Adaptation of the Vehicle Emission Model MOVES to Mexico

Final Technical Report

MEXICO LOW EMISSIONS DEVELOPMENT PROGRAM (MLED).

CONTRACT: AID-523-C-11-00001

January 31, 2016

Este informe fue elaborado por Eastern Research Group, Inc. para la Agencia de los Estados Unidos para el Desarrollo Internacional.

www.mledprogram.org

MOVES-Mexico Final Technical Report

El presente estudio fue elaborado por Eastern Research Group, Inc. Los autores principales son John Koupal, Allison DenBleyker, Scott Fincher, Sandeep Kishan y Verónica Garibay-Bravo (consultora de ORG+CO. para ERG en este proyecto) bajo la supervisión de Cynthia Menéndez y Ricardo Troncoso de WWF, con la colaboración técnica y de aporte de información del Instituto Nacional de Ecología y Cambio Climático (INECC) de México, en el marco del Programa para el Desarrollo Bajo en Emisiones de México (MLED), patrocinado por la Agencia de los Estados Unidos para el Desarrollo Internacional (USAID), bajo el contrato "AID-523-C-11-00001" implementado por Tetra Tech ES Inc.

Para mayor información, por favor contacte a: info@mledprogram.org

www.mledprogram.org

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AVFT	Alternative Vehicle Fuel Technology
CONAGUA	*Comisión Nacional Del Agua*
CONAPO	National Population Council
D.F.	*Distrito Federal*
E85	Fuel that is 85% ethanol by volume, 15% gasoline
EPA	Environmental Protection Agency
ERG	Eastern Research Group, Inc.
GIS	Geographical Information System
GUI	Graphical User Interface
HPMS	Highway Performance Monitoring System
I/M	Inspection and Maintenance
IMP	Mexican Petroleum Institute
INECC	National Institute of Ecology and Climate Change
INEGI	National Institute of Geography and Statistics
LDT	Light Duty Truck
LDV	Light Duty Vehicle
MOVES	Motor Vehicle Emission Simulator
MySQL	My Structured Query Language
MY	Model Year
NEI	National Emissions Inventory
NOM	*Norma Oficial Mexicana*
PEMEX	*Petróleos Mexicanos*

RSD	Remote Sensing Data
RVP	Reid Vapor Pressure
SHCP	Mexican Treasury and Customs Authority
SENER	*Secretaría de Energía*
SEMARNAT	*Secretaría de Medio Ambiente y Recursos Naturales*
SHO	Source Hours Operating
SIP	State Implementation Plan
SUV	Sport Utility Vehicle
VMT	Vehicle Miles Traveled
VKT	Vehicle Kilometers Traveled
VSP	Vehicle Specific Power
NO	Nitric oxide
NOx	Oxides of Nitrogen
CO	Carbon Monoxide
CO2	Carbon Dioxide
PM	Particulate Matter
GHG	Greenhouse Gas
NH3	Ammonia
HC	Hydrocarbon
THC	Total Hydrocarbons
VOC	Volatile Organic Compounds
N2O	Nitrous Oxide
CH4	Methane

Executive Summary

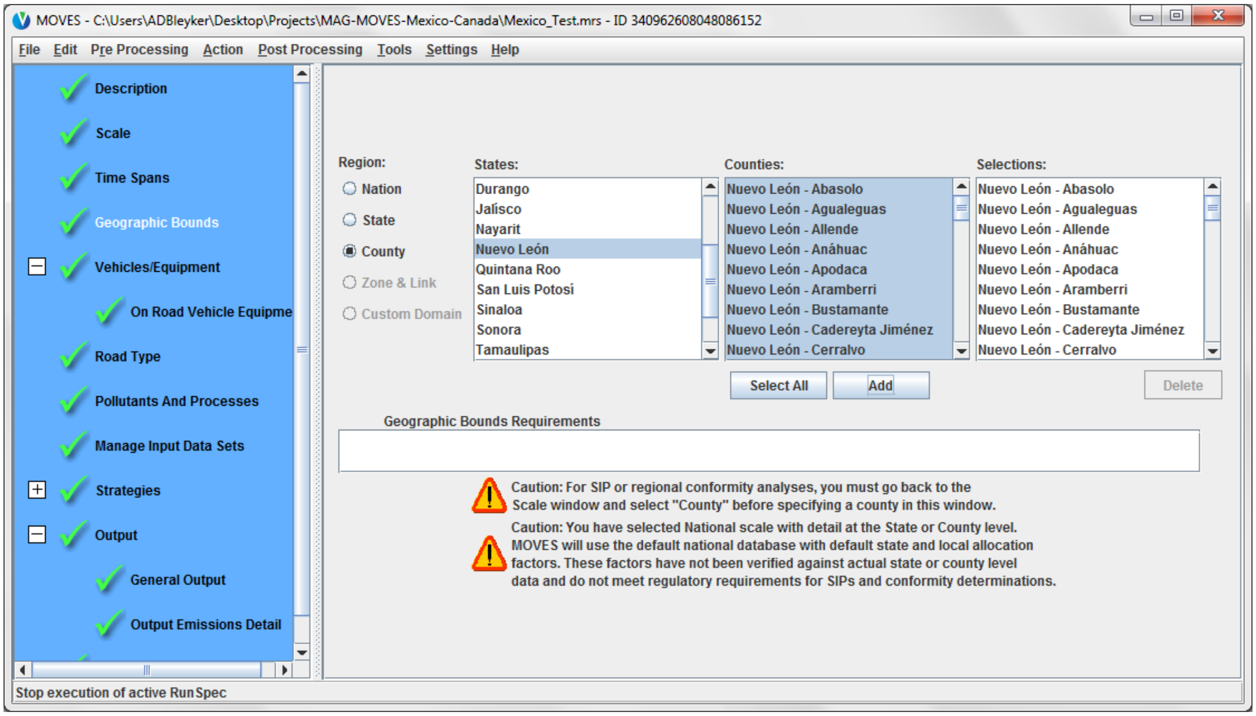
The U.S. EPA's Motor Vehicle Emission Simulator (MOVES) model has been adapted to Mexico, referred to as MOVES-Mexico. This version has been adapted from MOVES2014a, the most recent version of the MOVES model released by EPA, and reflects EPA's latest estimate of vehicle emissions and default U.S. activity data (U.S. EPA, 2015a). The focus on this adaptation was to create a basic MOVES-Mexico framework that is easy to use and can be improved over time as new data becomes available. Developing MOVES-Mexico required determining the best approach for updating the model, culling data on vehicle fleet and activity to replace U.S. defaults where possible, and reflecting significant differences in emission standards between Mexico and the U.S. The result was creation of a Mexico-specific MOVES database that can work directly with the U.S. version of MOVES2014a without any software modification, enabling estimation of onroad emissions for calendar years 1990 through 2050 at the nation, state or *municipio* level.

There were multiple options for adapting MOVES to Mexico, depending on the level of data available. The approach ERG ultimately took was to develop a national default database for Mexico because a) this approach was most amenable to the available data in Mexico; b) once developed, a national default database provides users with the ability to estimate emissions at the national, state or *municipio* level, for multiple years; and c) this default model can serve as a foundation for users who want to use MOVES to improve local inventories with specific data, or even for "hot spot" modeling. This approach makes MOVES-Mexico more easily transferable to all users in Mexico; addresses user needs the best, and provides a common and consistent foundation for other users within Mexico to apply their own data.

A significant amount of data on Mexico's vehicle fleet and emissions were analyzed to develop this Mexico-specific database for MOVES, much of it provided by Mexico's National Institute of Ecology and Climate Change (INECC). Compiling a national default database for Mexico required a) nation-wide totals of vehicle fleet and activity inputs such as populations, kilometers travelled, age distribution and speeds; b) factors to allocate vehicle population and activity to the Mexican *municipios*; c) localized data on meteorology, fuels and vehicle inspection/maintenance and d) updated emission rates to reflect significant differences between U.S. and Mexican vehicle standards. Data INECC provided included a robust database of roadside emissions measurements on about 250,000 vehicles across 24 Mexican cities. ERG's analysis of these data concluded that passenger car and light truck emissions in MOVES can be calibrated directly to these data, to develop emission rates for Mexico that reflects "real world" emission measurements. A detailed analysis of the these data was undertaken to determine how to calibrate MOVES emission rates for passenger car and truck NOx, CO and exhaust HC to these emission measurements.

Figure 3 shows a screen shot of the MOVES interface populated with Mexico states and *municipios*. Users of MOVES-Mexico will have the same capabilities as the U.S. version, adapted to Mexican conditions.

Figure ES-1: MOVES Interface Populated with Mexico States & *Municipios*



Once the Mexico-specific database was complete, ERG conducted testing and evaluation of the MOVES-Mexico model, beginning comparisons of total gasoline and diesel consumption against independent sales estimates from PEMEX and SENER (Figures ES-2 and ES-3). The fuel consumption estimates derived from MOVES-Mexico in 2013 are higher than the PEMEX gasoline sales estimate by 7 percent, and are lower than the PEMEX diesel sales estimate by 3 percent. Considering the uncertainties not only within MOVES, but in the energy content estimates used to calculate fuel consumption and the PEMEX estimates, we consider this a very good result, and indicative that the underlying vehicle fleet, activity and energy rates in the MOVES-Mexico are sound. MOVES-Mexico trends back in time, and into the future, were also compared against fuel production figures from SENER. For gasoline, MOVES tracks the SENER estimates well back through about 2009, then diverge as the MOVES estimates drop more sharply in the mid 2000s (looking backwards). The gap between historical SENER and MOVES-Mexico gasoline estimates appears to be due to illegal imports that are were not reflected in the official vehicle population estimates provided by INECC. The historical diesel trend for MOVES-Mexico tracks that of SENER, though the offset seen between SENER and MOVES (confirmed as an offset with the PEMEX 2013 estimates) persists, possibly due to inclusion of onroad fuel sold for offroad use in the SENER production estimates. Diversion in SENER projects vs. MOVES-Mexico is explained by differing assumptions made in projections. For example, INECC suggested that the SENER projections are higher in the future due to more aggressive growth assumptions than those provided by INECC for MOVES-Mexico.

Figure ES-2: Gasoline Fuel Consumption

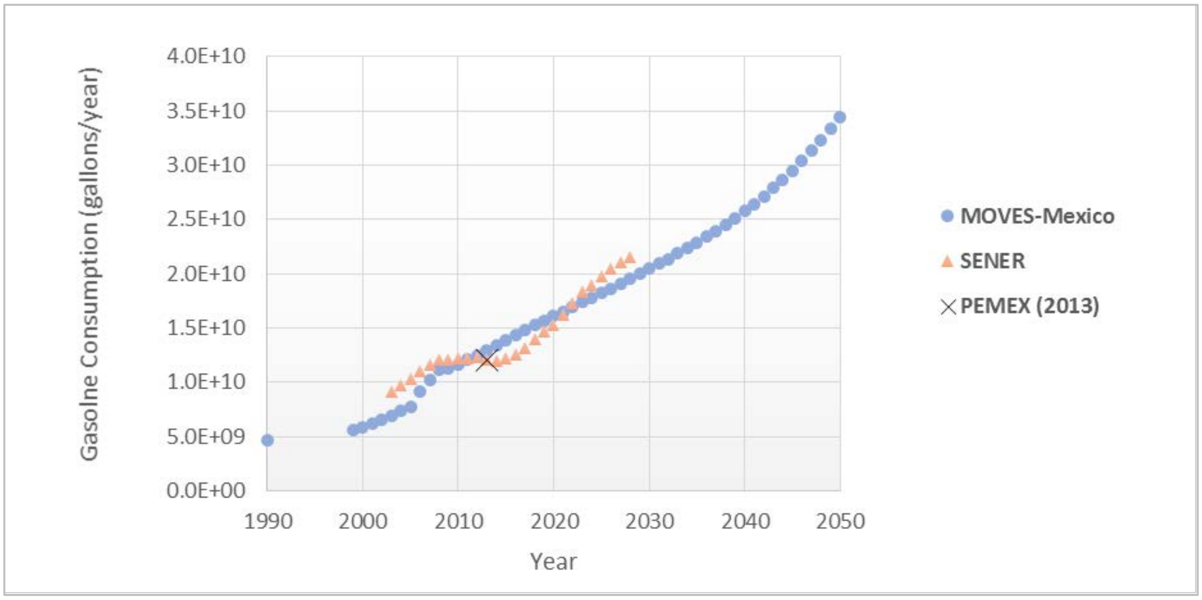
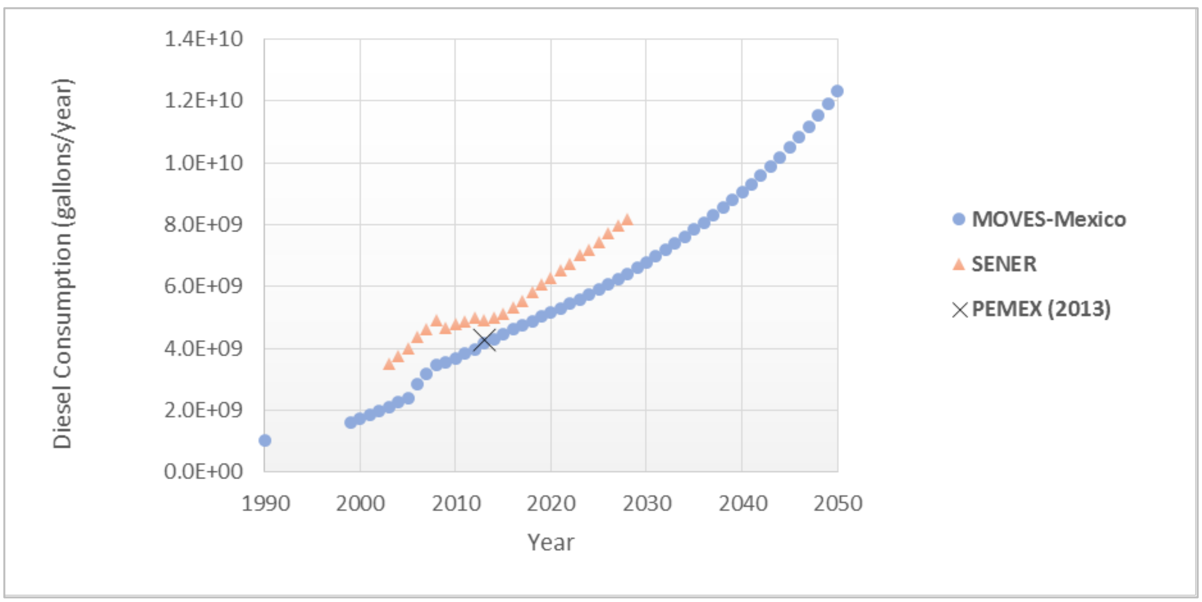


Figure 2: Diesel Fuel Consumption



ERG also generated annual, national totals for VOC, CO, NOx, and $PM_{2.5}$ to assess trends from calendar year 1990 to 2050. The per-mile emission factors for each pollutant show a decrease over time (though $PM_{2.5}$ levels off after 2010) as a result of NOM exhaust standards and fuel quality improvements, most notably the introduction of lower sulfur fuel in major cities in the late 2000s. As expected based on the calibration factor approach to developing MOVES-Mexico emission rates, the Mexico per-mile emissions are consistently higher than the comparable U.S. rates. The total onroad emissions results for Mexico and the U.S. show very different trends. While the U.S. projects a significant decline in emissions due to stringent vehicle and fuel standards coupled with modest VMT growth, Mexico's emission trends show an increasing trend for each pollutant through about 2015, and depending on the pollutant either a period of reduction in total emissions as NOM standards serve to offset VMT growth (CO and NOx), or a continued increase in emissions as VMT growth outpaces the impact of vehicle standards (VOC and $PM_{2.5}$). Onroad emissions in Mexico are projected to equal those in the U.S. by about 2030, and from 2040 onward all pollutants are projected to increase as VMT growth overtakes the influence of current vehicle standards.). Passenger cars and light trucks were shown to contribute most VOC and CO, while heavy diesel trucks and buses contribute about one half of NOx, and the majority of $PM_{2.5}$. Overall, this analysis demonstrates the value of MOVES-Mexico in assessing long term emission trends and evaluating the potential impact of more stringent vehicle and fuel standards.

Looking ahead, MOVES-Mexico users should consider model improvement an ongoing process as new data are collected. A primary benefit of having MOVES-Mexico in place is that it provides a framework for collecting data and improving the model over time. A great deal of Mexico-specific data provided by INECC and others was used to populate this version of MOVES-Mexico, but as noted in the earlier sections, a number of U.S. assumptions had to be carried over to Mexico to complete the database. Ongoing data collection on vehicle emissions and activity should continue become a regular part of the model update cycle. MOVES-Mexico will also need to be updated when new vehicle or fuel standards are put in place, to reflect the benefits of these in future onroad emission inventory projections.

Specific recommendations for maintaining and improving MOVES-Mexico are as follows:

- Researchers and model developers in Mexico should undertake research programs to collect data for the model where U.S. defaults were still required. Important data inputs this was the case for include average speed distribution, vehicle trip patterns, drive patterns (i.e. drive cycles), and I/M program benefits.
- The remote emissions measurement program should continue in multiple cities to continue to track real-world emissions, deterioration trends, and differences between cities. Field work could be expanded to include on-board emissions measurement on a subset of vehicles to supplement RSD collection; improved methods for measuring heavy-duty truck

emissions; and evaporative leak evaluation. These methods have been used in recent years in U.S. field studies.

- Measurement of PM emissions on both heavy trucks and light vehicles should be a focus of emissions research in Mexico, as all of the emission rates in MOVES-Mexico are based on U.S. research.
- Research, methods and databases could be shared by MOVES-Mexico users to improve the model collectively. This could take the form of workshops, data clearinghouses, training sessions and user forums to facilitate a broader understanding of data sources for MOVES-Mexico, and help improve the model.

1.0 Introduction

This report documents the data sources and analyses used to develop MOVES-Mexico, a version of U.S. EPA's MOVES vehicle emissions estimation model adapted to Mexico. MOVES-Mexico has been developed from MOVES2014a, the most recent version of the MOVES model released by EPA at the time of this work (U.S. EPA, 2015a). The core of MOVES-Mexico is a MySQL database that contains information on Mexico's vehicle fleet, activity and emissions; this database replaces the default U.S. database that is provided with MOVES2014a, and can be used directly in EPA's version of MOVES2014a without modification of the model software. This report is focused on how the MOVES-Mexico database was developed; instructions for installing and using MOVES-Mexico are contained in a separate user's manual.

MOVES is used in the U.S. to produce national vehicle emission inventories, and by state and local governments to produce detailed regional emission inventories and microscale "hot spot" emissions. Because MOVES was designed with flexibility, it has been adapted to provide these same capabilities in Mexico. The goal of this work was to create a basic MOVES-Mexico framework that is easy to use and can be improved over time as new data become available. Developing MOVES-Mexico required determining the best approach for updating the model, culling data on vehicle fleet and activity to replace U.S. defaults where possible, and accounting for significant differences in emission standards between Mexico and the U.S. The Mexico-specific database developed for MOVES allows estimation of vehicle emissions for calendar years 1990 through 2050 at the nation, state or *municipio* level.

This report details the data sources obtained to develop the MOVES database for Mexico, and methods to convert raw data into inputs MOVES needs to predict Mexico's vehicle emissions. Included is a detailed assessment of remote sensing device (RSD) measurements from 24 cities in Mexico, and how these data were used to develop Mexico-specific emission rates for MOVES-Mexico. Section 2 gives an overview of the MOVES-Mexico approach, Section 3 covers data sources obtained for developing model inputs, Section 4 covers the MOVES database tables that will be updated based on these data and methods used to populate the tables, and Section 5 addresses the RSD analysis and planned approach to update MOVES emission rates.

2.0 Overview of MOVES-Mexico Approach

The objective in developing MOVES-Mexico was to enable estimation of a total vehicle emissions inventory for all Mexican *municipios*, for all vehicle classes, as far back as 1990 and far forward as 2050. We set out to accomplish this so that MOVES-Mexico would have the same model functionality as the U.S. version of MOVES, allowing local areas to refine their inventories when local data are available. This section provides an overview of the approach taken to develop MOVES-Mexico to meet these objectives, to provide context for the database updates described later in the document.

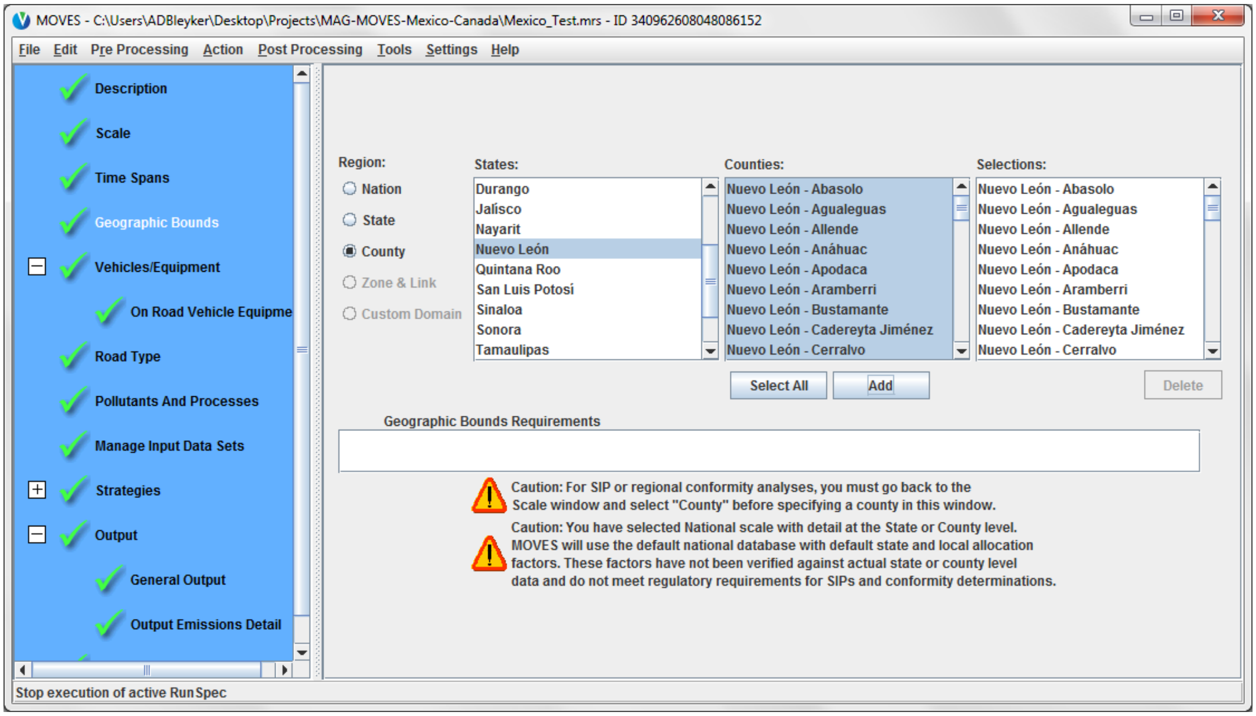
There are multiple ways to customize MOVES to local conditions. For U.S. use, MOVES provides a default database, which enables estimation of on-road emissions to significant detail (e.g. by vehicle class, fuel type, road type and model year) for all 3,222 counties in the U.S., for calendar years 1990, and each year from 1999 through 2050. To accomplish this requires a large underlying MySQL database with model inputs for vehicle activity, population, meteorology, fuel properties, road characteristics, projection factors and emission rates. Default results are generated when the National Scale is selected in MOVES, and rely heavily on a "top down" allocation approach, where national totals of vehicle population and activity are allocated to individual U.S. counties based on available county-level surrogates. As an alternative to the default National Scale approach, MOVES also provides the County Scale feature to allow users to improve estimates in a "bottom-up" fashion, allowing customization of many of these elements through data importers. When County Scale is selected, MOVES supplies a template for users to provide data directly at the county level (the County Data Manager). This feature is relied on for development of the U.S. National Emissions Inventory and modeling uses required in the U.S. Clean Air Act, such as State Implementation Plan (SIP) inventories and transportation conformity analyses. .

Customizing MOVES to Mexico could therefore be done following either the National or County Scale approaches, requiring a choice between them prior to proceeding with MOVES-Mexico development. The main consideration for this choice was the level of detailed data available for adapting to either scale. County Scale requires information such as vehicle population, vehicle miles travelled, etc. to be provided at the level of geographic detail being modeled. This approach was developed focused on local inventories, where detailed data is more likely to be available. U.S. EPA does use County Scale for the U.S. NEI, but even for this application local data are not available for many U.S. counties, requiring use of national defaults for around half of the U.S. counties (U.S. EPA, 2015b).

Our assessment of data available in Mexico determined that detailed information necessary to calculate Mexico-wide emission inventories using MOVES County Scale aren't available (as noted above, this level of detail isn't available in the U.S. either). Several good data sources were identified at more aggregate levels of detail (nation or state), however. The approach ERG took for MOVES-Mexico was to develop a national default database for Mexico because a) National Scale is more amenable to the available data in Mexico; b) once developed, a national default database provides users with the ability to estimate emissions at the national, state or *municipio* level, for multiple years; and c) this default model can serve as a foundation for users who want to use MOVES County Scale to improve local inventories with specific data, or even for "hot spot" modeling using MOVES Project Scale feature. This approach makes MOVES-Mexico more easily transferable to all users in Mexico; addresses user needs the best, and provides a common and consistent foundation for other users within Mexico to apply their own data.

Figure 3 shows a screen shot of the MOVES interface populated with Mexico states and *municipios*. Users of MOVES-Mexico will have the same capabilities as the U.S. version, adapted to Mexican conditions.

Figure 3: MOVES Interface Populated with Mexico States & *Municipios*



Compiling a national default database for Mexico required a) nation-wide totals of vehicle fleet and activity inputs such as populations, kilometers travelled, age distribution and speeds; b) factors to allocate vehicle population and activity to the Mexican *municipios*; c) localized data on meteorology, fuels and vehicle inspection/maintenance and d) updated emission rates to reflect significant differences between U.S. and Mexican vehicle standards. Section 3 discusses the data sources available to produce Mexico-specific inputs for these model parameters.

3.0 Data Sources

ERG and Ms. Garibay-Bravo obtained most of the data for developing Mexico-specific inputs from the National Institute of Ecology and Climate Change (INECC, in Spanish). Ms. Garibay-Bravo worked closely with representatives from INECC to obtain underlying data used in Mexico's development of the National Emissions Inventory, and provide to ERG for use in MOVES (José Andrés Aguilar-Gómez, personal communication, 2015). Many of these data were from studies and analyses that are not yet published; these data are provided electronically as part of the final project deliverable, according to filenames referenced. Where additional data were required beyond what INECC provided, ERG's team researched and evaluated data available from Mexico government agencies or other entities via the internet. Section 3 provides and overview of data to be used for population MOVES-Mexico, and Section 4 discusses how these data will be converted into the specific inputs needed by MOVES. Emission rates are discussed in Section 5.

Vehicle activity data sources in Mexico have traditionally been scarce compared to the U.S. Although several data sources are available pertaining to vehicle emissions, vehicle population and vehicle kilometers travelled (VKT), they may be inconsistent or based on outdated information. Recently, however, several studies have been carried by INECC, the National Institute of Geography and Statistics (INEGI, in Spanish), the National Population Council (CONAPO, in Spanish) and the state-owned fuels company (PEMEX) to overcome these limitations. Although most of the information generated in these studies has not yet been published, we were able to access internal reports and spreadsheets through direct communication with INECC staff, who shared the databases used in their most recent mobile source emission estimates for 2013. Hence, unless otherwise noted, the following information was provided directly by INECC.

3.1 Vehicle Population & Age Distribution

In Mexico, vehicle registration is carried out by state authorities, requiring different formats and level of detail, tailored to their particular needs. Usually, local authorities add new vehicles to the registry every year but very rarely remove vehicles that are no longer in use. According to Mexican emission inventory experts, this has historically led to an overestimation of the vehicle fleet in emissions inventories. To avoid this, we used INECC estimates of vehicle population and age distribution instead of vehicle registration. These are considered more realistic since INECC derived retirement rates from several field studies carried out between 2007 and 2012 by INECC and the Mexican Petroleum Institute (IMP, in Spanish). INECC applied these retirement rates to historical state-level vehicle sales provided by the automotive industry, resulting in adjusted vehicle population at the state level. Imported used vehicle registries from the Mexican Treasury and Customs Authority (SHCP, in Spanish) were also used to add these vehicles and obtain total population by age and vehicle type. These estimates were used for a recent 2013 emissions estimate developed by INECC. INECC provided estimates of 2013 vehicle populations by vehicle class, fuel type, and model year, in a file named "State-level vehicle fleet.xlsx," which we used to develop the model database tables containing population and age distributions. We have included this source data as an electronic file submitted with this report.

Vehicle field surveys provided by INECC provided supplemental data ("Surveys-raw data.xlsx,") to determine the split of personal and business use of light trucks in Mexico. INECC provided ERG with a vehicle survey of population and VKT from a category of light vehicles that includes passenger cars (*vehículo de pasajeros*, abbreviation VP) and light trucks (*camioneta ligera*, abbreviated as CL).

3.2 Vehicle Kilometers Travelled (VKT)

Inventories in Mexico have traditionally used one average VKT number for the whole country based on a limited number of surveys performed in Mexico City, or on a travel demand modeling exercise carried out for seven representative cities for the 1999 Mexico NEI. For MOVES-Mexico, INECC has provided a much more robust dataset based on surveys conducted by INECC between 2007 and 2011 in 15 cities, from which average national-level VKT by vehicle age and vehicle type (light, medium and heavy duty) were derived. The VKT data file that INECC prepared is named "National VKT-by age and vehicle type.xlsx" and accompanies this report.

3.3 Vehicle Population Projections

INECC provided a spreadsheet of active vehicles by calendar year, extending back in time to 1970 and projecting out to 2050. The number of vehicles accounts for new sales and scrappage, with separate worksheets for gasoline and diesel-fueled vehicles. The file "Flota-Mexico_historica-proyeccion_INECC (2050).xlsx".

