:
Combustion Emissions Benefits of Ethanol vs. Gasoline

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Technical Terms

- Oxygenate
- Volatile Organic Compounds (VOCs)
- Nitrogen Oxides (NOx)
- Particulate Matter (PM)
- Carbon Monoxide (CO)
- Double Bond Equivalent (DBE)
- Polycyclic Aromatic Hydrocarbon (PAH)
- United States Environmental Protection Agency (EPA)
- Motor Vehicle Emission Simulator (MOVES)
- State Implementation Plan (SIP)
- Particulate Matter Index (PMI)
- Methyl Tertiary Butyl Ether (MTBE)
- T50 (Temperature at which 50% of the fuel vaporizes)
- T90 (Temperature at which 90% of the fuel vaporizes)
- E200 (The volume percent gasoline evaporated at 200°F during distillation)
- E300 (The volume percent gasoline evaporated at 300°F during distillation)
- Maximum Incremental Reactivity (MIR)
- Cancer Risk

Presentation Overview

- Overview of Selected Air Pollutants from Gasoline Combustion
- Technical/Scientific Predictions of Ethanol's Impact on Gasoline Combustion Emissions
- Original U.S Environmental Protection Agency MOVES Modeling Runs
    - Chicago
        - Results of MOVES Modeling
        - Comparison of Chicago MOVES Modeling with Honda PMI Model
    - Mexico City
        - Previous Studies on Mexico City and High Altitude Locations
        - Mexico City MOVES Modeling Results

Overview of Selected Air Pollutants from Gasoline Combustion

Overview of Selected Air Pollutants from Gasoline Combustion

Source: Motor Gasolines Technical Review Motor Gasolines Technical Review (FTR-1) 2009 Chevron Corporation

- **"Volatile Organic Compounds:**
  1. **Exhaust VOC:** The vast majority of gasoline is burned before combustion gases exit the engine in a properly operating vehicle, but a small fraction, typically 1 percent to 5 percent, escapes the combustion chamber unburned. These **VOC emissions consist primarily of unburned hydrocarbons**
  2. **Evaporative Emissions:** VOC Exhaust gases are not the only source of VOC emissions from gasoline fueled vehicles. In fact, the U.S. EPA estimated that in 1990 more than half the VOCs emitted from gasoline vehicles came from evaporation. Evaporative VOC emissions differ from exhaust VOC emissions in that evaporative emissions contain no combustion products.
  3. VOCs are often referred to as Non methane organic gases (NMOG) minus methane. VOCs also exclude CO
- **Nitrogen Oxides:** Nitrogen is always present in a combustion chamber because air is roughly 80 percent nitrogen. The production of NOx occurs whenever residual oxygen is present during combustion and is **particularly prevalent with higher combustion temperatures**.
- **NOx and VOCs** can form Ozone in the presence of sunlight.
- **Carbon Monoxide:** CO is the result of incomplete combustion of fuel, and the main factor influencing its production is the ratio of air to fuel in an engine combustion chamber. "

Overview of Selected Air Pollutants from Gasoline Combustion

Source: Impact of gasoline composition on particulate matter emissions from a direct-injection gasoline engine: Applicability of the particulate matter index
Koichiro Aikawa and Jeff J Jetter; International J. of Engine Research
2014, Vol. 15(3) 298–306

- **"Particulate matter:** (PM) emitted from vehicle engines **consists of soot, ash, sulfates, a soluble organic fraction (SOF) containing unburned fuel and lube oil**, and other components.
  - Diffusion combustion of fuel is suspected to be responsible for the generation of soot, which is a large part of PM and it is highly related to fuel properties.
  - It is reported by Kufferath et al. that diffusion combustion in gasoline engines is initiated by the burning of residual fuel adhered to the piston and cylinder walls, where it is not vaporized and is burned in liquid form.
  - Low-volatility components in gasoline exhibit such behavior. Therefore, PM emissions are likely to be affected significantly by the volatility of gasoline components.
  - In addition to this vaporization factor, PM is also associated with the molecular structure of gasoline components. For example, it has been reported **that aromatics are related to PM emissions."**

Aromatics and PM Formation

Source: Atmospheric Processes Influencing Aerosols Generated by Combustion and the Inference of Their Impact on Public Exposure: A Review; Zhi Ning, Constantinos Sioutas; Aerosol and Air Quality Research, 10: 43–58, 2010:

