseline emissions factors used in the Planning Tool were derived using MOVES and region-specific activity level data
- Section 3 – Emission Reduction Factors
  - Describes how the alternative fuel emission reduction factors used in the Planning Tool that were not included in MOVES were developed using supplementary data and/or credible literature
- Section 4 – Scenario Analysis and Results
  - Presents and describes the results of running multiple AFV scenarios for the St. Louis region in the Planning Tool
- Section 5 – Tool User Guide
  - Presents a simple guide to using the AFAQ Tool.
- Section 6 – Conclusions

2 Methodology of Determining Baseline Emission Factors

ICF developed the following methodology to determine the baseline emissions factors that are required for estimating the air quality benefits from alternative fuel vehicle deployment. The St. Louis metropolitan area is used as an example for this study, although the methodology is generalized so that it may be used for any metropolitan area or region of interest.

Baseline emission factors are derived from the current version of the MOVES model (currently MOVES2010b), supplemented with other research studies. MOVES estimates tailpipe emissions covering a broad range of pollutants from cars, trucks, buses, and motorcycles. MOVES has two basic operating modes: it can be set to produce either emission inventories or emission factors. For regional-scale analyses, producing activity-weighted, regional average emission factors based on an inventory approach is simpler and faster than producing detailed tables of emission factors directly.

To produce aggregate baseline emission inventories in MOVES, meteorological, fuel, and fleet data was collected from regional MPOs, air quality agencies, and other state agencies. These data are used as inputs for modeling total baseline emissions of the selected pollutants and activity in MOVES. The ratio of emissions per selected activity is then used to create activity-weighted, regional average emission factors for baseline gasoline and diesel fuels.

2.1 Baseline MOVE Inputs and Activity Levels

For the St. Louis region, the activity measure considered for this analysis is vehicle miles of travel (VMT). ICF used MOVES to model baseline emission factors and activity levels for vehicle types listed in Table 3. All vehicle types listed had a population mix fueled by gasoline and diesel except motorcycles, which were solely powered by gasoline, and long-haul combination trucks and intercity buses, which were fueled only by diesel.

Table 3. MOVES Vehicle Types

Source Type ID	HPMS Type ID	Vehicle Type Name
21	20	Passenger Car
31	30	Passenger Truck
32	30	Light Commercial Truck
51	50	Refuse Truck
52	50	Single Unit Short-haul Truck
53	50	Single Unit Long-haul Truck
54	50	Motor Home
43	40	School Bus
42	40	Transit Bus
41	40	Intercity Bus
61	60	Combination Short-haul Truck
62	60	Combination Long-haul Truck
11	10	Motorcycle

To ensure accurate representation of the St. Louis metropolitan nonattainment area in baseline emissions and activity, ICF collected all inputs used in the regional conformity finding from agencies in the St. Louis region.[9] The East-West Gateway Council of Government (EWGCOG, the MPO for the St. Louis region), referred ICF to the Illinois Environmental Protection Agency (IL EPA) and the Missouri Department of Natural Resources (MO DNR) for the most current sets of MOVES inputs. St. Louis is a bi-state area where different agencies are responsible for preparation of their respective portions of the mobile source inventory for planning purposes, based on EWGCOG-provided VMT values. Both agencies provided input data and documentation for calendar year 2008, and selected future years for the conformity finding, based on the most recent PM2.5 and Ozone Plans developed for the region. In both cases, 2008 is the base year for estimations.

MO DNR provided the following non-default inputs for Franklin County, Jefferson County, St. Charles County, St. Louis County, and St. Louis City for 2008:

- Source Type Population
- Annual VMT by Source Type
- Road type Distribution
- Meteorological Data
- Age Distributions
- Inspection and Maintenance (I/M) Program

MO DNR applied an annual growth rate of 1.5% for VMT and source type population and used MOVES defaults for all other inputs when modeling future years.

IL EPA provided 2008, 2017, and 2025 inputs for the Metro-East St. Louis nonattainment area. These inputs had been aggregated to treat the entire region as a single pseudo-county referred to as St. Clair, which included the VMT data for Madison, Monroe, and St. Clair counties plus Baldwin Township.

ICF's analysis relied primarily on the provided inputs from MO DNR and IL EPA. However, we made the following modifications or simplifying assumptions:

- MO DNR "turned off" stage II refueling controls for future years based on a rule currently under development to remove this requirement in St. Louis due to widespread use of on-board refueling vapor recovery (ORVR). This rule was not included in our analysis since it has not yet been promulgated.
- Consistent with the MO DNR approach, an annual growth rate of 1.5% was applied to determine future year VMT.

[9] Air Quality Conformity Determination and Documentation 8-Hour Ozone & PM2.5 Amendment to the FY 2013-2016 Transportation Improvement Program and related amendments to Regional Transportation Plan 2040, the transportation plan for the St. Louis region – FINAL. St. Louis Metropolitan Area Board Approved January 30, 2013.

- The IL EPA approach (based on EPA MOVES Guidance) was followed for determining future year population from grown VMT using the MOVES default mileage accumulation by vehicle category, county, and year, and population share by vehicle type within each vehicle category.
- The analysis also relied on default I/M programs. This is a conservative assumption for future years where the I/M program's form is currently unknown.[10]

In all cases, the inputs for calendar years 2010, 2020, 2030, and 2040 were derived for each county. Table 4 summarizes the final inputs used in the baseline MOVES simulations.

Table 4. Inputs for Baseline MOVES Simulations

Parameter	Notes
Source_Population	Provided baseline data. Scaled from grown VMT with national default vehicle mileage accumulation.
HPMSV	Provided data. Grown to target year with 1.5% annual growth rate
VMT_Monthly	Used provided baseline data for all years.
VMT_Daily	Used provided baseline data for all years.
VMT_Hourly	Used provided baseline data for all years.
IM	Used MOVES defaults
Alternative Vehicle Fuels and Technologies (avft)	Used MOVES defaults
Fuel_Supply	Used MOVES defaults
Fuel_Formation	Used MOVES defaults
Met	Used MOVES defaults
Ramp_Fraction	Used provided baseline data for all years.
Road_Type_VMT_Fraction	Used provided baseline data for all years.
Age_Distribution	Used provided baseline data for all years.
Speed_Distribution	Used provided baseline data for all years.

2.2 Resulting Baseline Emissions Factors and Activity Levels

County-level MOVES simulations were conducted for each of the five Missouri counties and the one Illinois pseudo-county for each year to determine total baseline emissions for the pollutants NOx, fine particulates (PM2.5), coarse particulates (PM10), and VOC, and the activity for gasoline and diesel fueled vehicles. All regions were summed to determine VMT-weighted average running emission factors for the entire St. Louis nonattainment area for each vehicle type. These average factors are unique to each

[10] Note that the MOVES modeling here generates a set of emission factors representative of the St. Louis area for testing purposes only. For application to a real area, custom emission factors must be derived, and any of the assumptions here could be overridden.

vehicle-fuel combination and incorporate all the relevant, underlying drive cycle and meteorological data for the region.

Not all emissions processes are included here. Brake wear and tire wear are excluded as they would be uniform across all baseline and alternative fuels, and thus represent no reduction potential. Evaporative processes and starting emission process emission factors were also excluded from these results (and the tool that implements them) since alternative fuel reduction factor data is limited. Furthermore, simulating evaporative processes requires significant computational power to calculate hourly emissions for each county-year combination.[11] Accordingly, baseline emission factors include only running exhaust emissions and baseline activity factors include only VMT.

Although the structure of the tool relies on input for all 13 MOVES vehicle classes, the baseline emission factor results have been aggregated to a two-vehicle scheme: light and heavy vehicles. Table 5 presents the designation of each vehicle type in either the light or heavy duty class.