3.4 Road Network

ERG obtained GIS-based downloadable files containing detailed, state-level data of the road network (INEGI, 2015a). A separate technical report enabled harmonization of INEGI's road types to those used in MOVES (INEGI, 2015b). Significant analysis and processing these data were done to produce road type distributions by *municipio*, as described in Section 4. As discussed later, for this analysis we also used Mexico municipality boundary shapefiles (provided electronically, "mgm2013v6_0.zip"), Mexico human population data by municipality provided by INECC (file name "Population by *municipio* 2010.xlsx"), census bureau data on human population (U.S. Department of Commerce, 2014) and land area (U.S. Department of Commerce, 2015), and U.S. data on the fraction of urban roads at the county level from the MOVES2014 database (U.S. EPA, 2015a).

3.5 Fuels

In México, fuels are distributed and sold by a single, state-owned company (PEMEX). Gasoline and diesel sales are publicly available (Petróleos Mexicanos, 2015) but only at the state level. However, through INECC, we obtained fuel sales at the municipality level provided by PEMEX, for 2013. The 2013 data in the file "PEMEX sales.xlsx" is provided electronically with this report. For historical fuel properties, we used the NOM 086 standards published in 1994 for oxygenates and Reid Vapor Pressure (RVP), and the average sulfur content of 394 ppm for unleaded regular gasoline that PEMEX supplied to the Mexico City Metropolitan Area during the period 1997-2000 (Molina & Molina, 2002).

3.6 Inspection/Maintenance Programs

Inspection/Maintenance programs in Mexico are managed by state or even local environmental authorities. However, these are enforced only in a limited number of cities. For example, the I/M program in Mexico City has tighter controls and more stringent conditions than those in other cities, but some cities adjacent to the Mexico City Metropolitan Area have adopted these conditions to avoid transit restrictions. The Federal environmental authority (SEMARNAT) compiles compliance data from all states in Mexico periodically. We used the latest internal status report (2012) provided by INECC, with information gathered by SEMARNAT. This data is provided electronically, in the file "I_M program status - may 2012.xls." These information included state, whether there is an existing program, the program start year, the test type (static and/or dynamometer), test frequency, number of I/M facilities, and the number of vehicles tested by time period over several years (2005 through 2011). Remote sensing data (described in more detail in Section 4) was the basis for determining compliance factors.

3.7 Human Population

Human population is a common surrogate for allocating vehicle activity spatially, if direct vehicle activity data aren't available. Current population was taken from 2010 census counts at the municipality level (INEGI, 2015c) and projected population data from CONAPO (2015) were downloaded. These data were also used in our road network analysis, as discussed in Section 3.4. The file "Population by *municipio* 2010.xlsx" is provided electronically with this report.

3.8 Meteorology

Temperature data for 2011 was used to populate the database with hourly, seasonal values in degrees Fahrenheit (for the final version of MOVES-Mexico, we will provide an optional, external database table containing 2013 data). State-average maximum and minimum temperatures by year and month are published by the *Comisión Nacional Del Agua* (CONAGUA) *Servicio Meteorológico Nacional* (CONAGUA, 2015). Hourly temperatures were not available at this level of coverage; the information is available for individual weather stations across Mexico, but due to concerns with coverage and the level of effort necessary to convert these to *municipio*-specific meteorology, these were not pursued. Instead, as detailed in Section 4, an approach developed by EPA to convert min/max temperatures to hourly diurnal profiles was used to generate hour temperatures by state. Humidity estimates were then made based on local data climate maps of humidity (Find Local Weather, 2015).

3.9 Altitude

We obtained altitude data (height above mean sea level, in meters) for each locality in Mexico from the INEGI National Statistical Framework online catalog (INEGI, 2015d). As described in Section 4, these data were the basis for calculating average barometric pressure for each *municipio* to populate the model database.

4.0 Populating MOVES-Mexico Database Tables

The data sources outlined in Section 3 were processed, in some cases with additional analysis, into the format needed by MOVES. MOVES uses relational database with dozens of underlying, linked tables providing the model with information on the geography, vehicle fleet, activity, fuels, meteorology and emissions required to produce emission inventories specified in the run specification file, along with necessary information files. Only a subset of 29 tables were updated for Mexico, based on a) Mexico fleet, activity, meteorology and fuel data discussed in Section 3; b) informational tables needed to update U.S. counties and states to Mexico *municipios* and states; and c) the need to adapt MOVES emission rates to Mexico emission standards (discussed in Section 5). Table 1 provides a list of MOVES tables updated for Mexico. All other MOVES tables were left as in the U.S. default database. The result of this project is a complete database that can replace wholesale the default U.S. database provided by U.S. EPA in the installation package for MOVES2014a. The MOVES-Mexico database is a hybrid of the Mexico-specific inputs developed as described in Section 4 and 5, and U.S. defaults; however, for proper functioning with MOVES, it was better to combine these into a complete database that can be used by the model instead of the default U.S. database.

Table 1: MOVES Database Table Updates for MOVES-Mexico

MOVES-Mexico Database Table Name	Purpose/Description
County	List of *municipios* in Mexico.
State	List of states in Mexico.
CountyYear	Stage II refueling program efficiency.
FuelUsageFraction	E85 usage for flex fuel vehicles.
Year	List of the distinct “fuel year” assigned to each calendar year.
IMCoverage	Inspection and maintenance program description and coverage.
Link	Enables county-specific emissions output in an inventory run.
FuelSupply	Assigns specific fuels to each fuel region, by month and calendar year.
FuelFormulation	Parameters for every fuel (e.g., sulfur level and vapor pressure).
RegionCounty	Assignment of each county to a fuel region.
Zone	Allocation of the off-network activity from nationwide to *municipio*.
ZoneMonthHour	Diurnal temperature and relative humidity profiles for each month of year.
ZoneRoadType	Allocation of the on-network activity from nationwide to *municipio*. On-network activity includes source hours operating, which is how VMT gets allocated to each *municipio*.
HPMSVTypeYear	Nationwide VMT, annual total, by HPMS vehicle classification.
SourceTypeYear	Nationwide vehicle population by source use type classification.
SourceTypeAgeDistribution	Average fleet age distributions, Mexico nationwide average.

MOVES-Mexico Database Table Name	Purpose/Description
AVFT	Gasoline/diesel relative fractions, for each source use type and vehicle model year.
RoadTypeDistribution	Distribution of VMT to road types.
MonthVMTFraction	Allocates annual VMT to the twelve months of year.
EmissionRateByAge	Base emission rates by age, model year group, regulatory class, fuel type, pollutant, emission process, and operating mode.
EmissionRate	Base emission rates by model year group, regulatory class, fuel type, pollutant, emission process, and operating mode.
CumTVVCoeffs	Coefficients used by MOVES to calculate tank vapor venting
EmissionProcess	List of available emission processes in MOVES-Mexico.
HotellingCalendarYear	Extended idling is turned "off" here for Mexico.
SourceUseType	List of available source use types (vehicle classes) in MOVES-Mexico.
FuelType	List of available fuel types in MOVES-Mexico.
Region	List of distinct fuel regions in MOVES-Mexico.
ModelYearCutpoints	Defines gasoline sulfur phase-in (known as "GPA") in Mexico City during 2007-2008
GeneralFuelRatioExpression	Adjusts effect of sulfur phase-in on CO emissions during 2007-2008

The following sections include a description of how each of these tables were converted from U.S. to Mexico data. Where feasible, the sections include table and/or figure showing the contents of the specific database table. In some cases, however, the table is too large for either the main report or appendix; for example the inspection and maintenance coverage (IMCoverage) table has over 1.8 million records. Any table can be accessed, reviewed, and exported by querying the model database.

Nearly every table discussion section is concluded with a list of sequential steps that ERG undertook to create the specific table. From a user perspective however, when new data become available for MOVES-Mexico, it is not necessary to recreate any default database tables. It is far simpler to use the MOVES-Mexico graphical user interface (GUI) features and data importers to tailor individual model runs to specific locations and times which may have better data available than the default database. This topic is addressed in a separate user manual document.

4.1 County

The County table lists each municipality in Mexico, its barometric pressure, and an altitude assignment of H (high) or L (low). MOVES uses barometric pressure for calculations requiring absolute humidity and the altitude to estimate the amount of gasoline vapor generated within a vehicles' fuel tank. As pressure drops with increasing altitude, MOVES estimates additional tank vapor generated (U.S. EPA, 2014a).

The source data for this table was the INEGI National Statistical Framework (INEGI, 2015d). ERG downloaded nationwide datasets of altitude by locality – a finer resolution than municipality, with 304,680 localities across the country. For 2,455 out of the 2,457 municipalities in Mexico, ERG used the altitude of the primary, urban locality that typically had a locality code of 0001. For the remaining two municipalities, ERG used the altitude for the locality with the largest population: (1) *San Miguel La Sardina* locality for *Francisco León* in *Chiapas* and (2) *Villa de Arista* locality for *Villa de Arista* in *San Luis Potosí*.

ERG used these altitudes to calculate municipality level barometric pressure using Equation 1, derived from the ideal gas law (Seinfeld & Pandis, 2006). The equation describes how atmospheric pressure *p(z)* varies relative to sea level pressure p_0 with altitude *z*.

$$p(z) = p_0 e^{-\left(\frac{zRT}{M_{air}g}\right)/1000} \qquad \text{Eqn. 1}$$

Where *p(z)* = pressure at altitude *z*, units of inches of mercury (inHg)
P_0 = pressure at sea level, 29.92 inHg
z = altitude, units of meters
R = the ideal gas constant, 8.314 Joules/(K-mol)
T = temperature, 297 K
M_{air} = molecular weight of dry air, 28.97 g/mol
g = acceleration due to gravity, 9.8 m/s^2
1000 = unit conversion from m to km

In accordance with U.S. MOVES documentation, ERG assigned an altitude setting for each municipality, using a label of *H* where barometric pressure was less than or equal to 25.8403 inches of mercury (in Hg) and *L* where it exceeded this cutoff (U.S. EPA, 2014b).

All *municipios* in the Mexico City area (D.F. and Mexico state) were assigned GPAFraction=1. This change, in combination with updates made to the ModelYearCutpoints and GeneralFuelRatioExpression tables discussed later in this section, enables MOVES to model the period of transition to 30ppm fuel in these areas in 2007-2008 to account for sulfur poisoning effects on CO emissions.

4.2 State

The State table was updated to include all states in Mexico, by 1 or 2-digit integer code as can be seen in Table 2 below.

Table 2: Mexico States

stateID	stateName	stateAbbr	stateID	stateName	stateAbbr
1	Aguascalientes	AG	17	Morelos	MO
2	Baja California	BC	18	Nayarit	NA
3	Baja California Sur	BS	19	Nuevo Leon	NL
4	Campeche	CM	20	Oaxaca	OA
5	Coahuila de Zaragoza	CO	21	Puebla	PU
6	Colima	CL	22	Queretaro	QT
7	Chiapas	CS	23	Quintana Roo	QR
8	Chihuahua	CH	24	San Luis Potosi	SL
9	Distrito Federal	DF	25	Sinaloa	SI
10	Durango	DG	26	Sonora	SO
11	Guanajuato	GT	27	Tabasco	TB
12	Guerrero	GR	28	Tamaulipas	TM
13	Hidalgo	HG	29	Tlaxcala	TL
14	Jalisco	JA	30	Veracruz de Ignacio de la Llave	VE
15	Mexico	ME	31	Yucatan	YU
16	Michoacan de Ocampo	MI	32	Zacatecas	ZA

4.3 CountyYear

The CountyYear table contains fractions representing the efficiency of Stage II refueling control programs for each county and year. Stage II refueling emissions are hydrocarbons that evaporate into the atmosphere during gasoline refueling at service stations from either the pump dispenser itself (spillage losses) or the vehicle tank (vapor displacement losses). Control programs reduce these hydrocarbon emissions at the pump are termed Stage II. This table was a structuralupdate only to include all Mexican *municipio* codes. We created this table by inserting all combinations of *municipio* code and calendar year (1990; 1999-2050), and we set all Stage II control program effectiveness factors to zero.

4.4 FuelUsageFraction

The FuelUsageFraction table allows the user to specify relative fractions of gasoline versus E85 use in flex-fuel vehicles by *municipio* and calendar year (1990; 1999-2050). Because there was no data to indicate any E85 use in Mexico, we set E85 fuel usage fractions to zero so that any flex fuel vehicles use conventional gasoline.

4.5 Year

The Year table contains 53 records, one row for each calendar year (1990 and 1999-2050). The table assigns a unique "fuel year" to each calendar year which MOVES uses to determine the fuel supply to be used for a particular calendar year. For MOVES-Mexico, we assigned three fuel years: 1990, 2007, and 2009 based on changes in fuel properties over time discussed in Section 4.8. The 1990 fuels cover the years 1990 and 1999-2006; fuel year 2007 covers the calendar years 2007 and 2008, and the fuel year 2009 applies in 2009 and later.

4.6 IMCoverage

The IMCoverage table defines specifics of vehicle inspection/maintenance (I/M) programs by state. I/M programs in Mexico are comparable to U.S. programs in test method and implementation, so programs already defined in MOVES can be the starting point for defining the programs in Mexico. I/M programs in Mexico are mostly idle tests, although some dynamometer testing is done in a few states. To reflect this, we selected the Two-Speed Idle (TSI) test to represent the IM tests labeled as "Static" and the Accelerated Simulation Mode (ASM) to represent those labeled as "Dynamometer" in the raw data discussed in Section 3. Vehicles were assumed to become eligible for an I/M program beginning at age 4 years old, as data on this "grace period" were not available. The remainder of fields were populated using the local I/M program data discussed in Section 3, except for the parameter Compliance Factor. The Compliance Factor is a parameter in the IMCoverage table that limits the portion of the passenger car and light truck fleet that receives the emissions benefit of a particular I/M test, and so is the primary means to MOVES to account for the "true" benefit of an I/M program; a Compliance Factor of 100 percent results in the most I/M benefit available for the program specific, while a value of 0 results in no benefit (i.e. same as no I/M). A compliance factor was assigned for each state with an I/M program based either on RSD measurements within the state, where data were available; or, based on a national default calculated from Mexico City program statistics.

According to the INECC data ("I_M program status - may 2012.xls"), the number of vehicles that participate in the Federal District (D.F.) I/M program is 82 percent of the light-duty gasoline vehicle population. We used this figure directly for the Compliance Factor in D.F., and for all other states where RSD data were not available, representing a well-functioning I/M program

(D.F. had the lowest emissions across all of the cities where RSD was measured). I/M states with RSD were assigned a Compliance Factor based on a comparison of emissions measurements against states without I/M programs. This was in effect a calibration of MOVES to the RSD data across different cities, in order to better predict emissions in difference cities as a function of I/M program effectiveness. Compliance Factor for these cities was assessed as follows:

- **Puebla, Ensenada, and Rosarito** had average passenger car NO and CO RSD emissions comparable to or higher than the cities used as a benchmark for no I/M areas (Monterrey and Morelia, discussed further in Section 5). This was also the case for Guadalajara NO emissions. We therefore assigned a nominally low Compliance Factor of 5 percent for the states of Puebla, Baja California and Jalisco (for NO only), to reflect that RSD did not show much effect of the I/M program vs. a no I/M case.
- **Toluca** has average passenger car NO and CO RSD emissions slightly lower than the no I/M cities; INECC also clarified that the I/M program, though using the more effective Dyno method, is of limited scope. We therefore assigned a Compliance Factor of 10 percent for the state of Mexico.
- **Veracruz, Boca del Rio, Leon and Oaxaca** had average passenger car NO and CO RSD emissions that were within expected ranges compared to D.F. (effective Dyno I/M program) and no I/M cities, given the are Static programs. The states of Veracruz, Guanajato and Oaxaca were assigned the default 82 percent Compliance Factor.

4.7 Link

The Link table is informational to define county and road type combinations, and we updated it only to include all of the Mexican *municipio* codes.

4.8 FuelSupply & FuelFormulation

These tables provide the market share and properties of individual fuel formulations, broken down for each fuel region, month, and year. Details of these fuels are described in the discussion under RegionCounty table; the same fuels were assumed for 2009 and later.

Because PEMEX fuel quality certificates are not publicly available, we used the specifications in the current fuel quality standard as a reference. Actual sulfur concentrations in fuels, however, differ from the standard. We relied on expert opinion from INECC as to which municipalities have access to low-sulfur fuels. Table 3 below shows the historical pattern of fuels before 2009. There was a shift in 1994 when the first fuel regulations were introduced in Mexico; prior to this year there were no regulations. The year 1994, however, is not covered by the MOVES model, so the 1994 standards will be applied in 1999 through 2000. From 2001-2006 gasoline sulfur was estimated at 300 ppm, with 30 ppm entering the market beginning in 2007 in Mexico City. Because there is no information on fuel quality in 1990, the fuels in 1990 are assumed the same as those in 1999-2000. According to a published estimate by Molina and Molina (2002), the actual gasoline sulfur level prior to 2001 was approximately 394 ppm – the 1000 ppm level from the standard is the maximum allowed and may be unrealistically high for actual gasoline.

Table 3: Fuel Parameters by Region

Range of years covered in MOVES-Mexico	Fuel parameter	Northern Border States	Metropolitan Areas	Remainder of Mexico
1990; 1999-2000	Gasoline Sulfur	394 ppm	394 ppm	394 ppm
	Gasoline RVP	See Table 4	8.5 psi in Mexico City; 9.5 psi in Guadalajara and Monterrey	9.5 psi
	Gasoline Oxygenates	None	2% (MBTE)	None
	Diesel Sulfur	500 ppm	500 ppm	500 ppm
2001-2006	Gasoline Sulfur	300 ppm	300 ppm	300 ppm
	Gasoline RVP	See Table 4	8.5 psi in Mexico City; 9.5 psi in Guadalajara and Monterrey	9.5 psi
	Gasoline Oxygenates	None	2% (MBTE)	None
	Diesel Sulfur	500 ppm	500 ppm	500 ppm
2007-2008	Gasoline Sulfur	300 ppm	Mix of 50% 300 ppm and 50% 30 ppm in Mexico City; 300 ppm in Guadalajara and Monterrey	300 ppm
	Gasoline RVP	Same as 2006	Same as 2006	Same as 2006
	Gasoline Oxygenates	Same as 2006	Same as 2006	Same as 2006
	Diesel Sulfur	15 ppm	500 ppm	500 ppm
2009-2050	Gasoline Sulfur	Refer to the following section describing the RegionCounty table.		
	Gasoline RVP			
	Gasoline Oxygenates			
	Diesel Sulfur	15 ppm	15 ppm	500 ppm

Table 4: RVP Requirements in the Northern Border States Starting in 1994

Month	RVP (psi)
January	13.5
February	13.5
March	13.5
April	11.5
May	7.8
June	7.8
July	7.8
August	7.8
September	7.8
October	10.0

Month	RVP (psi)
November	13.5
December	13.5

4.9 RegionCounty

The RegionCounty table assigns each *municipio* to a "fuel region," defined as a broader geographic area that shares similar fuels. Source data on fuel formulations discussed in Section 3.1 specified differences in sulfur, RVP, and oxygenate use by *municipio*, depending on whether it was located (1) inside or outside a metropolitan area, (2) in a border or non-border state, and (3) RVP regions. This unique combination of metropolitan area, border state, and RVP region resulted in seven fuel regions in Mexico, shown in Table 5.

Table 5: Fuel Regions Defined for Mexico

Fuel Region ID	Metropolitan Area	Border State	Volatility Group
100000000	No	No	2
100010000*	Yes	No	3
200000000	No	Yes	2
300000000	No	Yes	1
400000000	Yes	No	3
500000000	No	No	1
600000000	Yes	Yes	1

*The fuel region ID of 100010000 applies only to the Guadalajara metropolitan area and prior to 2009. Starting in 2009, Guadalajara joins the region of Mexico City (400000000). Guadalajara adopted 30 ppm sulfur gasoline later than Mexico City and it historically had a more relaxed RVP requirement.

The fuel parameters discussed below apply only to calendar years 2009 and later. For information on pre-2009 fuels, refer to Table 1Table 3 above in Section 4.8. In 2009, diesel sulfur content is 15 ppm in border states and the Mexico City, Monterrey and Guadalajara metropolitan areas; and it is 500 ppm elsewhere. Gasoline sulfur content is 30 ppm in these three metropolitan areas; and elsewhere consists of a mix of 15% market share of 30 ppm and 85% 300 ppm sulfur fuel.

The fuel volatility (measured by RVP) requirements of gasoline varied throughout Mexico by month of the year. The three volatility groups listed above in Table 5 have the following RVP schedules:

- Volatility Group 1 – the area with least stringent RVP requirement
    - 69 kPa (10 psi) March to October
    - 79 kPa (11.5 psi) January-February and November-December

    - Covers the Monterrey metropolitan area and the states Nuevo León, Chihuahua, Durango, Coahuila, Tamaulipas, San Luis Potosí
  - Volatility Group 2 – moderate RVP restriction
    - 62 kPa (9 psi) June-August
    - 69 kPa (10 psi) Mar-May and Sep-Oct
    - 79 kPa (11.5 psi) Jan-Feb and Nov-Dec
    - Covers the states Aguascalientes, Jalisco, Guanajuato, Michoacán, Zacatecas, Morelos, Tlaxcala, Estado de México, Distrito Federal, Hidalgo, Querétaro, Veracruz, Campeche, Puebla, Tabasco, Yucatán, Quintana Roo, Baja California, Baja California Sur, Sonora, Sinaloa, Nayarit, Colima, Guerrero, Oaxaca, and Chiapas.
  - Volatility Group 3 – the most controlled RVP
    - 54 kPa (7.8 psi) year-round
    - Mexico City and Guadalajara metropolitan areas

4.10 Zone

The Zone table allocates off-network activity (related to the emission processes of start, evaporative and extended idle emissions) from nation to Mexico *municipio*. The activity allocated for off-network activity includes number of vehicle starts, source hours parked (SHP), and source hours idling (SHI). However, we did not include extended idling emissions because this activity was deemed significantly smaller in Mexico than in the U.S.

The starts allocation was created using surrogates, as follows:

1. National to State based on relative state-level vehicle population data
2. State to County based on relative county-level human population within each state

The SHP allocations were created by calculating SHP at the state level outside of MOVES to force the resulting MOVES-allocated vehicle to match state totals in the source data discussed in Section 3. The equation for this calculation was Target_Population – SHO = SHP. The SHP was then normalized at the state level to create fractions that summed to one (1) over state, which were then subsequently further subdivided into municipalities using relative human population by *municipio* within each state. Start and Park allocations are shown below in Table 8 with the VMT allocations discussion.

4.11 ZoneMonthHour

The ZoneMonthHour tables contains temperature and humidity data for each *municipio*, by month and hour of the the day. State-level averages where applied to each *municipio* in the state. 2011 min/max temperatures for each state and month from CONAGUA were run through the EPA's temperature profile generator (U.S. EPA, 2015c) to estimate hourly temperatures. Since no average humidity data were available for Mexico, humidity levels were assigned to Mexico states from U.S. states on the qualitative basis of whether the humidity is "Low," "Medium," or "High". Table 6 below summarizes the categorization of Mexico states based on local data climate maps of humidity for North America (Find Local Weather, 2015).

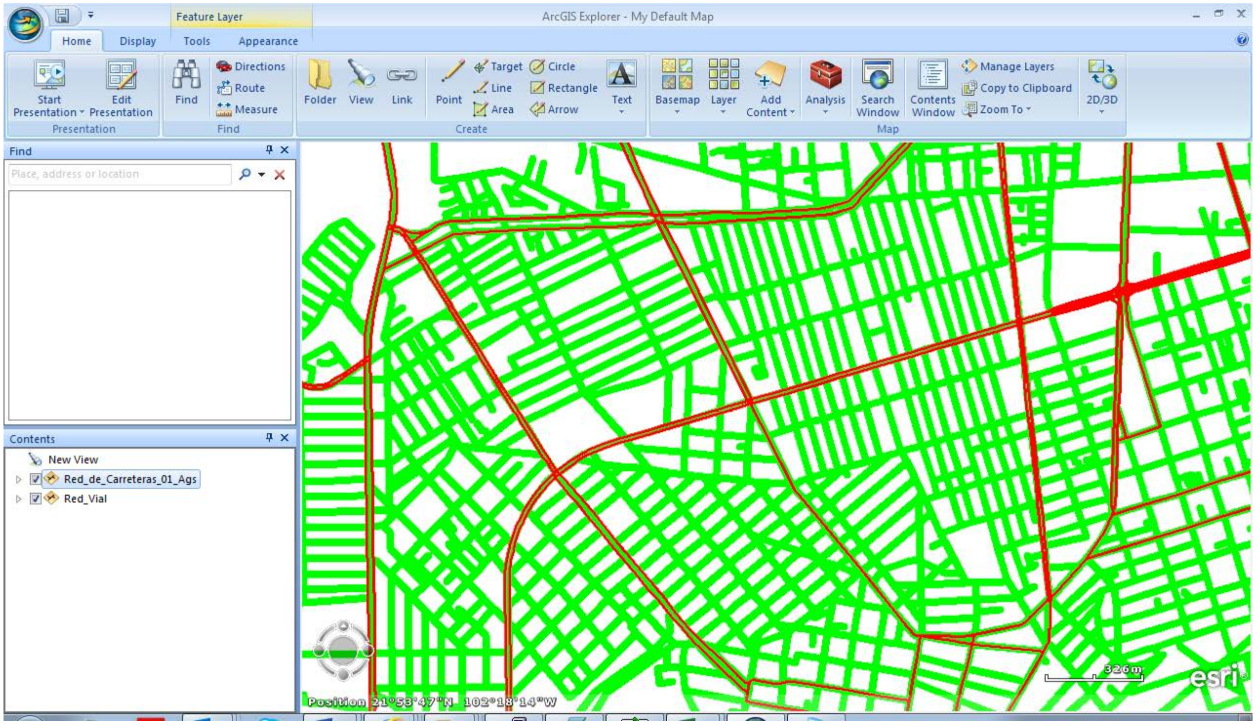
Table 6: Mapping of Mexico States to US States for Humidity

Relative Humidity Qualitative characterization	Mexican States	US State
Low (dry)	Baja California, Baja California Sur, Sonora, Chihuahua, Sinaloa, Durango, Nuevo Leon, Queretaro, Zacatecas	Arizona
Medium	Coahuila, Aguascalientes, Colima, Distrito Federal, Guanajuato, Hidalgo, Jalisco, Mexico, Michoacan, Morelos, Nayarit, Puebla, San Luis Potosi, Tamaulipas, Tlaxcala,	Texas
High (wet)	Campeche, Chiapas, Tabasco, Veracruz, Oaxaca, Guerrero, Yucatan, Quintana Roo	Florida

4.12 ZoneRoadType

The ZoneRoadType table contains allocations that distribute national total VMT to municipalities, separately by road type. The allocation from nation to state reflect relative VKT at the state level based on 2013 state-level vehicle populations and VKT data discussed in Section 3. However, there was no VKT information available at the *municipio* or state levels, so we used a surrogate of roadway distance from a GIS dataset where the roadway network included distinction by roadway type. The primary data used were state-level GIS shapefiles of lane-meters of roadway by Mexico road type from INEGI. The detail of Mexico road type allowed us to determine the mix of Unrestricted Access vs. Restricted. A sample view of GIS shapefile of the roadway network in state of Aguascalientes is shown in Figure 4 below.

Figure 4: Sample Road Network GIS Shapefile from INEGI



Using the GIS road data we performed a GIS intersection analysis to determine which links were located in each *municipio* and totaled their lane-meters (total roadway capacity) accordingly. Road types from the GIS dataset were mapped to either "Restricted Access" or "Unrestricted Access" MOVES definitions, as shown in Table 7, based on road definitions from INEGI (2015b).

Table 7: Road Type Mapping

GIS Road Type	MOVES Type
ANDADOR (PEDESTRIAN)	---
AVENIDA	UNRESTRICTED
BOULEVARD	RESTRICTED
CALZADA	UNRESTRICTED
CALLE	UNRESTRICTED
AMPLIACION	UNRESTRICTED
CALLEJON*	UNRESTRICTED
CERRADA*	UNRESTRICTED
CIRCUITO	RESTRICTED
CIRCUNVALACION	UNRESTRICTED
CONTINUACION	UNRESTRICTED
CORREDOR	UNRESTRICTED
DIAGONAL	UNRESTRICTED
EJE VIAL	UNRESTRICTED

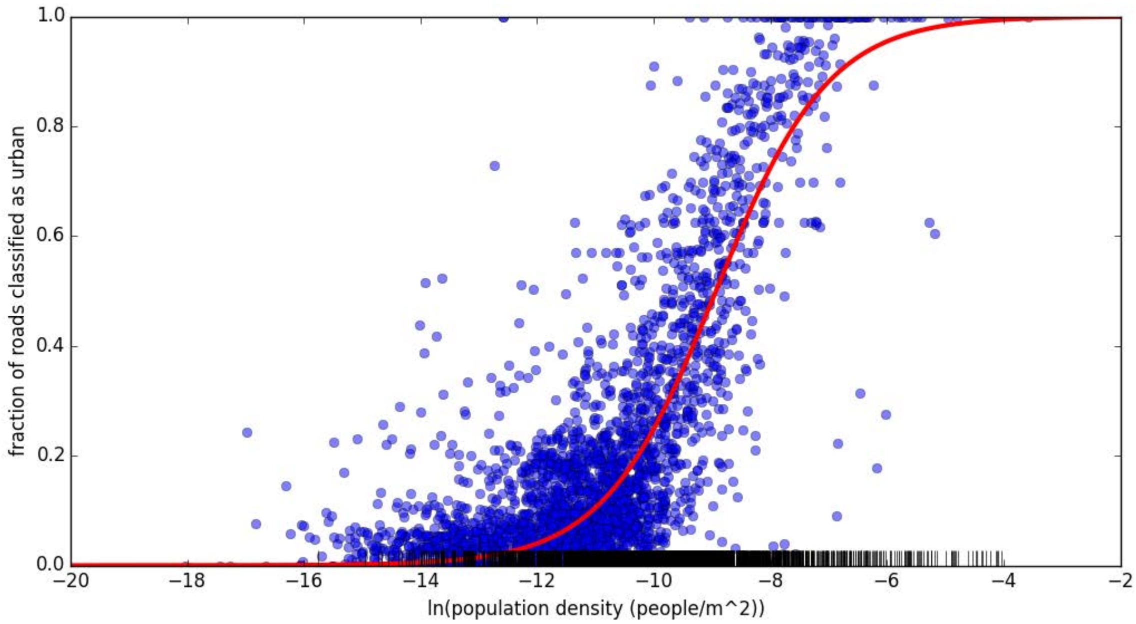
GIS Road Type	MOVES Type
PASAJE (PEDESTRIAN)	---
PEATONAL (PEDESTRIAN)	---
PERIFERICO	RESTRICTED
PRIVADA*	UNRESTRICTED
PROLONGACION	UNRESTRICTED
RETORNO	UNRESTRICTED
VIADUCTO	RESTRICTED
CARRETERA	RESTRICTED

**PRIVADA*, *CALLEJÓN*, and *CERRADA* are very narrow roads or backstreets, with less, very slow traffic. These are mostly limited access destined for houses.