- "Particles in the atmosphere can be divided into two broad categories: primary and secondary particles.
  - Primary particles are directly emitted from combustion sources
  - Secondary aerosols comprise a large fraction of fine particles in urban areas
  - Secondary particles are largely composed of sulfate, nitrate, ammonium and secondary organic aerosols (SOA).
  - Generally, SOA are formed by photo oxidation of gas phase volatile organic compounds (VOC) in the atmosphere."
- Source: Urban Air Initiative:
  - **PAHs are semi-volatile organic compounds (SVOCs) found in both gaseous and particle form. They comprise the largest mass fraction of Ultra Fine Particles"**
  - "DBE (Double Bond Equivalent) is essentially an indication of the degree of unsaturation of a molecule. **The higher distillation aromatics (high molecular weight, HMW), have higher double-bond equivalents (DBEs).Fuel components with high DBE values are typically polyaromatic hydrocarbons (PAHs). PAHs in the fuel are known to be precursors for exhaust particulates."**

Ozone Potential

- Ozone potential provides a **measure of the smog forming potential** of organic compounds
  - **Different species have different ozone potential**
- Maximum Incremental Reactivity (MIR) is used by government regulators to evaluate fuels
- Ozone potential based on:

  MIR × tons/year for each species

Species	MIR
MTBE	0.78
Benzene	0.69
Hexane	1.15
Misc Hydrocarbon	3
2,2,4-Trimethylpentane	1.2
Ethanol	1.45
Styrene	1.65
Ethyl Benzene	2.93
Toluene	3.88
Acetaldehyde	6.34
Propionaldehyde	6.83
Acrolein	7.24
Xylene	7.44
Formaldehyde	9.24
1,3-Butadiene	12.21

Sources: Carter, W. P. (2010) Development of the SAPRC-07 Chemical Mechanism and Updated Ozone Reactivity Scales. California Air Resources Board Contracts 02-318 and 07-730

Unnasch, S., S. Huey and L. Browning (1996) Evaluation of Fuel Cycle Emissions on a Reactivity Basis. Prepared for ARB under Contract A166-134.

Cancer Risk

- Unit risk factors represent long term cancer risk for exposure to compounds
- Only 4 organic compounds are "listed" carcinogens (high burden of proof)
- Normalize risk factor

    CRF × tons/year to show cancer potential

Species		Cancer Risk
Acetaldehyde		1
Formaldehyde		2.22
Benzene		10.74
1,3-Butadiene		62.96

Source: Budroe, J., Brown, J., Collins, J., & et al. (2009). Technical Support Document for Cancer Potency Factors.

Technical/Scientific Predictions of Ethanol's Impact on Gasoline Combustion Emissions

Particulate Matter Emissions: Particulate Matter Index (PMI) Model

- The PMI-based predictive model for PM emissions from gasoline fuels was first proposed by Aikawa et al.
- It is based on the observed direct correlation between the weight fraction, vapor pressure, and Double Bond Equivalent (DBE) of gasoline fuel and the production of PM emissions.
- The DBE value is a measure of the number of double bonds and rings in the fuel molecule, such as found in olefins, aromatics, and cycloalkanes and is defined as the number of hydrogen atoms which would be required to fully saturate the molecule.
- **Components of fuel with high DBE values were observed to more readily form particulate emissions** in a vehicle with a 2.3L turbocharged engine. The **DBE value for ethanol** and paraffins such as isooctane **is zero**, whereas for aromatics it is in the range of four to seven.
- Thus, aromatic hydrocarbons (which tend to have high DBE values and low vapor pressure) disproportionately contribute to PM formation, and increasing paraffin or ethanol content of the fuel tends to decrease PM.

VOC/NMOG Emissions

Source: "An Overview of the Effects of Ethanol-Gasoline Blends on SI Engine Performance, Fuel Efficiency, and Emissions" Stein, Anderson, Wallington; SAE 2013