Table 5. Vehicle Definitions for Baseline Activity Factors

Designation	HPMS Class	MOVES use type
Light Duty	Motorcycles	11. Motorcycle
	Passenger Cars	21. Passenger Car
	Other 2-axle / 4-tire Vehicles	31. Passenger Truck 32. Light Commercial Truck
Heavy Duty	Buses	41. Intercity Bus 42. Transit Bus 43. School Bus
	Single Unit Trucks	51. Refuse Truck 52. Single-Unit Short-Haul Truck 53. Single-Unit Long-Haul Truck 54. Motor Home
	Combination Trucks	61. Combination Short-Haul Truck 62. Combination Long-Haul Truck

Table 6 summarizes the aggregate, activity-weighted, baseline emission factors derived from MOVES within this scheme.

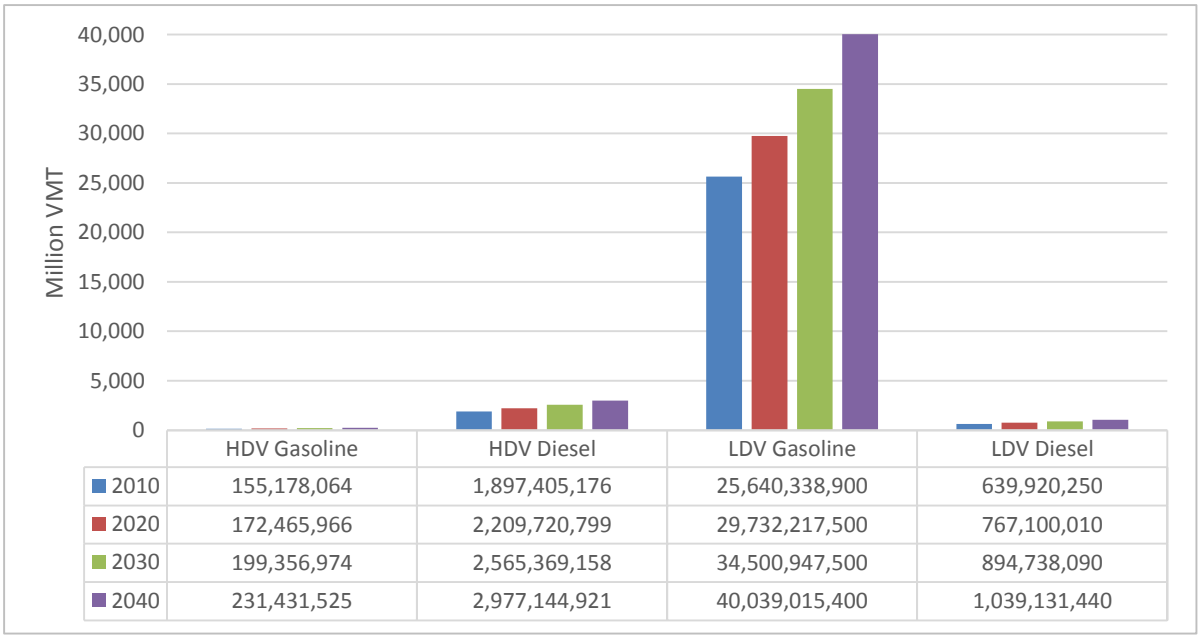
[11] Instead, monthly resolution was used throughout as a compromise. This generally increases accuracy over annual aggregation, is reasonably fast in execution, and avoids a model bug involving annual aggregation at the county level for leap years.

Table 6. Two-Vehicle Category Baseline Net Emission Rates (g/mi)

	HDV				LDV			
	2010	2020	2030	2040	2010	2020	2030	2040
NOx								
Gasoline	1.92	1.67	1.65	1.65	0.38	0.12	0.09	0.09
Diesel Fuel	5.58	1.26	0.78	0.73	1.84	0.57	0.33	0.31
PM10 Total Exhaust								
Gasoline	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Diesel Fuel	0.29	0.04	0.02	0.01	0.12	0.02	0.01	0.00
PM2.5 Total Exhaust								
Gasoline	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Diesel Fuel	0.28	0.04	0.02	0.01	0.12	0.02	0.01	0.00
VOC								
Gasoline	0.41	0.34	0.34	0.34	0.08	0.03	0.02	0.02
Diesel Fuel	0.29	0.05	0.02	0.02	0.27	0.05	0.01	0.01

Baseline activity imported to the tool was also taken from the MOVES simulations.[12] Figure 2 presents the baseline activity metric – total annual VMT– for the modeled area using the same two-vehicle and fuel categories shown in Table 5.

Figure 2. Annual Projected Baseline VMT, 2010-2040



[12] Note that this activity is identical to the baseline activity collected from the regions and input to the MOVES simulations, although reformatted slightly to agree with the same vehicle and fuel categories as the model's emissions outputs.

3 Emission Reduction Factors

Although MOVES is structured to eventually allow modeling of most of the alternative fuels of interest, the current version of MOVES does not simulate high ethanol blends (E85), electric vehicles (EVs), or propane (LPG). Compressed natural gas (CNG) is currently included only for transit buses. B100 emission reduction factors are derived from MOVES model runs. Therefore, ICF needed to develop emission reduction factors outside of MOVES. For all fuels but biodiesel, supplementary data and/or emission factors from literature results were included in the tool. The reduction factors are then applied to the baseline (e.g., gasoline or diesel) emission factors derived from MOVES to estimate emission reduction potential for each alternative fuel.

The emissions impacts of alternative fuels compared to gasoline and diesel is still an area of ongoing research. With the rapidly changing emission standards and emission control technologies for conventional and alternative fuel vehicles, it is difficult for research to stay current and supply an apples-to-apples comparison of comparable vehicles, engine sizes, and operation duty cycles.[13] The three main sources of information used to develop the emission reduction factors were a University of Minnesota (UMN) study on biofuels[14], certification data from the California Air Resources Board (CARB)[15], and data from the EV Project[16]. Because of limited data for all criteria pollutants for all alternative fuels, ICF developed estimates for which assumptions were necessary. These are described below.

Table 7 shows the emission reduction factors from the Tool. The following section of the report discusses how each emission reduction factor was developed and the corresponding literature source. Emission reduction factors are defined as the emission factor of the alternative fuel divided by emission factor of the conventional fuel (as shown in the equation below), so 100% represents no reduction and 0% means no alternative fuel emissions.

$$\text{Reduction Factor} = \frac{EF_{Alternative\ Fuel}}{EF_{Baseline\ Fuel}}$$

Table 7. Emission Reduction Factors

Vehicle Weight Class	Pollutant	Gasoline						Diesel								
		CNG	E85	BEV	LPG	PHE V10	PHE V40	CNG	E85	BEV	LPG	PHE V10	PHE V40	B20	B50	B100
Light-Duty	NOx	75%	73%	0%	100%	76%	27%	33%	67%	0%	100%	76%	27%	100%	101%	102%
	PM10	100%	80%	0%	100%	76%	27%	79%	63%	0%	100%	76%	27%	97%	92%	84%
	PM2.5	100%	80%	0%	100%	76%	27%	75%	60%	0%	100%	76%	27%	97%	92%	84%
	VOC	11%	110%	0%	100%	76%	27%	18%	181%	0%	100%	76%	27%	97%	93%	86%

[13] It is generally accepted that test cycles currently used to assess vehicle emissions are not representative of real road driving conditions. For its national emissions program, EPA and NHTSA crudely account for this disparity by affecting conventional vehicles with a 20% factor and PEV with a 30% factor.

