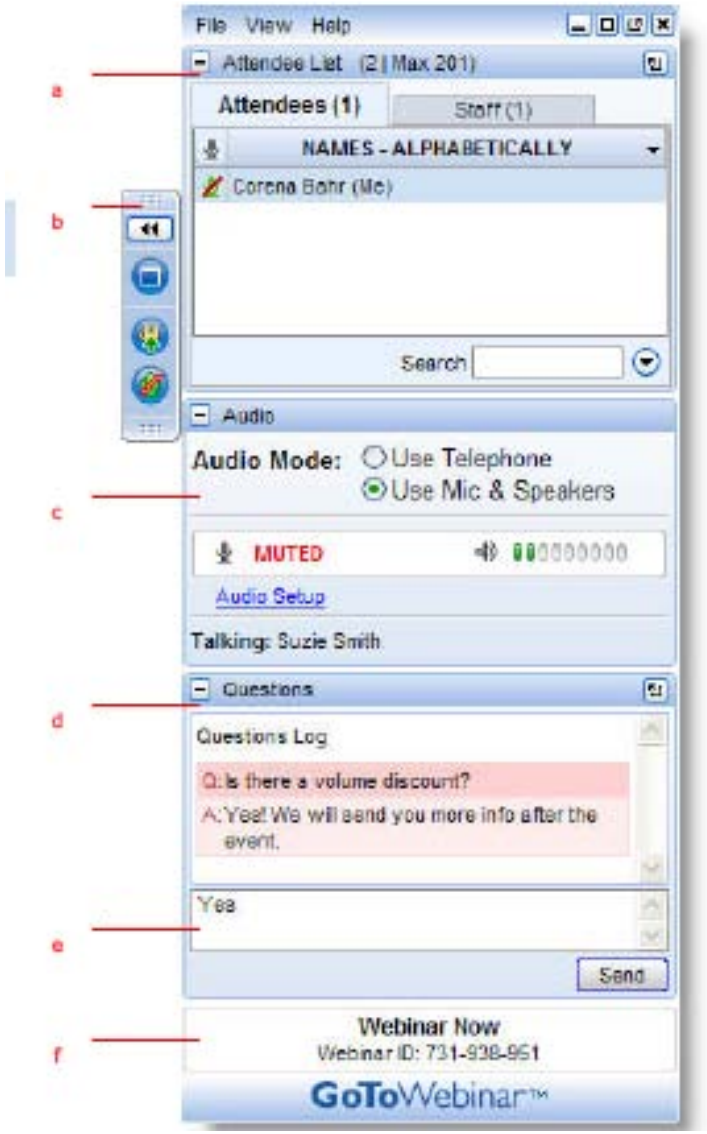
Introduction to MOVES2010

EPA Office of Transportation and Air Quality

FHWA Resource Center

Webinar Logistics

- **Please use “question box” on your control panel to send your questions**
  - We’ll pause periodically during the webinar to answer them
  - We can address any unanswered questions after the webinar
- **During this webinar, we’ll conduct a few polls**
  - Please participate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Course Outline

- What is MOVES?
- How is MOVES different from MOBILE?
- Why are emissions different from MOBILE?
- How has MOVES improved over time?
- How does MOVES work?
  - Demonstration of MOVES2010 interface
- What other information is available for MOVES?

Course Goals

- **Provide a general overview of MOVES for non-modelers who need to understand the transition from MOBILE to MOVES**
- **Provide background information on MOVES for modelers**
  - Formerly provided this kind of information in our hands-on course but we removed it from there to give more time for detailed exercises
- **First of a series of webinars**
  - Some will be more technical
  - Others will focus more on policy
  - Will talk more about webinars and other training at the end of this course

What is MOVES?

- **MOtor Vehicle Emission Simulator**
- **State-of-the-art modeling framework**
- **Replaces MOBILE for on-road vehicle emissions**
  - Significant expansion of capabilities compared to MOBILE
  - Will also eventually include nonroad emissions to replace separate NONROAD model
- **Designed to allow easier incorporation of large amounts of in-use data from a variety of sources**
  - MOBILE structure limited ability to incorporate new emissions data

Why Did EPA Develop MOVES?

- CAA requires EPA to regularly update emission factors and emission factor models
- FORTRAN code used in MOBILE6.2 is obsolete and increasingly difficult to maintain
- Modular database structure more modern, easier to update with new emissions, fleet and activity data

Why Did EPA Develop MOVES?

- **National Research Council 2000 review of EPA's mobile source modeling program included several recommendations that are addressed by MOVES:**
  - Support for smaller-scale analyses (project-level analysis)
  - Improved characterization of high emitters, heavy-duty vehicles and nonroad sources
  - Improved characterization of particulate matter and toxics
  - Improved model evaluation and uncertainty analysis
  - Improved ability to interface with other models

How Is MOVES Different from MOBILE?

MOVES Software Structure Is More Flexible

- **MOVES uses a Graphical User Interface (GUI)**
  - MOBILE used text input and output files
- **MOVES uses Java and MySQL software and operates in Windows**
  - MOBILE written in Fortran and operated in DOS
- **MOVES uses a relational database structure to store data in tables that are easy to modify and update**
  - In MOBILE, many data elements were hard-coded, requiring changes to model code to update

MOVES Offers More Output Options

- **MOVES can estimate total emissions as well as emission rates**
  - MOBILE only provided emission rates, requiring extensive external post-processing to produce an emission inventory
- **MOVES output is easily customizable with many levels of aggregation and disaggregation possible**
  - MOBILE had limited fixed output formats

MOVES Covers Multiple Scales and Time Periods

- **MOVES can generate emissions estimates at multiple geographic scales, from national level to county level to project level with different input options at each level**
  - MOBILE only produced emissions based on regional-scale trip patterns with no geographic specificity
- **MOVES can generate emissions by hour, day (weekday or weekend), month, or year**
  - MOBILE had very limited temporal capabilities

MOVES Is a Modal Model

- **MOVES emission rates are based on "operating modes" that can account for different patterns of acceleration, cruising, and deceleration, as well as average speed**
  - MOBILE was based on aggregate driving cycles and only accounted for differences in average speed

MOVES Is Also a Greenhouse Gas Model

- MOVES was designed from the ground up as an energy consumption model incorporating the latest methods for GHG estimation
- Also estimates methane, N_2O

Why Did Emissions Estimates Change from MOBILE to MOVES?