The INEGI road network did not provide any information on rural vs. urban split, and ERG was not able to find any information to allocate this split in Mexico. We therefore conducted an analysis to develop a relationship between urban/rural split and population density that could be applied to each *municipio*, based on MOVES default road distribution by county and U.S. county population density data from the U.S. Census. For this analysis, we obtained U.S. county population and land area data from the U.S. Census Bureau, respectively (U.S. Department of Commerce 2014and 2015). We determined the fraction of roads that are urban using data from the default MOVES 2014 database. We obtained population densities for Mexican *municipios* from the *Censo Nacional de Población y Vivienda* (INEGI, 2015c) and the fractions of unrestricted and restricted lane miles in the *municipios* from our GIS analysis.

Generation of the primary categories in the RoadTypeDistribution table (fractions of urban restricted, urban unrestricted, rural restricted, and rural unrestricted road types) required an estimate of both the fraction of roads classified as urban and the number of restricted and unrestricted lane miles. Direct information on urban fraction in the Mexican *municipios* was unavailable, so we used data from U.S. counties to derive a relationship between population density and urban fraction. Population and land area data were obtained from the U.S. Census Bureau, as described in Section 3; from these, population density can be calculated. The urban fractions for U.S. counties were calculated using the ZoneRoadType and RoadTypeDistribution tables from MOVES2014. The relationship between urban fraction and population density was satisfactorily captured by a logistic function (Figure 5). Using this best-fit line, we estimated urban fractions for the *municipios* based on their population densities. To determine the fraction of restricted and unrestricted lane miles, we extracted total urban and restricted lane miles from the INEGI GIS dat. Using the product of the urban (rural) fraction and the unrestricted (restricted) lane miles, normalized by total lane miles, we then calculated the RoadTypeVMTFraction for each road type and applied this to all source use types.

Figure 5: U.S. Population Density vs. Urban Road Fraction



After assigning urban road fractions to each *municipio*, the lane-meters by *municipio* from the GIS analysis were multiplied by urban fractions and (rural fractions, as 1 – urban) to result in the surrogate of total roadway distance by the four MOVES road types for each *municipio*. The total roadway distances were normalized by MOVES road type, to fit the format of the ZoneRoadType table. The state level VKT determined part of the allocations from national to state, but the GIS and population density analysis drive the allocation from state to *municipio*. Shown in Table 8 are the aggregated state-level allocations for roadways (SHO), along with allocations for starts and park discussed earlier. The U.S. version of MOVES also includes allocations for extended idle for heavy trucks (source hours idling) but this phenomena is not expected to occur in Mexico, so inputs have not been updated for Mexico.

Table 8: Allocation Factors by Mexican State

Province	Running (SHO)	Start	Park (SHP)
Aguascalientes	0.013	0.013	0.012
Baja California	0.047	0.047	0.042
Baja California Sur	0.012	0.012	0.011
Campeche	0.007	0.007	0.005
Coahuila de Zaragoza	0.027	0.027	0.026
Colima	0.008	0.008	0.007
Chiapas	0.016	0.016	0.013

Province	Running (SHO)	Start	Park (SHP)
Chihuahua	0.048	0.048	0.045
Distrito Federal	0.133	0.133	0.132
Durango	0.015	0.015	0.014
Guanajuato	0.041	0.041	0.043
Guerrero	0.021	0.021	0.022
Hidalgo	0.024	0.024	0.025
Jalisco	0.088	0.088	0.092
México	0.076	0.076	0.078
Michoacán de Ocampo	0.047	0.047	0.049
Morelos	0.014	0.014	0.015
Nayarit	0.010	0.010	0.010
Nuevo León	0.059	0.059	0.061
Oaxaca	0.019	0.013	0.014
Puebla	0.030	0.036	0.037
Querétaro	0.013	0.013	0.013
Quintana Roo	0.010	0.010	0.010
San Luis Potosí	0.024	0.024	0.024
Sinaloa	0.029	0.029	0.030
Sonora	0.029	0.029	0.030
Tabasco	0.013	0.013	0.013
Tamaulipas	0.041	0.041	0.042
Tlaxcala	0.006	0.006	0.006
Veracruz de Ignacio de la Llave	0.045	0.045	0.046
Yucatán	0.015	0.015	0.015
Zacatecas	0.018	0.018	0.019

To summarize this analysis described above, ERG performed the following steps to create the ZoneRoadType database table.

1. **Gather data sources**.
    a. INEGI state-level roadway network GIS files (INEGI, 2015a).
    b. “mgm2013v6_0.zip” contains the GIS files for *municipio* boundaries and land area.
    c. U.S. Census Data – human population at the county level (U.S. Department of Commerce, 2014).
    d. U.S. Census Data – land surface area at the county level (U.S. Department of Commerce, 2015).
    e. U.S. MOVES database (U.S. EPA, 2015a).
    f. “Population by *municipio* 2010.xlsx” from INECC, contained human population by *municipio*.
    g. “State-level vehicle fleet.xlsx” contained the vehicle populations for 2013.

   h. "National VKT-by age and vehicle type.xlsx" contained annual kilometers traveled per vehicle in 2013.

2. **Calculate total lane-meters by *municipio* and MOVES road type.** We performed a GIS intersection analysis using the *municipio* shapefiles and the INEGI roadway network shapefiles. After this step, we exported a sum of the total lane-meters of roadway network, summed by *municipio* and the native road types classifications in the INEGI GIS dataset, listed previously in Table 7. Outside of GIS, we mapped the Mexico road types to either Unrestricted or Restricted Access type according to Table 7 and summed the lane-meter distances again by these two categories. The intermediate product after this step was lane-meters by *municipio* and Restricted/Unrestricted Access Road type.
3. **Disaggregate lane-meters into Urban and Rural fractions**. First, we calculated the human population density of each *municipio* by dividing human population by land area from the *municipio* shapefile. We also calculated the U.S. county level population density using U.S. census data. Next, we developed a regression curve (shown previously in Figure 5) to understand the U.S. relationship between human population density and the relative fraction of urban road driving. Using the equation that modeled the U.S. data and the *municipio*-level human population density we estimated the urban fraction of driving for each *municipio.*
4. **Calculate the Source Hours Operating allocation (SHOalloc) fractions.** As a last step, we normalized the lane-miles by dividing the *municipio* value by the national total, separately for the following road types.
   a. Rural Restricted Access roads
   b. Rural Unrestricted Access roads
   c. Urban Restricted Access roads
   d. Urban Unrestricted Access roads
5. **Adjust state total SHOalloc totals so that they match relative VKT by state, derived from the INECC state level data.** First, we calculated the relative VKT by state in Mexico. We did this because VKT is a better surrogate than roadway length for the SHOalloc. The calculation of VKT by state was straightforward – we simply multiplied 2013 population by state with the 2013 VKT per vehicle per year, and then normalized over states so that fractions summed to one (1) over the 32 states. Finally, we overlaid these results onto the previous analysis of *municipio* roadway miles. This was accomplished by preserving the distribution of SHO to municipios within each state, and using state level relative VKT.

4.13 HPMSVTypeYear

This table contains annual, nationwide total vehicle miles traveled (VMT), by calendar year and Highway Performance Monitoring System (HPMS) vehicle groups. The source data for the HPMSVTypeYear table was previously discussed in Section 3, and includes: (1) 2013 state-level vehicle population, (2) 2013 national VKT per vehicle per year, and (3) projections of vehicle populations from 1970-2050. We prepared this database table by first calculating nationwide VMT and then converting the native vehicle classification system in the source data into vehicle categories needed for MOVES for this table. Table 9 shows the HPMS vehicle categories, their constituent source use types, and the 2013 VMT data we put into the database table. The full HPMSVtypeYear table includes all of years available in the US MOVES model (1990 and 1999-2050), but for simplicity we show only the 2013 data below. In order to populate the other years, we back-casted the 2013 VMT to 1990 and 1999-2012 and projected it to 2014-2050 using INECC's vehicle population projections, shown later on in Figure 6. Table 10 shows the output VMT by source type results produced by a 2013 nationwide run of MOVES-Mexico. The total VMT in Table 10 (model output) is 0.002% smaller than the total from Table 9 (model input) due to computer rounding.

Table 9: HPMS Vehicle Definitions and 2013 HPMSVtypeYear Table Data

HPMS Vehicle ID	HPMS Vehicle Name	MOVES-Mexico Source Type IDs	2013 VMT Data (miles)
10	Motorcycles	11	21,791,561,060
25	Light Duty Vehicles	21,31,32	228,775,000,000
40	Buses	42	5,242,574,900
50	Single Unit Trucks	52,53	11,605,805,567
60	Combination Unit Trucks	61,62	15,890,468,791
Total			*283,305,410,318*

Table 10: Annual Mexico Nationwide VMT Estimates by Source Type in 2013

Source Type	2013 VMT
Motorcycles	21,791,130,112
Passenger Cars & Taxis	128,064,601,088
Passenger Trucks	97,322,202,112
Light Commercial Trucks	3,383,771,008
Transit Buses	5,242,464,000
Single Unit Short Haul	10,953,739,904
Single Unit Long Haul	651,836,984
Combination Short Haul	4,766,392,064
Combination Long Haul	11,123,769,856
Total	*283,299,907,128*

The steps ERG used to produce the HPMSVtypeYear database table are listed below.

1. **Gather data sources**.
   a. “State-level vehicle fleet.xlsx” contained the vehicle populations for 2013.
   b. “National VKT-by age and vehicle type.xlsx” contained annual kilometers traveled per vehicle in 2013.
   c. “Surveys-raw data.xlsx” contained information on the number of personal vs. business use of light-duty trucks.
   d. “Flota-Mexico_historica-proyeccion_INECC (2050).xlsx” contained a basis for projecting 2013 results to other years in MOVES (1990 and 1999-2050).
2. **Calculate VMT for each Mexico vehicle class for one year**. First, we multiplied the VKT per vehicle per year and the number of vehicles. Then we converted kilometers to miles to arrive at VMT.
3. **Change the vehicle categories to those used by MOVES**. Convert the VMT by Mexico vehicle types into the MOVES source use types using Table 11. Next, sum over the MOVES source types to arrive at MOVES HPMS vehicle types using Table 9.
4. **Project data to other years**. We estimated VMT for other years (1990, 1999-2012, 2014-2050) using a surrogate data source. To estimate years other than 2013, we multiplied the 2013 VMT estimate by the ratio of surrogate data for the target year to year 2013.

4.14 SourceTypeYear

This table contains national total vehicle population by source use type by calendar year. The source data was 2013 state-level vehicle population by Mexico vehicle type previously discussed in Section 3. The raw data were categorized by Mexico vehicle classes, which needed to be mapped to MOVES source use types to represent the Mexico fleet. The cross-reference to go from Mexico vehicle class to MOVES source use type is shown below in Table 11. Several of the Mexico vehicle categories had straightforward matches in MOVES, such as motorcycles, passenger cars, and taxis. INECC informed us that “Public light transport trucks” include SUVs and vans but not pickups, and “Pickup Trucks” are for transferring a product (both passenger and commercial). Based on their definitions, we mapped these to the MOVES source use types 31 and 32 (Passenger Truck and Light Commercial Trucks). Population in the class “Trucks with GVW > 3 ton” was mapped to Single Unit Trucks, and the “Trailer trucks” were mapped to Combination Unit Trucks.

In order to split the vehicle population between MOVES source types Passenger Truck (source type 31) vs. Light Commercial Truck (source type 32) we used vehicle surveys provided by INECC (previously discussed in Section 3) to determine the split of personal and business use of light trucks in Mexico. INECC provided ERG with a vehicle survey of population and VKT from a category of light vehicles that includes passenger cars (*vehículo de pasajeros*, abbreviated as VP) and light trucks (*camioneta ligera*, abbreviated as CL). We filtered the data to analyze only the light truck or *CL* vehicles and calculated the percent of vehicle population and VKT from those marked as personal use (*uso personal*) or business-use (*negocio*). In INECC’s “refined” (base depurada) data set, 97% of the light trucks were personal use and 3% business. We used these values to split the total light trucks according to Mexico classifications into MOVES definitions of source use types 31 and 32.

Table 11: Vehicle Classes in Mexico Data Mapped to MOVES Source Types

No.	Mexico Vehicle Type	MOVES Source Type ID	MOVES Source Use Type Name
1	Motorcycles	11	Motorcycle
2	Passenger cars	21	Passenger car
3	Taxi		
4 5 6	Public transport light truck Pickup trucks Trucks with GVW < 3 ton	31	97% Passenger Truck
		32	3% Light Commercial Truck
7	Buses	42	Transit Bus
8	Microbus/Midibus		
9	Trucks with GVW > 3 ton	52	96% Single Unit Short-haul Truck
		53	4% Single Unit Long-haul Truck
10	Trailer trucks	61	49% Combination Short-haul Truck
		62	51% Combination Long-haul Truck

Because we do not have use type data to distinguish long-haul vs. short-haul activity, US default splits were used (96%/4% for single unit trucks and 49%/51% for combination trucks in the table above). The 2013 population was back-casted to 1990 and 1999-2012 and projected to 2014-2050 using INECC's vehicle population projections discussed in Section 3. The projection data are the same that we used to back-cast and forecast VMT, and the projections are illustrated below in Figure 6.

Population estimates for the entire country in 2013 by source type (as mapped from Mexico vehicle classes from Table 11 above), are shown in Table 12.

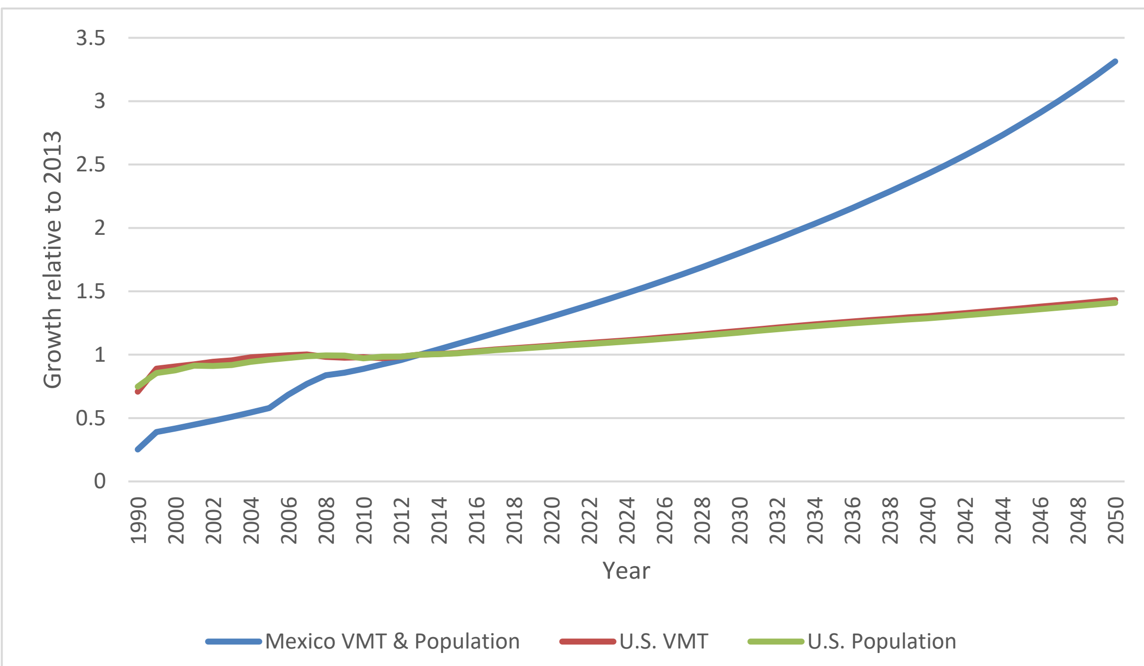
Table 12: Mexico Nationwide Vehicle Population Estimates by Source Type in 2013

Source Type	2013 Population
Motorcycles	1,216,210
Passenger Cars & Taxis	12,880,100
Passenger Trucks	9,140,180
Light Commercial Trucks	317,793
Transit Buses	180,580

Source Type	2013 Population
Single Unit Short Haul	630,598
Single Unit Long Haul	26,275
Combination Short Haul	116,331
Combination Long Haul	122,053
Total	24,630,120

VMT and population estimates were backcast to 1990 and forecast to 2050 based on sales data and projections provided by INECC. We summed the total population of all vehicles for gasoline and diesel in each year and divided it by the 2013 population, thereby calculating projections from a 2013 basis. Figure 6 below shows the resulting growth curve (relative to 2013, so 2013 has a value of one), comparing Mexico and the U.S. growth for VMT and population from the U.S. version of MOVES2014. The rate of growth from 2013 is much faster in Mexico than the U.S.

Figure 6: VMT and Population Growth Trends for Mexico and the U.S.



The steps ERG used to produce the SourceTypeYear database table are listed below.

1. **Gather data sources**.

   a. "State-level vehicle fleet.xlsx" contained the vehicle populations for 2013.
   b. "Surveys-raw data.xlsx" contained information on the number of personal vs. business use of light-duty trucks.
   c. "Flota-Mexico_historica-proyeccion_INECC (2050).xlsx" contained a basis for projecting 2013 results to other years in MOVES (1990 and 1999-2050).
2. **Calculate Population for each Mexico vehicle class for one year**. We summed vehicle population over fuel type, model year, and state, which produced 2013 nationwide population by Mexico vehicle class.
3. **Change the vehicle categories to those used by MOVES**. We converted vehicle classifications into the MOVES source use types using Table 11.
4. **Project data to other years**. We estimated population for other years (1990, 1999-2012, 2014-2050) using a surrogate data source. To estimate years other than 2013, we multiplied the 2013 population estimate by the ratio of surrogate data (vehicle population projected to future years, provided by INECC) for the target year to year 2013.

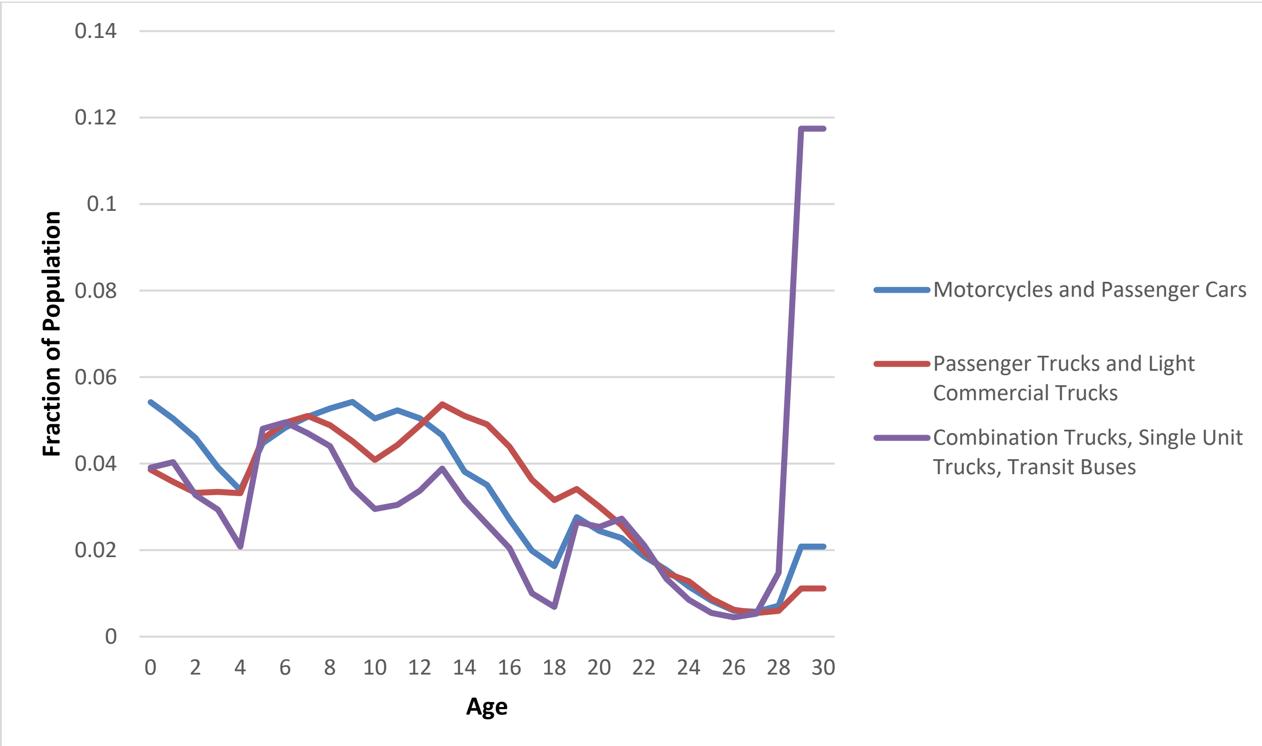
4.15 SourceTypeAgeDistribution

The raw data source for this table was the 2013 state-level vehicle population data previously discussed in Section 3. The data consisted of vehicle populations by the model years 1984 through 2013, Mexico categorization of vehicle classes, fuel type, and state. We converted this raw data into the format of the SourceTypeAgeDistribution table in several steps. First, we translated the vehicle classifications from their native categories ("Mexico Vehicle Type" in Table 11) into the MOVES source use types (also in Table 11). We then aggregated the vehicles by MOVES source type ID and model year and divided by the source type total population to normalize the distributions. In the end, this work produced age fractions for each MOVES source type that summed to one (1) over 31 age bins. Because MOVES uses 31 years (age 0 to 30, inclusive) but the raw data contained only 30 years (1984-2013 are age 0 to 29 in 2013), we divided the age bin 29 population by two to cover the age bins 29 and 30.

To populate the full table, we repeated the same 2013 age distribution for other years of the model (1990, 1999-2050). The US version of MOVES can dynamically project age distribution from any base year (e.g., 2013) into the future using U.S.-based sales growth and scrappage assumptions. Because these underlying data do not apply in Mexico so this feature of MOVES was not enabled for MOVES-Mexico.

The national age distributions are shown below in Figure 7. The data shows a large proportion of very old combination trucks (nearly 12% from model year 1984 or earlier), based on the data INECC provided. This will have a very strong influence on heavy truck emissions, so is worth reaffirming.

Figure 7: National Age Distribution for all Source Use Types



The steps ERG used to produce the SourceTypeAgeDistribution database table are listed below.

1. **Gather data sources**. The sole data source was the file "State-level vehicle fleet.xlsx," which contained the vehicle populations for 2013.
2. **Calculate population by model year for each Mexico vehicle class**. First, we summed the population over fuel type and state to arrive at national totals by Mexico vehicle class and model year. We added the model year 1983 and reallocated half of the 1984 vehicle population to 1983 in order to fit the 31 age bin resolution of the database table.
3. **Change the vehicle categories to those used by MOVES**. We converted the Mexico vehicle types into MOVES source use type groups using the approach outlined previously in Table 11, but omitting the step to further split the combined source type groups (i.e., the 31+32, 52+53, and 61+62 groups) into source types. The result after this step was population categorized by the following subgroups (a) through (f). There was no need to further split out the combined groups because the raw data did not have detail to produce unique age distributions based on usage patterns.
    a. Source Type 11 (Motorcycles)
    b. Source Type 21 (Passenger Car and Taxis)
    c. Source Types 31+32 together (Light Trucks, Passenger and Commercial use)
    d. Source Type 42 (Transit Bus)
    e. Source Types 52+53 together (Single Unit Trucks, Short and Long-haul use)
    f. Source Types 61+62 together (Combination Unit Trucks, Short and Long-haul use)

4. **Normalize the populations and fill the table.** After converting vehicle classifications, we divided each source type group's model year population by the source type group total populations. This calculation produced fractions for each model year that sum to one (1) over 31 age bins, for each source type group. We then populated the table with a 2013 age distribution for each Mexico source type ID (11, 21, 31, 32, 42, 52, 53, 61, and 62) using these results. The distributions for source types 31 and 32 were identical to each other, and analogously 52/53 and 61/62 shared the same distribution. In a final step, we populated the other years (1990, 1999-2012, and 2014-2050) using the 2013 distributions but with an updated year to enable the model to run for other years.

4.16 Alternative Vehicle & Fuel Technology (AVFT)

The AVFT table determines the distribution of fuel types by source type and vehicle model year. The source data was the 2013 state-level vehicle population data discussed in Section 3, which included a split of population by gas and diesel (MOVES also has the capability to model ethanol blends up to E85, biodiesel blends up to B20, and CNG transit buses). We mapped the Mexico vehicle classes to MOVES source use types using the methods described for the SourceTypeYear table summarized previously in Table 11. We then normalized the vehicle population over fuel type, resulting in fuel fractions that summed to one (1) for each source type and vehicle model year. Table 13 summarizes AVFT table contents in the MOVES-Mexico database. Although fractions of fuel types are allowed to vary by model year, the raw data showed the same fractions over 1984-2013.

Table 13: Mexico Alternative Vehicle and Fuel Technology

Model Years	Fuel Type	Motorcycle	Passenger Car and Taxi	Passenger and Light Commercial Trucks	Transit Buses	Single Unit Trucks	Combination Unit Trucks
All	Gasoline	1	0.9994	0.9951	0.4109	0.3737	0
	Diesel	0	0.0006	0.0049	0.5891	0.6263	1
	E85	0	0	0	N/A	N/A	N/A
	CNG	N/A	N/A	N/A	0	N/A	N/A

N/A (Not Applicable) means that MOVES does not have emission factors for this fuel/vehicle combination.

The steps ERG used to produce the AVFT database table are listed below.

1. **Gather data sources**. The sole data source was the file "State-level vehicle fleet.xlsx," which contained the vehicle populations for 2013.
2. **Calculate population by model year and fuel type for each Mexico vehicle class**. First, we summed the population over state to arrive at national totals by Mexico vehicle class, fuel type, and model year.

3. **Change the vehicle categories to those used by MOVES**. We converted the Mexico vehicle types into MOVES source use type groups using the approach outlined previously in Table 11, but omitting the step of splitting some of the combined source type groups (31+32, 52+53, and 61+62) into source types. The result after this step was population categorized by the following subgroups (a) through (f). There was no need to further split out the combined groups because the raw data did not have detail to produce unique fuel type distributions based on different usage patterns.
   a. Source Type 11 (Motorcycles)
   b. Source Type 21 (Passenger Car and Taxis)
   c. Source Types 31+32 together (Light Trucks, Passenger and Commercial use)
   d. Source Type 42 (Transit Bus)
   e. Source Types 52+53 together (Single Unit Trucks, Short and Long-haul use)
   f. Source Types 61+62 together (Combination Unit Trucks, Short and Long-haul use)
4. **Normalize the populations and fill the table.** After converting vehicle classifications, we divided each model year's population by fuel type by the total model year population, resulting in fractions that sum to one (1) over gasoline and diesel fuel types, for each source type group and vehicle model year. To our surprise, each model year had the same fuel fraction based on the raw data. We then populated the AVFT table with the fuel type fractions resulting from this analysis for each Mexico source type ID (11, 21, 31, 32, 42, 52, 53, 61, and 62) and each vehicle model year in MOVES (1960 through 2050). The distributions for source types 31 and 32 were identical to each other, and analogously 52/53 and 61/62 shared the same distribution. In a final step, we populated the other vehicle model years (1960-1983 and 2014-2050) using the fuel type fractions over 1984-2013.

4.17 RoadTypeDistribution

The RoadTypeDistribution table contains national average fractions of VMT that occur on each the four MOVES road types, by source type. This analysis for this table leveraged from the roadway network analysis described previously for the ZoneRoadType table. At the stage where total lane-meters are stored by the four MOVES road types, we summed over the nation by road type and normalized so that road type fractions summed to one (1) over the four MOVES road types. The national road type distribution is shown in Table 14 below. The distribution is the same for each source type, since no information was available to allow them to vary by source type, and the U.S. defaults weren't considered applicable in this case.

Table 14: Mexico Domain Road Type Fraction by Source Type

Source Type	Rural Restricted	Rural Unrestricted	Urban Restricted	Urban Unrestricted
All Source Types	0.232	0.284	0.107	0.376

The steps ERG used to produce the RoadTypeDistribution database table are listed below.

1. **Gather data sources**. We leveraged off the analysis for the ZoneRoadType table, so the beginning data source was lane-meters by *municipio* and the four MOVES road types.
2. **Sum over *municipio*.** We aggregated the lane-meters over municipio, resulting in total lane-meters by MOVES road type for the nation.
3. **Normalize over MOVES road type.** Next, we divided each road type's lane-meters by the national total, producing a fraction for each of the four road type that sums to one (1) for the nation. We applied these road type fractions for each source use type.