[14] Tessum, Christopher, et. al.,"Tank to Wheel Emissions of Ethanol and Biodiesel Powered Vehicles as Compared to Petroleum Alternatives," University of Minnesota, July 2010. http://www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1408

[15] CARB On-Road New Vehicle & Engine Certification Program, http://www.arb.ca.gov/msprog/onroad/cert/cert.php

[16] http://www.theevproject.com/documents.php

Medium-Duty	NOx	75%	73%	0%	100%	76%	27%	34%	34%	0%	45%	76%	27%	100%	101%	102%
	PM10	100%	100%	0%	100%	76%	27%	33%	33%	0%	33%	76%	27%	97%	92%	84%
	PM2.5	100%	100%	0%	100%	76%	27%	31%	31%	0%	31%	76%	27%	97%	92%	84%
	VOC	11%	87%	0%	81%	76%	27%	12%	70%	0%	64%	76%	27%	97%	93%	86%
Heavy-Duty	NOx	94%	78%	0%	118%	76%	27%	89%	40%	0%	60%	76%	27%	100%	101%	102%
	PM10	100%	100%	0%	100%	76%	27%	85%	25%	0%	25%	76%	27%	97%	92%	84%
	PM2.5	100%	100%	0%	100%	76%	27%	85%	24%	0%	24%	76%	27%	97%	92%	84%
	VOC	37%	94%	0%	180%	76%	27%	83%	765%	0%	1562%	76%	27%	97%	93%	86%

Note: NOx = nitrogen oxides; PM10 = particulate matter less than 10 microns in diameter; PM2.5 = particulate matter less than 2.5 microns in diameter; VOC = volatile organic compounds

3.1 Biodiesel

Nearly identical MOVES2010b simulations to those described in Section 2.1 were used to determine emission factors for B100, the only alternative fuel currently characterized in MOVES for all vehicle types. Fuel formulation (Table 7) was taken as 100% biodiesel for diesel fueled vehicles. (No gasoline fueled emissions were considered.) For other fractions of biodiesel (e.g., B20, B50), ICF assumed a linear scaling of the B100 emission factors based on the percent biodiesel included.

3.2 CNG

CNG Compared to Gasoline

- For Light-duty (LD), Medium-Duty (MD), and Heavy-Duty (HD) vehicles, the emission reduction factors are based on gasoline versus CNG CARB certification tests of similar makes and engine sizes. Since PM certification data is not given for LD and MD gasoline and CNG vehicles because the values are so low, it is assumed that there are no emission reductions.

CNG Compared to Diesel

- For LD and MD vehicles, the VOC and NOx emission reductions are based on CARB certification tests of similar makes and engine sizes. The PM emission reduction factors (ERF) are calculated based on the CNG/gasoline emission reduction factors and ratio of gasoline to diesel MOVES emission factors (EF) from the same vehicle class. See the calculation below for an example:

$$ERF_{CNG/DIESEL} = ERF_{CNG/GAS} * \frac{EF_{GAS}}{EF_{DIESEL}} = \frac{EF_{CNG}}{\cancel{EF_{GAS}}} * \frac{\cancel{EF_{GAS}}}{EF_{DIESEL}} = \frac{EF_{CNG}}{EF_{DIESEL}}$$

  This calculation was performed since PM certification data is not given for LD and MD gasoline and CNG vehicles, only HD.
- For HD vehicles, the emission reduction factors are based on CARB certification tests of similar makes and engine sizes.

3.3 E85

E85 Compared to Gasoline

- For LD, the emission reduction factors are based on the UMN study.
- For MD and HD, the emission reduction factors are based on CARB certification tests of similar makes and engine sizes.

E85 Compared to Diesel

- For LD, the VOC and NOx emission reductions are based on CARB certification tests of similar makes and engine sizes. The PM emission reduction factors are calculated based on the E85/gasoline emission reduction factors and ratio of gasoline to diesel MOVES emission factors from the same vehicle class for PM. The calculation is same as shown for CNG compared to diesel. This calculation was performed since PM certification data is not given for gasoline and E85 vehicles and the UMN report only compared E85 with gasoline.
- For MD and HD, the VOC and NOx emission reductions are based on E85 and gasoline emission reduction factors and the ratio of gasoline to diesel CARB certification tests of similar makes and engine sizes. The PM emission reduction factors are calculated based on the E85/gasoline emission reduction factors and ratio of gasoline to diesel MOVES emission factors from the same vehicle class. The calculation is same as shown for CNG compared to diesel. This calculation was performed since PM certification data is not given for gasoline and E85 vehicles and the UMN report only compared E85 with gasoline.

3.4 Electricity (BEV, PHEV10, and PHEV40)

BEV Compared to Gasoline and Diesel

- For LD, MD, and HD there are 100% emission reductions since BEVs have zero tailpipe emissions.

PHEV10 and PHEV40 Compared to Gasoline

Unlike BEVs, preparing a fair and representative assessment of the emissions from plug-in hybrid electric platforms is generally challenging. Part of the reason is that there exist different PHEV configurations, each of which would yield different results. Additionally, emissions would depend heavily on the availability of charging infrastructure and the charging behavior on the part of the drivers. This is an evolving area of research. With this in mind, estimates are based on the following considerations.

- For LD, the emission reduction factors for NOx, PM, and VOC are based on data from The EV Project. According to data from the EV Project, PHEV owners drive an average of 41 miles per day. GM Volt owners (PHEV40) drive an average of 30 miles per day in all-electric mode, implying that 27% of PHEV miles (41-30=11) are in gasoline mode. For PHEV10, ICF has made the conservative and simplifying assumption of 10 miles in all-electric mode each day, resulting in 76% of miles (41-10=31) in gasoline mode.

  The assumptions made here for PHEV10 and PHEV40 are conservative, since these behavioral data does not allow us to make robust inferences about the fraction of miles that can typically

be driven by a PHEV on electric mode. It could well be that the average number of electric miles that could be extracted from a PHEV40 is over or under 30 miles. The number of electric miles can be correlated with the availability of charging infrastructure, as well with consumer charging behavior. If the average driving mileage of PHEV owners is 41 miles, but these drivers had access to charging infrastructure during their driving tour, then it would be expected that more than 73% of miles driven to be electric. These behavioral data do not necessarily always reflect the potential of the technology, but ICF made the conservative assumption of 24% and 73% of the miles in all electric mode for PHEV10 and PHEV40.

- For MD and HD the simplifying assumption is made that emission reduction factors for LD carry-over into the MD and HD segments. The assumption is based on the CARB EMFAC model, in which MD vehicles have similar daily VMT to LD vehicles and that HD vehicles, if they have higher daily VMT, would take advantage of opportunity charging and achieve a similar percent of all-electric mode miles.

PHEV10 and PHEV40 Compared to Diesel

- For all vehicle classes, the emission reduction factors for gasoline are assumed to be the same for diesel based on the assumption that PHEVs replacing diesel vehicles would be diesel-PHEVs.

3.5 Propane (LPG)

LPG Compared to Gasoline

- For LD, due to lack of data and stringent tailpipe emission standards, the assumption was made that LPG has no emission reductions. This assumption is validated by US Department of Energy (DOE) Alternative Fuels Data Center, which states that “emissions from propane vehicles are comparable to those of gasoline and diesel vehicles with modern emissions controls.”
- For MD and HD, the emission reduction factors are based on CARB certification tests of similar makes and engine sizes.

LPG Compared to Diesel

- For LD, due to lack of data and stringent tailpipe emission standards, the assumption was made that LPG has no LD emission reductions. This assumption is validated by the DOE’s Alternative Fuels Data Center, which states that “emissions from propane vehicles are comparable to those of gasoline and diesel vehicles with modern emissions controls.”
- For MD and HD, the VOC and NOx emission reductions are based on LPG and gasoline emission reduction factors and the ratio of gasoline to diesel CARB certification tests of similar makes and engine sizes. The PM emission reduction factors are calculated based on the LPG/gasoline emission reduction factors and the ratio of gasoline to diesel MOVES emission factors from the same vehicle class. The calculation is same as shown for CNG compared to diesel. This calculation was performed since PM certification data for similar makes and engine sizes for LPG, gasoline, and diesel were not available.