Summary of Data Differences

- **MOVES includes a much larger data set, including the first in-use data on light duty vehicles meeting Tier 1 and NLEV standards**
  - MOBILE had in-use data for pre-1994 vehicles; 1994-and-later vehicle emissions were primarily based on certification data
- **MOVES includes first in-use PM data for light duty vehicles with temperature effects**
  - MOBILE PM based on certification data with no temperature effects
- **MOVES includes first in-use data for heavy duty vehicles, including speed effects and crankcase, start, and extended idle emissions**
  - MOBILE based on certification data with no speed effects, or crankcase, start, and extended idle emissions.

Extensive Analysis of Car & Light Truck Emissions

- **HC/CO/NOx rates based on ~ 70,000 vehicles randomly selected from Arizona IM program**
  - Able to tease out emissions from I/M and non I/M areas
- **Checked against data from multiple sources**
  - I/M data from Illinois, New York, Missouri and Colorado
  - Roadside remote sensing data from several cities
  - Kansas City Study
- **Extended to newest technology vehicles using compliance data**
  - In-use emissions data manufacturers required to collect
  - About 2,000 laboratory tests per year

Gasoline PM a Major Focus

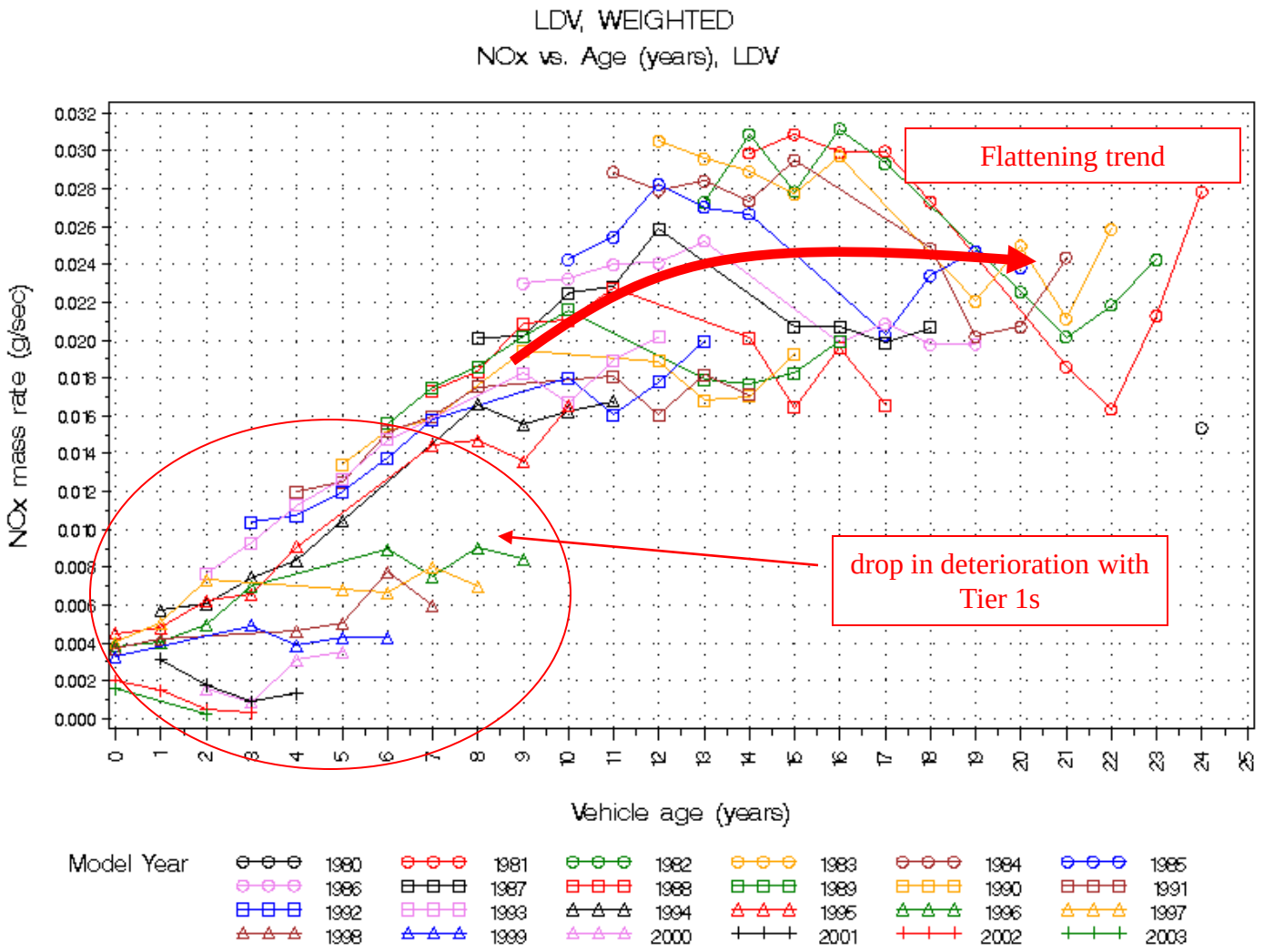
- **Landmark study conducted in Kansas City 2004-05 to improve gas PM estimates**
  - Collaboration between EPA, DOE, DOT, States, Auto/Oils
- **496 gasoline light-duty cars and trucks tested**
  - Model Years 1968-2005
- **Summer and winter testing**
  - ~ half of the vehicles tested each season @ ambient temps
  - 43 vehicles tested in both winter and summer
- **More information at**

  http://www.epa.gov/otaq/emission-factors-research/

What We've Learned About Car & Light Truck Emissions

- **New standards have been successful in reducing deterioration of HC/CO/NOx emissions**
- **On-Board Diagnostic (OBD) systems are a contributing factor to lower deterioration**
  - Owner response to repair identified malfunctions is better than MOBILE6 projected, particularly in non-I/M areas
- **Gas PM emissions are much higher than MOBILE6 projected**
  - Higher in-use deterioration
  - Significant increase at cold temperatures

Arizona I/M NOx data by Model Year and Age



Heavy Duty Diesel Emissions Updated Based on Real World Data

- **MOBILE6 relied on certification data**
  - Engine tests only
- **Much research on in-use trucks since MOBILE6**
  - CRC E-55
    - 75 trucks on chassis dynamometer
    - Only real-time PM data of it's kind
  - On-Board Measurement: ~350 trucks on road
    - Provided most robust assessment of NOx emissions available
- **Extended idle, crankcase, starts, tampering & mal-maintenance factored in (not in MOBILE6)**

What We've Learned About Heavy Duty Diesel Emissions

- **NOx**
  - In-use emissions moderately higher than MOBILE6 projected
  - Extended idle (hoteling) emissions are significant
    - And projected to grow as percent of NOx inventory
- **PM**
  - Significant speed effect
    - MOBILE6 did not model any speed impacts
    - Large increase in emissions at lower speeds vs. MOBILE6
  - Crankcase emissions significant

How Do Emissions Differ from MOBILE?