- Evaporative emissions consist of:
  - Refueling, diurnal temperature change, running loss, hot-soak, and permeation
- Most evaporative emissions derive from fuel vapors generated in the fuel tank and thus their magnitude is generally a function of fuel RVP**. <u>Ethanol added to gasoline at low to moderate concentrations (E5-E30) increases fuel RVP and thus vapor concentration</u>**
- Evaporative emissions **<u>are controlled by capture using active carbon canisters</u>** and then later purging then into the intake air and combusting them in the engine. Ethanol has little to no effect on the capture on activated carbon and regeneration "**<u>Running loss vapors are immediately combusted with engine intake air"</u>**
- An investigation into the emissions of ethanol-gasoline blends from one 2006 model year and six 2007 model year was conducted by the Coordinating Research Council. The results for the US06 driving cycle showed a **<u>statistically significant trend of decreasing NMOG with increasing ethanol content</u>.**

NOx Emissions

Masum et al 2013; Effect of ethanol–gasoline blend on NOx emission in SI engine; Renewable and Sustainable Energy Reviews 24 (2013); B.M. Masum et. al. 2013.

- Literature varies widely on findings for ethanol gasoline blends.
- “Many literatures have showed that, NOx emission decrease with the increase in content of ethanol.
- Turner et al. investigated NOx emission in a direct injection spark ignition (DISI) engine on a 1500 rpm and 3.4 bar indicated mean effective pressure (IMEP) with ethanol–gasoline blends. When the ethanol portion increased up to 85% in the blend, NOx emission was reduced. They attributed this reduction to reduction in flame temperature, which was corroborated by a reduction in exhaust temperature. “

Source: Stein et al. SAE 2013:

- ”Ethanol’s high heat of vaporization (920 kJ/kg fuel vs ~350 for gasoline) results in charge cooling (particularly with DI engines”

Carbon Monoxide

- Original intent of adding oxygenates to fuel was to reduce carbon monoxide emissions
- Ethanol is an oxygenate. Adding oxygenates results in more complete combustion – similar effect to increasing combustion air
- "Oxygenated Fuels Help Reduce Carbon Monoxide" (GAO Report RCED-91-176: Published: Aug 13, 1991)
- Alternatively or in conjunction vehicles can adjust Air to Fuel (A/F) control systems to compensate for oxygen in fuel

Cancer Risk

- Stein et al./SAE In. J. Engines / Volume 6, Issue 1 (May 2013):
  - **"Increased ethanol in gasoline should decrease emission of 1,3 butadiene and benzene and increase emissions of acetaldehyde and formaldehyde** (later two due to incomplete combustion of ethanol). Due to much **higher toxicity weighting factors, 1,3-butadiene and benzene dominate the weighted sum** of these four toxics even in high ethanol content"
- "Unnasch and Henderson (2014) "Change in Air Quality Impacts Associated with the Use of E15 Blends Instead of E10".
  - Analysis of CRC Study E80 showed that "a change from E10 to E15 results in a 6.6% reduction in toxic risk. Furthermore, a "**reduction in 1,3 butadiene and benzene produces a decrease in impacts that is greater than their relative decrease in mass emissions"**
- Schifter et al (2011) "Assessment of Mexico's program to use ethanol as transportation fuel: impact of 6% ethanol-blended fuel on emissions of light-duty gasoline vehicles":
  - Small increase in air toxins, less so for low emitters.

Control Technologies

Pollutant Emission	Control Technology or Design Features
Carbon Monoxide	• Precise control of air: fuel ratio • Multi-point injection • Compact combustion chambers • Precise ignition timing • Catalytic converters
Hydrocarbons	• Crankcase ventilation systems • Evaporative emission sealing • Ignition timing • Catalytic converters
Nitrogen Oxides	• Exhaust gas recirculation • Combustion chamber shape alteration in combination with reduced compression ratios • Engine designed to operate on weak mixture • Computer-controlled ignition timing • Optimized valve timing • Fitting intercoolers to turbocharged engines • Three-way catalytic converters

(Bioethanol for Sustainable Transport, 2008)

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Original MOVES Modeling Runs Conducted by:

University of Illinois at Chicago
Life Cycle Associates
O’Shea Environmental Associates
Kmoore Consulting

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Chicago Area Ethanol Modeling

Evaluated Emissions using Two Different Models

1. U.S. EPA's Motor Vehicle Emission Simulator (MOVES) model used for State Implementation Plan (SIP) development and transportation conformity analyses.

   Note: A State Implementation Plan (SIP) is a United States state plan for complying with the federal Clean Air Act, administered by the Environmental Protection Agency (EPA). The SIP consists of narrative, and agreements that an individual state will use to clean up polluted areas., rules, technical documentation.