4 Scenario Analysis and Results

4.1 Scenario Development

ICF developed scenarios for alternative fuel vehicle (AFV) penetrations based on input from MAC and key St. Louis metro stakeholders to illustrate the potential air quality benefits of alternative fuels. The following boundaries for the pilot study of St. Louis region were chosen for the analysis:

- Baseline Year: 2010 (based on activity data from 2008)
- Forecast Years: 2020, 2030, and 2040
- Alternative Fuels Selected: B100, CNG, Propane, EVs, and E85

Table 8 presents the AFV scenarios developed for the analysis, which includes the market segments and corresponding alternative fuel penetrations for each of the forecast years. The scenarios were developed as aggressive but achievable market penetrations to understand the emission reduction potential of alternative fuels in different market segments.

Table 8. AFV Scenarios

Market Segment	Fuel	2020	2030	2040
Transit Buses	B100	100%	100%	100%
	CNG	50%	75%	100%
	Propane	5%	10%	15%
School Buses	B100	100%	100%	100%
	CNG	50%	75%	100%
	Propane	5%	10%	15%
Refuse Trucks	CNG	100%	100%	100%
Light Duty Autos and Trucks	EVs	5%	10%	20%
	CNG	2.5%	5%	7.5%
	E85	10%	20%	30%
Heavy Duty Trucks	CNG/LNG	5%	15%	25%
Medium Duty Trucks	Propane	5%	10%	15%

4.2 Scenario Analysis Results

ICF ran an analysis of each AFV scenario using the AFAQ Tool that was developed using the baseline and emissions reductions factors described in Section 2 and 3 of this report.

Light-Duty Autos and Trucks

For LD autos and trucks, three AFV scenarios for increased use of electric vehicles, CNG, and E85 were run in the Alternative Fuels for Air Quality (AFAQ) Tool. Table 9 shows the results from the tool for the baseline emissions, scenario emissions, and the emissions reductions for each of the three scenarios.

Table 9. Light Duty Auto and Truck Scenario Results (tons/year)

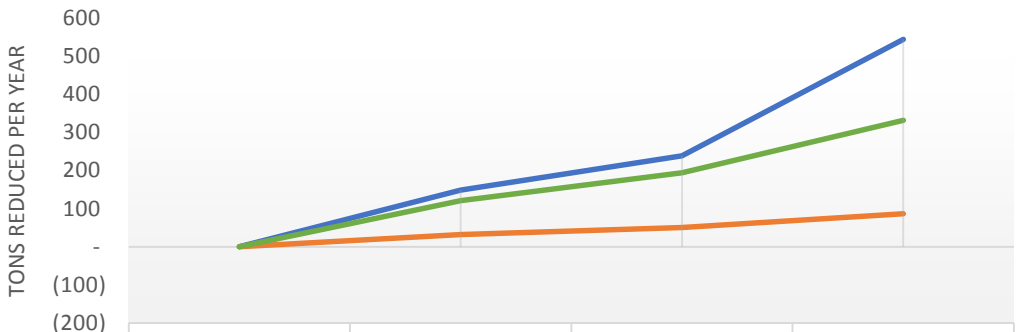
AFV Scenario	Air Pollutant	Baseline Emissions				Scenario Emissions				Emission Reductions			
		2010	2020	2030	2040	2010	2020	2030	2040	2010	2020	2030	2040
LD – EVs[1] *(5% in 2020, 10% in 2030, 20% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,721	5,954	6,409	-	148.7	239.2	544.5
	PM10	877	282	228	256	877	277	217	229	-	5.8	11.7	26.9
	PM2.5	841	266	213	238	841	261	202	214	-	5.3	10.8	24.8
	VOC	3,163	1,068	895	1,022	3,163	1,041	851	922	-	26.3	43.6	100.4
LD – CNG *(2.5% in 2020, 5% in 2030, 7.5% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,837	6,142	6,867	-	32.5	51.0	86.5
	PM10	877	282	228	256	877	282	228	256	-	0.1	0.1	0.1
	PM2.5	841	266	213	238	841	266	213	238	-	0.1	0.1	0.1
	VOC	3,163	1,068	895	1,022	3,163	1,051	866	973	-	17.2	28.6	49.4
LD – E85 *(10% in 2020, 20% in 2030, 30% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,748	5,999	6,621	-	121.5	194.7	332.2
	PM10	877	282	228	256	877	279	221	244	-	3.7	7.1	12.2
	PM2.5	841	266	213	238	841	263	206	227	-	3.5	6.6	11.3
	VOC	3,163	1,068	895	1,022	3,163	1,079	910	1,047	-	(10.9)	(14.9)	(25.1)

[1] Assumed electrical vehicle fleet comprised of 25% BEV, 25% PHEV10 and 50% PHEV40, based on data from the DOE's Annual Energy Outlook 2014 report

The LD auto and truck vehicle sectors have the greatest potential for emission reductions of any vehicle sector due to the high activity levels (VMT) as shown in Figure 2. For this sector, the increased penetration of electric vehicles creates the most emissions reductions overall. Figure 3 through Figure 6 below present the LD auto and truck AFV scenario emissions reduction trends for each type of air pollutant analyzed within the tool.

In the St. Louis region, gasoline makes up 98% of current and 97% of forecasted LD VMT. Compared to a gasoline baseline, BEVs reduce NOx emissions by 100% while CNG and E85 have lower reduction potentials of 25% and 27% respectively. Figure 3 below shows that the E85 LD AFV scenario reduces more emissions per year than CNG; however, this is due to the stronger assumed penetration rates of E85 (10% in 2020, 20% in 2030, 30% in 2040) compared to CNG (2.5% in 2020, 5% in 2030, 7.5% in 2040).

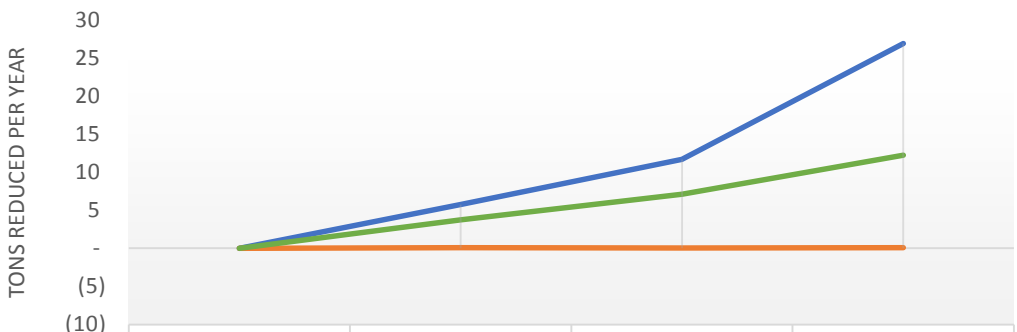
Figure 3. LD AFV Scenarios - NOx Emissions Reductions



	2010	2020	2030	2040
Evs	-	149	239	545
CNG	-	33	51	86
E85	-	122	195	332

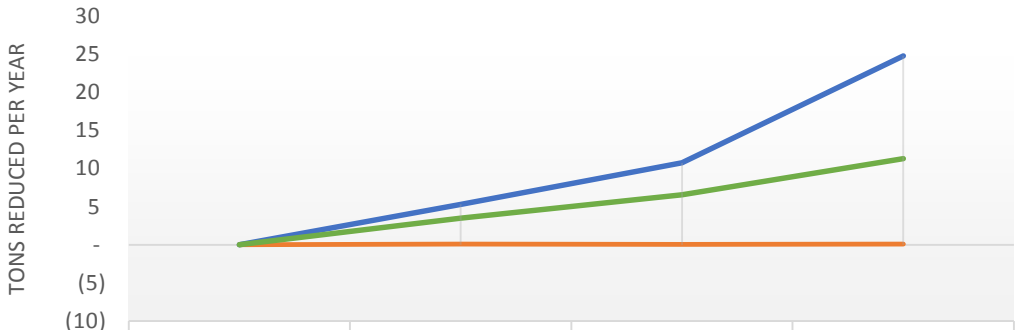
For PM10 and PM2.5 emissions, BEVs again clearly contribute the greatest emission reduction potential. While CNG has NOx reduction potential, it does not reduce PM emissions from LD vehicles, as illustrated in Figure 4 and Figure 5 below.