Analysis of Local Area Impacts

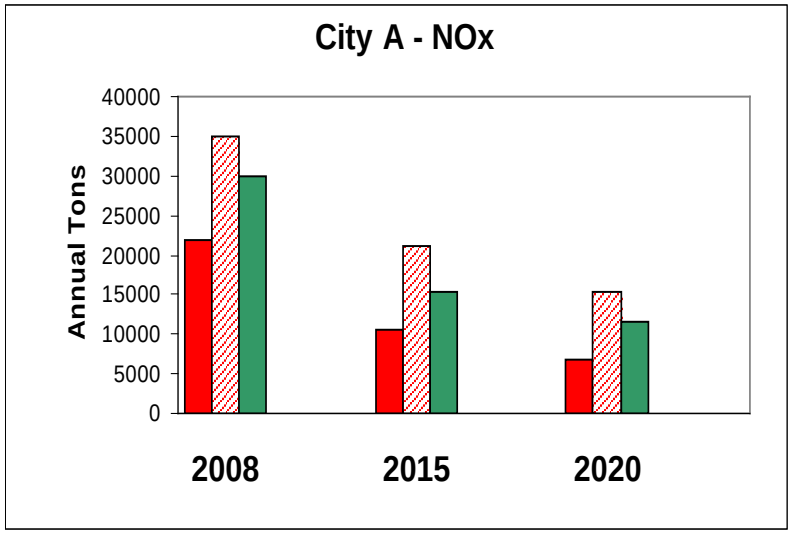
- **EPA compared MOVES2010 and MOBILE6 using surrogate local data to represent 3 different urban counties**
  - Local data very limited, may not be consistent with what states will actually use
- **Local data varied by:**
  - Fleet age distribution
  - Fraction of light and heavy duty VMT
  - Local fuel specifications
  - Meteorology
  - Other input factors

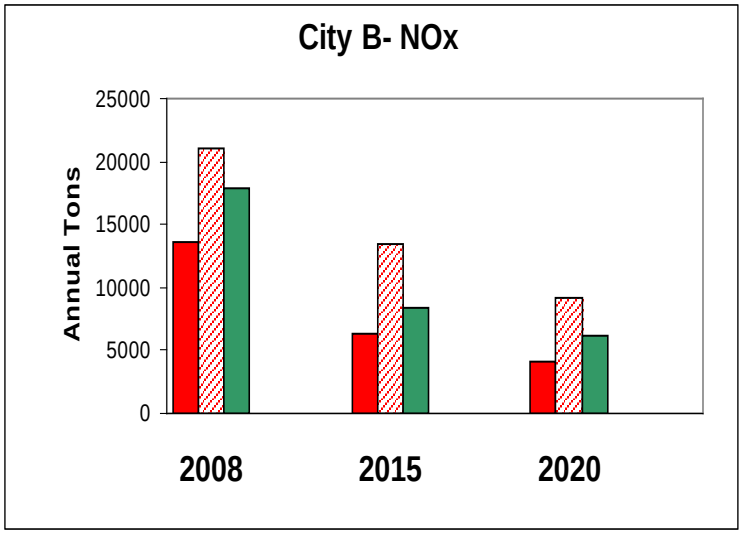
MOVES2010 Results

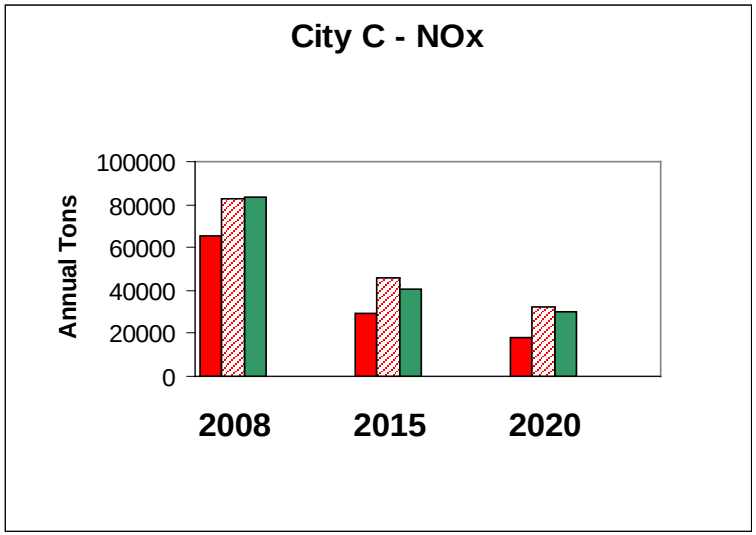
- **Data collected since MOBILE6 released drives differences between MOVES and MOBILE6**
- **National trends**
  - HC and CO emissions similar or lower than MOBILE6.2
  - Total NOx emissions higher than MOBILE6.2
  - Total PM emissions substantially higher than MOBILE6.2
- **Local results may vary**
  - Local fleet mix, fuels, activity are important
  - Temperature drives PM emissions
- **For attainment analysis, relative change in emissions between base year and attainment year is more important than absolute emissions**

NO_x

- I/M program data shows MOBILE6 underestimated NOx emissions from light trucks
- On-road data on heavy trucks shows higher emissions than MOBILE6 estimated from cert data
- Extended idle emissions become significant share of heavy-duty inventory in future