4.18 MonthVMTFraction

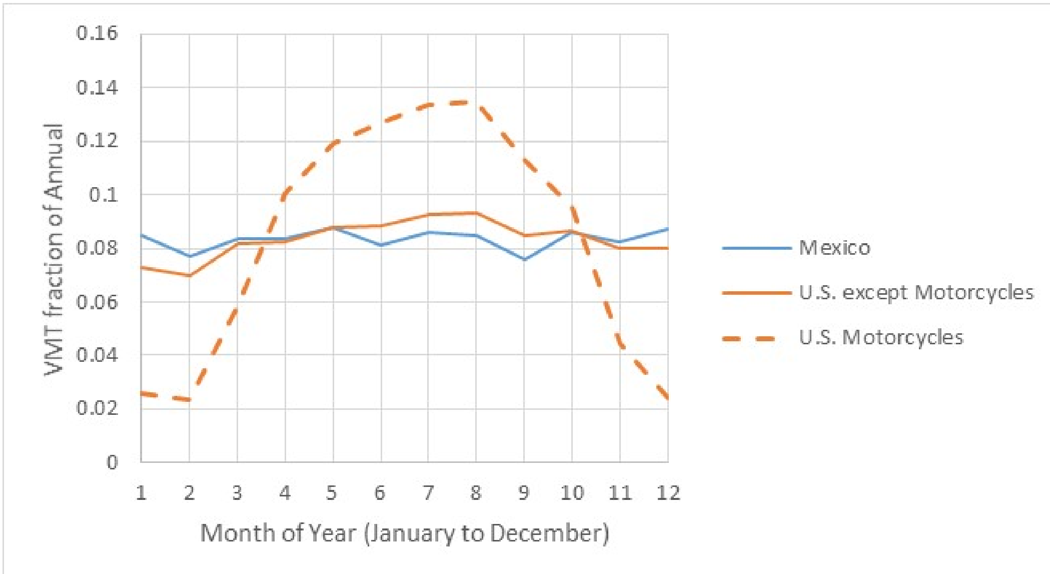
MOVES uses the MonthVMTFraction table to allocate annual VMT from the HPMSVtypeYear table to months. The fractions in this table are listed by source use type and month of the year, and they sum to one (1) over 12 months, with the possibility of different distributions for unique source use types.

Table 15 and Figure 8 show the month fractions for Mexico, which apply to all vehicle classes. For purpose of comparison, Figure 8 also shows the default US values – where motorcycles are used infrequently during winter months for a national average. We created the MonthVMTFraction table using domestic PEMEX total fuel sales (gasoline + diesel together) in each month and divided by the sum of fuel sales over all months in the year 2013. The assumption is that VMT will track with fuel sales. This data source file was "PEMEX sales.xlsx," previously discussed in Section 3.

Table 15: Monthly VMT Fractions

Source Use Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
All	0.085	0.077	0.083	0.084	0.088	0.081	0.086	0.085	0.076	0.086	0.082	0.087

Figure 8: Month VMT Fractions in the Mexico and U.S. Databases



The steps ERG used to produce the MonthVMTFraction database table are listed below.

1. **Gather data sources.** The sole data source was the file "PEMEX sales.xlsx," which contained fuel sales by *municipio* for each month of 2013.
2. **Calculate month fractions.** We added the national total volumes together for Magna, Premium, and Diesel fuels for each month. Then, we divided each month's total fuel sales by the annual value. This resulted in fractions of vehicle fuel sold by month of year that summed to one (1). We applied the same month fractions to each source type ID to populate the MonthVMTFraction table.

4.19 EmissionRateByAge, EmissionRate, and CumTVVCoeffs

See Section 5.

4.20 EmissionProcess

The EmissionProcess table lists each of the emission processes (e.g., running, starts, etc) available in the U.S. version of MOVES, and it populates the list of options available in the model GUI. For MOVES-Mexico, our only change to this table was to prevent three emission processes from appearing in the GUI (Extended Idle, Crankcase Extended Idle, and Auxiliary Power Exhaust). These three emission processes are associated with "hotelling" activity in the U.S. whereby long-haul truck drivers are required by U.S. law to take rest periods during long trips (and drivers often do so with an engine on, for purpose of comfort and convenience). This activity likely does not occur in Mexico at the same levels as the U.S., so we disabled hotelling-related emission calculations.

4.21 HotellingCalendarYear

The HotellingCalendarYear table contains each year (1990; 1999-2050) and the fraction of Rural Restricted Access road VMT that equals the total hours of hotelling at the national level. In the U.S. version of MOVES, the hotelling hours are calculated as 0.055415 multiplied by Rural Restricted Access road VMT; however, for MOVES-Mexico we set this fraction to 0 to turn off the hotelling calculations.

4.22 SourceUseType

The SourceUseType table lists each source type ID that will appear as options in the GUI. To create this table, we simply deleted the U.S. MOVES source use types not used for Mexico.

4.23 FuelType

The FuelType table lists the fuel types that appear in the MOVES GUI. For MOVES-Mexico, we deleted all fuels besides gasoline and diesel. Although the U.S. version of MOVES has emission rate data for E85 (for light-duty vehicles) and CNG (for transit buses), these fuels aren't used in Mexico so we removed them from the table.

4.24 ModelYearCutpoints

The ModelYearCutpoints table defines the calendar years where sulfur phase-in occurs (known as "GPA" in MOVES). This is important because areas with a mix of gasoline sulfur in the same fuel pool (i.e. Magna) effect emissions differently in MOVES than areas with one sulfur level in the pool. To reflect the phase-in on 30ppm in Mexico City in 2007-2008, the fields sulfurModelGPAPhaseInStart and sulfurModelGPAPhaseInEnd were changed to 2007 and 2008, respectively.

4.25 GeneralFuelRatioExpression

The GeneralFuelRatioExpression table contains the equations for the effect of fuel properties on emissions. Separate equations are included for sulfur phase-in (GPA) areas. The GPA equation was changed for CO so that during 2007-2008, when a mix of sulfur exists in Mexico City, CO emissions will behave as if the vehicle is fueled only on 300ppm. This is based on research showing that sulfur poisoning on a vehicle's catalytic convertor has a more permanent effect on CO emissions, vs. other pollutants (U.S. EPA, 2014c).

5.0 Approach for MOVES-Mexico Emission Rates

5.1 Overview of Approach

Emission rates for MOVES-Mexico were updated from the default U.S. rates to reflect significant differences in vehicle emission controls between Mexico and the U.S. Two different methods were used to estimate emissions rates for the Mexico fleet, depending on vehicle class and pollutant. Passenger car and light-truck NOx, CO, and exhaust HC were updated based on RSD measurements provided by INECC across 24 cities in Mexico. For these cases, future projections were based on a combination of RSD measurement on the newest model years, and differences between U.S. and Mexico emission standards. Passenger car and light-truck PM, NH_3, and evaporative HC were updated based on mapping of U.S. technologies to Mexico technologies by model year, depending on implementation of NOM42 standards. All heavy duty gas and diesel truck emissions were updated based on mapping of U.S. technologies to Mexico technologies by model year, depending on implementation of NOM44 and NOM76 standards. Details of each approach, including results from an extensive analysis of the Mexico RSD data, are provided in the following sections.

GHG emissions were updated in MOVES by way of adjusting Total Energy rates, on which CO_2 emissions are based. This adjustment was only made beginning in the 2012 model year for light cars and trucks, however, so that the impact of aggressive U.S. fuel economy standards would not be carried over to Mexico as well, which has yet to finalize such standards. U.S. GHG emission rates prior to model year 2012 for light cars and trucks, and in all years for other vehicles, were not changed. Sufficient data do not exist to adjust GHG emissions in Mexico relative to the U.S. rates for these historical model years, and as noted in Section 6, comparison of MOVES fuel consumption vs. top-down fuel sales shows good agreement. Lacking data, all pollutants for motorcycles remain at U.S. levels as well.

5.2 Passenger Car & Light Truck NOx, CO & Exhaust HC (RSD Analysis)

5.2.1 Remote Sensing Data

INECC provided a large volume of roadside remote sensing device (RSD) data to enable evaluation and calibration of MOVES-Mexico emission rates to field data from Mexico. In total, the RSD dataset included over 250,000 measurements, covering most vehicle classes (though predominantly passenger cars and light trucks), across 24 cities, with individual city measurement campaigns ranging from 2008 to 2014. The RSD measurements provide short (~one second) emission snapshots of emissions concentrations for NO, CO, CO_2 and propane (a proxy for HC). Opacity measurements, a proxy for PM, are also included. A number of vehicle information fields include make, model year and number of cylinders. Some data sets from border cities identify the origin of the vehicle, e.g. Mexico, U.S. or imported.

The scope of this dataset presented a challenge to synthesize for use in MOVES-Mexico; data are included for many vehicle classes, fuels, inspection programs, locations, and vehicle ages over a span of six years. Some scoping decisions were therefore made after initial evaluation of the data, based on ERG's previous experience analyzing RSD datasets. The first was to limit use of the dataset to evaluate cars and lights trucks only. The sample sizes for other classes are not robust enough, as shown in Table 16. RSD sample sizes in the U.S. usually contain no less than 10,000 vehicles, to ensure representative sample across multiple vehicle makes and model years. As shown in Table 16, passenger cars (including taxis) and light trucks (the sum of SUVs, pickups, and vans) are well above this level, while the other classes are well below this level.

Table 16: RSD Samples Size by Vehicle Class

Passenger cars	SUVs	Pick ups	Taxis	Vans	Passenger vans
A1	A2	A3	A4	A5	A6
124,893	55,197	44,212	34,014	2,612	2,434

Microbus	Urban buses	Buses (tourism)	Light heavy truck	Medium heavy truck	Heavy heavy truck	2-wheelers
B1	B2	B3	C1	C2	C3	D1
222	1,475	24	1,934	578	24	16

The second scoping decision was to focus on NO and CO only, using CO_2 in the denominator to produce fuel-specific emissions (grams/kg fuel) based on molar weights of each pollutant, as is common in analysis of RSD emission programs (Slott, 2007). Based on past experience, other pollutants in RSD datasets are of limited value; in particular, HC measurement are only a subset of HC species (this dataset indicated the HC field was propane emissions), and corrections are usually applied to estimate total HC; for the purpose of evaluating model predictions, we don't consider this a valid approach. Likewise, opacity measurements could be a surrogate for PM, but don't correlate well with PM emissions, especially from gasoline vehicles. In contrast, NO (RSD doesn't measure NO_2) and CO measurements have been shown to be more accurate, and are more directly comparable to MOVES pollutants.

The third scoping decision was to group cities based on the following criteria:

- IM: No I/M, Dynamometer-based (Dyno), Idle-based (Static)
- Sulfur: 30ppm, 300ppm
- Border vs. non border

Regarding sulfur, no city had 100% 30ppm gasoline at the time of measurement; however, Mexico City (D.F.) had a significant share of 30ppm when RSD data was collected in late 2008 (estimated at 50%), and was the only city defined in the lower sulfur group.

A list of cities with their designations is shown below in Table 17.

Table 17: List of RSD Cities and their Designations

City	Start Date	Sulfur	I/M	Border
		Note: at the time of measurement		
Monterrey	5/27/08	300 ppm	No	No
DF	9/18/08	30 ppm	Dyno	No
Matamoros	10/6/08	300 ppm	No	Yes
Reynosa	10/13/08	300 ppm	No	Yes
Morelia	11/10/08	300 ppm	No	No
Toluca	3/27/09	300 ppm	Limited Dyno[a]	No
Guadalajara	5/25/09	30 ppm	Static	No
Nogales	7/23/09	300 ppm	No	Yes
León	11/23/09	300 ppm	Static	No
Puebla	11/22/10	300 ppm	Dyno	No
Mexicali	12/6/10	300 ppm	Static	Yes
Tijuana	12/13/10	300 ppm	Static	Yes
Ensenada	2/21/11	300 ppm	Static	No
Rosarito	2/23/11	300 ppm	Static	No
Tecate	2/24/11	300 ppm	Static	Yes
Campeche	5/12/11	300 ppm	No	No
Tuxtla	5/18/11	300 ppm	No	No
Veracruz	5/23/11	300 ppm	Static	No
Boca del Río	5/26/11	300 ppm	Static	No
Oaxaca	6/6/11	300 ppm	Static	No
Chetumal	2/24/14	300 ppm	No	No
Playa del Carmen	2/26/14	300 ppm	No	No
Cancún	2/28/14	300 ppm	No	No

a For Toluca's program only a portion of the fleet are subject to dynamometer testing.

5.2.2 Benchmark Cities

The basic approach for evaluating MOVES using RSD was to define "benchmark" cities that would represent the extremes of emissions in Mexico: on the higher end are non-border cities with 300 ppm sulfur, without I/M. For initial evaluation (including analysis shown in the figures below), cities meeting these criteria with measurements from 2008-2011 were included: Monterrey, Morelia, Campeche and Tuxtla. As discussed in Section 5.3, when developing emissions rates the benchmark cities were further restricted to programs occurring in 2008, so that there could be a direct comparison with D.F., and to provide a basis for analyzing deterioration in data from later years. High emission benchmark cities were subsequently limited to Monterrey and Morelia (referred to simply as the benchmark cities), though the average emission levels from these two cities were similar to the original benchmark set.

Mexico City (D.F.) was chosen as the low emission benchmark, because it has 30 ppm fuel and a strict I/M program, resulting in low overall emissions among all of the cities in the sample. With this approach, the benchmark cities are the target for “No I/M” emission rates in MOVES (accounting for sulfur effects), and the D.F. emissions are the target for “With I/M” emission rates (variations in I/M can be modeled between these two in MOVES, as discussed in Section 4). A comparison of emission rates is shown in Figure 9 and Figure 10. Differences between benchmark and D.F. are higher for NO vs. CO. For both pollutants, emissions beyond age 18 are not significantly different. The peak in NO emissions around age 15 is likely a result of tradeoffs in NOx when tighter CO and HC standards were implemented, observed in the U.S. in the 1970s and 80s. Drops in emissions after 15 years (or leveling after 20 years for CO) also suggests a trend observed in the U.S. known as “survival of the fittest”, where dirtier malfunctioning vehicles drop out of the fleet, lowering the overall fleet average.

Figure 9: RSD Comparison (Passenger Car NO)

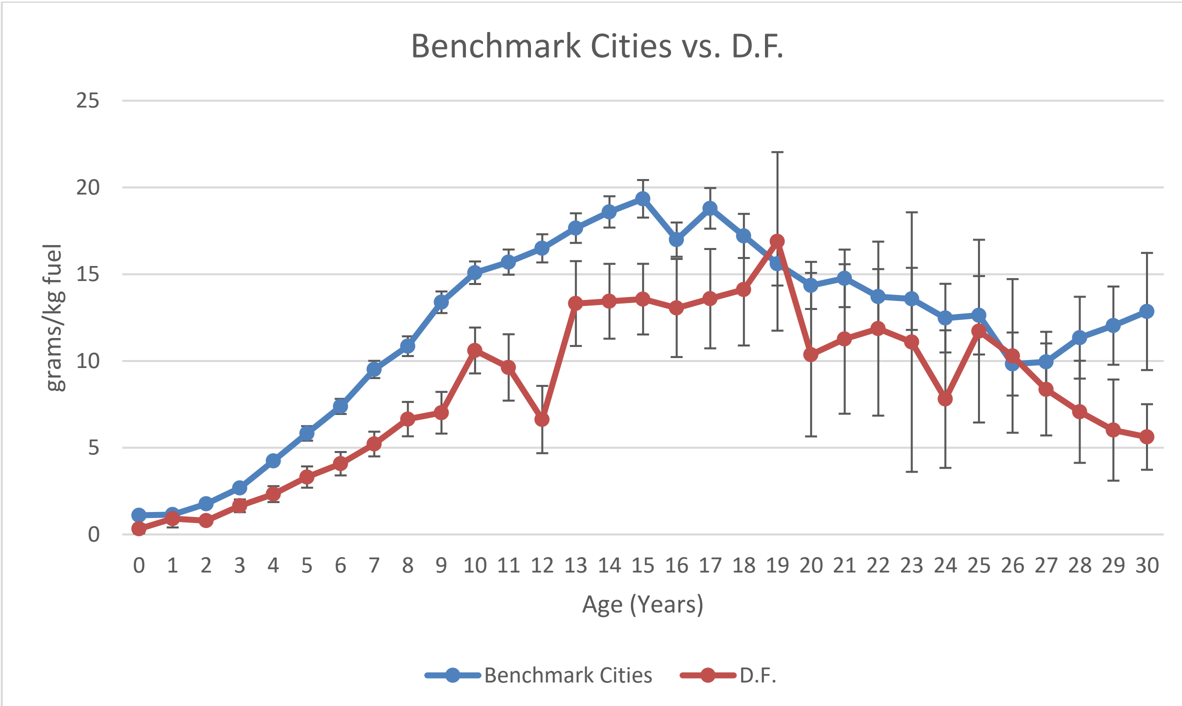
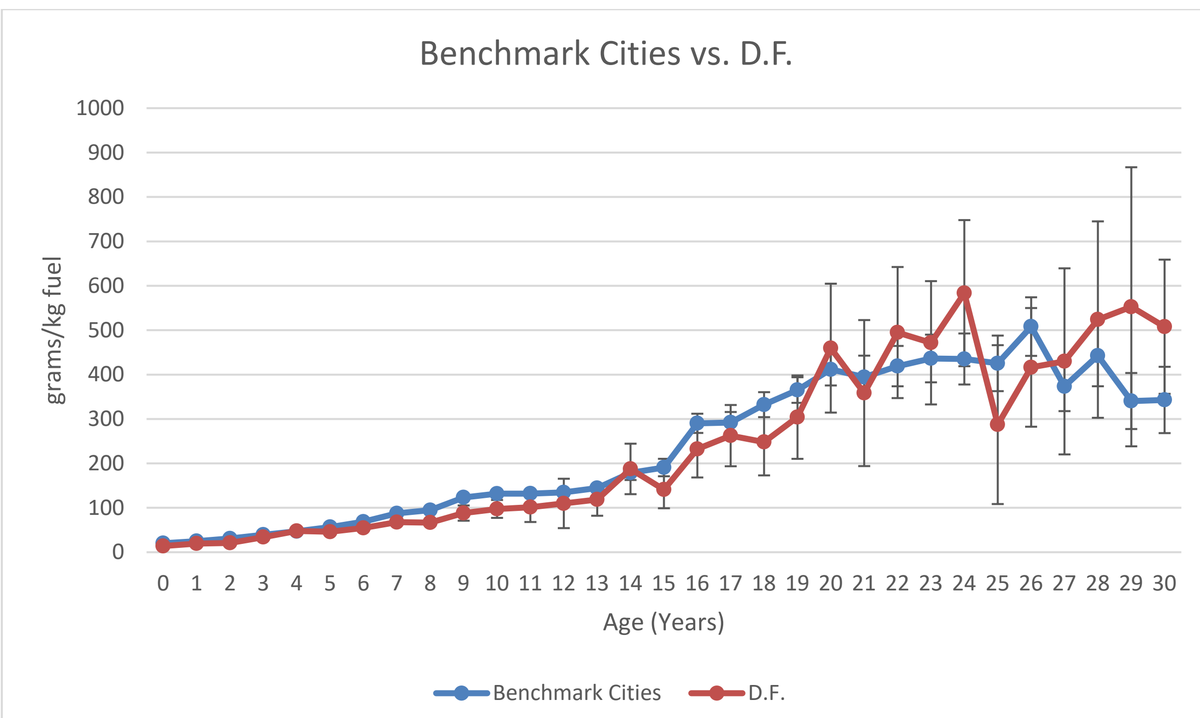


Figure 10: RSD Comparison (Passenger Car CO)



5.2.3 I/M & Border Effects

Other cities in the RSD sample were also grouped according to sulfur, I/M and border/non-border status to compare to the benchmark. Because each city has different operational patterns, these comparisons were restricted to two MOVES vehicle-specific power (VSP) bins (13 & 14) where the majority of measurements occurred. Figure 11 and Figure 12 show the Benchmark (No I/M) cities and D.F. (strict I/M program) along with static I/M programs (León, Ensenada, Rosarito, Veracruz, Boca del Río, Oaxaca). This shows differences between the static programs and stricter D.F. program, though sulfur level and altitude contribute to the differences as well. Once MOVES "No I/M" and "With I/M" emission rates are established for Mexico based on benchmark and D.F. RSD data, individual I/M program parameters for any individual city can be calibrated based on RSD measurements to capture the real-world differences in I/M program effectiveness observed between cities.

Figure 11: I/M Comparison Passenger Car NO

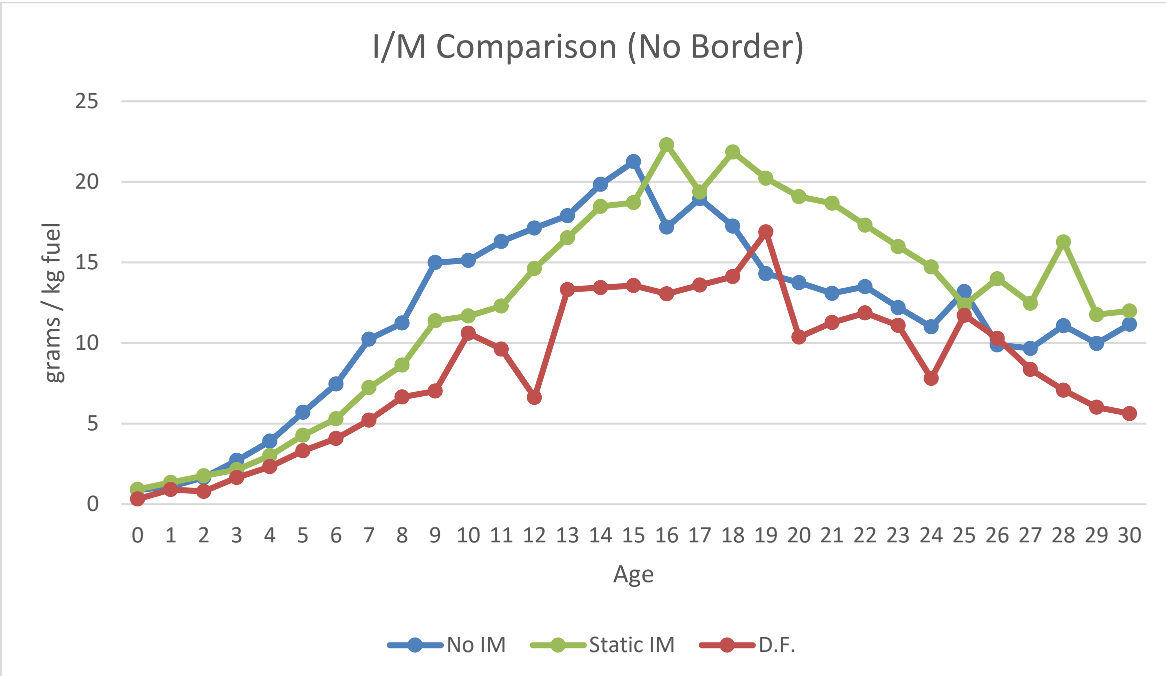
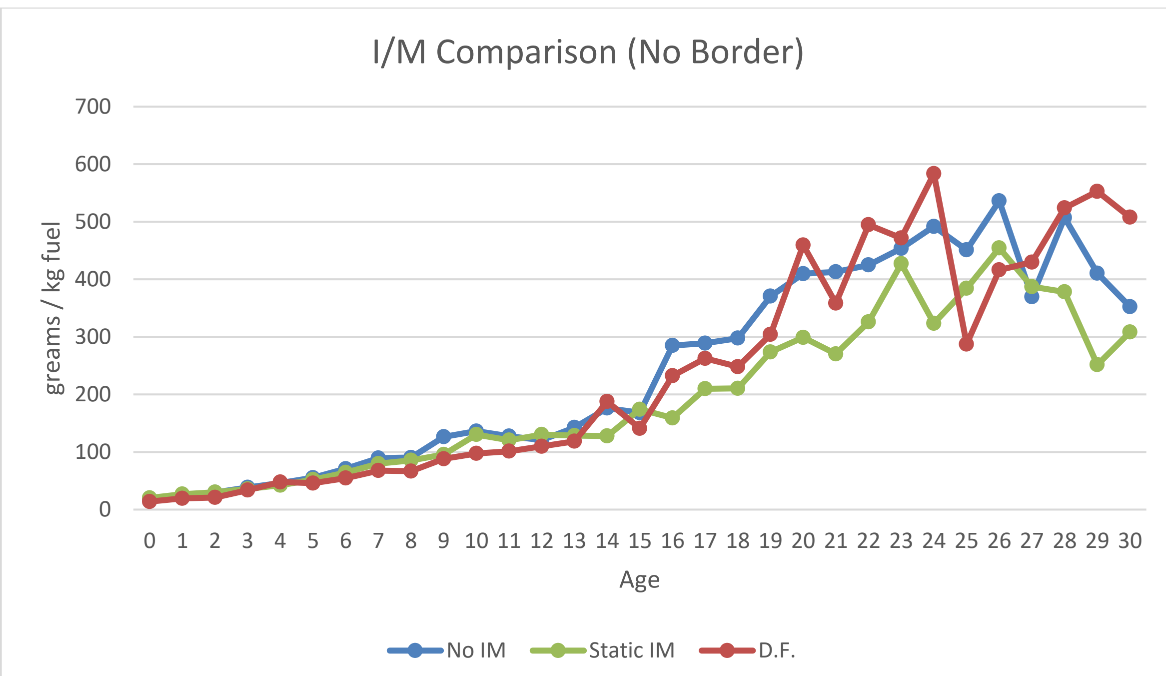


Figure 12: I/M Comparison for Passenger Car CO



Several border cities had comparable emissions to Mexico City, though they have 300ppm and/or less stringent I/M, but this is judged to be due to the higher proportion of U.S. vehicles crossing the border. Figure 13 and Figure 14 show a comparison of border cities with 300ppm and no I/M to the benchmark, showing significantly lower emissions for most ages. Cross-border vehicles will need to be addressed in Mexico emission modeling, border cities were not included in the benchmark because they do not represent the overall fleet in Mexico. ERG will propose a method to account for cross-border vehicles separately in the final MOVES-Mexico documentation and training; for the initial version of MOVES-Mexico, separate runs of MOVES with Mexico and U.S. emission rates may be required.

Figure 13: Border Effect for Passenger Car NO

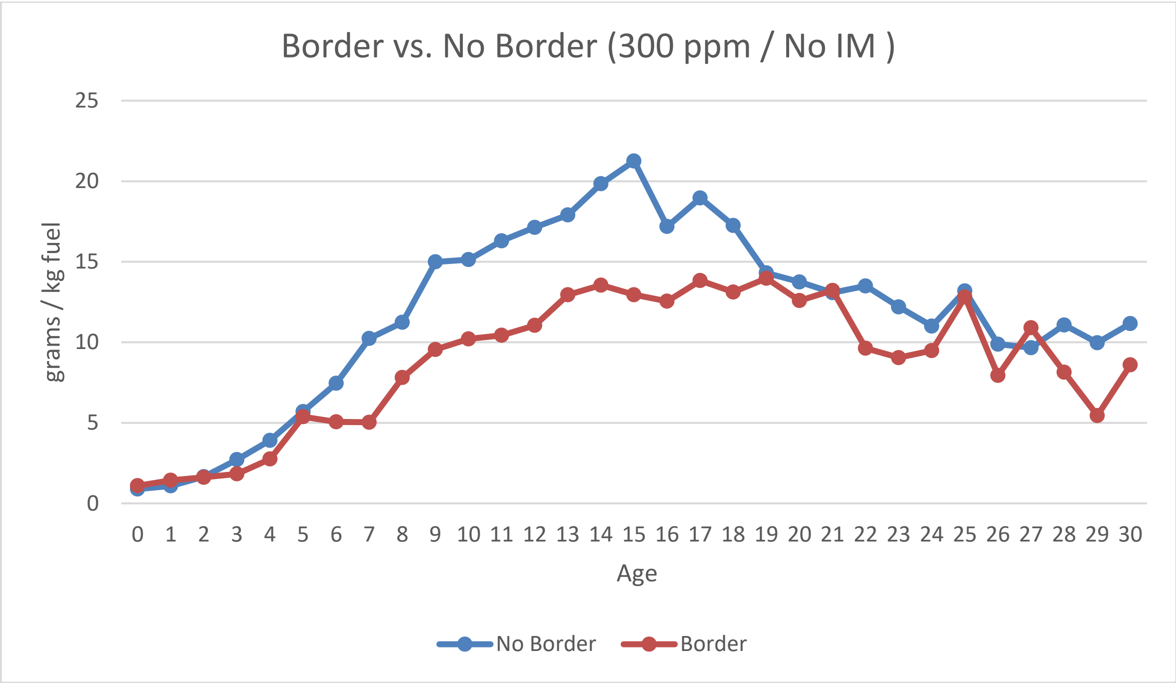
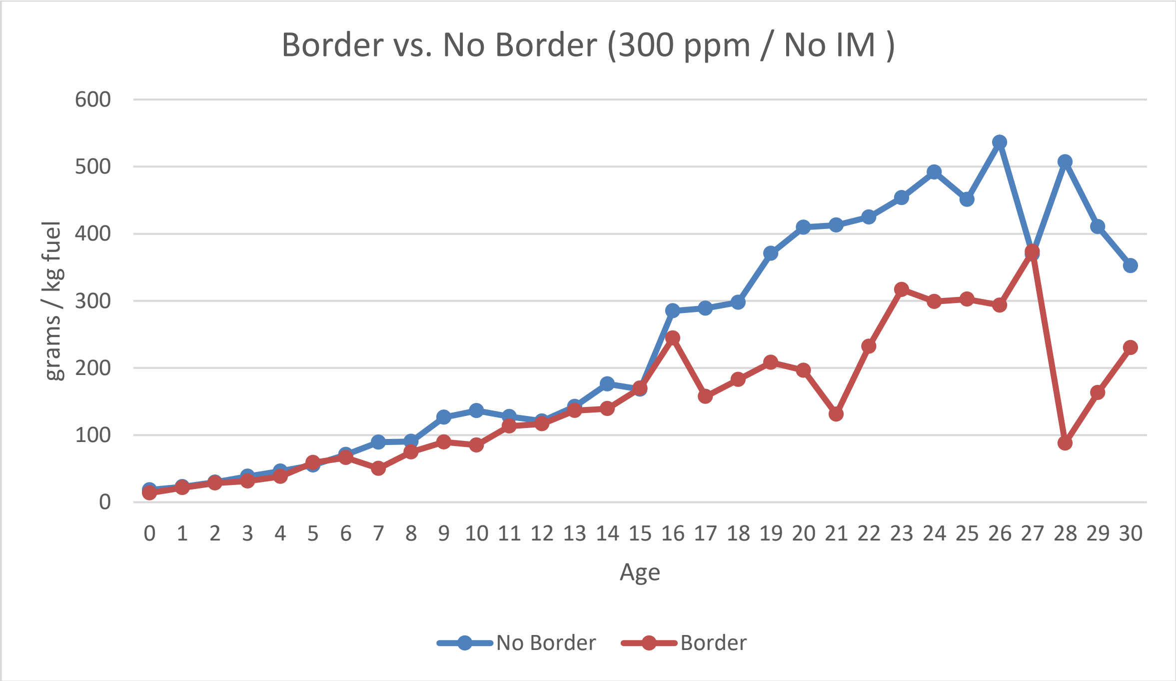