2. Compared findings to Particulate Matter Index (PMI) developed by Honda as a predictive model of particulate matter emissions
   - Collected fuel samples at 6 Chicago area gas stations
   - Splash blended E10 samples to E15, E20, E25, and E30 fractions
   - Performed Detailed Hydrocarbon Analysis

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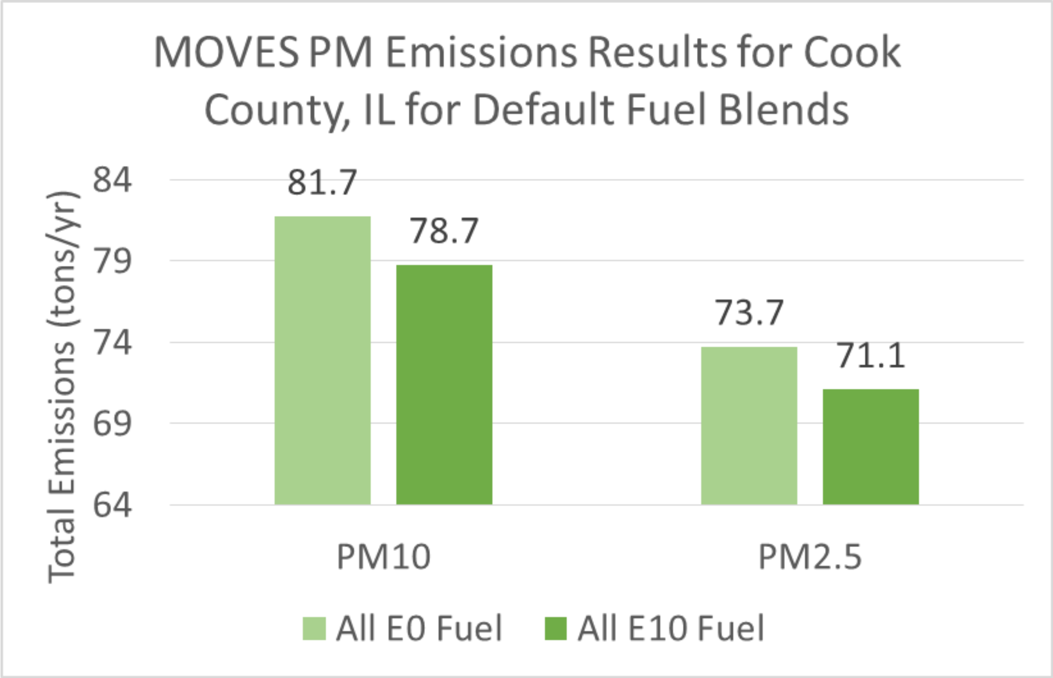
EPA MOVES Model

- EPA's **MO**tor **V**ehicle **E**mission Simulator (MOVES) is a state-of-the-science emission modeling system that estimates emissions for mobile sources at the national, county, and project level for criteria air pollutants, greenhouse gases, and air toxics.
- MOVEs is used for State Implementation Plan (SIP) development and transportation conformity analyses – Meaning the model is used to document, for example, how states who do not meet air quality standards can come back into compliance.
- MOVES takes into account parameters like regional fuel formulation, vehicle types and ages, market shares, etc.