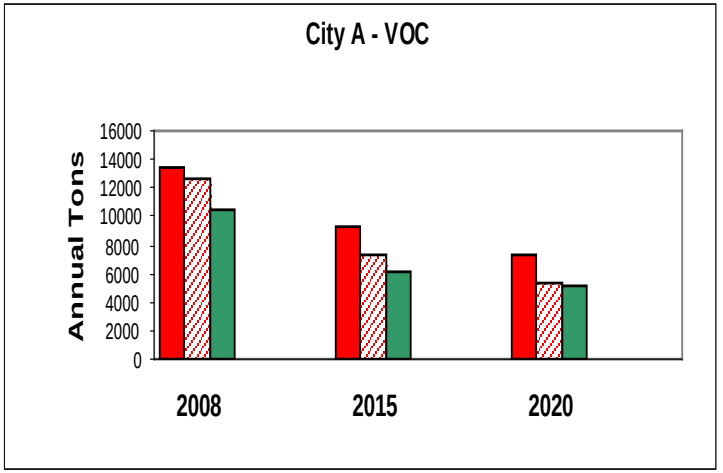


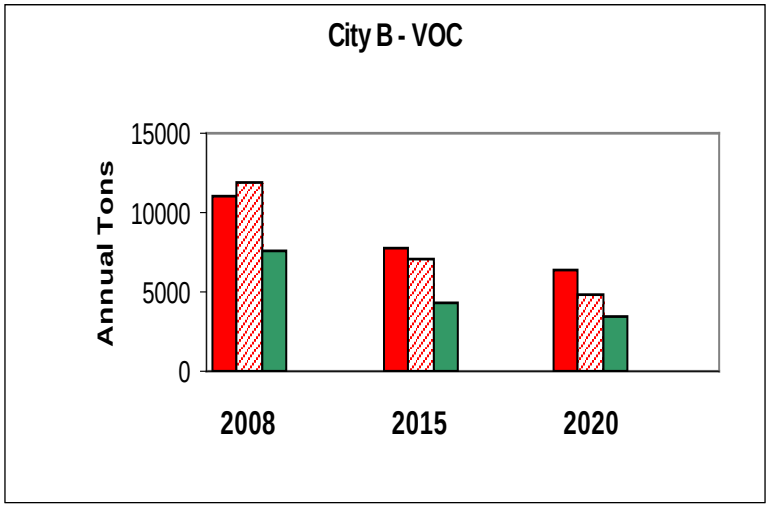


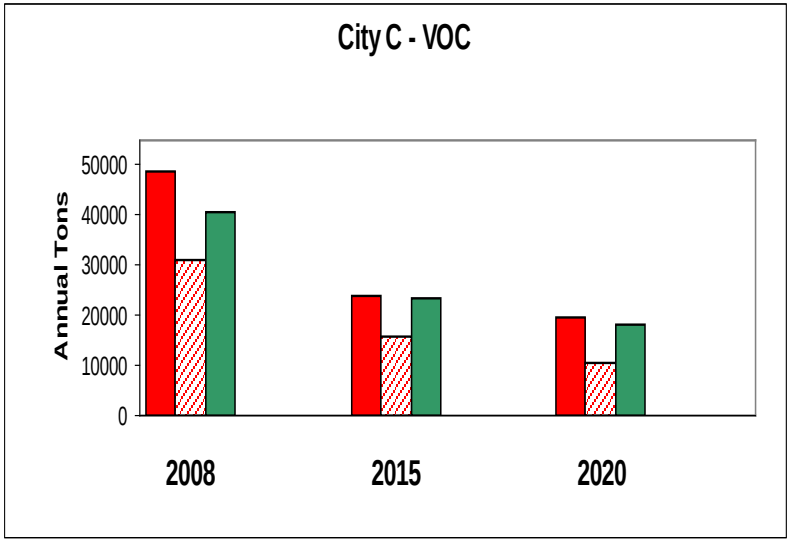
M6 DraftMOVES2009 MOVES2010

VOC

- I/M program data shows MOBILE6 overestimated HC emissions from newer technology cars
- Evaporative emissions on newer technology vehicles very low