Figure 4. LD AFV Scenarios - PM10 Emissions Reductions



	2010	2020	2030	2040
Evs	-	5.8	12	27
CNG	-	0.1	0.1	0.1
E85	-	3.7	7.1	12

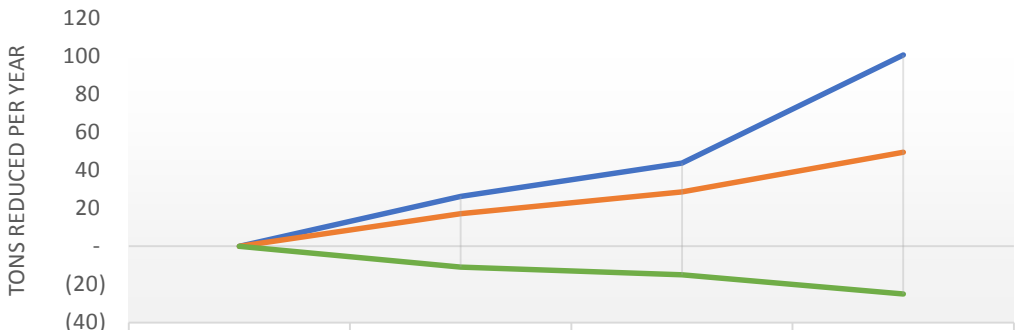
Figure 5. LD AFV Scenarios - PM2.5 Emissions Reductions



	2010	2020	2030	2040
Evs	-	5.3	11	25
CNG	-	0.1	0.1	0.1
E85	-	3.5	6.6	11

For VOC emissions, BEVs and CNG have reduction factors of 100% and 89%, respectively. Both can contribute to significant reductions in regional VOC emissions, as shown in Figure 5. E85 results in higher VOC emissions compared to the gasoline baseline, as shown in Figure 6.

Figure 6. LD AFV Scenarios - VOC Emissions Reductions



	2010	2020	2030	2040
Evs	-	26	44	100
CNG	-	17	29	49
E85	-	(11)	(15)	(25)

Medium and Heavy Duty Trucks

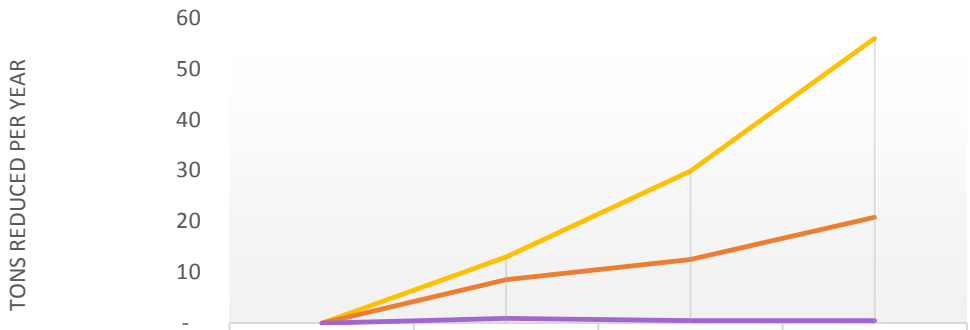
For MD, HD, and refuse trucks, three AFV scenarios for increased use of CNG or propane were run in the AFAQ Tool. Table 10 shows the results output from the tool for the baseline emissions, scenario emissions, and the emissions reductions for each of the three MD and HD truck scenarios.

Table 10. Medium, Heavy and Refuse Truck Scenario Results (tons/year)

AFV Scenario	Air Pollutant	Baseline Emissions				Scenario Emissions				Emission Reductions			
		2010	2020	2030	2040	2010	2020	2030	2040	2010	2020	2030	2040
HD Trucks CNG *(5% in 2020, 10% in 2030, 25% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,857	6,163	6,897	-	13.04	29.90	56.04
	PM10	877	282	228	256	877	282	227	254	-	0.58	0.89	1.60
	PM2.5	841	266	213	238	841	266	212	237	-	0.56	0.86	1.56
	VOC	3,163	1,068	895	1,022	3,163	1,067	894	1,020	-	0.70	1.26	2.32
MD Trucks Propane *(5% in 2020, 10% in 2030, 15% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,861	6,181	6,933	-	8.54	12.49	20.82
	PM10	877	282	228	256	877	282	228	256	-	0.32	0.27	0.42
	PM2.5	841	266	213	238	841	266	213	238	-	0.32	0.26	0.42
	VOC	3,163	1,068	895	1,022	3,163	1,067	893	1,019	-	0.97	1.66	2.84
Refuse Trucks CNG *(100% in 2020, 2030, and 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,869	6,193	6,953	-	0.90	0.50	0.48
	PM10	877	282	228	256	877	282	228	256	-	0.04	0.01	0.01
	PM2.5	841	266	213	238	841	266	213	238	-	0.04	0.01	0.01
	VOC	3,163	1,068	895	1,022	3,163	1,068	895	1,022	-	0.15	0.10	0.10

For this sector, increased use of CNG for heavy-duty trucks results in the largest emissions reductions overall. While these reductions are small in comparison to the LD vehicle AFV scenario results, the reductions per vehicle are significantly higher compared to LD vehicles. Figure 7 through Figure 10 below present the MD and HD truck AFV scenario emissions reductions for each type of air pollutant. The axis of each figure is scaled to the sector's AFV emissions reductions for the purposes of illustrating trends over time. Note that the axes of other sectors' AFV scenario charts are different, given the varying intensity of activity levels (VMT) and magnitude of reductions.

Figure 7. HD & MD Truck AFV Scenarios - NOx Emissions Reductions

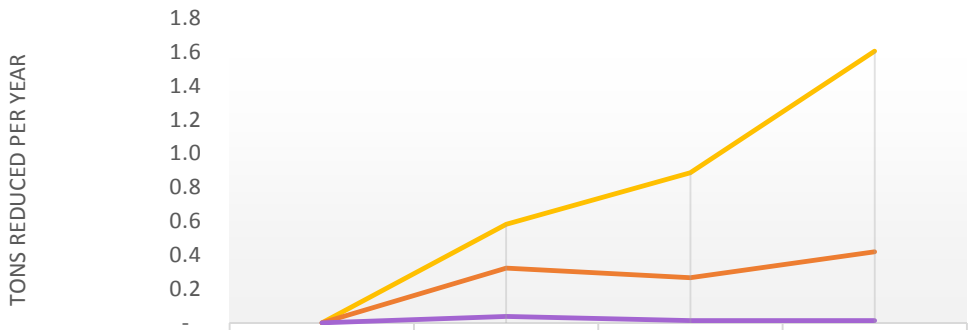


	2010	2020	2030	2040
HD Trucks CNG	-	13	30	56
MD Trucks Propane	-	8.5	12	21
Refuse Trucks CNG	-	0.9	0.5	0.5

CNG reduces NOx emissions by 6% for HD gasoline trucks and 11% for HD diesel. Propane reduces NOx emission by 55% compared to MD diesel trucks, but has no significant effect on emission for gasoline trucks. As shown in Figure 7, CNG produces the largest potential emission reduction for the scenario analyzed, mainly because HD trucks are responsible for 77% of total VMT within the MD and HD vehicle classes combined, while MD accounts for 23% of VMT and refuse only 1%.