Figure 14: Border Effect for Passenger Car CO



5.2.4 Comparison to MOVES

5.2.4.1 Baseline Comparison

MOVES2014a with default U.S. emission rates was run to replicate the conditions for the Benchmark and D.F. RSD datasets. While the exact conditions of each measurement can't be replicated, they can be approximated on average, with the main factors to account for being fuel sulfur, I/M and vehicle operation. The latter is characterized in MOVES by the distribution of VSP bins. VSP bin distributions for passenger cars were calculated from the RSD data and fed into MOVES emissions along with sulfur level (300ppm for benchmark, and a mix of 50% 300 ppm and 50% 30 ppm for D.F.) and I/M program (using I/M program parameters from D.F. discussed in Section 4). The ModelYearCutpoints and GeneralFuelRatioExpression updates discussed in Section 4 were used for D.F., to simulate sulfur poisoning effects on CO in sulfur phase-in areas. CO, NO and CO_2 grams were estimated by model year for a 2008 run, and used to calculate fuel-specific NO and CO emissions (gram/kg fuel) for direct comparison to the RSD data. RSD NO and CO had to be converted to fuel-specific emissions based on measured CO_2 concentration, on a molar basis. The initial comparisons are shown in Figure 15 and Figure 16 for NO. The peaks in model-year results result from variability in the year-to-year data. As discussed in Section 5.2.5, these initial comparisons were refined (and made for light trucks as well) to develop the emission rates for MOVES-Mexico, including the use of three-year averages for the RSD to help smooth out year-to-year variability

Figure 15: Benchmark RSD vs. MOVES U.S. (Passenger Car NO, inc. Taxis)

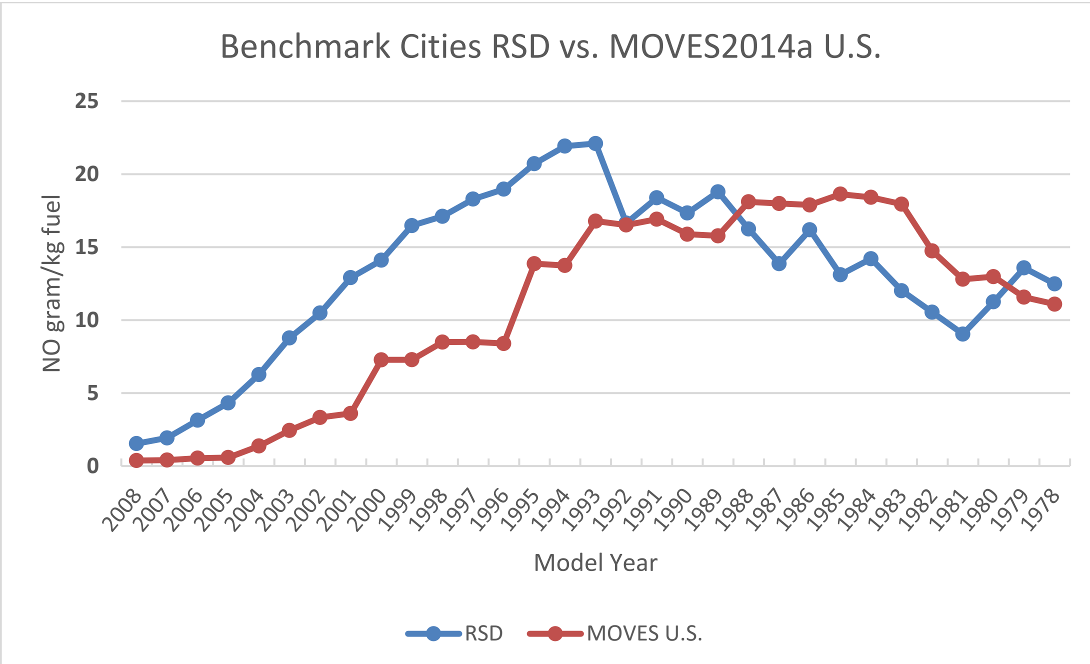
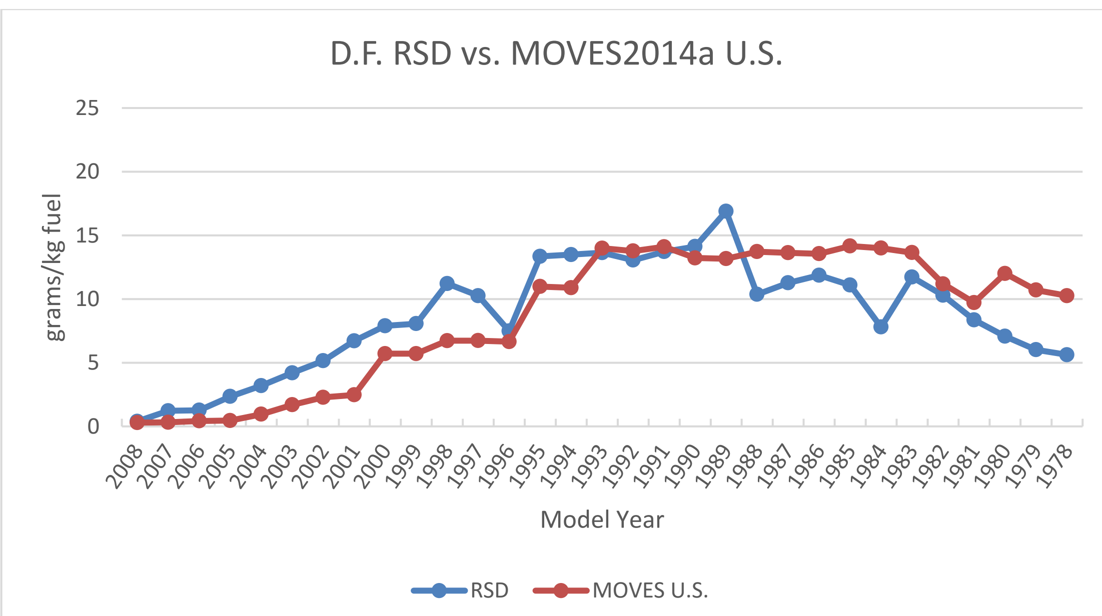


Figure 16 D.F. RSD vs. MOVES U.S. (Passenger Car NO, inc. Taxis)



For NO the trend that emerges for both the benchmark and D.F. comparison is that the RSD is higher than U.S. rates, back to the early 1990s model years, when RSD is about the same or below the MOVES U.S. estimates.

Similar comparisons are shown for CO in Figure 17 and Figure 18. For both cases, RSD is consistently higher than the U.S. rates.

Figure 17: Benchmark RSD vs. MOVES U.S. (Passenger Car CO, inc. Taxis)

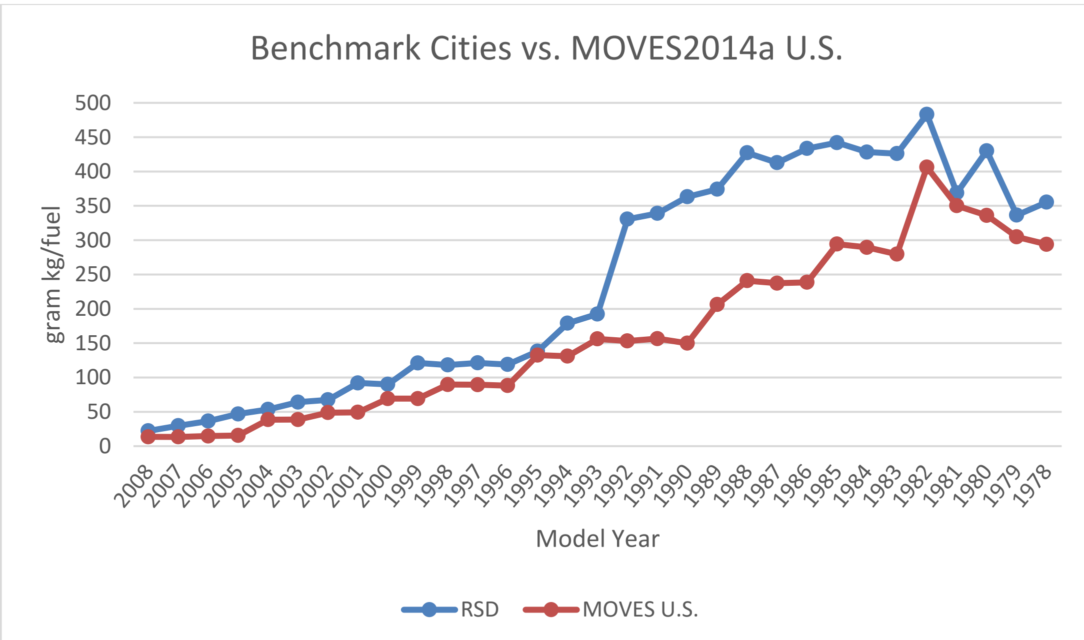
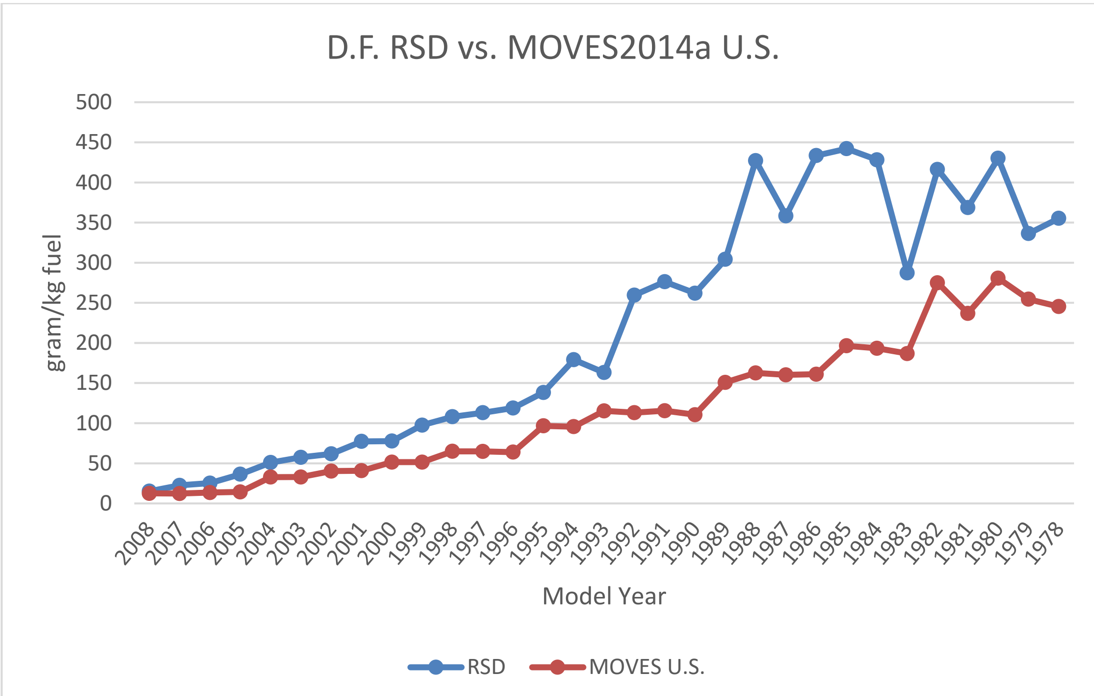


Figure 18: D.F. RSD vs. MOVES U.S. (Passenger Car CO, Inc. Taxis)



5.2.4.2 Deterioration Rate Comparison

Because the RSD dataset includes measurements from 2008 through 2014, the deterioration rates of individual model years could also be assessed, and compared to default MOVES deterioration rates. In MOVES, deterioration is modeled as a function of vehicle age rather than vehicle mileage, which made it easier to use the RSD data directly (vehicle mileage isn't known in the RSD data, but age is). Data only existed for the benchmark cities to perform a comparison of emissions over time, with measurement years for all 300ppm, no I/M, no border cities shown as follows:

- Calendar Year 2008: Monterrey, Morelia
- Calendar Year 2011: Campeche, Tuxtla (3 years of aging relative to 2008)
- Calendar Year 2014: Chetumal, Playa Del Carmen, Cancun (6 years of aging relative to 2008)

Initial evaluation of passenger car deterioration trends for these three groups of cities showed strong trends for 2001 and later model years; prior to these years, the trends were not clear. A comparison was made of the relative emissions deterioration in NO and CO, and cars and light trucks, between 2008 → 2011 (3 years' deterioration); and 2008 → 2014 (6 years' deterioration). To provide a cleaner comparison between years, data were restricted to only similar operating conditions (operating modes 13 and 14, the most common in the RSD data). These relative deterioration rates were then compared to the same rates that MOVES would estimate based on U.S. defaults. As an example, the resulting comparison is shown for passengers cars in Figure 19 and Figure 20 for NO and CO, which each set of bars representing an individual model year from 2001 through 2008. In these charts, a deterioration rate of 1.0 means no change in emissions from 2008 to 2014. These charts show that deterioration rates from the RSD data are much higher than MOVES default, and about a factor of 4.0 for some model years over a six year period; the conclusion from these comparisons was that higher rates of deterioration observed in the RSD need to be accounted for in MOVES-Mexico Emission Rates. Though not shown, the comparison for light trucks yielded a similar finding, and were used in the development of MOVES-Mexico light truck emission rates.

Figure 19: Deterioration Rate in RSD vs. MOVES U.S. (Passenger Car NO)

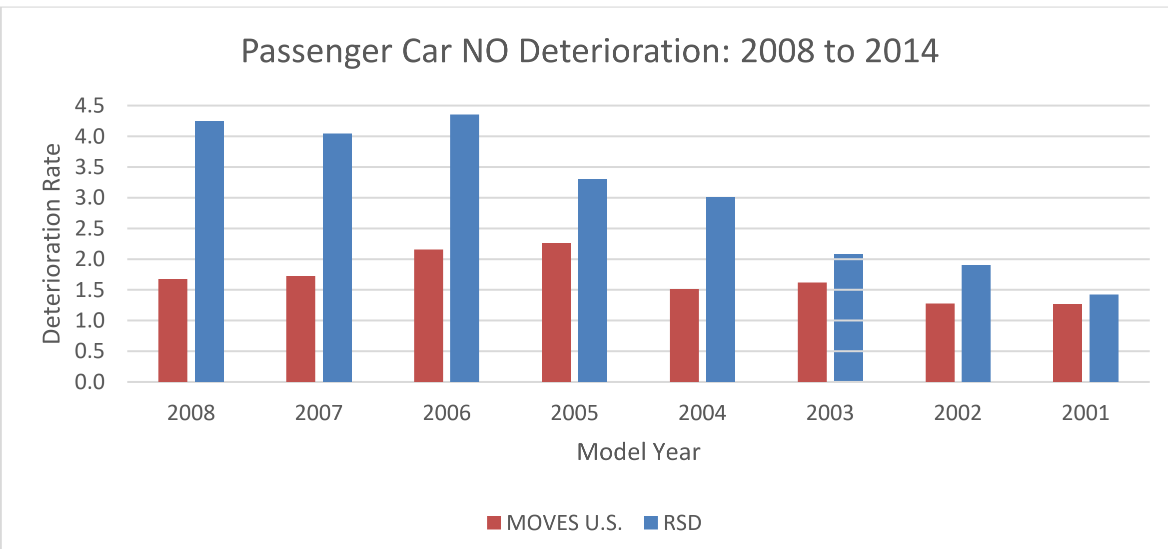
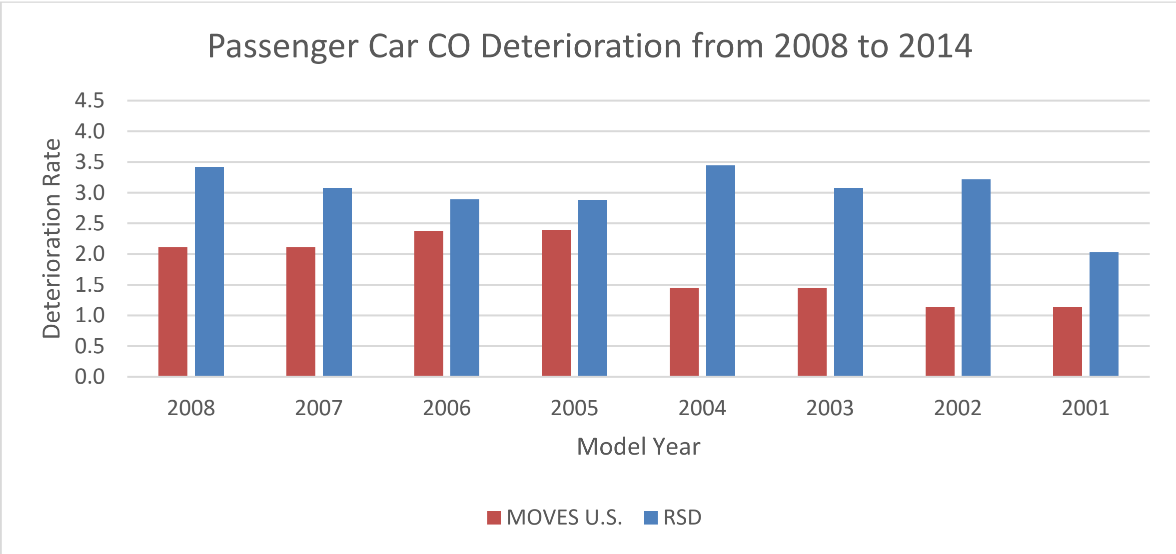


Figure 20: Deterioration Rate in RSD vs. MOVES U.S. (Passenger Car CO)



5.2.5 Method for Developing MOVES-Mexico Emission Rates

Based on the above analysis, for passenger car and light truck NOx, CO, and exhaust HC we developed MOVES-Mexico emission rates by adjusting the default MOVES U.S. emission rates using "calibration factors" based on the ratio of Mexico RSD measurements to MOVES U.S estimates, and accounting for higher deterioration rates observed in Mexico. This allowed real-world Mexico emissions to dictate the MOVES-Mexico emission rates, including the influence of vehicle certified to stricter emissions standards from the U.S. and Europe. Calibration factors were developed for passenger cars (LDV) and light trucks (LDT) by age, model year, and I/M (The MOVES emission rate database has separate "No IM" and "With IM" rates). Taxis, shown to have much higher emissions than passenger cars in the RSD data, were accounted for in the MOVES passenger car rates as well.

The method for determining calibration factors, and using these factors to develop emission rates for MOVES-Mexico, is detailed in seven steps below:

1. **Gather data sources**. Raw RSD data from 24 cities were compiled into one Excel file ("Master_Final.xls"). Cities were categorized by IM program (No, Dyno, or Static), fuel sulfur level (300 ppm or 30 ppm), and border (yes or no). Gram/kg fuel values were calculated, and MOVES operating mode bin assigned to each measurement according the reported VSP values. Gram/kg fuel values are calculated based on CO_2 concentration also measured by RSD and the molecular weight of a given pollutant. The equation used for this is shown as follows from Slott, 2007:

$$\text{Emission Rates (g/kg fuel)} = \frac{\left(\frac{[pollutant]}{[CO_2]}\right)}{\left(\frac{[CO]}{[CO_2]}\right) + \left(\frac{[CO_2]}{[CO_2]}\right) + 6 \times 2 \times \left(\frac{[HC]}{[CO_2]}\right)} \times \frac{MW\left(\frac{g}{mole}\right)}{0.014\left(\frac{kg\ fuel}{mole}\right)}$$

2. **Calculate RSD values by model year in 2008**: Average NO and CO gram/kg fuel values were calculated by model year separately for passenger car (A1), light trucks (combination of A2, A3 and A5) and Taxis (A4). This was done for two cases: No I/M benchmark (combined Monterrey and Morelia) and I/M benchmark (D.F.).
3. **Weight & Average RSD values:** Weighted LDV values were calculated using a weighting of 0.85 Passenger Car and 0.15 Taxi, based on the fraction of national LDV VMT driven by Taxis from INECC estimates. For LDV and LDT, 1998 and earlier model years were averaged in three year increments (e.g. 1996-1998, 1993-1995 etc.) to smooth variability causes by smaller samples sizes. 2007-2008 model years were also averaged to provide a more robust basis for future projections.
4. **Calculate MOVES U.S. values by model year in 2008:** MOVES was run with default U.S. emission rates in 2008 for a 300 ppm / No IM condition, and a mix of 300 & 30 ppm / Mexico City IM condition, using the operating mode distributions from the RSD data in each case. For each case, average NO and CO gram/kg fuel values were calculated by model year separately for LDV and LDT, using regulatory class output.
5. **Calculate ratios of RSD:MOVES U.S. in 2008:** ratios by model year were calculated by dividing RSD (weighted and averaged as described in Step 3) by MOVES values for each case and pollutant. Ratios below 1 were set = 1 (i.e. emissions for Mexico the same as U.S.)
6. **Calculate ratios of RSD:MOVES U.S. 3 & 6 year deterioration rates:** For model years 2001-2008, 3 year and 6 year deterioration rates were calculated as the ratio of RSD emissions in 300ppm/No IM/No Border cities between 2011 and 2008, and 2014 and 2008 for MOVES operating mode bins 13 and 14. This was done separately for passenger cars and light trucks (Taxis were not included). MOVES runs were done in 2014, 2011 and 2008 to produce the default MOVES 3 year and 6 year deterioration rates (3yearDR and 6yearDR) for LDV and LDT. The ratio of RSD:MOVES deterioration rates were calculated, representing the "additional" deterioration observed in the RSD that needs to be accounted for in MOVES-Mexico rates.
7. **Develop Calibration Factor Matrices:** The results of Steps 5 and 6 were combined into Calibration Factors (the number to multiply MOVES U.S. emission rates by to get MOVES-Mexico emission rates) that varied by LDV/LDT, No IM/IM, pollutant, model year and age. For I/M areas, because no additional data were available to establish deterioration rates, the ratios from Step 5 were simply used for all model years and age groups. For No I/M areas, because there were data available to generate 3 year and 6 year deterioration rates in Step 6, these were used in developing the No I/M calibration factors The rubric used to develop these matrices for the No I/M case is shown in

Table 18 below ("2008" are the ratios from Step 5; "3yearDR" and "6yearDR" are the results of Step 6).

Table 18: Rubric for Developing No I/M Calibration Factor Matrices

Bold italics indicate where RSD data were available; plain text is where extrapolation was required

Model Year	Vehicle Age (years)				
	0-3	**4-5**	**6-7**	**8-9**	**10+**
Before 2001	2008	2008	***2008***	***2008***	***2008***
2001	2008	2008	***2008***	2008	***2008*6yearDR***
2002	2008	2008	***2008***	***2008*3yearDR***	***2008*6yearDR***
2003	2008	***2008***	2008	***2008*3yearDR***	***2008*6yearDR***
2004	2008	***2008***	***2008*3yearDR***	***2008*3yearDR***	***2008*6yearDR***
2005	***2008***	2008	***2008*3yearDR***	***2008*6yearDR***	2008*6yearDR
2006	***2008***	***2008*3yearDR***	***2008*3yearDR***	***2008*6yearDR***	2008*6yearDR
2007	***2008***	***2008*3yearDR***	***2008*6yearDR***	2008*6yearDR	2008*6yearDR
2008[a]	***2008***	***2008*3yearDR***	***2008*6yearDR***	2008*6yearDR	2008*6yearDR

[a]2007&2008 data for age 0-3 combined to develop more robust calibration factor in newest model years.

Calibration factors for model years 2009 through 2050 (for which RSD data weren't available) were set as the minimum of a) the 2008 calibration factors or b) the ratio of U.S. and NOM44 useful life emission standards by model year. This approach accounts for the phase-in of NOM standards through model year 2013, but also any overcompliance with standards that was evident in the most recent model year RSD data.

The Calibration Factors that resulted from this step are contained in Annex A for all cases. An example for the LDV NOx No I/M and I/M cases are shown in Figure 21 and Figure 22. As noted in Step 7, No I/M Calibration Factors are multiplied by MOVES U.S. No I/M emission rates, and I/M Calibration Factors are multiplied by MOVES U.S. I/M rates. The charts highlight some important trends in the factors: first, the factors are largest in the post 2000 model year range, as the RSD data showed the largest relative different with MOVES predictions for these years. In older model year years, the ratios are close to, or even less than 1. Second, age trends are present for the No I/M cases due to 3 and 6 year deterioration rates, which reflect the "additional" deterioration observed in the RSD data, but are not present in the I/M cases where RSD-based deterioration rates could not be developed (the MOVES default deterioration rates would still apply for the I/M cases).

Figure 21: Example Calibration Factors (LDV NOx No I/M)

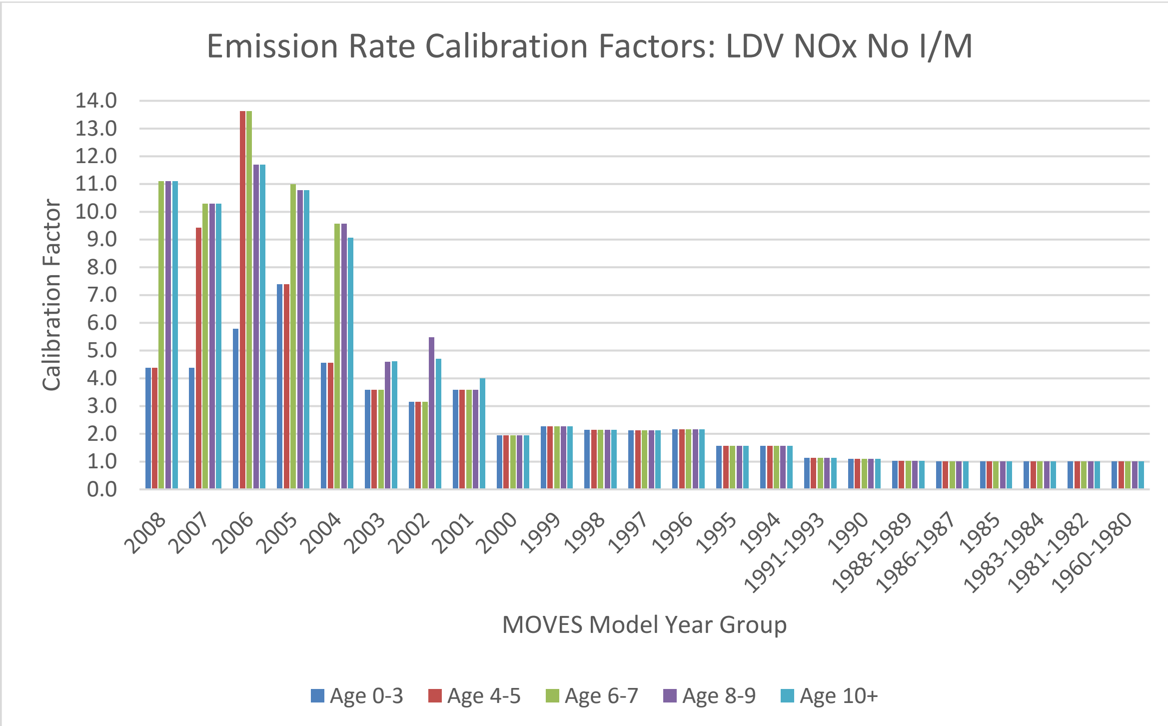
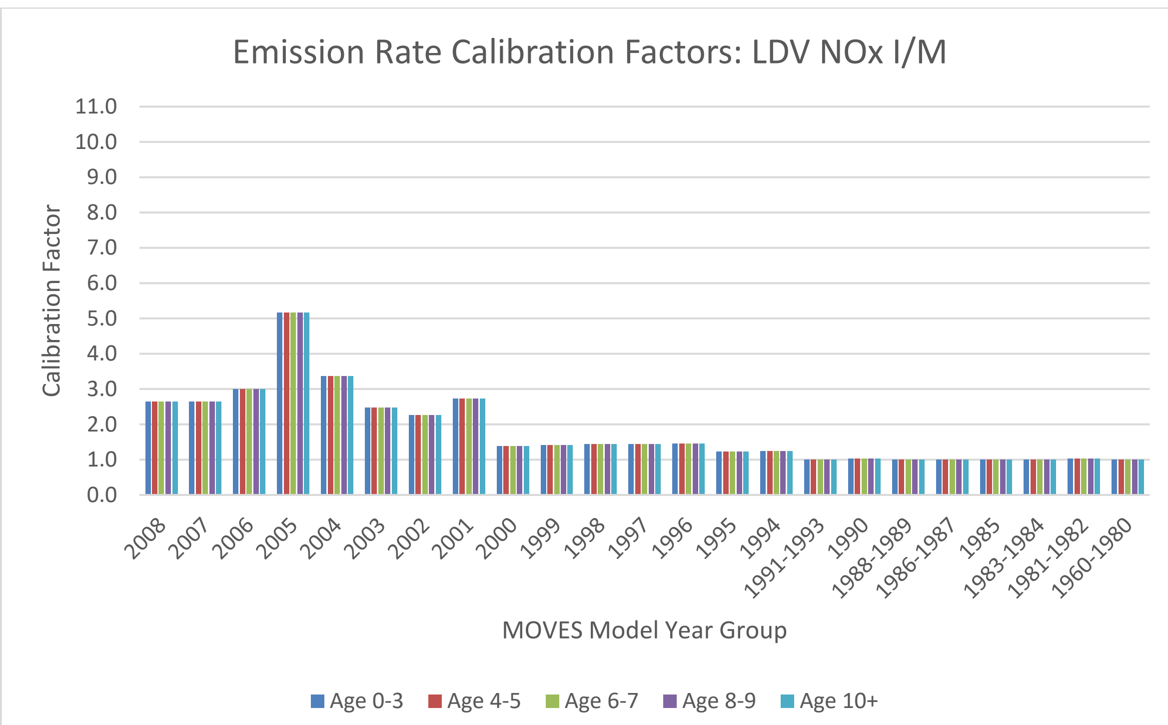


Figure 22: Example Calibration Factors (LDV NOx I/M)



8. **Calculate MOVES-Mexico emission rates in EmissionRatebyAge table:** the final step was the generate MOVES-Mexico emission rates for LDVs and LDTs. This was done with scripts programmed in R that took U.S. emission rates from the default U.S. emissionRateByAge table and multiplied them by the Calibration Factors applicable to the pollutant, vehicle class, model year group, age and I/M case. The same Calibration Factors were used for all operating modes within a model year and age combination. For example, MOVES-Mexico emission rates for LDV, No I/M, Model year 2002, Age 4-5 (all operating modes) was the product of the U.S. rates for the same case (the field meanBaseRate in the emissionRateByAge table, or meanBaseRateIM for IM cases), and the Calibration Factors for LDV NOx, No I/M, Model year 2002, Age 4-5 shown in Annex C. Running and start emission rates from emissionRatebyAge were multiplied by the Calibration Factors to derive MOVES-Mexico start and running rates. Calibration Factors for CO were also used to generate MOVES-Mexico Total Hydrocarbon (THC) running and start rates, by multiplying these with default U.S. THC rates, since these pollutants track closely for exhaust, and HC measurements in RSD (propane only) are not robust enough to support a unique set of calibration factor; the ratio of U.S. to NOM standards for HC were used as the cap for calibration factors in model years 2009-2050, however.