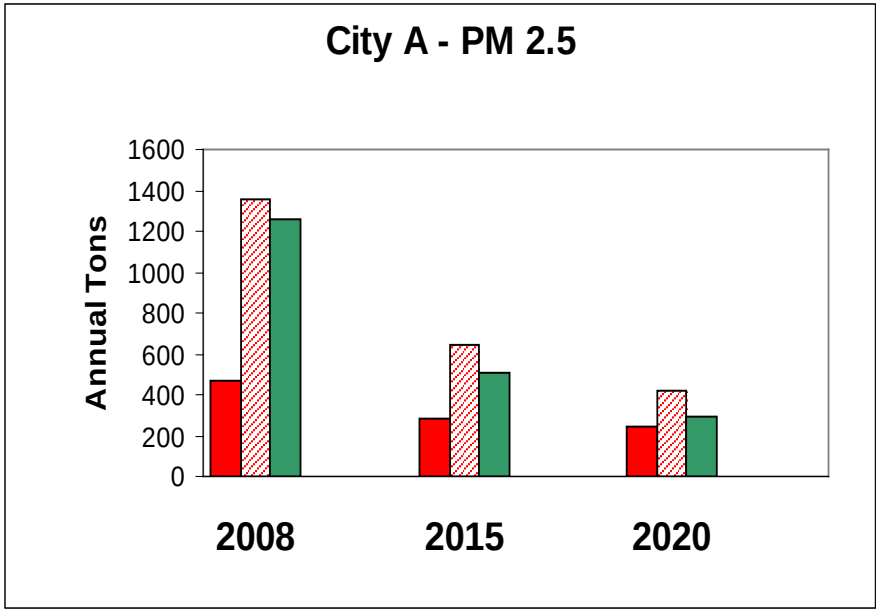


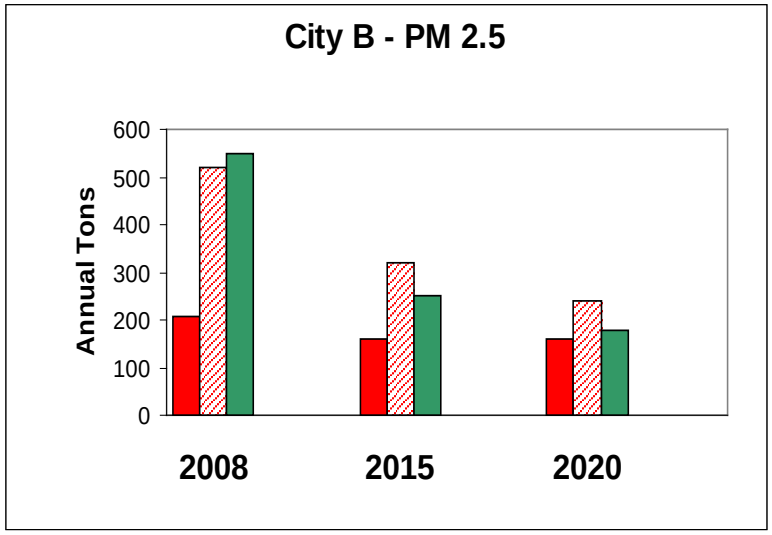


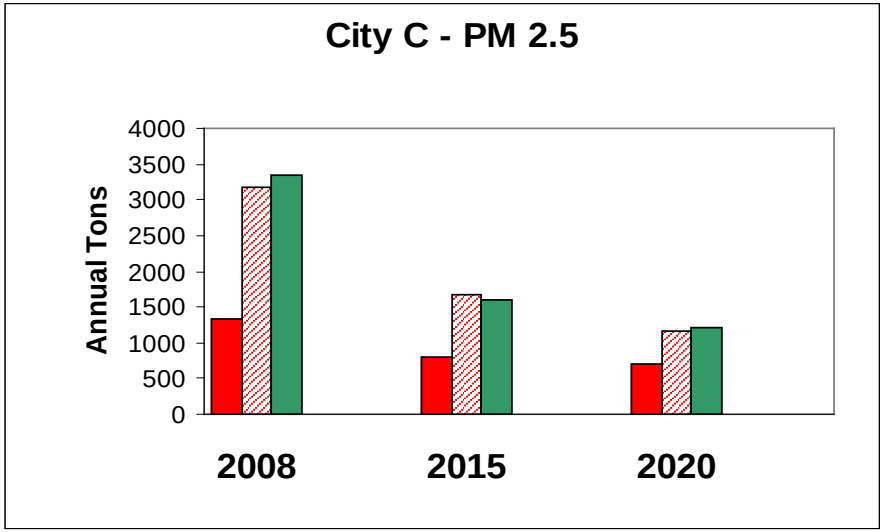
M6 DraftMOVES2009 MOVES2010

$PM_{2.5}$

- Kansas City program found high gas PM emissions esp. at cold temps
- New data on heavy trucks shows higher deterioration than MOBILE6
- MOVES accounts for impact of vehicle speed – MOBILE did not







M6 DraftMOVES2009 MOVES2010

Percent Reduction in On-Road Emissions 2008 to 2015

	City A		City B		City C	
	M6	MOVES2010	M6	MOVES2010	M6	MOVES2010
VOC	31%	41%	30%	43%	51%	42%
NOx	52%	49%	53%	53%	56%	51%
PM2.5	40%	60%	23%	54%	40%	52%

What It Means

- **Higher NOx and PM emissions mean on-road mobile sources have bigger role in attainment**
- **Percent reduction from base year is key to attainment analysis**
  - PM2.5 shows higher overall emissions and higher % reductions
    - Effect on attainment demonstrations could be positive
  - NOx shows higher overall emissions but lower % reduction
    - Could be harder to show attainment
    - Future NOx control measures could have a bigger impact
- **States need to evaluate these impacts and consider their effects on SIP and conformity requirements**

I/M Effects In MOVES

- **Benefits are comparable to MOBILE6 now, but will shrink over time.**
  - Conservative M6 OBD assumptions not supported by data
    - CRC did comprehensive survey of MIL response in non-I/M areas
    - Found high response even after warranty
  - Our analysis of I/M program data confirms that OBD works

How Has MOVES Improved Over Time?

MOVES Versions

- **Draft MOVES2009**
  - Draft model released April 2009
- **MOVES2010**
  - Released December 2009
  - Approved March 2010 for use in SIPs and regional conformity analyses
  - Improved emission rates database
  - Added start and evap emissions to emissions rate calculator
  - Faster performance
  - Added new features
  - Added new pollutants and pollutant processes
  - Added motorcycle emissions

Updates After MOVES2010 Release

- **These updates add features, improve performance and correct errors**
  - Impact on criteria pollutants is small
  - They are not considered new emission models for SIPs and conformity
- **5/15/2010 Database**
  - Updated MOVES database that corrects several minor errors in the original MOVES2010 default database
  - To use this database, it must be installed separately from the MOVES2010 installation
- **MOVES2010a released September**

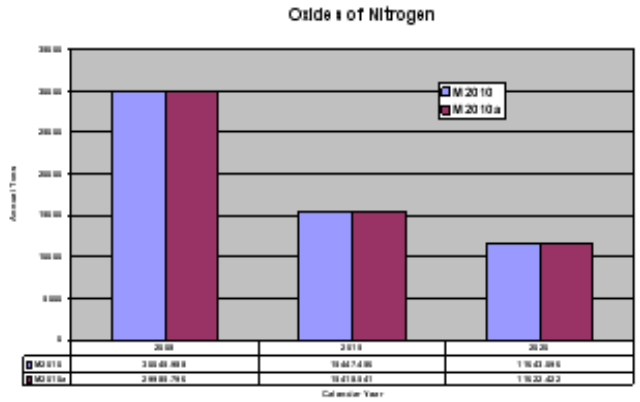
What is MOVES2010a?

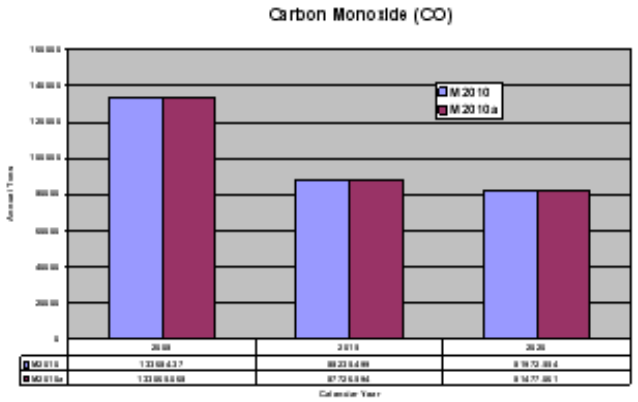
- **Developed to allow users to easily estimate emissions that incorporate new car and light truck energy and greenhouse gas rates.**
  - LD GHG 2012+
  - LD GHG 2008 – 2011
- **Also**
  - Improved methane algorithm
  - Improved ramp algorithm
  - Faster runtime
  - Code modified to make more compatible with LINUX operating systems
  - Includes 5/15 database in installation package
  - Other improvements
- **SIP/Conformity Policy-- users can choose to continue significant work with 2010 or switch to 2010a.**