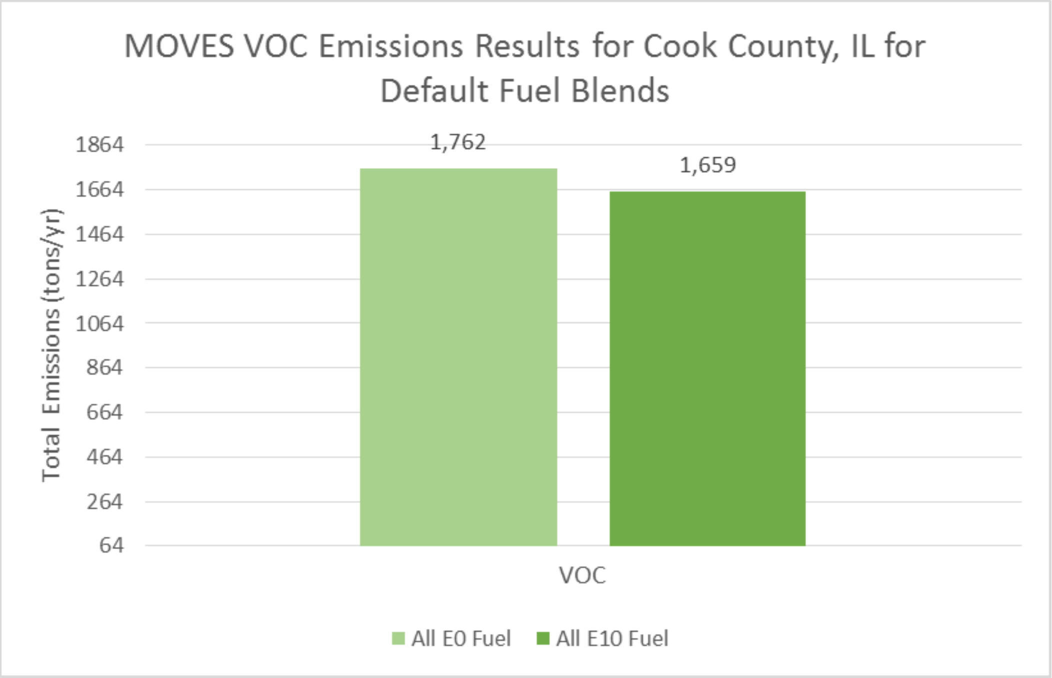
MOVES Chicago: PM Emissions

- We obtained the MOVES file for Cook County (Chicago Area) from the Illinois Environmental Protection Agency
- For Chicago Area E10 shows PM10 and PM2.5 reductions over E0



MOVES Chicago: VOC Emissions

- We obtained the MOVES file for Cook County (Chicago Area) from the Illinois Environmental Protection Agency
- For Chicago Area E10 shows VOC reductions over E0