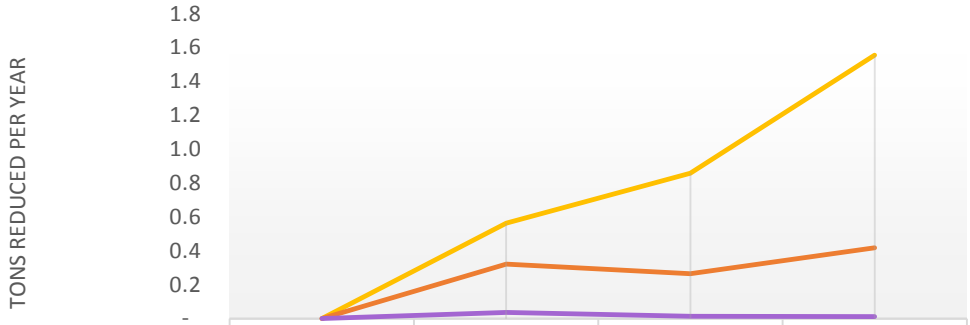
A similar pattern follows for PM10 and PM2.5 shown in Figure 8 and Figure 9.

Figure 8. HD&MD Truck AFV Scenarios - PM10 Emissions Reductions



	2010	2020	2030	2040
HD Trucks CNG	-	0.6	0.9	1.6
MD Trucks Propane	-	0.3	0.3	0.4
Refuse Trucks CNG	-	0.04	0.01	0.01

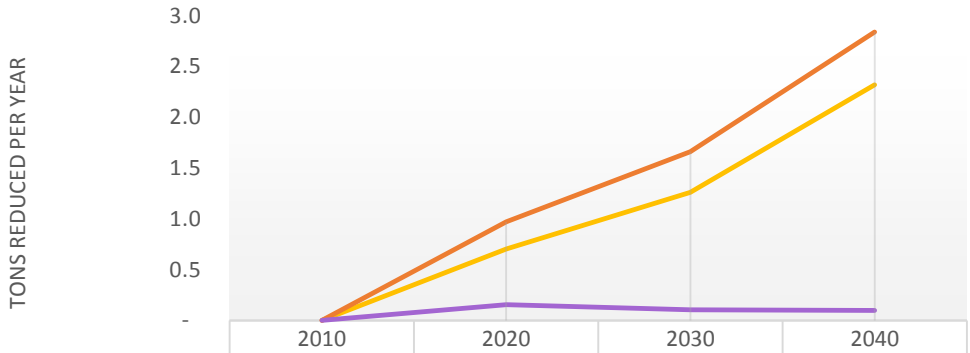
Figure 9. HD & MD Truck AFV Scenarios - PM2.5 Emissions Reductions



	2010	2020	2030	2040
HD Trucks CNG	-	0.6	0.9	1.6
MD Trucks Propane	-	0.3	0.3	0.4
Refuse Trucks CNG	-	0.04	0.01	0.01

For VOC emissions, the use of propane in MD trucks contributes more to emission reductions than the use of CNG in HD trucks and refuse trucks. This is due to LPG having a higher VOC emissions reduction factor for replacing gasoline (19%) and diesel (36%), while CNG only reduces 17% of VOC emissions compared to diesel.

Figure 10. HD & MD Truck AFV Scenarios - VOC Emissions Reductions



	2010	2020	2030	2040
HD Trucks CNG	-	0.7	1.3	2.3
MD Trucks Propane	-	1.0	1.7	2.8
Refuse Trucks CNG	-	0.2	0.1	0.1

Transit and School Buses

For transit and school buses, three AFV scenarios for increased use of B100, CNG, and propane were run in the AFAQ Tool. Table 11 shows the results from the tool for the baseline emissions, scenario emissions, and the emission reductions for each of the three scenarios.

Table 11. Transit & School Bus Scenario Results (tons/year)

AFV Scenario	Air Pollutant	Baseline Emissions				Scenario Emissions				Emission Reductions			
		2010	2020	2030	2040	2010	2020	2030	2040	2010	2020	2030	2040
B100 *(100% in 2020, 2030, & 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,872	6,194	6,954	-	(2.10)	(1.00)	(0.81)
	PM10	877	282	228	256	877	282	228	256	-	0.79	0.25	0.13
	PM2.5	841	266	213	238	841	266	213	238	-	0.76	0.24	0.12
	VOC	3,163	1,068	895	1,022	3,163	1,067	894	1,022	-	1.07	0.40	0.22
CNG *(50% in 2020, 75% in 2030, & 100% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,864	6,189	6,949	-	5.89	4.29	4.72
	PM10	877	282	228	256	877	282	228	256	-	0.37	0.18	0.12
	PM2.5	841	266	213	238	841	266	213	238	-	0.36	0.17	0.12
	VOC	3,163	1,068	895	1,022	3,163	1,067	894	1,021	-	1.00	0.89	1.09
PROPANE *(5% in 2020, 10% in 2030, & 15% in 2040)*	NOx	24,059	7,870	6,193	6,953	24,059	7,868	6,191	6,951	-	2.06	1.92	2.30
	PM10	877	282	228	256	877	282	228	256	-	0.18	0.12	0.09
	PM2.5	841	266	213	238	841	266	213	238	-	0.18	0.12	0.09
	VOC	3,163	1,068	895	1,022	3,163	1,073	899	1,026	-	(5.62)	(4.22)	(3.64)

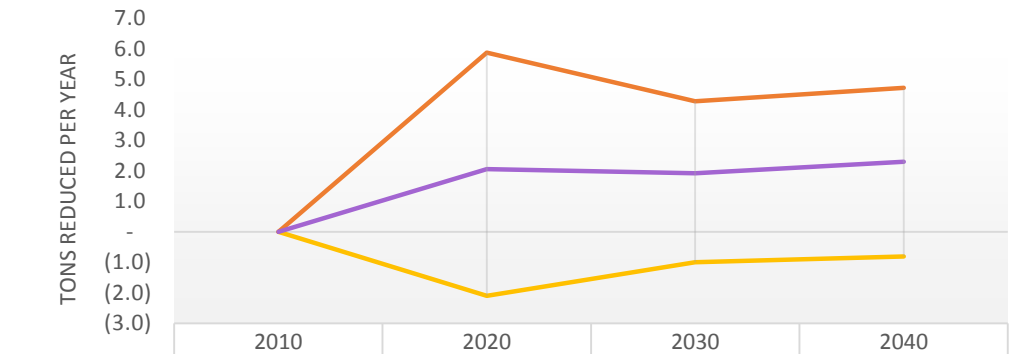
For this sector, CNG has the largest emissions reductions overall. While these gains are significantly less than the total LD vehicle AFV scenario results, the reductions per vehicle are much higher compared to LD vehicles.

In the St. Louis region, 94% of current and 96% of forecasted VMT for transit and school buses are diesel. Compared to a diesel baseline, NOx emissions increase 2% for B100 and decrease by 11% and 40% for CNG and propane respectively. This is apparent in Figure 11, in which the very strong assumed penetration rates of B100 (100% in 2020-2040) are driving the NOx abatement curve down, while moderate to strong assumed penetrations of CNG (50% in 2020, 75% in 2030, and 100% in 2040) are responsible for more reductions compared to the smaller penetration rates of propane (5% in 2020, 10% in 2030 and 15% in 2040).

Figure 11 through Figure 14 below present the transit and school bus AFV scenario emissions reductions for each type of air pollutant. Similar to the MD and HD truck figures, the axis is scaled to the sector's AFV emissions reductions for the purposes of illustrating trends over time. Please note that the axes of other sectors' AFV scenario graphs are different given the varying intensity of activity levels (VMT) and magnitude of reductions.

In the St. Louis region, 94% of current and 96% of forecasted VMT for transit and school buses are diesel. Compared to a diesel baseline, NOx emissions increase 2% for B100 and decrease by 11% and 40% for CNG and propane respectively. This is apparent in Figure 11, in which the very strong assumed penetration rates of B100 (100% in 2020-2040) are driving the NOx abatement curve down, while moderate to strong assumed penetrations of CNG (50% in 2020, 75% in 2030, and 100% in 2040) are responsible for more reductions compared to the smaller penetration rates of propane (5% in 2020, 10% in 2030 and 15% in 2040).