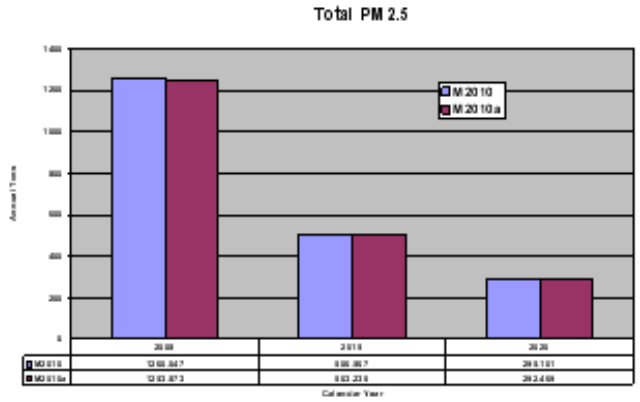
2010 vs. 2010a Inventory Comparisons

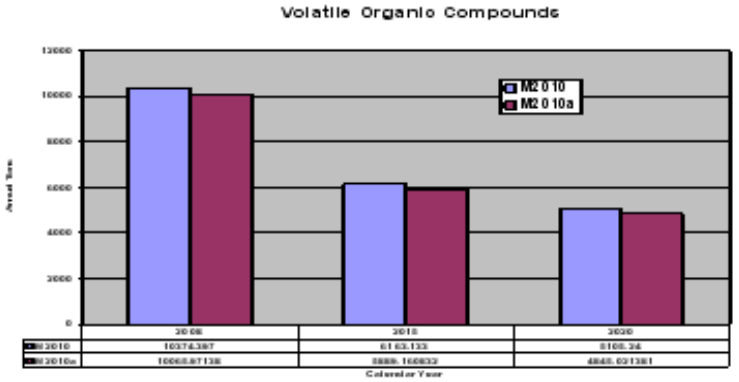
Net impact

- Reduced future year Energy
- Increased CH4
- Small (3-5%) decrease in VOC



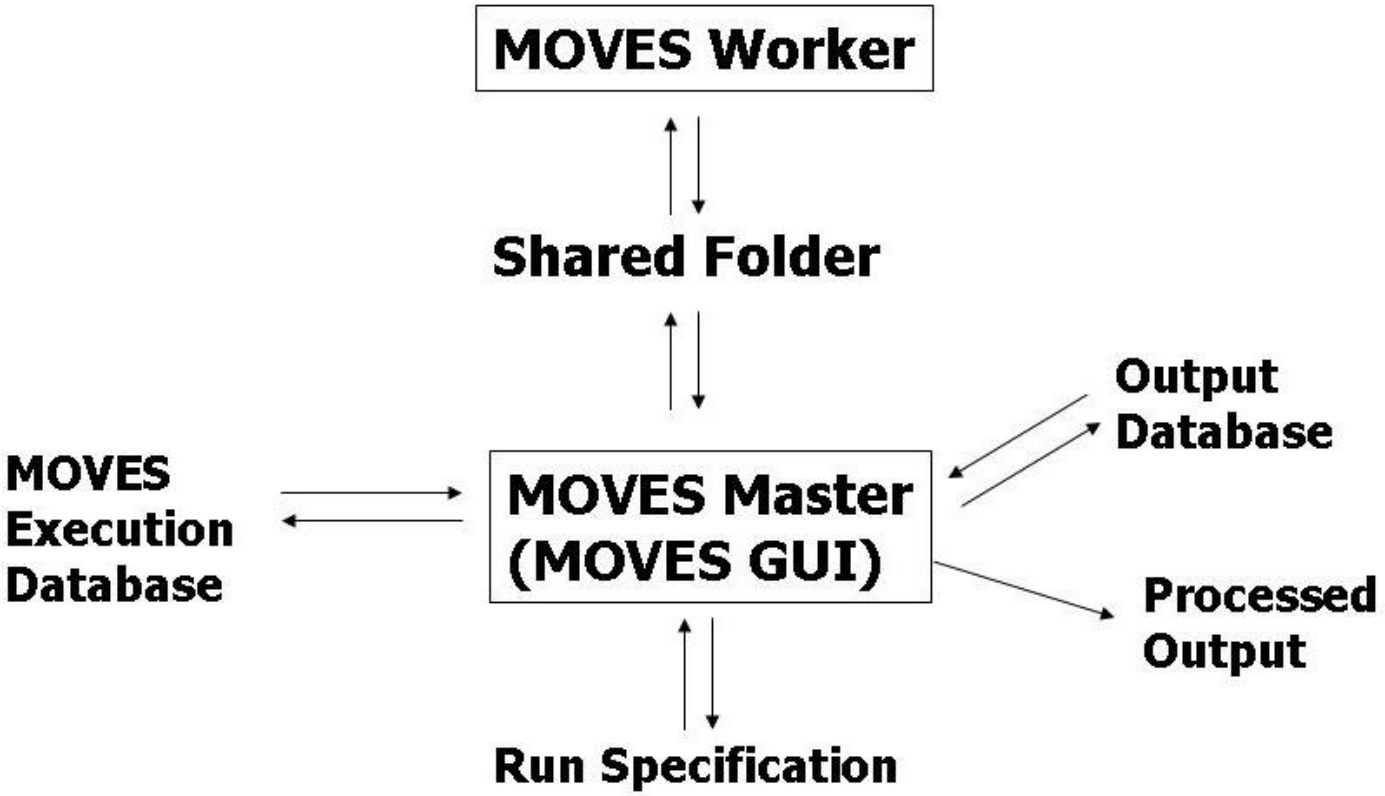






How Does MOVES Work?

Master – Worker Structure



Geography and Time in MOVES

- **Modeling domain is entire U.S.**
  - 50 States plus (DC, Puerto Rico, & Virgin Islands)
  - 3222 Political subdivisions (counties as of CY 1999)
- **Calendar years (1990, 1999-2050)**
  - 12 months of the year
  - Week days and weekend days
  - 24 hours of the day

Emission Processes

- **Running Exhaust**
- **Start Exhaust**
- **Extended Idle**
- **Evaporative Processes**
  - Permeation, Vapor Venting, Leaks, Refueling Displacement, Refueling Spillage
- **Crankcase**
- **Tire Wear**
- **Brake Wear**

MOVES Source Types (vs. HPMS Vehicle Types)

HPMS Vehicle Type	MOVES SourceType
Motorcycle	Motorcycle
Passenger Car	Passenger Car
Other 4-tire, 2-axle	Passenger Truck
	Light Commercial Truck
Bus	Intercity Bus
	Transit Bus
	School Bus
Single Unit Truck	Refuse Truck
	Short-haul Single Unit
	Long-haul Single Unit
	Motor home
Combination Truck	Short-haul Comb. Truck
	Long-haul Comb. Truck

Sub-categories (like refuse trucks and motor homes) are discussed in guidance; EPA does not expect areas to have local data for all subcategories.