Overall, this approach was taken to calibrate MOVES-Mexico's emission rates to Mexico's RSD data to the maximum extent possible. With both I/M and No I/M rates based on Mexico's data, differences between cities can be accounted for in MOVES through fuel sulfur, I/M program inputs (e.g. Compliance Factor as discussed in Section 4) and vehicle operation. Border vs. non-border differences can be accounted for as well, but may require multiple runs of MOVES for the initial version.

5.3 Other Pollutants & Vehicle Classes

For other light-duty pollutants to be adjusted for Mexico (PM and NH_3), and all pollutants for other vehicle classes (mainly heavy trucks), emission rates have been generated for MOVES-Mexico by adapting the U.S.-based emission rates to Mexico based on differences between the two countries in the level of emission standard and implementation years. This is because a) RSD isn't sufficient to support direct calibration of these MOVES emission rates, and b) heavier vehicle classes are less likely influenced by U.S. and Euro sales. The mapping approach is more straightforward for heavy vehicles because there is a direct correspondence between Mexico vehicle standard levels and previous year U.S. standards, as detailed in the next section.

5.3.1 Mexico Emission Standards

INECC provided information on Mexico vehicle standards relative to U.S. standards for light vehicles and heavy-duty trucks, summarized in Table 19. Overall, Mexican vehicle emission standards are outdated compared to U.S. standards. For light duty vehicles, current Mexican specifications (known as NOM 42) were partially adapted from a combination of Tier 1 and Tier 2 Bins 5 through 9 EPA limit values, with a 50,000 miles durability. European Euro 4 certificates are also accepted. Emissions from medium duty vehicles are not currently regulated in Mexico. Heavy-duty gas and diesel vehicles are regulated based on NOM 76 and NOM 44 respectively, a primary difference being that Mexico has yet to implement the low NOx and PM diesel standards implanted in the U.S. beginning in 2007. Although light-duty vehicle emissions for NOx, CO and exhaust HC will be determined by RSD rather than the NOM emission standards, PM, NH_3 and evaporative HC will be based on the standards shown below. All heavy-duty vehicles will be based on the NOM standards as well.

Table 19: Mexico Vehicle Standard Information Provided by INECC

<table>
<tr><th>Cars & Light Trucks (NOM 42)</th><th>Heavy Duty Trucks & Buses (NOM 44 & 76)</th></tr>
<tr><td>
MY 1990 and older. No aftertreatment, no fuel injection to carburetor.
MY 1991-1992. 2 and 3-way catalytic converters
MY1993-2005. U.S. Tier 0 Emission limits at 0 km (no durability requirements).
MY1999-2005. U.S. Tier 0 Emission limits at 0 km, no OBD required.
MY2007-2009. Emission limits at 80,000 km and OBD requirements. Phase-in: 2007, 25%; 2008, 50%; 2009, 75%.
MY2007-2009. U.S. Tier1 emission limits for PM; U.S. Tier 2 Bin 10 limits for NOx (Euro 3 accepted). Phase-in: 2007, 25%; 2008, 50%; 2009, 75%; 2010, 75%; 2011, 50%; 2012, 30%.
MY2010 onwards. U.S. Tier 1 emission limits for PM and U.S. Tier 2 Bin 7 limits for NOx. Euro 4 also accepted. Phase-in: 2010, 25%; 2011, 50%; 2012, 70%; 2013, 100%.
</td><td>
<u>Diesel (NOM 44)</u>
< MY 1994: No control
MY 1994- 1997: same as U.S.
MY 1998-2008: U.S. 1998 (or similar Euro)
MY 2009+: U.S. 2004 (or similar Euro)

Timeline of Mexico and EPA/Euro standards
<table>
<tr><th></th><th>Standard</th><th>Year</th><th>Required in México</th></tr>
<tr><td rowspan="6">US</td><td>EPA 1991</td><td>1991</td><td>1993</td></tr>
<tr><td>EPA 1994</td><td>1994</td><td>1994</td></tr>
<tr><td>EPA 1998</td><td>1998</td><td>1998</td></tr>
<tr><td>EPA 2004</td><td>2002</td><td>2008</td></tr>
<tr><td>EPA 2007</td><td>2007</td><td>Not considered in Mexican regulations</td></tr>
<tr><td>EPA 2010</td><td>2010</td><td>Proposed phase-in starting 2018.</td></tr>
<tr><td rowspan="6">Europe</td><td>EURO I</td><td>1992</td><td>Not sold in Mexico</td></tr>
<tr><td>EURO II</td><td>1996</td><td>Not sold in Mexico</td></tr>
<tr><td>EURO III</td><td>2000</td><td>2006</td></tr>
<tr><td>EURO IV</td><td>2005</td><td>2008</td></tr>
<tr><td>EURO V</td><td></td><td>Not considered in current Mexican regulations</td></tr>
<tr><td>EURO VI</td><td>2013</td><td>Proposed phase-in starting 2018.</td></tr>
</table>

<u>Gas (NOM 76)</u>
< MY 1998: No Control
1998 onward: NOM 076 “A” (Comparable to U.S. Tier 1 HD Gas Standards)
</td></tr>
</table>

To facilitate the development of Mexico rates, a mapping between Mexico and U.S. vehicle standards was required. This was developed based on the information provided by INECC from Table 19. Table 20-Table 22 show the mapping of Mexico standards to U.S. standards, and how model years were correlated to enact this mapping.

Table 20: Car & Light Truck (Regulatory Class 20 & 30) Mappings - PM & NH_3 Only

Mexico Model Year Range	Correlated U.S. Technology/Standard	U.S. Model Year or Bins Applied
1980-1990	Pre-Catalyst	1970
1991-1992	Catalyst	1980
1993-2006	Tier 0	1990
2007-2009	Tier 2 Bin 10 Phase-In	25/50/75%
2010-2012	Tier 2 Bin 7 Phase-In	25/50/70%
2013 and later	Tier 2 Bin 7	100%

Table 21: Heavy Diesel Truck (Regulatory Class 40-48) Mappings – All Pollutants

Mexico Model Year Range	Correlated U.S. Technology/Standard	U.S. Model Year or Bins Applied
1980-1992	Pre-Control	1980
1993	"1991"	1992
1994-1997	"1994"	1996
1998-2008	"1998" (Electronic Control)	2000
2009 and later	"2004" (EGR)	2004

Table 22: Heavy Gas Truck (Regulatory Class 40-48) Mappings – All Pollutants

Mexico Model Year Range	Correlated U.S. Technology/Standard	U.S. Model Year or Bins Applied
1980-1997	Pre-Control	1980
1998 and later	Tier 1	1998

To implement the mapping of U.S. to Mexico rates ERG developed a series of MySQL scripts to shift the default U.S. emission rates provided in the MOVES emissionRateByAge table by model year, according to the tables presented above. All age groups and operating modes of a given model year were shifted based on these mappings. These rates were then combined with the passenger car and light truck rates derived from RSD data described in the previous section to arrive at a single emissionRatebyAge table included in the final MOVES-Mexico database.

5.3.2 Evaporative Emissions

Evaporative emissions are regulated under NOM-042. The requirement for evaporative emissions is comparable to that in place in the U.S. through the early 1990s, before so-called "enhanced" evaporative systems were required on cars and light trucks. For the purpose of this work, it was assumed that the level of evaporative control is therefore comparable to U.S. vehicles from the "pre-enhanced" control era. These vehicles are equipped with charcoal canisters for the capture of evaporative hydrocarbons, but the canisters are not sized for the more extensive multiple day and refueling tests that were required under the "enhanced" evaporative and on-board refueling vapor recovery standards that were implemented in the U.S. in the late 1990s. In MOVES, evaporative emissions are divided into hose and tank permeation, venting of pressure-induced vapor, and fuel leaks. Fuel leaks in MOVES are not affected by technology level, so were not changed for MOVES-Mexico. Permeation and vapor vehicle emissions were updated to reflect pre-enhanced technology in Mexico. These updates took the form of two updated database tables: Cumulative Tank Vapor Venting Coefficient (CumTVVCoeff) table, addressing "parked" vapor emissions, and emissionRateByAge table, addressing "running loss" and "hot soak" vapor emissions as well as permeation emissions. These tables were prepared based on the mappings show in Table 23, for cars/light trucks and heavy gas trucks.

Table 23: Evaporative Model Year Mappings

Mexico Model Year Range	Correlated U.S. Technology/Standard	U.S. Model Year Range Applied
1960-1977	Uncontrolled	1960-1977
1978-2050	Pre-Enhanced Control	1978-1995

5.3.3 Greenhouse Gas Emissions

GHG emissions were updated in MOVES by way of adjusting Total Energy rates, on which CO_2 emissions are based. This adjustment was only made beginning in the 2012 model year for light cars and trucks, however, so that the impact of aggressive U.S. fuel economy standards would not be carried over to Mexico as well, which has yet to finalize such standards. Instead, beginning in model year 2012, Total Energy rates for LDVs and LDTs in the emissionRate table were reduced by 1 percent off of the preceding model year through model year 2031, when rates were held constant through model year 2050. This was done for running and start emissions, across all operating modes. This had the effect of reducing CO_2 emissions and increasing MOVES' implied fuel economy by 1 percent per year, a figure provided by INECC to reflect expected natural improvement in the fuel economy of the Mexican fleet due to U.S. and European sales. The improvement was made only for gasoline vehicles.

U.S. GHG emission rates prior to model year 2012 for light cars and trucks, and in all years for other vehicles, were not changed, nor where N_2O or CH_4 emissions updated. Sufficient data do not exist to adjust GHG emissions in Mexico relative to the U.S. rates for these historical model years, and as noted in Section 6, comparison of MOVES fuel consumption vs. top-down fuel sales shows good agreement.

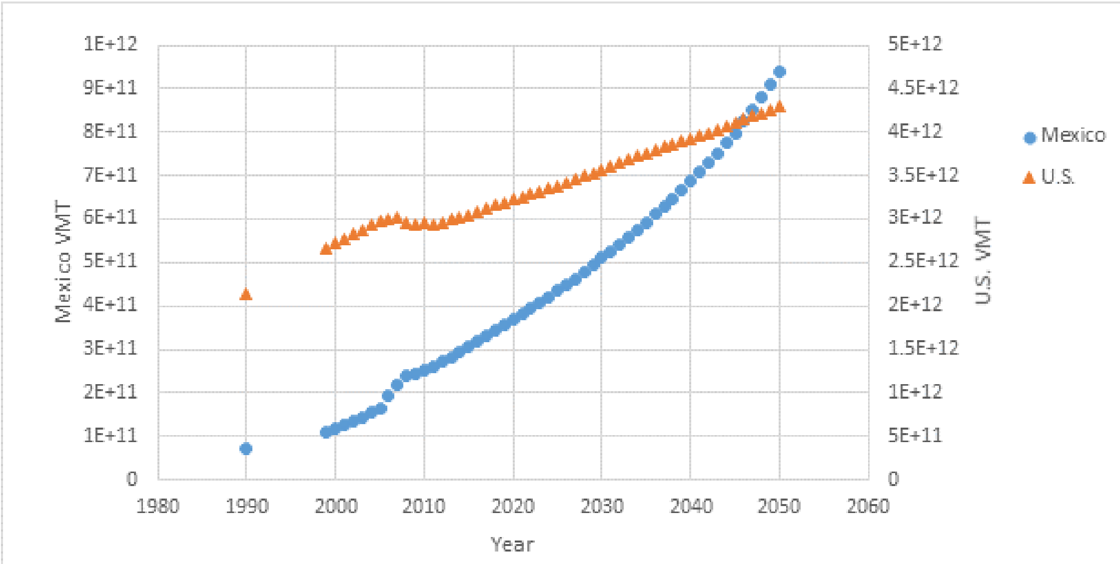
6.0 Results from the MOVES-Mexico Model

The result of the work described in Sections 4 and 5 is a complete database for MOVES2014a that replaces wholesale the default U.S. database, and can be run directly with the version of MOVES2014a available for download on U.S. EPA's website. To test the model and evaluate model results, ERG conducted a serious of runs to produce national totals of Total Energy (allowing estimation of fuel consumption), NOx, $PM_{2.5}$, CO and VOC from all on-road sources in Mexico, for calendar years spanning from 1990 through 2050. To ERG's knowledge, this is the broadest analysis of motor vehicle emissions conducted in Mexico, and showcases the abilities of MOVES-Mexico for researchers, analysts and policy makers. The results shown here are generally at their most aggregate level, total national onroad emissions, but it is possible to produce estimates at finer levels of detail including by state, *municipio*, vehicle class, fuel type, model year, and emission process. The results presented here only scratch the surface of the estimates that can be generated by the model.

6.1 Vehicle Travel

The primary components of emission inventory are vehicle travel (vehicle miles, or kilometers, travelled – VMT or VKT. MOVES works with miles, so VMT is the activity basis discussed here). As discussed in Sections 3 and 4, VMT estimates are a product of data provided by INECC for a) vehicle populations in 2013; b) historical and projected vehicle populations; and c) per-vehicle travel by age. Combined, what is produced is total miles travelled by all on-road vehicles in Mexico for calendar years from 1990 through 2050. These estimates are shown in Figure 23, on the left axis. For comparison, on the right axis is total U.S. VMT (note that the values on the U.S. axis are five times larger than on the Mexico axis). Of note is that the growth rate of Mexico's VMT is much higher than the U.S. This is function of saturation in the U.S. vehicle market, where vehicles will be added to the fleet relatively slower than in Mexico. VMT growth rates in the U.S. are typically around 2 percent or less, while the Mexico VMT growth rates are closer to 4 percent. In 2010, Mexico's VMT was less than ten percent of the U.S., while in 2050 this is project to rise to about 20 percent.

Figure 23: VMT Trend



6.2 Fuel Consumption Trend & Evaluation

ERG first evaluated fuel consumption predictions from MOVES-Mexico, as comparison to independent fuel sales estimates is a common method to evaluate model predictions. Fuel production and sales is a relatively well-known quantity, so proves a good “top-down” check against “bottom-up” estimates produced by the model. MOVES does not estimate fuel consumption directly, but produces estimates of Total Energy consumed, which can be converted to fuel consumption outside of the model based on assumptions of fuel energy content. For this analysis, values of 124 MJ/gallon were used for energy density of gasoline, and 137 MJ/gallon for diesel, for consistency with MOVES energy inputs (U.S. EPA, 2015a). The resulting estimates of total onroad fuel consumption for 1990 through 2050 are shown for gasoline in Figure 24, and diesel for Figure 25. Superimposed on these trends are two estimates of fuel consumption and production; one from SENER, combining historical production data from 2003 and projections through 2027. The second estimate is fuel sales from PEMEX for 2013. 2013 is the “base year” used in the development of the MOVES-Mexico database, so is a good year of comparison. The fuel consumption estimates derived from MOVES-Mexico are higher than the PEMEX gasoline sales estimate by 7 percent, and are lower than the PEMEX diesel sales estimate by 3 percent. Considering the uncertainties not only within MOVES, but in the energy content estimates used to calculate fuel consumption and the PEMEX estimates, we consider this a very good result, and indicative that the underlying vehicle fleet, activity and energy rates in the MOVES-Mexico are sound.

Comparison to the SENER estimates reveals some interesting trends. First, while SENER agrees with the 2013 PEMEX estimate for gasoline in 2013, the SENER diesel estimate is about 15 percent higher than the PEMEX estimate. This gap may indicate uncertainty in on vs. offroad diesel sales, since offroad sources (e.g. construction and agricultural equipment) are significant source of overall diesel consumption. Beyond this, the historical and future trends of SENER diverge from MOVES-Mexico, for explainable reasons. For gasoline, MOVES tracks the SENER estimates well back through about 2009, then diverge as the MOVES estimates drop more sharply in the mid 2000s (looking backwards). In consultation with INECC, this was explained by a rapid shift in vehicle population estimates occurring with legalization of U.S. import vehicles in this timeframe. Prior to this, the gap between historical SENER and MOVES-Mexico estimates appears to be due to illegal imports that are were not reflected in the official vehicle population estimates provided by INECC. The historical diesel trend for MOVES-Mexico tracks that of SENER, though the offset seen between SENER and MOVES (confirmed as an offset with the PEMEX 2013 estimates) persists, possibly due to inclusion of onroad fuel sold for offroad use in the SENER production estimates. Diversion in SENER projects vs. MOVES-Mexico is explained by differing assumptions made in projections. For example, INECC suggested that the SENER projections are higher in the future due to more aggressive growth assumptions than those provided by INECC for MOVES-Mexico.

Figure 24: Gasoline Fuel Consumption

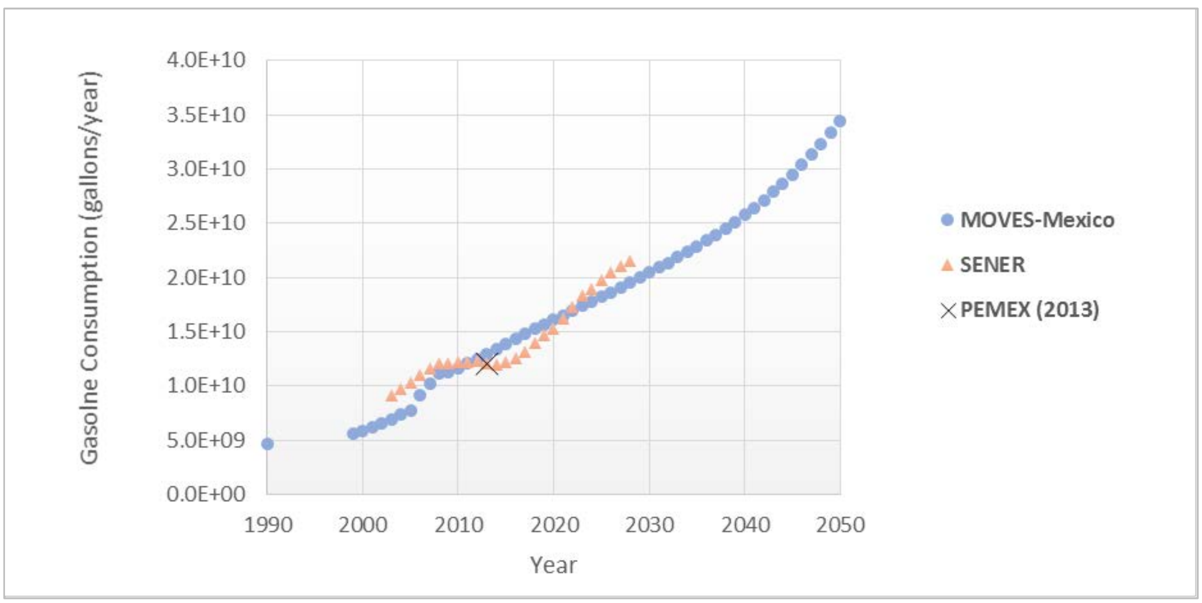
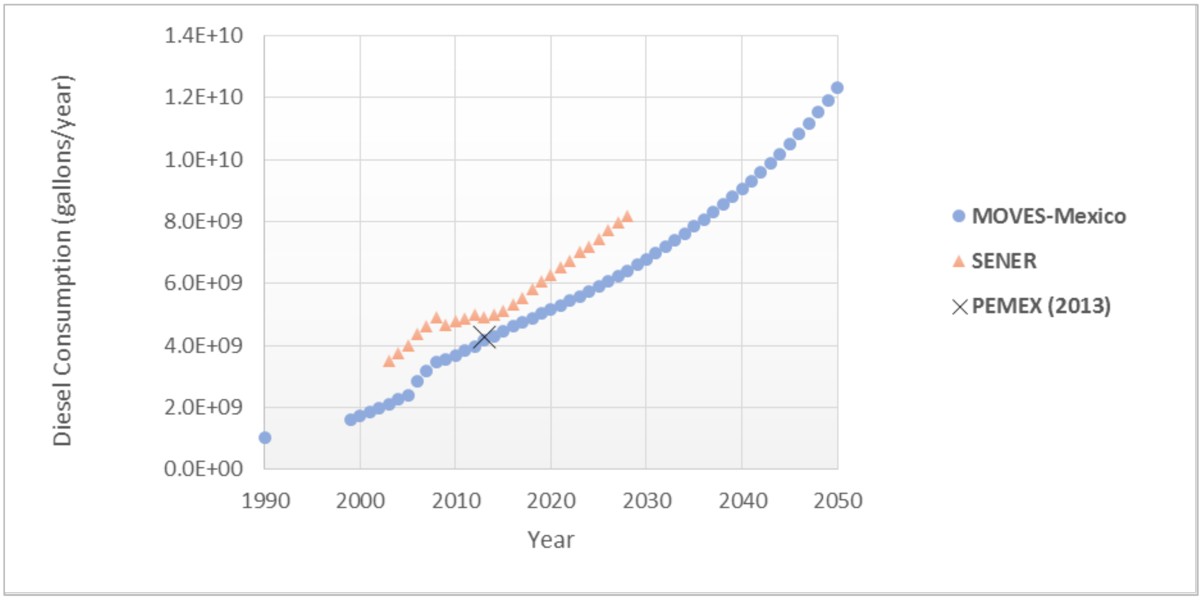


Figure 25: Diesel Fuel Consumption



6.3 Criteria Pollutant Trends

ERG also generated annual, national totals for VOC, CO, NOx, and $PM_{2.5}$ (so-called "criteria" pollutants) for all the years MOVES covers, 1990, 1999-2050. With total emissions, and the VMT estimates presented in Figure 23 above, fleetwide emission factors for each pollutant can also be generated for each calendar year, which provides a useful check on result and understanding of how the emission rate updates discussed in Section 5 affect total emissions on an individual vehicle basis. Emission factors (grams/mile) and national emission totals (tons) are shown both for MOVES-Mexico, and the U.S. version of MOVES2014a, to provide a comparison between the two. This section presents results for the criteria pollutants in terms of per-mile emission factor, and total tons, by calendar year.

Figures 24 through 31 show the per-mile and total inventory results for VOC, CO, NOx, and $PM_{2.5}$. VOC includes both exhaust and evaporative emissions. Results for both Mexico and the U.S. (based on the default MOVES2014a U.S. database) are shown for comparison. The per-mile emission factors for each pollutant show a decrease over time (though $PM_{2.5}$ levels off after 2010) as a result of NOM exhaust standards and fuel quality improvements, most notably the introduction of lower sulfur fuel in major cities in the late 2000s. For VOC, while the total per-mile emission rate decreases over time, the evaporative emission rate is stable, with these emissions projected to contribute the majority of VOC from about 2025 onward. As expected based on the calibration factor approach used to develop MOVES-Mexico emission rates, the Mexico per-mile emissions are consistently higher than the comparable U.S. rates. The total onroad emissions results for Mexico and the U.S. show very different trends. The U.S. values, on the right axis (note the much larger scale) show significant reductions in emissions through about 2030, as the U.S fleet is projected to turn over to vehicle complying with stringent vehicle tailpipe and fuel standards (e.g. Tier 2 and 3 Light-Duty, and 2007/2010 Heavy-Duty standards), combined with relatively modest VMT growth projections. In contrast, Mexico's emission trends reflect more modest emission reductions from existing NOM standards, combined with more aggressive VMT growth projections. The result is an increasing trend for each pollutant through about 2010, and depending on the pollutant either a drop in emissions as NOM standards serve to offset VMT growth (CO and NOx), or a continued increase in emissions as VMT growth outpaces the impact of vehicle standards (VOC and $PM_{2.5}$). Onroad emissions in Mexico are projected to equal those in the U.S. by about 2030, and from 2040 onward all pollutants are projected to increase as VMT growth overtakes the influence of current vehicle standards.). The "bump" shown in most pollutants in the 2007-2009 timeframe is the due to the offsetting impact of rapid VMT growth in that period as official vehicle population estimate provided by INECC began account for import vehicles, and the introduction of low sulfur fuel in 2009.