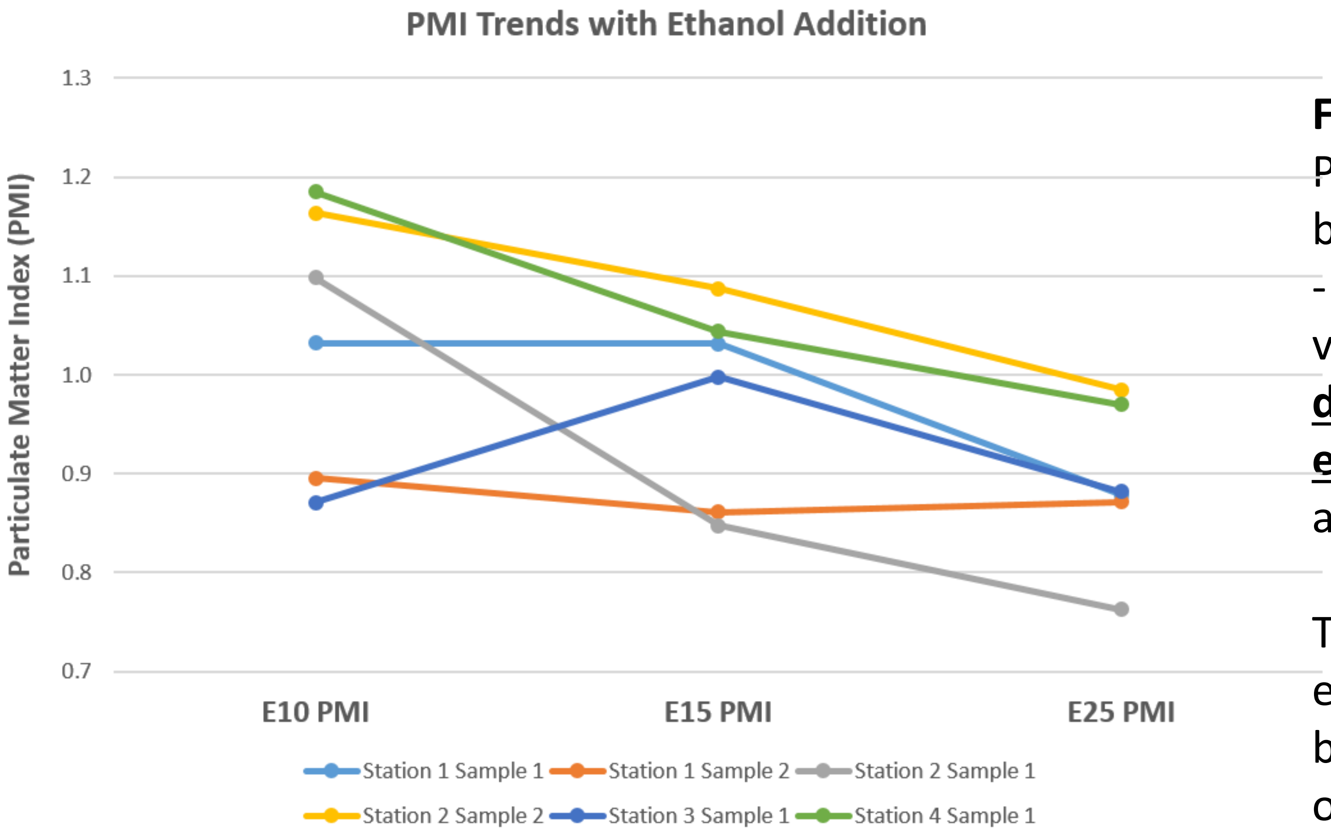
PMI Modeling Using Chicago Area Fuels

Sample Location	Fuel Grade	E10 (Original Sample)	E15	E20	E25	E30
Station 1 (2 samples)	Premium Gasoline	●	●	●	●	
Station 2 (2 samples)	Regular Gasoline	●	●		●	●
Station 3 (1 sample)	Regular Gasoline	●	●	●	●	●
Station 4 (1 sample)	Regular Gasoline	●	●	●	●	●

Sample Property	Test Method
Detailed Hydrocarbon Analysis, including total aromatic, olefin, and benzene content	ASTM D6730
Aromatics in Gasoline (GCMS)	ASTM D1319 correlated to ASTM D5769
Vapor Pressure (DVPE)	ASTM D5191
Ethanol Content	ASTM D4815
Distillation Curve (IBP, T10, T20, T30, T40, T50, T60, T70, T80, T90, T95, FBP, e200, e300)	ASTM D86
Heating Value (BTU)	ASTM D240
Octane	ASTM D2699 and ASTM D2700

* Sample properties entered into MOVES Fuel Formulation tab. Detailed hydrocarbon analysis required for PMI calculations.

PM Emissions – PMI Model



Finding:
PMI Model: Samples behaved as expected - Decreasing PMI value and therefore **decreasing PM emissions** with the addition of ethanol.

This is expected given ethanol's double-bond equivalent value of zero.

Mexico City

Previous Studies on Mexico City and High Altitude Locations

Isaac Schifter · Luis Díaz · Rene Rodríguez ·Lucia Salazar, 2011
"Assessment of Mexico's program to use ethanol as transportation fuel: impact of 6% ethanol-blended fuel on emissions of light-duty gasoline vehicles"

From the publication:

- "Mexican government launched a national program encouraging the blending of renewable fuels in engine fuel.
- Therefore environmental consequences of gasoline fuel additives, ethanol and methyl tert-butyl ether, on the tailpipe and the evaporative emissions of Mexico sold cars was investigated.
- Regulated exhaust and evaporative emissions, such as carbon monoxide, non-methane hydrocarbons, and nitrogen oxides, and 15 unregulated emissions were measured under various conditions on a set of 2005–2008 model light-duty vehicles selected based on sales statistics for the Mexico City metropolitan area provided by car manufacturers.
- Splash blends of **6% Ethanol blend vs 11% MTBE** (i.e. 2% oxygen) were produced"

Results

- The total vehicular emission amount estimated by the data analysis is 490,007 tons per year for the MTBE fuel and 475,449 tons per year in the case of the ethanol fuel.
- CO emissions are expected to decrease by 3.5% with the ethanol fuel, but there is a <u>3.7% increase in total hydrocarbons and 1% decrease in NOx emissions.</u>

Impact of Altitude on Emissions Rates of Ozone Precursors from Gasoline Driven Light Duty Commercial Vehicles
Nagpure et al. Atmospheric Environment 2011

- Emissions assessment in three different cities in India at different altitudes: Delhi (225 m / 736 ft), Dehradun (682 m / 2237 ft), Mussoorie (1826 m / 5990 ft) based on IVE Model.
- VOC: Higher amounts of VOCs emitted "presumably due to incomplete combustion or unburned fuel associated with high altitudes."
- NOx: Decrease in NOx emissions with increasing altitude. "Possible reason for this could be the use of rich fuel/air mixture during combustion at high altitude, resulting in relatively less emission of NOx."