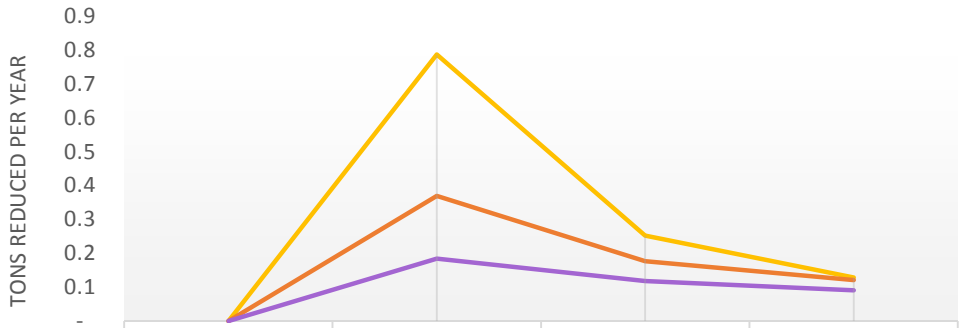
Figure 11. Transit & School Bus AFV Scenarios - NOx Emissions Reductions



	2010	2020	2030	2040
B100	-	(2.1)	(1.0)	(0.8)
CNG	-	5.9	4.3	4.7
PROPANE	-	2.1	1.9	2.3

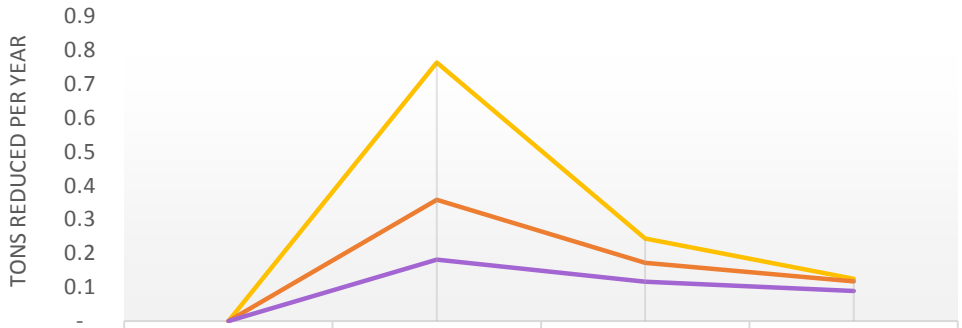
Figure 12 and Figure 13 below illustrate how the PM10 and PM2.5 emissions reductions differ between the three AFV scenarios. For both of these air pollutants, B100 and CNG have similar reduction factors as compared to the diesel baseline (16% and 15% respectively), while propane has much higher reduction potential (75-76%). Although the CNG and propane reduction factors are similar on a grams per mile basis, the CNG scenario reduces more tons per year than propane because the penetration rates of CNG between 2020 and 2040 are stronger than that of propane.

Figure 12. Transit & School Bus AFV Scenarios - PM10 Emissions Reductions



	2010	2020	2030	2040
B100	-	0.8	0.3	0.1
CNG	-	0.4	0.2	0.1
PROPANE	-	0.2	0.1	0.1

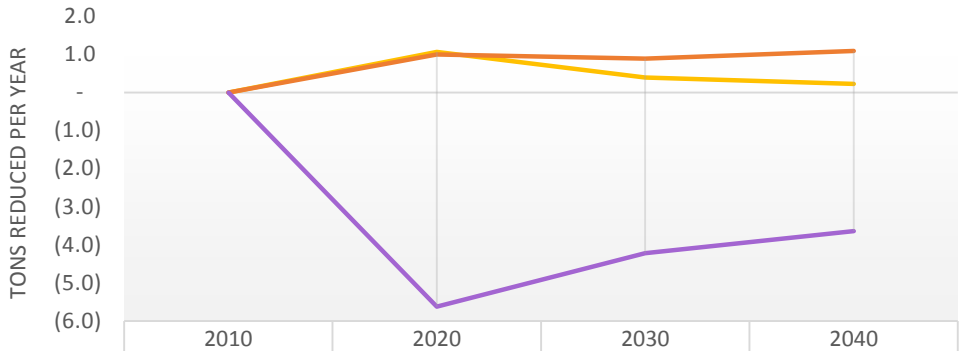
Figure 13. Transit & School Bus AFV Scenarios - PM2.5 Emissions Reductions



	2010	2020	2030	2040
B100	-	0.8	0.2	0.1
CNG	-	0.4	0.2	0.1
PROPANE	-	0.2	0.1	0.1

For VOC emissions, propane increases emissions significantly compared to the baseline, while B100 and CNG have modest reductions, as shown in Figure 14 below.

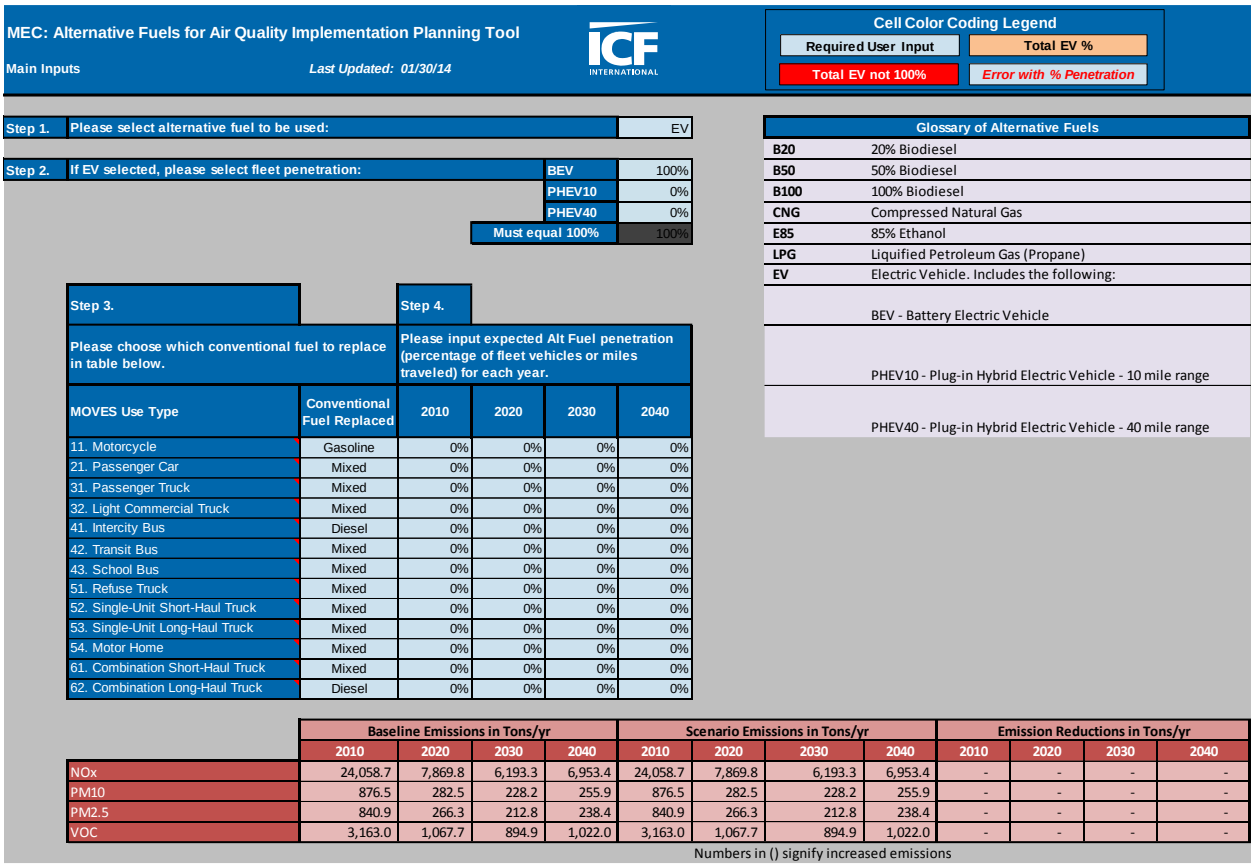
Figure 14. Transit & School Bus AFV Scenarios - VOC Emissions Reductions



	2010	2020	2030	2040
B100	-	1.1	0.4	0.2
CNG	-	1.0	0.9	1.1
PROPANE	-	(5.6)	(4.2)	(3.6)

5 Tool User Guide

This section presents a simple guide to using the Alternative Fuels for Air Quality (AFAQ) Tool. The Tool has been developed in Microsoft Excel, with all user inputs and results contained on a single sheet. A screenshot of the Tool main page is shown below.