Figure 26: National Onroad VOC Emissions Per Mile Trend

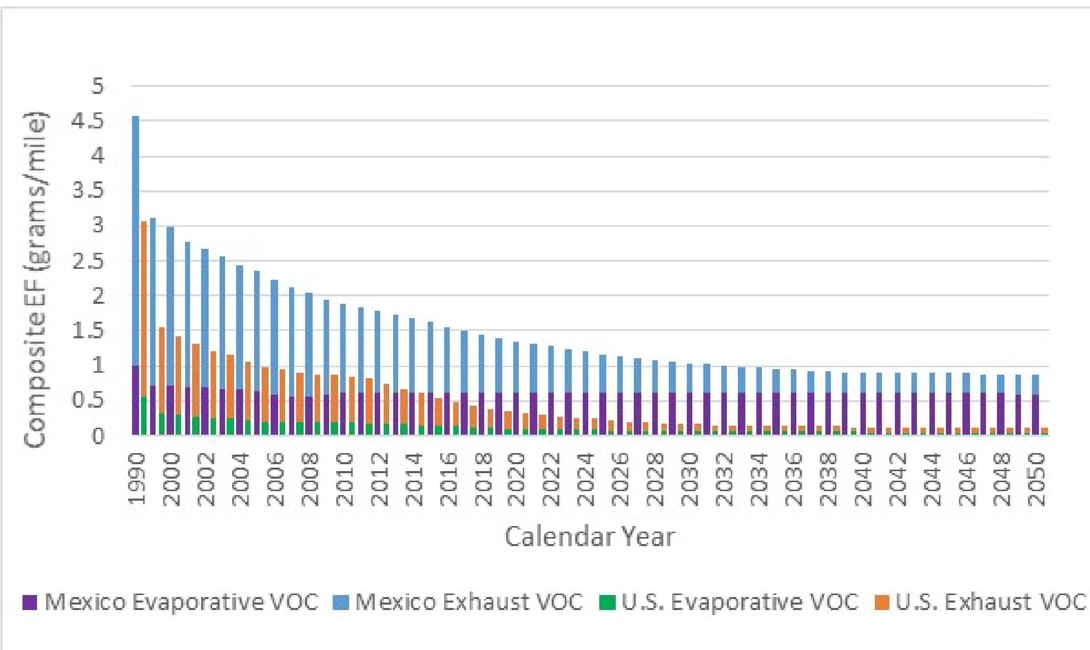


Figure 27: National Onroad VOC Total Emissions Trend

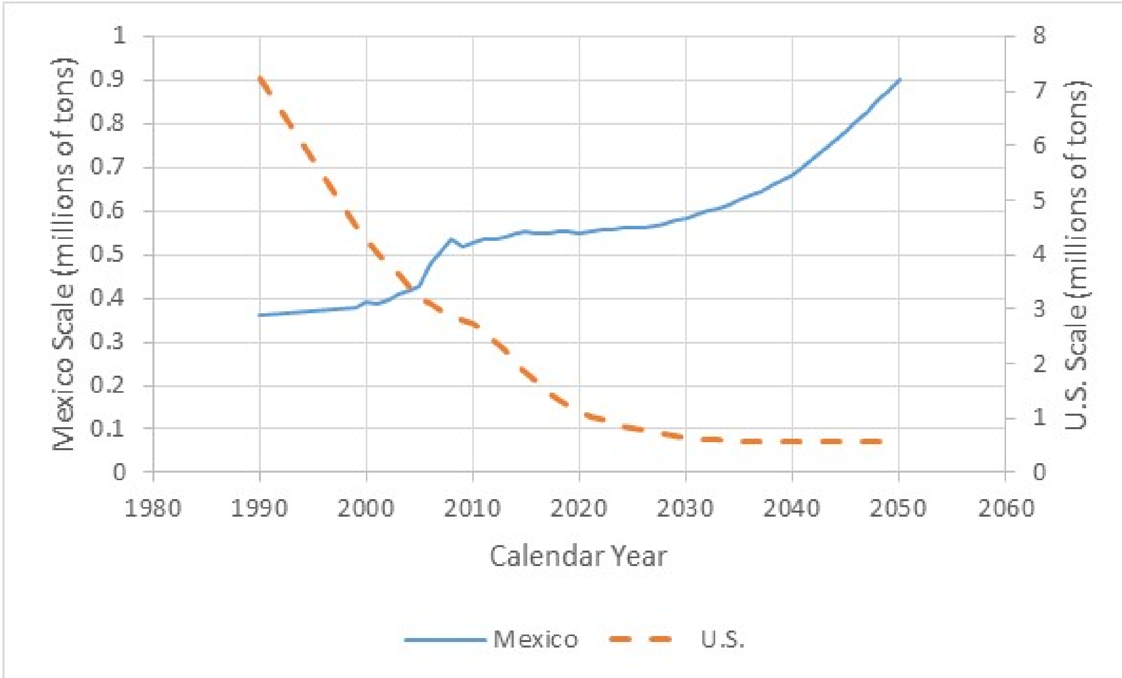


Figure 28: National Onroad CO Emissions Per Mile Trend

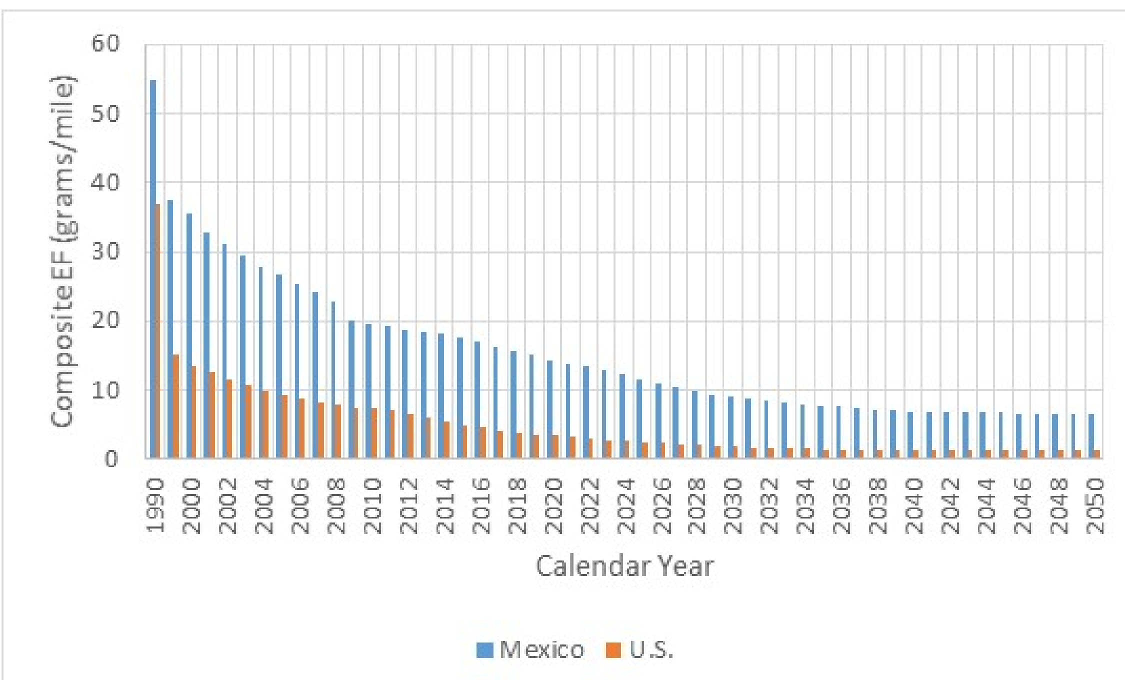


Figure 29: National Onroad CO Total Emissions Trend

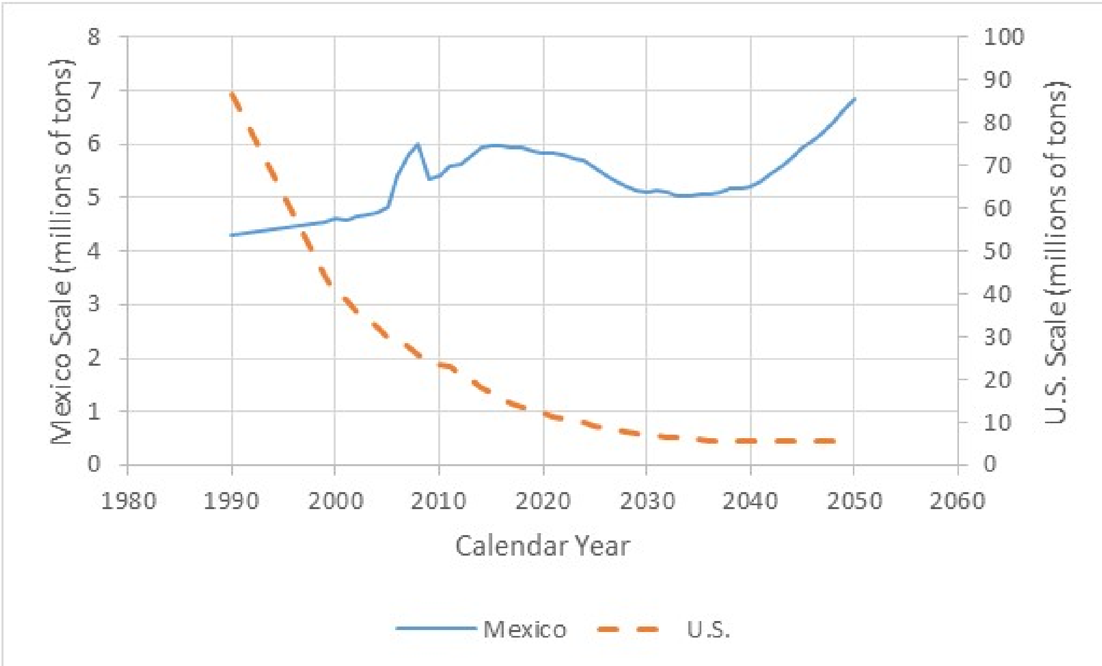


Figure 30: National Onroad NO_X Emissions Per Mile Trend

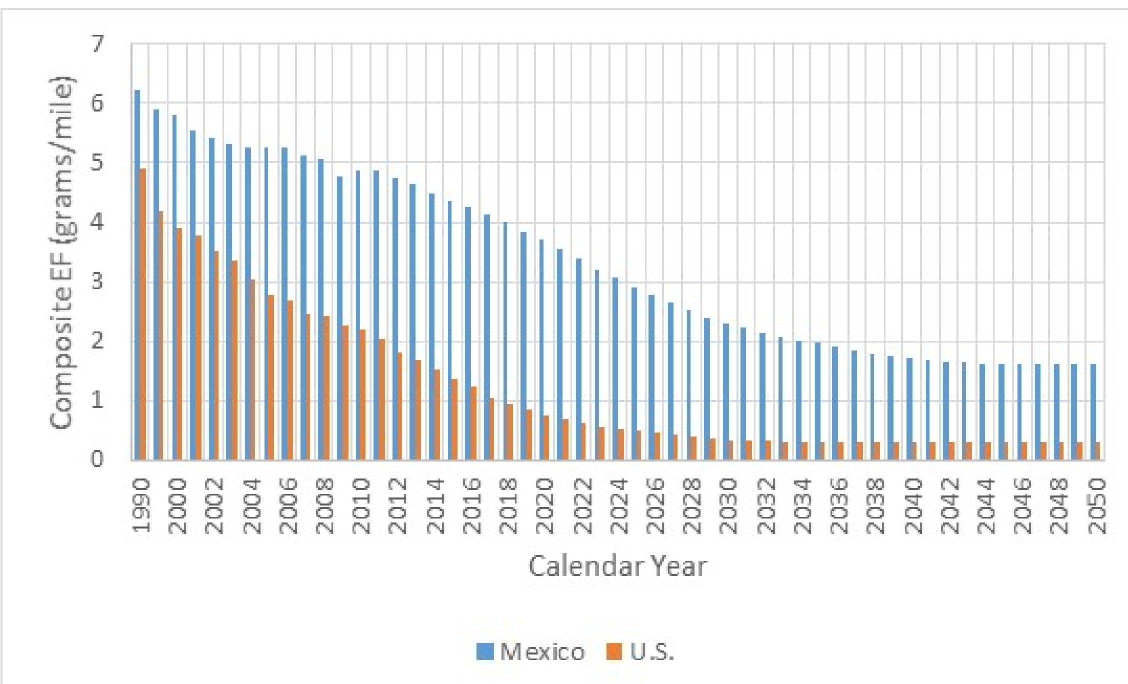


Figure 31: National Onroad NO_X Total Emissions Trend

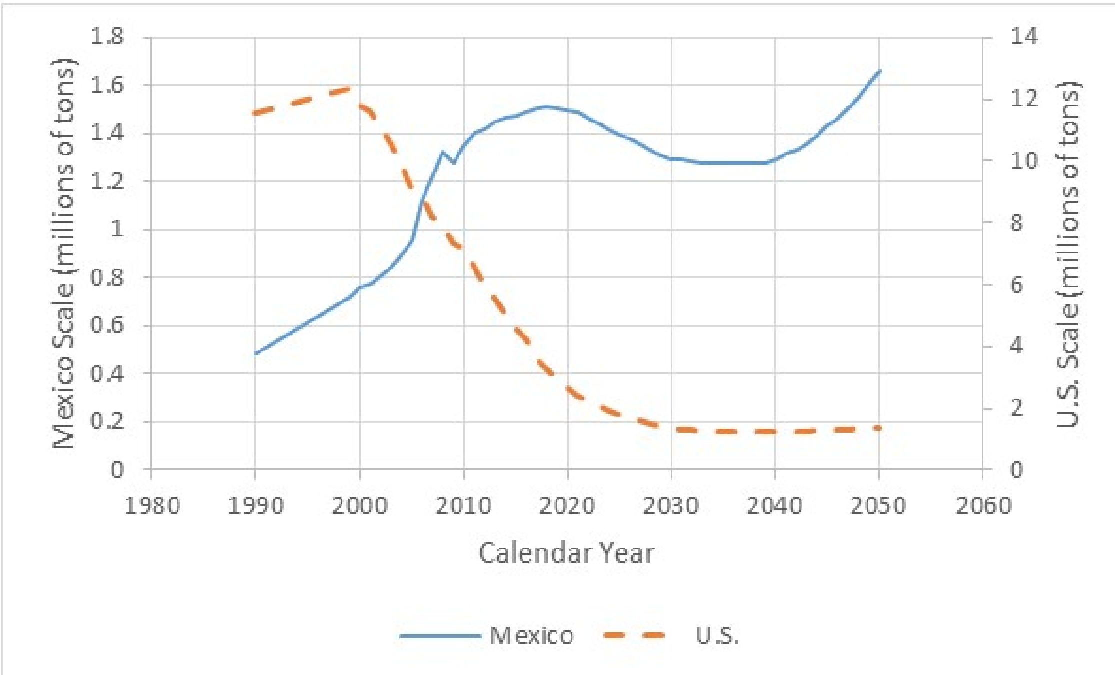


Figure 32: National Onroad $PM_{2.5}$ Emissions Per Mile Trend

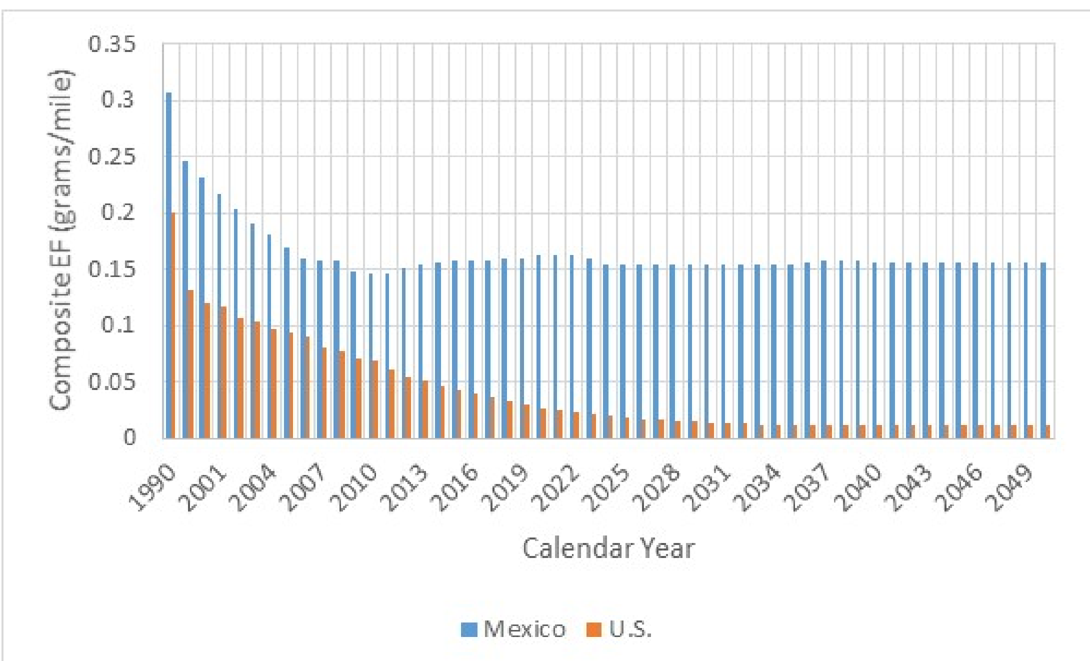


Figure 33: National Onroad $PM_{2.5}$ Total Emissions Trend

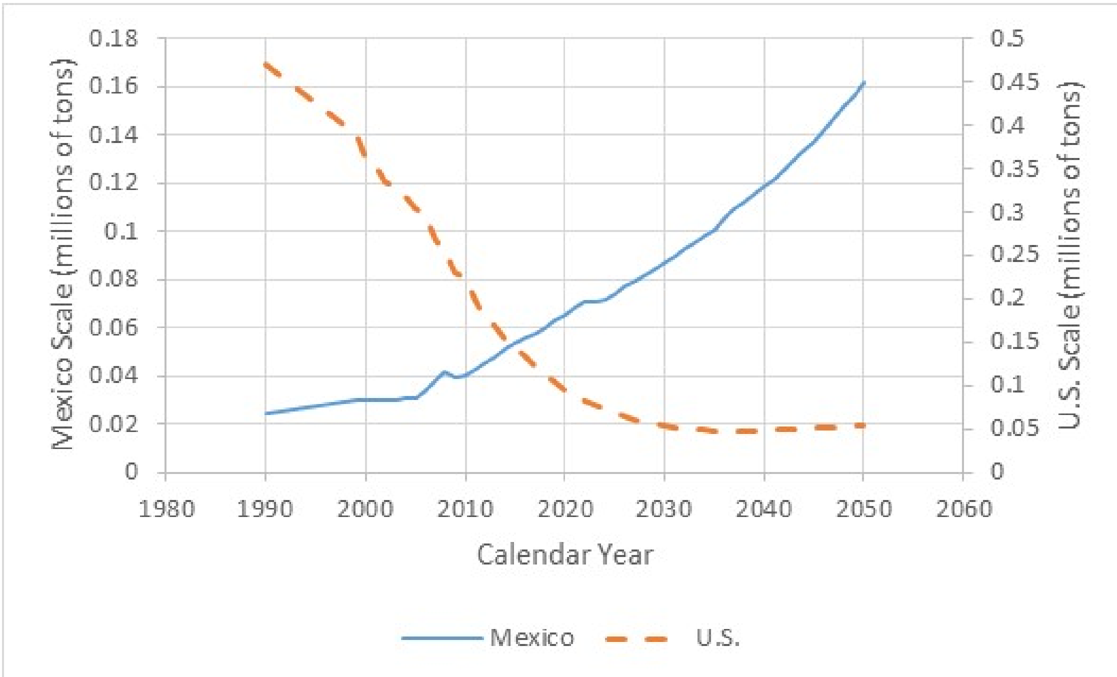
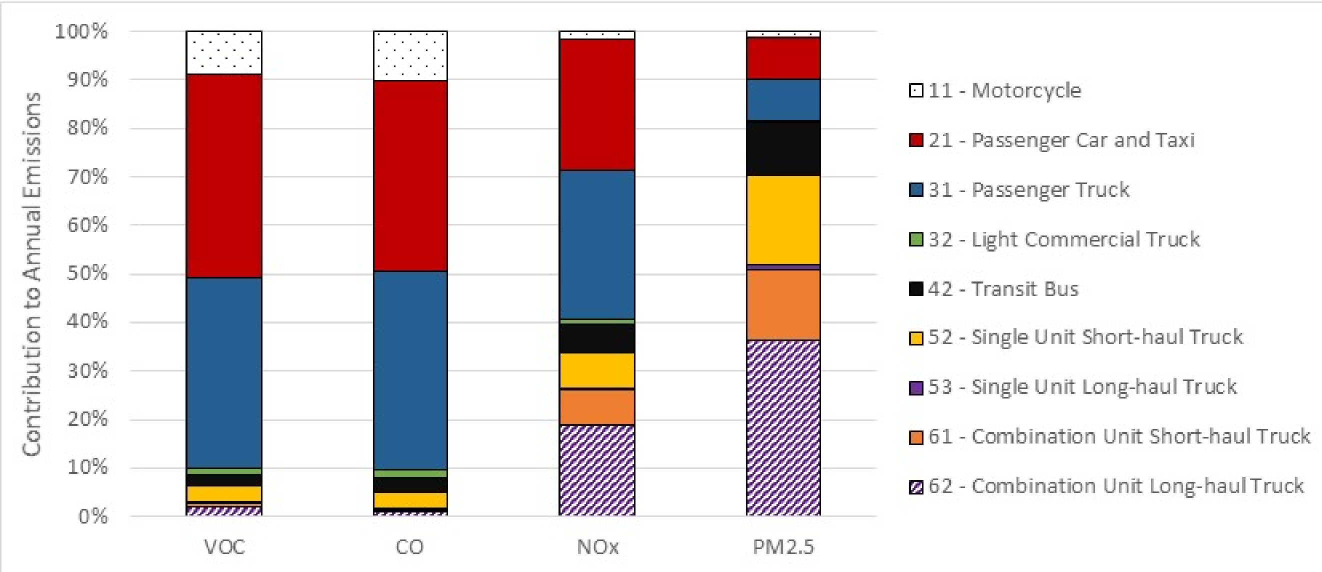


Figure 32 shows the contribution of each vehicle class to total national onroad emissions in 2013. This breakdown shows expected trends; VOC and CO are dominated by passenger cars and trucks, while heavy-duty truck and bus emissions contribute a larger share of NOx, and the majority of $PM_{2.5}$. Overtime, we expect the contribution of light vehicles to decrease as this fleet turns over to final NOM42 standards.

Figure 34: 2013 Emissions Contribution by Source Use Type



7.0 Conclusions & Future Recommendations

USAID and INECC, through Eastern Research Group, Inc. (ERG) and consultant Verónica Garibay-Bravo have developed a version of EPA's MOVES model adapted to Mexico, referred to as MOVES-Mexico. This version has been adapted to MOVES2014a, the most recent version of the MOVES model released by EPA, and reflects EPA's latest estimate of vehicle emissions and default U.S. activity data (U.S. EPA, 2015a). The focus on this adaptation was to create a basic MOVES-Mexico framework that is easy to use and can be improved over time as new data becomes available. Developing MOVES-Mexico required determining the best approach for updating the model, culling data on vehicle fleet and activity to replace U.S. defaults where possible, and reflecting significant differences in emission standards between Mexico and the U.S. The result was creation of a Mexico-specific MOVES database that can work directly with the U.S. version of MOVES2014a without any software modification, enabling estimation of onroad emissions for calendar years 1990 through 2050 at the nation, state or *municipio* level.

INECC provided a significant amount of data to develop this Mexico-specific database for MOVES. These data include fundamental inputs such as vehicle activity, vehicle population, age distribution, and emission standards. INECC also provided a robust RSD database with measurements across 24 Mexican cities. ERG's analysis of these data concluded that passenger car and light truck emissions can be calibrated directly to these data, to develop emission rates for Mexico that reflects "real world" emission measurements. A detailed analysis of the RSD data was undertaken to determine how to calibrate MOVES emission rates for passenger car and truck NOx, CO and exhaust HC to the RSD, accounting for the impacts of I/M program, sulfur level and deterioration observed in the data. Emissions for heavy-duty vehicles were based on a mapping of Mexico and U.S standards, to account for differences in emission control technology implementation between the two countries.

Once the Mexico-specific database was complete, ERG conducted testing and evaluation of the MOVES-Mexico model. The fuel consumption estimates derived from MOVES-Mexico are higher than the PEMEX gasoline sales estimate by 7 percent, and are lower than the PEMEX diesel sales estimate by 3 percent. Considering the uncertainties not only within MOVES, but in the energy content estimates used to calculate fuel consumption and the PEMEX estimates, we consider this a very good result, and indicative that the underlying vehicle fleet, activity and energy rates in the MOVES-Mexico are sound. MOVES-Mexico trends back in time, and into the future, were also compared against fuel production figures from SENER. For gasoline, MOVES tracks the SENER estimates well back through about 2009, then diverge as the MOVES estimates drop more sharply in the mid 2000s (looking backwards). In consultation with INECC, this was explained by a rapid shift in vehicle population estimates occurring with legalization of U.S. import vehicles in this timeframe. Prior to this, the gap between historical SENER and MOVES-Mexico estimates appears to be due to illegal imports that are were not reflected in the official vehicle population estimates provided by INECC. The historical diesel trend for MOVES-Mexico tracks that of SENER, though the offset seen between SENER and MOVES (confirmed as an offset with the PEMEX 2013 estimates) persists, possibly due to inclusion of onroad fuel sold for offroad use in the SENER production estimates. Diversion in SENER projects vs. MOVES-Mexico is explained by differing assumptions made in projections. For example, INECC suggested that the SENER projections are higher in the future due to more aggressive growth assumptions than those provided by INECC for MOVES-Mexico.

ERG also generated annual, national totals for VOC, CO, NOx, and $PM_{2.5}$ to assess trends from calendar year 1990 to 2050. The per-mile emission factors for each pollutant show a decrease over time (though $PM_{2.5}$ levels off after 2010) as a result of NOM exhaust standards and fuel quality improvements, most notably the introduction of lower sulfur fuel in major cities in the late 2000s. As expected based on the calibration factor approach to developing MOVES-Mexico emission rates, the Mexico per-mile emissions are consistently higher than the comparable U.S. rates. The total onroad emissions results for Mexico and the U.S. show very different trends. While the U.S. projects a significant decline in emissions due to stringent vehicle and fuel standards coupled with modest VMT growth, Mexico's emission trends show an increasing trend for each pollutant through about 2015, and depending on the pollutant either a period of reduction in total emissions as NOM standards serve to offset VMT growth (CO and NOx), or a continued increase in emissions as VMT growth outpaces the impact of vehicle standards (VOC and $PM_{2.5}$). Onroad emissions in Mexico are projected to equal those in the U.S. by about 2030, and from 2040 onward all pollutants are projected to increase as VMT growth overtakes the influence of current vehicle standards.). Passenger cars and light trucks were shown to contribute most VOC and CO, while heavy diesel trucks and buses contribute about one half of NOx, and the majority of $PM_{2.5}$. Overall, this analysis demonstrates the value of MOVES-Mexico in assessing long-term emission trends and evaluating the potential impact of more stringent vehicle and fuel standards.

This project resulted in the first implementation of MOVES-Mexico, but model users should consider model improvement an ongoing process as new data are collected. A primary benefit of having MOVES-Mexico in place is that it provides a framework for collecting data and improving the model over time. A great deal of Mexico-specific data provided by INECC and others was used to populate this version of MOVES-Mexico, but as noted in the earlier sections, a number of U.S. assumptions had to be carried over to Mexico to complete the database. Ongoing data collection on vehicle emissions and activity should continue become a regular part of the model update cycle. MOVES-Mexico will also need to be updated when new vehicle or fuel standards are put in place, to reflect the benefits of these in future onroad emission inventory projections.

Specific recommendations for maintaining and improving MOVES-Mexico are as follows:

- Researchers and model developers in Mexico should undertake research programs to collect data for the model where U.S. defaults were still required. Important data inputs this was the case for include average speed distribution, vehicle trip patterns, drive patterns (i.e. drive cycles), and I/M program benefits.
- The RSD program should continue in multiple cities to continue to track real-world emissions, deterioration trends, and differences between cities. Field work could be expanded to include on-board emissions measurement on a subset of vehicles to supplement RSD collection; improved methods for measuring heavy-duty truck emissions; and evaporative leak evaluation. These methods have been used in recent years in U.S. field studies.
- Measurement of PM emissions on both heavy trucks and light vehicles should be a focus of emissions research in Mexico, as all of the emission rates in MOVES-Mexico are based on U.S. research.
- Research, methods and databases could be shared by MOVES-Mexico users to improve the model collectively. This could take the form of workshops, data clearinghouses, training sessions and user forums to facilitate a broader understanding of data sources for MOVES-Mexico, and help improve the model.

8.0 Acknowledgements

The authors gratefully acknowledge the project sponsor USAID Mexico, and project leaders Ricardo Troncoso and Cynthia Menéndez; we would also like to thank José Andrés Aguilar Gómez and Sergio Zirath Hernández Villaseñor of INECC for supplying the data mentioned in this document, and providing ongoing project guidance and support.

9.0 References

CONAGUA. (2015). *Temperaturas y Lluvia*. Available from http://smn.cna.gob.mx/index.php?option=com_content&view=article&id=12&Itemid=77.

CONAPO. (2015). *Estimaciones y proyecciones de la población por entidad federativa. Archivo. Datos de proyecciones.* Available from http://www.conapo.gob.mx/es/CONAPO/Proyecciones_Datos.

Find Local Weather. (2015). *North America Relative Humidity Maps.* Available from http://www.findlocalweather.com/weather_maps/humidity_north_america.html.

INEGI. (2015a). *Conjunto de Datos Vectoriales de Carreteras y Vialidades Urbanas Edición 1.0 (Distribución por Entidad Federativa).* Available from http://www.inegi.org.mx/geo/contenidos/topografia/vectoriales_carreteras.aspx.

INEGI. (2015b). *Diccionario de datos de localidades urbanas.* Retrieved from http://www.inegi.org.mx/geo/contenidos/urbana/doc/diccionario_datos_localidades_urbanas_ver_definitiva_septiembre07.pdf.

INEGI. (2015c). *Población total con estimación en 2010 según tamaño localidad 2 tam - total. Sistema de consulta. Sistema Estatal y Municipal de Base de Datos.* Available from http://sc.inegi.org.mx/cobdem/resultados.jsp?w=24&Backidhecho=199&Backconstem=198&constembd=199&tm='Backidhecho:3,Backconstem:3,constembd:3'.

INEGI. (2015d). *Catálogo Único de Claves de Áreas Geoestadísticas Estatales, Municipales y Localidades - consulta y descarga.* Available from http://www.inegi.org.mx/geo/contenidos/geoestadistica/catalogoclaves.aspx.

Molina, L.T., & Molina, M.J. (2002). *Air Quality in the Mexico Megacity, an Integrated Assessment*. Dordrect, The Netherlands: Kluwer Academic Publishers. Table 2.3.

Petróleos Mexicanos. (2015). *PEMEX sales data by state*. Available from http://www.pemex.com/en/Paginas/default.aspx.

Seinfeld, J.H. & Pandis, S.N. (2006). *Atmospheric Chemistry and Physics, From Air Pollution to Climate Change, Second Edition.* Canada and Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

Slott, R.S. (2007). *CRC Report E-23: Remote Sensing in Four Cities to Determine the Change in On-Road Vehicle Fleet Emissions Over Time*. Retrieved from http://www.crcao.com/reports/recentstudies2008/E-23%20Final%20Report/E-23%20Slott%20FINAL%20revised%207%2009DEC2007.pdf.

U.S. Department of Commerce. (2014). *Annual Estimates of the Resident Population for Counties: April 1, 2010 to July 1, 2014.* Retrieved from http://www.census.gov/popest/data/counties/totals/2014/CO-EST2014-01.html.

U.S. Department of Commerce. (2015). *2014 U.S. Gazetteer Files.* Retrieved from http://www.census.gov/geo/maps-data/data/gazetteer2014.html.

U.S. EPA. (2014a). *Evaporative Emissions from On-road Vehicles in MOVES2014*. Retrieved from http://www3.epa.gov/otaq/models/moves/documents/420r14014.pdf.

U.S. EPA, (2014b). *MOVES2014 User Interface Manual*. Retrieved from http://www3.epa.gov/otaq/models/moves/documents/420b14057.pdf.

U.S. EPA, (2014c). *The Effects of Ultra-Low Sulfur Gasoline on Emissions from Tier 2 Vehicles in the In-Use Fleet.* Retrieved from http://www3.epa.gov/otaq/models/moves/documents/420r14002.pdf

U.S. EPA. (2015a). *Motor Vehicle Emission Simulator Model version 2014a (MOVES2014a).* Available from http://www3.epa.gov/otaq/models/moves/.

U.S. EPA. (2015b). *The 2011 National Emissions Inventory.* Available from http://www.epa.gov/ttnchie1/net/2011inventory.html.

U.S. EPA. (2015c). *Meteorological Data Converter MOBILE6.* Retrieved from http://www3.epa.gov/otaq/models/moves/tools/meteorologicaldataconverter_mobile6.xls.