Road Types

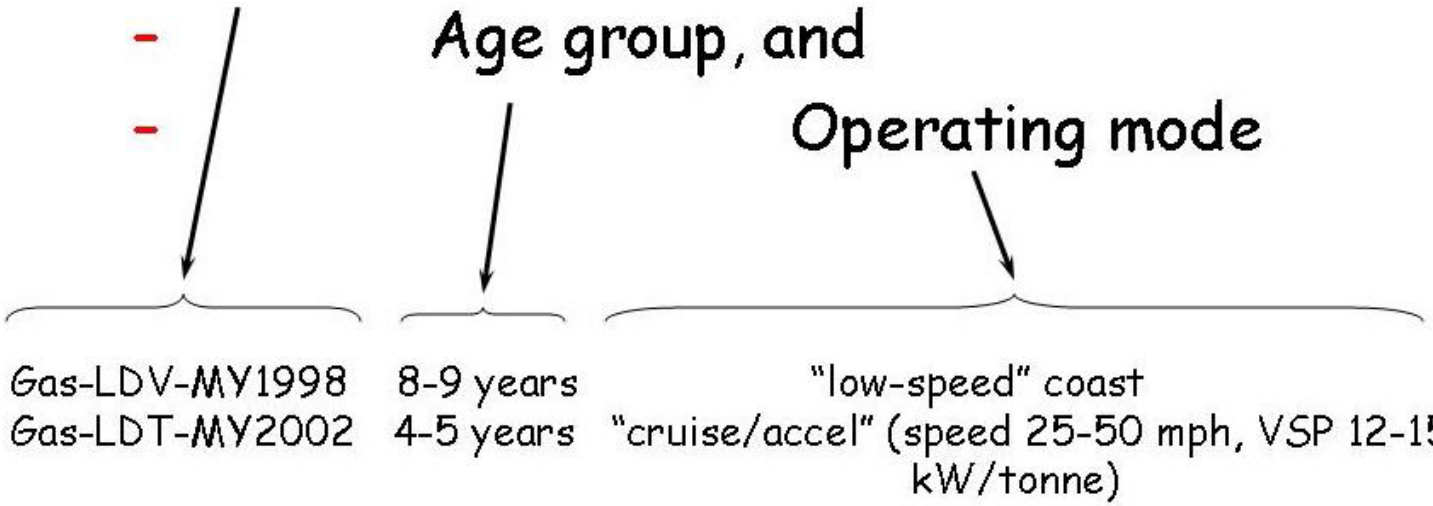
- For running emissions, county-level VMT is distributed to four road types:
  - Rural Restricted Access (freeways and Interstates),
  - Rural Unrestricted Access,
  - Urban Restricted Access (freeways and Interstates),
  - Urban Unrestricted Access
- A fifth road type, “off-network”, is included to capture start, evaporative and extended idle emissions
  - This is not the same as “off-network” vehicle activity in the travel modeling world.

Vehicle Ages

- ✓ Emission rates can vary by age as well as model year; activity also varies by age
- ✓ Vehicles 0-29 & 30+ years old modeled
- ✓ Age groups used for emissions calculations
  - 0 to 3 years old
  - 4 or 5 years old
  - 6 or 7 years old
  - 8 or 9 years old
  - 10 to 14 years old
  - 15 to 19 years old
  - 20 or more years old

Emissions by Source, Age, Mode

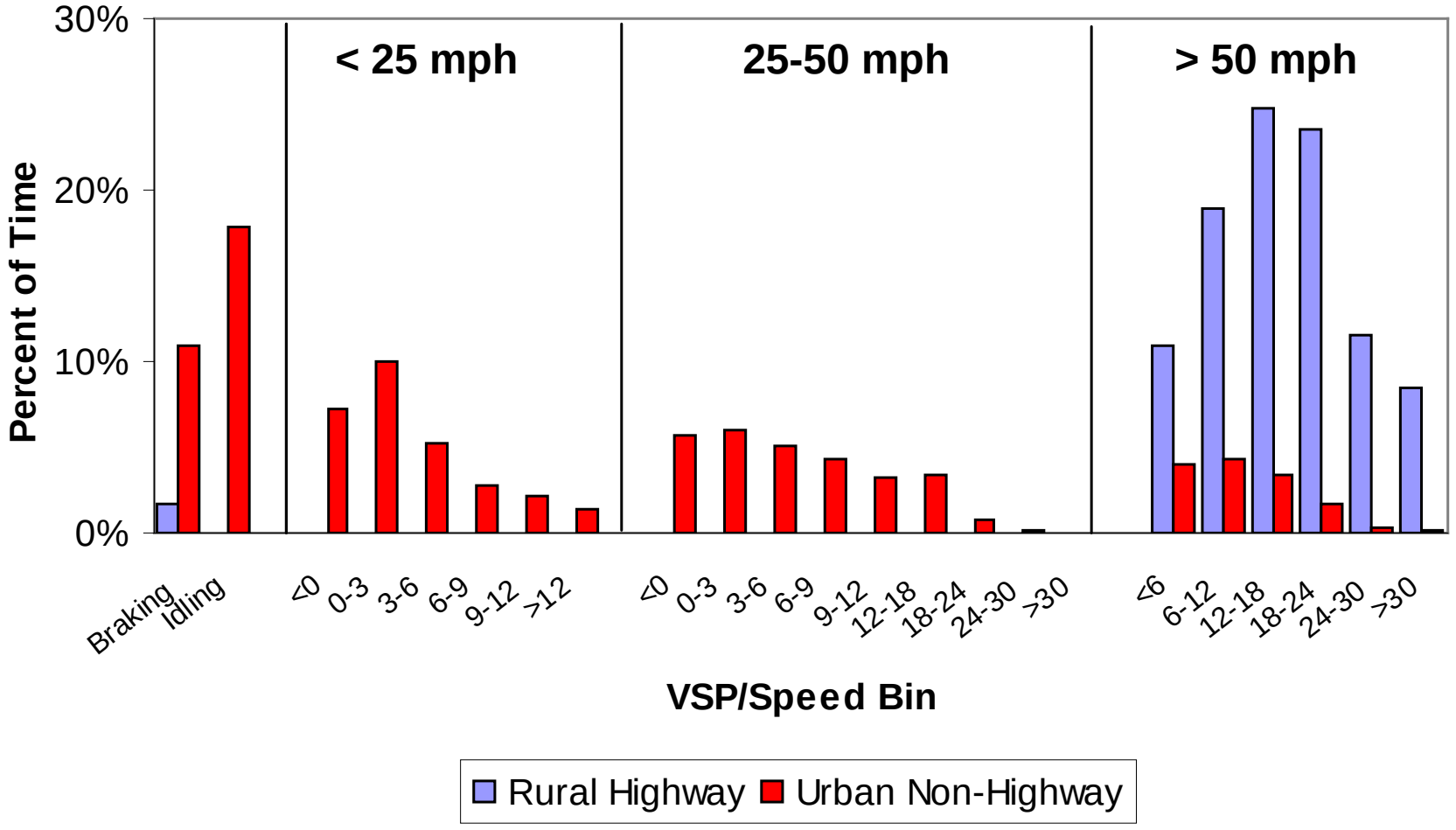
- ✓ MOVES uses a different rate for each combination of:
  - Source,
  - Age group, and
  - Operating mode



MOVES: Operating Mode Bins

- Division of total activity into categories that differentiate emissions
- Defined by speed and power for running emissions
- There are additional operating mode distributions for start and evaporative emissions

Distribution of Time by Mode



Operating Modes Facilitate Project Level Analysis

- **Modal emission structure allow more flexibility in calculation of Project-level emission changes**
  - Changes in operating mode distribution → changes in emissions
- **Includes an "importer" to help users input project-specific information on driving activity**
  - Users can enter operating mode distribution or driving pattern by link
- **Creates opportunity to estimate emissions when changing road design affects operating modes**
  - Adding lanes?
  - Synchronizing signals?
  - Replacing stop signs with rotaries?