MEC: Alternative Fuels for Air Quality Implementation Planning Tool

Main Inputs — *Last Updated: 01/30/14*

Cell Color Coding Legend: Required User Input | Total EV % | Total EV not 100% | *Error with % Penetration*

Step 1.	Please select alternative fuel to be used:	EV
Step 2.	If EV selected, please select fleet penetration: BEV	100%
	PHEV10	0%
	PHEV40	0%
	Must equal 100%	100%

Glossary of Alternative Fuels	
B20	20% Biodiesel
B50	50% Biodiesel
B100	100% Biodiesel
CNG	Compressed Natural Gas
E85	85% Ethanol
LPG	Liquified Petroleum Gas (Propane)
EV	Electric Vehicle. Includes the following:
	BEV - Battery Electric Vehicle
	PHEV10 - Plug-in Hybrid Electric Vehicle - 10 mile range
	PHEV40 - Plug-in Hybrid Electric Vehicle - 40 mile range

Step 3. Please choose which conventional fuel to replace in table below.		Step 4. Please input expected Alt Fuel penetration (percentage of fleet vehicles or miles traveled) for each year.			
MOVES Use Type	Conventional Fuel Replaced	2010	2020	2030	2040
11. Motorcycle	Gasoline	0%	0%	0%	0%
21. Passenger Car	Mixed	0%	0%	0%	0%
31. Passenger Truck	Mixed	0%	0%	0%	0%
32. Light Commercial Truck	Mixed	0%	0%	0%	0%
41. Intercity Bus	Diesel	0%	0%	0%	0%
42. Transit Bus	Mixed	0%	0%	0%	0%
43. School Bus	Mixed	0%	0%	0%	0%
51. Refuse Truck	Mixed	0%	0%	0%	0%
52. Single-Unit Short-Haul Truck	Mixed	0%	0%	0%	0%
53. Single-Unit Long-Haul Truck	Mixed	0%	0%	0%	0%
54. Motor Home	Mixed	0%	0%	0%	0%
61. Combination Short-Haul Truck	Mixed	0%	0%	0%	0%
62. Combination Long-Haul Truck	Diesel	0%	0%	0%	0%

	Baseline Emissions in Tons/yr				Scenario Emissions in Tons/yr				Emission Reductions in Tons/yr			
	2010	2020	2030	2040	2010	2020	2030	2040	2010	2020	2030	2040
NOx	24,058.7	7,869.8	6,193.3	6,953.4	24,058.7	7,869.8	6,193.3	6,953.4	-	-	-	-
PM10	876.5	282.5	228.2	255.9	876.5	282.5	228.2	255.9	-	-	-	-
PM2.5	840.9	266.3	212.8	238.4	840.9	266.3	212.8	238.4	-	-	-	-
VOC	3,163.0	1,067.7	894.9	1,022.0	3,163.0	1,067.7	894.9	1,022.0	-	-	-	-

Numbers in () signify increased emissions

A "Read Me" sheet provides simple instructions for the user. User inputs are performed in the following four steps:

- **Step 1 - Selection of Alternative Fuel**. The user should select the desired alternative fuel from the drop down window in cell H7. The options are: B20, B50, B100, CNG, E85, LPG, and EV.
- **Step 2 – Determine EV Fleet Breakdown**. If "EV" is selected as the alternative fuel, it is necessary to enter what the fleet breakdown is for EVs between BEV, PHEV10 and PHEV40. These three categories must sum to 100%. For example, if the EV fleet penetration for BEV, PHEV10 and PHEV40 is 50%, 25%, and 25%, respectively, then 50%, 25%, 25% would be entered in cells H9, H10, and H11, respectively.
- **Step 3 – Choose the Conventional Fuel** (Gasoline, Diesel or Mixed (Both)) that the alternative fuel replaces. The purpose of selecting the conventional fuel to be replaced is alternative fuels have different emission reductions when they are compared to gasoline or diesel. Gasoline and diesel have different baseline emission factors and most alternative fuels have different emission reduction factors compared to gasoline or diesel. For all alternative fuels but biodiesel,

if the user is unsure what conventional fuel to replace, select the default conventional fuel to be replaced shown in the table below:

MOVES Use Type	Conventional Fuel Replaced
11. Motorcycle	Gasoline
21. Passenger Car	Mixed
31. Passenger Truck	Mixed
32. Light Commercial Truck	Mixed
41. Intercity Bus	Diesel
42. Transit Bus	Mixed
43. School Bus	Mixed
51. Refuse Truck	Mixed
52. Single-Unit Short-Haul Truck	Mixed
53. Single-Unit Long-Haul Truck	Mixed
54. Motor Home	Mixed
61. Combination Short-Haul Truck	Mixed
62. Combination Long-Haul Truck	Diesel

If a biodiesel blend is selected as the alternative, set the conventional fuel replaced to "diesel" since biodiesel can only replace diesel. For example, if use is determining the air quality benefits of EVs in the passenger car use type that replace both gasoline and diesel, the user would select "mixed" in cell D19.

- **Step 4 – Input the Alternative Fuel Penetration for Each Year**. In columns E, F, G and H input the expected alternative fuel penetration (where the assumption is the percentage of fleet vehicles is equal to the percentage of fleet VMT) for the use type being analyzed. For example, if the user was determining the air quality benefits of EVs in the passenger car use type with a fleet percentage of 10%, 20%, and 30% in 2020, 2030, and 2040, respectively, then 10%, 20%, and 30% would be entered in cells F19, G19, and H19, respectively.

Other sheets contained in the Tool should not require modification for standard use of the Tool, but could be modified with new data for emission reduction factors and new or non-St Louis regional specific MOVES activity data and modeling results.

The **Calculated Inputs** sheet contains formulas to convert the inputs from the **Main Interface** sheet into values that can be used by subsequent sheets. There is no need to modify this sheet.

The **Baseline Fleet EFs and Activity** sheet contains the MOVES modeling results for emission rates and activity by class for each year and vehicle class. This sheet does not require any modifications for the St. Louis region. For other regions, the sheet can be modified with region specific MOVES outputs produced using a methodology similar to what was done for the St. Louis region described in Section 2.

The **Reduction Factors** sheet contains the emission reductions factors described in Section 3. These factors can be modified based on new and improved data.

The **Net Emis** sheet contains the formulas and calculations to quantify the emissions reduced based on the values from the other sheets. There is no need to modify this sheet.

6 Conclusion

The goal of this study is to provide MEC and other partner organizations with the information and tools necessary to make informed and strategic decisions around incorporating alternative fuel vehicles into their air quality and transportation planning processes. To do so, ICF first developed methodologies for determining the baseline and scenario emissions factors for each type of alternative fuel and vehicle class. These emissions factors, along with activity level data (VMT) provided by local and state agencies, became the basis of the Alternative Fuels for Air Quality (AFAQ) Tool. The Tool was then tested through the pilot study using the St. Louis metropolitan area. AFV scenarios for various market segments and fuels were developed in consultation with MAC and key St. Louis region stakeholders. The scenarios were developed as aggressive but achievable market penetrations to understand the emission reduction potential of alternative fuels in different market segments. The results of these scenarios were compared to show how various AFV penetration rates affect different vehicle class sectors and overall air pollutant emissions. The pilot study for the St. Louis region was successful in demonstrating the tool can be used as part of the air quality and transportation planning process.