ANNEX A

Calibration Factors used to Calculate MOVES-Mexico Emission Rates for LDV and LDT NOx, CO and THC Running and Start Emissions

LDV NOx No I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	7.50	4.38	4.38	11.10	11.10	11.10
2029	7.50	4.38	4.38	11.10	11.10	11.10
2028	7.50	4.38	4.38	11.10	11.10	11.10
2027	7.50	4.38	4.38	11.10	11.10	11.10
2026	7.50	4.38	4.38	11.10	11.10	11.10
2025	7.50	4.38	4.38	11.10	11.10	11.10
2024	5.87	4.38	4.38	11.10	11.10	11.10
2023	4.82	4.38	4.38	11.10	11.10	11.10
2022	4.09	4.09	4.09	10.38	10.38	10.38
2021	3.55	3.55	3.55	9.01	9.01	9.01
2020	3.14	3.14	3.14	7.96	7.96	7.96
2019	2.81	2.81	2.81	7.13	7.13	7.13
2018	2.55	2.55	2.55	6.46	6.46	6.46
2017	2.33	2.33	2.33	5.90	5.90	5.90
2016	2.14	2.14	2.14	5.44	5.44	5.44
2015	2.14	2.14	2.14	5.44	5.44	5.44
2014	2.14	2.14	2.14	5.44	5.44	5.44
2013	2.14	2.14	2.14	5.44	5.44	5.44
2012	4.07	4.07	4.07	10.33	10.33	10.33
2011	5.36	4.38	4.38	11.10	11.10	11.10
2010	6.96	4.38	4.38	11.10	11.10	11.10
2009	-	4.38	4.38	11.10	11.10	11.10
2008	-	4.38	4.38	11.10	11.10	11.10
2007	-	4.38	9.42	10.28	10.28	10.28
2006	-	5.78	13.63	13.63	11.69	11.69
2005	-	7.39	7.39	10.99	10.77	10.77
2004	-	4.56	4.56	9.57	9.57	9.06
2003	-	3.59	3.59	3.59	4.59	4.62
2002	-	3.15	3.15	3.15	5.47	4.70
2001	-	3.58	3.58	3.58	3.58	4.00
2000	-	1.94	1.94	1.94	1.94	1.94
1999	-	2.26	2.26	2.26	2.26	2.26
1998	-	2.13	2.13	2.13	2.13	2.13
1997	-	2.13	2.13	2.13	2.13	2.13
1996	-	2.16	2.16	2.16	2.16	2.16
1995	-	1.56	1.56	1.56	1.56	1.56
1994	-	1.57	1.57	1.57	1.57	1.57
1991-1993	-	1.12	1.12	1.12	1.12	1.12
1990	-	1.10	1.10	1.10	1.10	1.10
1988-1989	-	1.02	1.02	1.02	1.02	1.02
1986-1987	-	1.00	1.00	1.00	1.00	1.00
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.00	1.00	1.00	1.00	1.00
1981-1982	-	1.00	1.00	1.00	1.00	1.00
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDV NOx I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	7.50	2.64	2.64	2.64	2.64	2.64
2029	7.50	2.64	2.64	2.64	2.64	2.64
2028	7.50	2.64	2.64	2.64	2.64	2.64
2027	7.50	2.64	2.64	2.64	2.64	2.64
2026	7.50	2.64	2.64	2.64	2.64	2.64
2025	7.50	2.64	2.64	2.64	2.64	2.64
2024	5.87	2.64	2.64	2.64	2.64	2.64
2023	4.82	2.64	2.64	2.64	2.64	2.64
2022	4.09	2.64	2.64	2.64	2.64	2.64
2021	3.55	2.64	2.64	2.64	2.64	2.64
2020	3.14	2.64	2.64	2.64	2.64	2.64
2019	2.81	2.64	2.64	2.64	2.64	2.64
2018	2.55	2.55	2.55	2.55	2.55	2.55
2017	2.33	2.33	2.33	2.33	2.33	2.33
2016	2.14	2.14	2.14	2.14	2.14	2.14
2015	2.14	2.14	2.14	2.14	2.14	2.14
2014	2.14	2.14	2.14	2.14	2.14	2.14
2013	2.14	2.14	2.14	2.14	2.14	2.14
2012	4.07	2.64	2.64	2.64	2.64	2.64
2011	5.36	2.64	2.64	2.64	2.64	2.64
2010	6.96	2.64	2.64	2.64	2.64	2.64
2009	-	2.64	2.64	2.64	2.64	2.64
2008	-	2.64	2.64	2.64	2.64	2.64
2007	-	2.64	2.64	2.64	2.64	2.64
2006	-	2.99	2.99	2.99	2.99	2.99
2005	-	5.16	5.16	5.16	5.16	5.16
2004	-	3.37	3.37	3.37	3.37	3.37
2003	-	2.48	2.48	2.48	2.48	2.48
2002	-	2.26	2.26	2.26	2.26	2.26
2001	-	2.72	2.72	2.72	2.72	2.72
2000	-	1.38	1.38	1.38	1.38	1.38
1999	-	1.41	1.41	1.41	1.41	1.41
1998	-	1.44	1.44	1.44	1.44	1.44
1997	-	1.43	1.43	1.43	1.43	1.43
1996	-	1.45	1.45	1.45	1.45	1.45
1995	-	1.23	1.23	1.23	1.23	1.23
1994	-	1.24	1.24	1.24	1.24	1.24
1991-1993	-	1.00	1.00	1.00	1.00	1.00
1990	-	1.03	1.03	1.03	1.03	1.03
1988-1989	-	1.00	1.00	1.00	1.00	1.00
1986-1987	-	1.00	1.00	1.00	1.00	1.00
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.00	1.00	1.00	1.00	1.00
1981-1982	-	1.02	1.02	1.02	1.02	1.02
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDT NOx No I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	7.50	5.52	5.52	11.44	11.44	11.44
2029	7.50	5.52	5.52	11.44	11.44	11.44
2028	7.50	5.52	5.52	11.44	11.44	11.44
2027	7.50	5.52	5.52	11.44	11.44	11.44
2026	7.50	5.52	5.52	11.44	11.44	11.44
2025	7.50	5.52	5.52	11.44	11.44	11.44
2024	5.87	5.52	5.52	11.44	11.44	11.44
2023	4.82	4.82	4.82	9.98	9.98	9.98
2022	4.09	4.09	4.09	8.47	8.47	8.47
2021	3.55	3.55	3.55	7.36	7.36	7.36
2020	3.14	3.14	3.14	6.50	6.50	6.50
2019	2.81	2.81	2.81	5.82	5.82	5.82
2018	2.55	2.55	2.55	5.27	5.27	5.27
2017	2.33	2.33	2.33	4.82	4.82	4.82
2016	2.14	2.14	2.14	4.44	4.44	4.44
2015	2.14	2.14	2.14	4.44	4.44	4.44
2014	2.14	2.14	2.14	4.44	4.44	4.44
2013	2.14	2.14	2.14	4.44	4.44	4.44
2012	4.07	4.07	4.07	8.43	8.43	8.43
2011	5.36	5.36	5.36	11.09	11.09	11.09
2010	6.96	5.52	5.52	11.44	11.44	11.44
2009	-	5.52	5.52	11.44	11.44	11.44
2008	-	5.52	5.52	11.44	11.44	11.44
2007	-	5.52	10.12	10.89	10.89	10.89
2006	-	7.64	15.35	15.35	12.98	12.98
2005	-	7.12	7.12	9.48	9.16	9.16
2004	-	3.67	3.67	6.89	6.89	6.43
2003	-	2.24	2.24	2.24	2.70	2.72
2002	-	2.50	2.50	2.50	4.08	3.52
2001	-	2.82	2.82	2.82	2.82	2.97
2000	-	1.60	1.60	1.60	1.60	1.60
1999	-	1.82	1.82	1.82	1.82	1.82
1998	-	1.87	1.87	1.87	1.87	1.87
1997	-	1.87	1.87	1.87	1.87	1.87
1996	-	1.63	1.63	1.63	1.63	1.63
1995	-	1.00	1.00	1.00	1.00	1.00
1994	-	1.00	1.00	1.00	1.00	1.00
1991-1993	-	1.00	1.00	1.00	1.00	1.00
1990	-	1.00	1.00	1.00	1.00	1.00
1988-1989	-	1.00	1.00	1.00	1.00	1.00
1986-1987	-	1.00	1.00	1.00	1.00	1.00
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.00	1.00	1.00	1.00	1.00
1981-1982	-	1.00	1.00	1.00	1.00	1.00
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDT NOx I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	7.50	6.16	6.16	6.16	6.16	6.16
2029	7.50	6.16	6.16	6.16	6.16	6.16
2028	7.50	6.16	6.16	6.16	6.16	6.16
2027	7.50	6.16	6.16	6.16	6.16	6.16
2026	7.50	6.16	6.16	6.16	6.16	6.16
2025	7.50	6.16	6.16	6.16	6.16	6.16
2024	5.87	5.87	5.87	5.87	5.87	5.87
2023	4.82	4.82	4.82	4.82	4.82	4.82
2022	4.09	4.09	4.09	4.09	4.09	4.09
2021	3.55	3.55	3.55	3.55	3.55	3.55
2020	3.14	3.14	3.14	3.14	3.14	3.14
2019	2.81	2.81	2.81	2.81	2.81	2.81
2018	2.55	2.55	2.55	2.55	2.55	2.55
2017	2.33	2.33	2.33	2.33	2.33	2.33
2016	2.14	2.14	2.14	2.14	2.14	2.14
2015	2.14	2.14	2.14	2.14	2.14	2.14
2014	2.14	2.14	2.14	2.14	2.14	2.14
2013	2.14	2.14	2.14	2.14	2.14	2.14
2012	4.07	4.07	4.07	4.07	4.07	4.07
2011	5.36	5.36	5.36	5.36	5.36	5.36
2010	6.96	6.16	6.16	6.16	6.16	6.16
2009	-	6.16	6.16	6.16	6.16	6.16
2008	-	6.16	6.16	6.16	6.16	6.16
2007	-	6.16	6.16	6.16	6.16	6.16
2006	-	4.49	4.49	4.49	4.49	4.49
2005	-	3.21	3.21	3.21	3.21	3.21
2004	-	2.25	2.25	2.25	2.25	2.25
2003	-	1.36	1.36	1.36	1.36	1.36
2002	-	1.41	1.41	1.41	1.41	1.41
2001	-	1.39	1.39	1.39	1.39	1.39
2000	-	1.00	1.00	1.00	1.00	1.00
1999	-	1.26	1.26	1.26	1.26	1.26
1998	-	1.34	1.34	1.34	1.34	1.34
1997	-	1.34	1.34	1.34	1.34	1.34
1996	-	1.17	1.17	1.17	1.17	1.17
1995	-	1.00	1.00	1.00	1.00	1.00
1994	-	1.00	1.00	1.00	1.00	1.00
1991-1993	-	1.00	1.00	1.00	1.00	1.00
1990	-	1.00	1.00	1.00	1.00	1.00
1988-1989	-	1.00	1.00	1.00	1.00	1.00
1986-1987	-	1.00	1.00	1.00	1.00	1.00
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.00	1.00	1.00	1.00	1.00
1981-1982	-	1.00	1.00	1.00	1.00	1.00
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDV CO No I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	2.00	1.93	1.93	3.13	3.13	3.13
2029	2.00	1.93	1.93	3.13	3.13	3.13
2028	2.00	1.93	1.93	3.13	3.13	3.13
2027	2.00	1.93	1.93	3.13	3.13	3.13
2026	2.00	1.93	1.93	3.13	3.13	3.13
2025	2.00	1.93	1.93	3.13	3.13	3.13
2024	1.80	1.80	1.80	2.92	2.92	2.92
2023	1.64	1.64	1.64	2.66	2.66	2.66
2022	1.50	1.50	1.50	2.44	2.44	2.44
2021	1.38	1.38	1.38	2.25	2.25	2.25
2020	1.29	1.29	1.29	2.09	2.09	2.09
2019	1.20	1.20	1.20	1.95	1.95	1.95
2018	1.13	1.13	1.13	1.83	1.83	1.83
2017	1.06	1.06	1.06	1.72	1.72	1.72
2016	1.00	1.00	1.00	1.62	1.62	1.62
2015	1.00	1.00	1.00	1.62	1.62	1.62
2014	1.00	1.00	1.00	1.62	1.62	1.62
2013	1.00	1.00	1.00	1.62	1.62	1.62
2012	1.00	1.00	1.00	1.62	1.62	1.62
2011	1.00	1.00	1.00	1.62	1.62	1.62
2010	1.00	1.00	1.00	1.62	1.62	1.62
2009	-	1.93	1.93	3.13	3.13	3.13
2008	-	1.93	1.93	3.13	3.13	3.13
2007	-	1.93	2.34	2.81	2.81	2.81
2006	-	2.49	2.94	2.94	3.02	3.02
2005	-	3.01	3.01	3.17	3.62	3.62
2004	-	1.39	1.39	2.59	2.59	3.30
2003	-	1.65	1.65	1.65	2.64	3.50
2002	-	1.38	1.38	1.38	3.39	3.92
2001	-	1.86	1.86	1.86	1.86	3.34
2000	-	1.30	1.30	1.30	1.30	1.30
1999	-	1.75	1.75	1.75	1.75	1.75
1998	-	1.33	1.33	1.33	1.33	1.33
1997	-	1.33	1.33	1.33	1.33	1.33
1996	-	1.36	1.36	1.36	1.36	1.36
1995	-	1.28	1.28	1.28	1.28	1.28
1994	-	1.30	1.30	1.30	1.30	1.30
1991-1993	-	1.84	1.84	1.84	1.84	1.84
1990	-	2.30	2.30	2.30	2.30	2.30
1988-1989	-	1.82	1.82	1.82	1.82	1.82
1986-1987	-	1.76	1.76	1.76	1.76	1.76
1985	-	1.48	1.48	1.48	1.48	1.48
1983-1984	-	1.51	1.51	1.51	1.51	1.51
1981-1982	-	1.13	1.13	1.13	1.13	1.13
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDV CO I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	2.00	1.52	1.52	1.52	1.52	1.52
2029	2.00	1.52	1.52	1.52	1.52	1.52
2028	2.00	1.52	1.52	1.52	1.52	1.52
2027	2.00	1.52	1.52	1.52	1.52	1.52
2026	2.00	1.52	1.52	1.52	1.52	1.52
2025	2.00	1.52	1.52	1.52	1.52	1.52
2024	1.80	1.52	1.52	1.52	1.52	1.52
2023	1.64	1.52	1.52	1.52	1.52	1.52
2022	1.50	1.50	1.50	1.50	1.50	1.50
2021	1.38	1.38	1.38	1.38	1.38	1.38
2020	1.29	1.29	1.29	1.29	1.29	1.29
2019	1.20	1.20	1.20	1.20	1.20	1.20
2018	1.13	1.13	1.13	1.13	1.13	1.13
2017	1.06	1.06	1.06	1.06	1.06	1.06
2016	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.00	1.00	1.00	1.00	1.00	1.00
2011	1.00	1.00	1.00	1.00	1.00	1.00
2010	1.00	1.00	1.00	1.00	1.00	1.00
2009	-	1.52	1.52	1.52	1.52	1.52
2008	-	1.52	1.52	1.52	1.52	1.52
2007	-	1.52	1.52	1.52	1.52	1.52
2006	-	1.87	1.87	1.87	1.87	1.87
2005	-	2.53	2.53	2.53	2.53	2.53
2004	-	1.56	1.56	1.56	1.56	1.56
2003	-	1.75	1.75	1.75	1.75	1.75
2002	-	1.53	1.53	1.53	1.53	1.53
2001	-	1.90	1.90	1.90	1.90	1.90
2000	-	1.51	1.51	1.51	1.51	1.51
1999	-	1.89	1.89	1.89	1.89	1.89
1998	-	1.74	1.74	1.74	1.74	1.74
1997	-	1.75	1.75	1.75	1.75	1.75
1996	-	1.77	1.77	1.77	1.77	1.77
1995	-	1.66	1.66	1.66	1.66	1.66
1994	-	1.67	1.67	1.67	1.67	1.67
1991-1993	-	2.01	2.01	2.01	2.01	2.01
1990	-	2.41	2.41	2.41	2.41	2.41
1988-1989	-	2.32	2.32	2.32	2.32	2.32
1986-1987	-	2.48	2.48	2.48	2.48	2.48
1985	-	2.21	2.21	2.21	2.21	2.21
1983-1984	-	2.08	2.08	2.08	2.08	2.08
1981-1982	-	1.40	1.40	1.40	1.40	1.40
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDT CO No I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	2.00	2.00	2.00	3.11	3.11	3.11
2029	2.00	2.00	2.00	3.11	3.11	3.11
2028	2.00	2.00	2.00	3.11	3.11	3.11
2027	2.00	2.00	2.00	3.11	3.11	3.11
2026	2.00	2.00	2.00	3.11	3.11	3.11
2025	2.00	2.00	2.00	3.11	3.11	3.11
2024	1.80	1.80	1.80	2.80	2.80	2.80
2023	1.64	1.64	1.64	2.55	2.55	2.55
2022	1.50	1.50	1.50	2.33	2.33	2.33
2021	1.38	1.38	1.38	2.15	2.15	2.15
2020	1.29	1.29	1.29	2.00	2.00	2.00
2019	1.20	1.20	1.20	1.87	1.87	1.87
2018	1.13	1.13	1.13	1.75	1.75	1.75
2017	1.06	1.06	1.06	1.65	1.65	1.65
2016	1.00	1.00	1.00	1.56	1.56	1.56
2015	1.00	1.00	1.00	1.56	1.56	1.56
2014	1.00	1.00	1.00	1.56	1.56	1.56
2013	1.00	1.00	1.00	1.56	1.56	1.56
2012	1.00	1.00	1.00	1.56	1.56	1.56
2011	1.00	1.00	1.00	1.56	1.56	1.56
2010	1.00	1.00	1.00	1.56	1.56	1.56
2009	-	2.49	2.49	3.88	3.88	3.88
2008	-	2.49	2.49	3.88	3.88	3.88
2007	-	2.49	2.87	3.47	3.47	3.47
2006	-	2.93	3.29	3.29	3.44	3.44
2005	-	3.29	3.29	3.32	3.82	3.82
2004	-	1.66	1.66	2.91	2.91	3.74
2003	-	1.25	1.25	1.25	1.86	2.49
2002	-	1.12	1.12	1.12	2.56	2.97
2001	-	1.20	1.20	1.20	1.20	2.02
2000	-	1.19	1.19	1.19	1.19	1.19
1999	-	1.21	1.21	1.21	1.21	1.21
1998	-	1.00	1.00	1.00	1.00	1.00
1997	-	1.00	1.00	1.00	1.00	1.00
1996	-	1.00	1.00	1.00	1.00	1.00
1995	-	1.00	1.00	1.00	1.00	1.00
1994	-	1.00	1.00	1.00	1.00	1.00
1991-1993	-	1.00	1.00	1.00	1.00	1.00
1990	-	1.04	1.04	1.04	1.04	1.04
1988-1989	-	1.04	1.04	1.04	1.04	1.04
1986-1987	-	1.17	1.17	1.17	1.17	1.17
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.00	1.00	1.00	1.00	1.00
1981-1982	-	1.04	1.04	1.04	1.04	1.04
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDT CO I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	2.00	1.93	1.93	1.93	1.93	1.93
2029	2.00	1.93	1.93	1.93	1.93	1.93
2028	2.00	1.93	1.93	1.93	1.93	1.93
2027	2.00	1.93	1.93	1.93	1.93	1.93
2026	2.00	1.93	1.93	1.93	1.93	1.93
2025	2.00	1.93	1.93	1.93	1.93	1.93
2024	1.80	1.80	1.80	1.80	1.80	1.80
2023	1.64	1.64	1.64	1.64	1.64	1.64
2022	1.50	1.50	1.50	1.50	1.50	1.50
2021	1.38	1.38	1.38	1.38	1.38	1.38
2020	1.29	1.29	1.29	1.29	1.29	1.29
2019	1.20	1.20	1.20	1.20	1.20	1.20
2018	1.13	1.13	1.13	1.13	1.13	1.13
2017	1.06	1.06	1.06	1.06	1.06	1.06
2016	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.00	1.00	1.00	1.00	1.00	1.00
2011	1.00	1.00	1.00	1.00	1.00	1.00
2010	1.00	1.00	1.00	1.00	1.00	1.00
2009	-	1.93	1.93	1.93	1.93	1.93
2008	-	1.93	1.93	1.93	1.93	1.93
2007	-	1.93	1.93	1.93	1.93	1.93
2006	-	1.64	1.64	1.64	1.64	1.64
2005	-	2.23	2.23	2.23	2.23	2.23
2004	-	1.01	1.01	1.01	1.01	1.01
2003	-	1.00	1.00	1.00	1.00	1.00
2002	-	1.00	1.00	1.00	1.00	1.00
2001	-	1.00	1.00	1.00	1.00	1.00
2000	-	1.24	1.24	1.24	1.24	1.24
1999	-	1.00	1.00	1.00	1.00	1.00
1998	-	1.07	1.07	1.07	1.07	1.07
1997	-	1.08	1.08	1.08	1.08	1.08
1996	-	1.18	1.18	1.18	1.18	1.18
1995	-	1.00	1.00	1.00	1.00	1.00
1994	-	1.00	1.00	1.00	1.00	1.00
1991-1993	-	1.12	1.12	1.12	1.12	1.12
1990	-	1.26	1.26	1.26	1.26	1.26
1988-1989	-	1.49	1.49	1.49	1.49	1.49
1986-1987	-	1.65	1.65	1.65	1.65	1.65
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.17	1.17	1.17	1.17	1.17
1981-1982	-	1.54	1.54	1.54	1.54	1.54
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDV THC No I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	9.00	1.93	1.93	3.13	3.13	3.13
2029	9.00	1.93	1.93	3.13	3.13	3.13
2028	9.00	1.93	1.93	3.13	3.13	3.13
2027	9.00	1.93	1.93	3.13	3.13	3.13
2026	9.00	1.93	1.93	3.13	3.13	3.13
2025	9.00	1.93	1.93	3.13	3.13	3.13
2024	4.76	1.93	1.93	3.13	3.13	3.13
2023	3.24	1.93	1.93	3.13	3.13	3.13
2022	2.45	1.93	1.93	3.13	3.13	3.13
2021	1.98	1.93	1.93	3.13	3.13	3.13
2020	1.65	1.65	1.65	2.69	2.69	2.69
2019	1.42	1.42	1.42	2.31	2.31	2.31
2018	1.25	1.25	1.25	2.02	2.02	2.02
2017	1.11	1.11	1.11	1.80	1.80	1.80
2016	1.00	1.00	1.00	1.62	1.62	1.62
2015	1.00	1.00	1.00	1.62	1.62	1.62
2014	1.00	1.00	1.00	1.62	1.62	1.62
2013	1.00	1.00	1.00	1.62	1.62	1.62
2012	1.22	1.22	1.22	1.98	1.98	1.98
2011	1.37	1.37	1.37	2.22	2.22	2.22
2010	1.55	1.55	1.55	2.52	2.52	2.52
2009	-	1.93	1.93	3.13	3.13	3.13
2008	-	1.93	1.93	3.13	3.13	3.13
2007	-	1.93	2.34	2.81	2.81	2.81
2006	-	2.49	2.94	2.94	3.02	3.02
2005	-	3.01	3.01	3.17	3.62	3.62
2004	-	1.39	1.39	2.59	2.59	3.30
2003	-	1.65	1.65	1.65	2.64	3.50
2002	-	1.38	1.38	1.38	3.39	3.92
2001	-	1.86	1.86	1.86	1.86	3.34
2000	-	1.30	1.30	1.30	1.30	1.30
1999	-	1.75	1.75	1.75	1.75	1.75
1998	-	1.33	1.33	1.33	1.33	1.33
1997	-	1.33	1.33	1.33	1.33	1.33
1996	-	1.36	1.36	1.36	1.36	1.36
1995	-	1.28	1.28	1.28	1.28	1.28
1994	-	1.30	1.30	1.30	1.30	1.30
1991-1993	-	1.84	1.84	1.84	1.84	1.84
1990	-	2.30	2.30	2.30	2.30	2.30
1988-1989	-	1.82	1.82	1.82	1.82	1.82
1986-1987	-	1.76	1.76	1.76	1.76	1.76
1985	-	1.48	1.48	1.48	1.48	1.48
1983-1984	-	1.51	1.51	1.51	1.51	1.51
1981-1982	-	1.13	1.13	1.13	1.13	1.13
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDV THC I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	9.00	1.52	1.52	1.52	1.52	1.52
2029	9.00	1.52	1.52	1.52	1.52	1.52
2028	9.00	1.52	1.52	1.52	1.52	1.52
2027	9.00	1.52	1.52	1.52	1.52	1.52
2026	9.00	1.52	1.52	1.52	1.52	1.52
2025	9.00	1.52	1.52	1.52	1.52	1.52
2024	4.76	1.52	1.52	1.52	1.52	1.52
2023	3.24	1.52	1.52	1.52	1.52	1.52
2022	2.45	1.52	1.52	1.52	1.52	1.52
2021	1.98	1.52	1.52	1.52	1.52	1.52
2020	1.65	1.52	1.52	1.52	1.52	1.52
2019	1.42	1.42	1.42	1.42	1.42	1.42
2018	1.25	1.25	1.25	1.25	1.25	1.25
2017	1.11	1.11	1.11	1.11	1.11	1.11
2016	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.22	1.22	1.22	1.22	1.22	1.22
2011	1.37	1.37	1.37	1.37	1.37	1.37
2010	1.55	1.52	1.52	1.52	1.52	1.52
2009	-	1.52	1.52	1.52	1.52	1.52
2008	-	1.52	1.52	1.52	1.52	1.52
2007	-	1.52	1.52	1.52	1.52	1.52
2006	-	1.87	1.87	1.87	1.87	1.87
2005	-	2.53	2.53	2.53	2.53	2.53
2004	-	1.56	1.56	1.56	1.56	1.56
2003	-	1.75	1.75	1.75	1.75	1.75
2002	-	1.53	1.53	1.53	1.53	1.53
2001	-	1.90	1.90	1.90	1.90	1.90
2000	-	1.51	1.51	1.51	1.51	1.51
1999	-	1.89	1.89	1.89	1.89	1.89
1998	-	1.74	1.74	1.74	1.74	1.74
1997	-	1.75	1.75	1.75	1.75	1.75
1996	-	1.77	1.77	1.77	1.77	1.77
1995	-	1.66	1.66	1.66	1.66	1.66
1994	-	1.67	1.67	1.67	1.67	1.67
1991-1993	-	2.01	2.01	2.01	2.01	2.01
1990	-	2.41	2.41	2.41	2.41	2.41
1988-1989	-	2.32	2.32	2.32	2.32	2.32
1986-1987	-	2.48	2.48	2.48	2.48	2.48
1985	-	2.21	2.21	2.21	2.21	2.21
1983-1984	-	2.08	2.08	2.08	2.08	2.08
1981-1982	-	1.40	1.40	1.40	1.40	1.40
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDT THC No I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	9.00	2.49	2.49	3.88	3.88	3.88
2029	9.00	2.49	2.49	3.88	3.88	3.88
2028	9.00	2.49	2.49	3.88	3.88	3.88
2027	9.00	2.49	2.49	3.88	3.88	3.88
2026	9.00	2.49	2.49	3.88	3.88	3.88
2025	9.00	2.49	2.49	3.88	3.88	3.88
2024	4.76	2.49	2.49	3.88	3.88	3.88
2023	3.24	2.49	2.49	3.88	3.88	3.88
2022	2.45	2.45	2.45	3.82	3.82	3.82
2021	1.98	1.98	1.98	3.07	3.07	3.07
2020	1.65	1.65	1.65	2.57	2.57	2.57
2019	1.42	1.42	1.42	2.21	2.21	2.21
2018	1.25	1.25	1.25	1.94	1.94	1.94
2017	1.11	1.11	1.11	1.73	1.73	1.73
2016	1.00	1.00	1.00	1.56	1.56	1.56
2015	1.00	1.00	1.00	1.56	1.56	1.56
2014	1.00	1.00	1.00	1.56	1.56	1.56
2013	1.00	1.00	1.00	1.56	1.56	1.56
2012	1.22	1.22	1.22	1.90	1.90	1.90
2011	1.37	1.37	1.37	2.13	2.13	2.13
2010	1.55	1.55	1.55	2.41	2.41	2.41
2009	-	2.49	2.49	3.88	3.88	3.88
2008	-	2.49	2.49	3.88	3.88	3.88
2007	-	2.49	2.87	3.47	3.47	3.47
2006	-	2.93	3.29	3.29	3.44	3.44
2005	-	3.29	3.29	3.32	3.82	3.82
2004	-	1.66	1.66	2.91	2.91	3.74
2003	-	1.25	1.25	1.25	1.86	2.49
2002	-	1.12	1.12	1.12	2.56	2.97
2001	-	1.20	1.20	1.20	1.20	2.02
2000	-	1.19	1.19	1.19	1.19	1.19
1999	-	1.21	1.21	1.21	1.21	1.21
1998	-	1.00	1.00	1.00	1.00	1.00
1997	-	1.00	1.00	1.00	1.00	1.00
1996	-	1.00	1.00	1.00	1.00	1.00
1995	-	1.00	1.00	1.00	1.00	1.00
1994	-	1.00	1.00	1.00	1.00	1.00
1991-1993	-	1.00	1.00	1.00	1.00	1.00
1990	-	1.04	1.04	1.04	1.04	1.04
1988-1989	-	1.04	1.04	1.04	1.04	1.04
1986-1987	-	1.17	1.17	1.17	1.17	1.17
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.00	1.00	1.00	1.00	1.00
1981-1982	-	1.04	1.04	1.04	1.04	1.04
1960-1980	-	1.00	1.00	1.00	1.00	1.00

LDT THC I/M		U.S. → Mexico Calibration Factors by Age				
Model Years	Standard Ratio	0-3	4-5	6-7	8-9	10+
2030-2050	9.00	1.93	1.93	1.93	1.93	1.93
2029	9.00	1.93	1.93	1.93	1.93	1.93
2028	9.00	1.93	1.93	1.93	1.93	1.93
2027	9.00	1.93	1.93	1.93	1.93	1.93
2026	9.00	1.93	1.93	1.93	1.93	1.93
2025	9.00	1.93	1.93	1.93	1.93	1.93
2024	4.76	1.93	1.93	1.93	1.93	1.93
2023	3.24	1.93	1.93	1.93	1.93	1.93
2022	2.45	1.93	1.93	1.93	1.93	1.93
2021	1.98	1.93	1.93	1.93	1.93	1.93
2020	1.65	1.65	1.65	1.65	1.65	1.65
2019	1.42	1.42	1.42	1.42	1.42	1.42
2018	1.25	1.25	1.25	1.25	1.25	1.25
2017	1.11	1.11	1.11	1.11	1.11	1.11
2016	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.00	1.00	1.00	1.00	1.00	1.00
2012	1.22	1.22	1.22	1.22	1.22	1.22
2011	1.37	1.37	1.37	1.37	1.37	1.37
2010	1.55	1.55	1.55	1.55	1.55	1.55
2009	-	1.93	1.93	1.93	1.93	1.93
2008	-	1.93	1.93	1.93	1.93	1.93
2007	-	1.93	1.93	1.93	1.93	1.93
2006	-	1.64	1.64	1.64	1.64	1.64
2005	-	2.23	2.23	2.23	2.23	2.23
2004	-	1.01	1.01	1.01	1.01	1.01
2003	-	1.00	1.00	1.00	1.00	1.00
2002	-	1.00	1.00	1.00	1.00	1.00
2001	-	1.00	1.00	1.00	1.00	1.00
2000	-	1.24	1.24	1.24	1.24	1.24
1999	-	1.00	1.00	1.00	1.00	1.00
1998	-	1.07	1.07	1.07	1.07	1.07
1997	-	1.08	1.08	1.08	1.08	1.08
1996	-	1.18	1.18	1.18	1.18	1.18
1995	-	1.00	1.00	1.00	1.00	1.00
1994	-	1.00	1.00	1.00	1.00	1.00
1991-1993	-	1.12	1.12	1.12	1.12	1.12
1990	-	1.26	1.26	1.26	1.26	1.26
1988-1989	-	1.49	1.49	1.49	1.49	1.49
1986-1987	-	1.65	1.65	1.65	1.65	1.65
1985	-	1.00	1.00	1.00	1.00	1.00
1983-1984	-	1.17	1.17	1.17	1.17	1.17
1981-1982	-	1.54	1.54	1.54	1.54	1.54
1960-1980	-	1.00	1.00	1.00	1.00	1.00

www.mledprogram.org