MOVES Databases

- **MOVES stores information in MySQL databases**
- **The MOVES2010 default database has over 100 different tables that store**
  - Lookup/reference information
  - Conversion/adjustment factors
  - Emissions data
  - Activity data
- **MOVES also uses databases to store intermediate results and final output**

MOVES Databases

- **Input Databases (default or user-created)**
  - Default Input Database
  - User Input Database(s) (optional-MOVES will run with just defaults for the National Scale)
- **Execution Database (created by MOVES)**
  - Resolves differences between the user input and default data
  - Contains information needed for a particular run
  - Temporary storage for intermediate results
  - Resources for new modeling applications
  - Interpreting tables can be complicated
- **Output Database (created by user)**
  - Run results
  - Run diagnostics and documentation

Output

- **MOVES Summary Reports**
  - Summary reporter that provides limited options for displaying MOVES output is provided with MOVES
- **MySQL can also be used to summarize output**
  - Full relational database capabilities for managing and manipulating output
  - Users can create, save, and share scripts to automate post-processing tasks
  - Can be done through MySQL Query Browser (GUI interface) or through a DOS window
  - Option to work though other database managers such as Access
  - Can also export data from MySQL Query Browser to Excel or other spreadsheet programs for additional post-processing

Demonstration of MOVES2010 Interface

MOVES Documentation

MOVES Documentation

- User Guide
- Guidance Documents
- Software Design/Reference Manual
- Technical documentation
- Presentations and other materials

MOVES User Guide

- **The MOVES User Guide describes:**
  - Installation instructions
  - The features of the graphical user interface (GUI)
  - Instructions on how to access each feature
  - Step-by-step example run
  - Exporting results to MS Access
  - Running MOVES in a batch mode
  - “MOVES Decoder”

MOVES Policy and Guidance Documents

- **Federal Register Notice of Availability**
  - Published March 2, 2010 (75 FR 9411)
    - Link at www.epa.gov/otaq/models/moves/index.htm
  - Approves the use of MOVES2010 for SIPs in states other than California
  - Starts a two-year grace period for use of MOVES2010 in regional conformity analyses
- **MOVES2010 SIP and Conformity Policy Guidance**
  - Published December 2009
    - www.epa.gov/otaq/models/moves/420b09046.pdf
  - Provides detailed guidance on when MOVES2010 should be used in SIPs and transportation conformity analyses

MOVES Policy and Guidance Documents

- **MOVES2010 Technical Guidance**
  - Published December 2009
    - www.epa.gov/otaq/models/moves/420b10023.pdf
  - Provides guidance on appropriate inputs for MOVES2010 in SIPs and regional conformity analyses
    - Defaults vs. local information
    - Developing appropriate local inputs
- **Guidance documents under development**
  - Quantitative PM hot-spot analyses for transportation conformity (includes PM project-level MOVES guidance)
  - CO project-level MOVES guidance
  - MOVES to be approved for PM and CO hot-spot conformity analyses once guidance finalized (with grace period)

MOVES Software Design and Reference Manual

- **The Software Design and Reference Manual (SDRM) describes:**
  - The hardware and software requirements
  - Software design components
  - Overview of processing, data and control flow
  - Functional design:
    - Generators (process input data)
    - Calculators (generate results)
    - Aggregators (summarize input and outputs)
  - Input and output database tables and design
- **Draft available, final will be posted when complete**

MOVES Database Documentation

- **MOVES database documentation is included when MOVES is installed**
- **The documentation is located in the "ReadMe" directory of the MOVES MySQL database folder**
- **Documents include:**
  - Table and field descriptions with units
  - Table relationship charts
  - Database quality checks

Technical Reports

- **MOVES technical reports describe the development of:**
  - Activity algorithms and default data
  - Adjustment factors (fuels, temperature, etc.)
  - Emission rate algorithms and default data
- **These reports address the sources of the data used by MOVES**
- **New reports are written when the algorithms or the default data are updated**
- **Drafts are available, final versions will be posted when complete**

MOVES Presentations and Other Materials

- **Presentations (such as this one) are made available on the MOVES web site**
  - Presentations can provide a summarized version of the information in the more detailed documentation
  - Presentations often contain examples that were not included in the original detailed documentation
- **The MOVES web site contains other documents that may be of interest to MOVES users:**
  - Physical Emission Rate Estimator (PERE)
  - MOVES Design and Emissions Analysis Plans
  - Federal Advisory Committee Act (FACA) Modeling Workgroup materials
  - MOVES Training materials
  - Validation results

MOVES Training

- **MOVES training a cooperative effort of EPA and FHWA staff**
  - Last year, gave hands-on Draft MOVES2009 training in 20 locations to over 400 participants
- **Currently giving MOVES2010 hands-on course:**
  - Training already given in 9 locations
  - 6 more locations have been scheduled
  - Several additional locations yet to be scheduled
- **Starting a series of webinars**
  - Introduction to MOVES is the first
  - Planning two upcoming technical webinars on running MOVES in batch mode and on a distributive network
  - Will schedule additional webinars as we develop them
  - Suggest a topic and we will see what we can do!

Visit the MOVES Website:

- **Main Page**
  - www.epa.gov/otaq/models/moves/
- **Training Sessions**
  - www.epa.gov/otaq/models/moves/trainingsessions.htm
- **Training Materials**
  - www.epa.gov/otaq/models/moves/training.htm
- **Background Information**
  - www.epa.gov/otaq/models/moves/movesback.htm
- **Listserver Information**
  - www.epa.gov/otaq/models/mobilelist.htm

Thank You

- Thanks for attending this Introduction to MOVES
- Please answer the questions in the webinar exit survey to help us improve our training
- If you have additional questions, email us:
  - mobile@epa.gov