Mexico City MOVES Modeling Results

EPA MOVES Model

- EPA MOVES Model predicts vehicle exhaust and evaporative emissions
  - Different fuel formulations
  - Vehicle age distribution
  - Climate conditions
- Model responds to key Fuel parameters

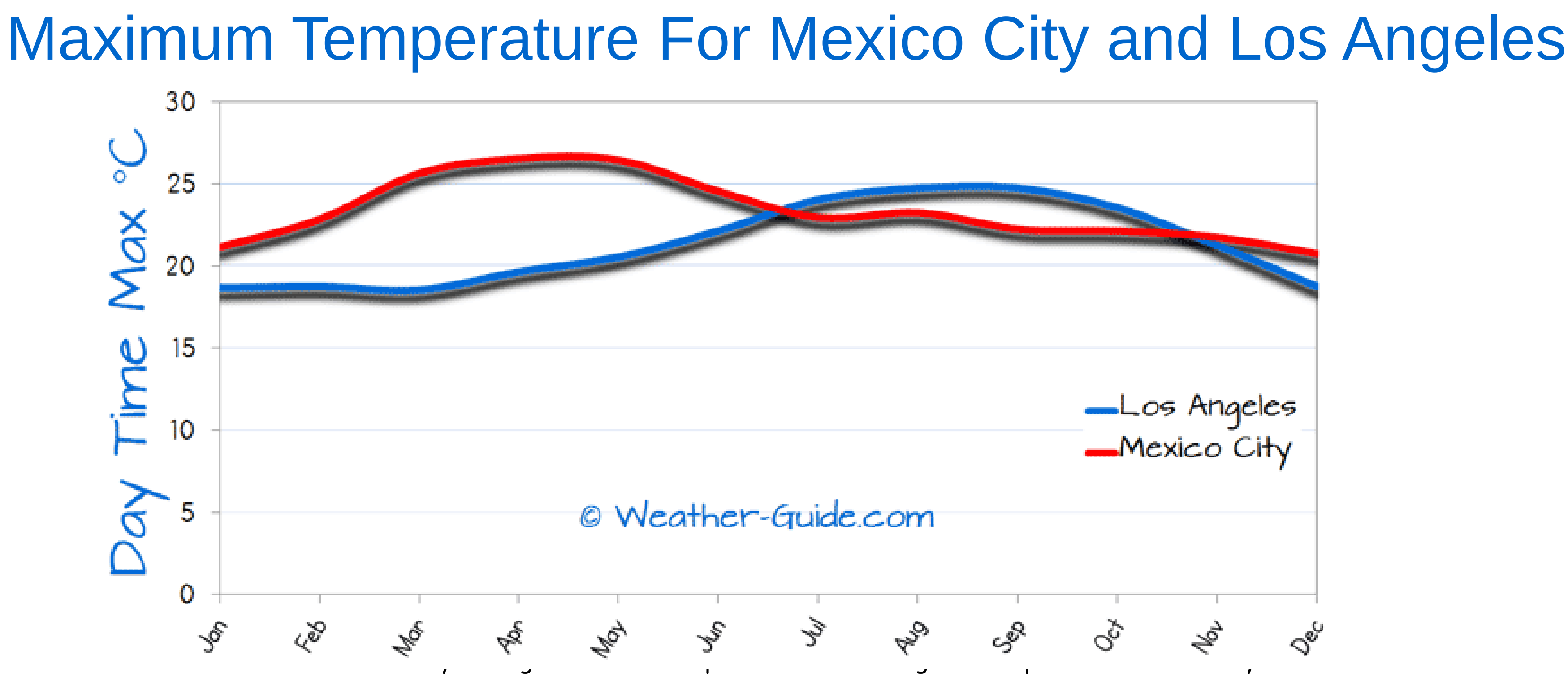
processid

ID	processName
1	Running Exhaust
2	Start Exhaust
9	Brakewear
10	Tirewear
11	Evap Permeation
12	Evap Fuel Vapor Venting
13	Evap Fuel Leaks
15	Crankcase Running Exhaust
16	Crankcase Start Exhaust
17	Crankcase Extended Idle Exhaust
18	Refueling Displacement Vapor Loss
19	Refueling Spillage Loss
90	Extended Idle Exhaust
91	Auxiliary Power Exhaust
99	Well-to-Pump

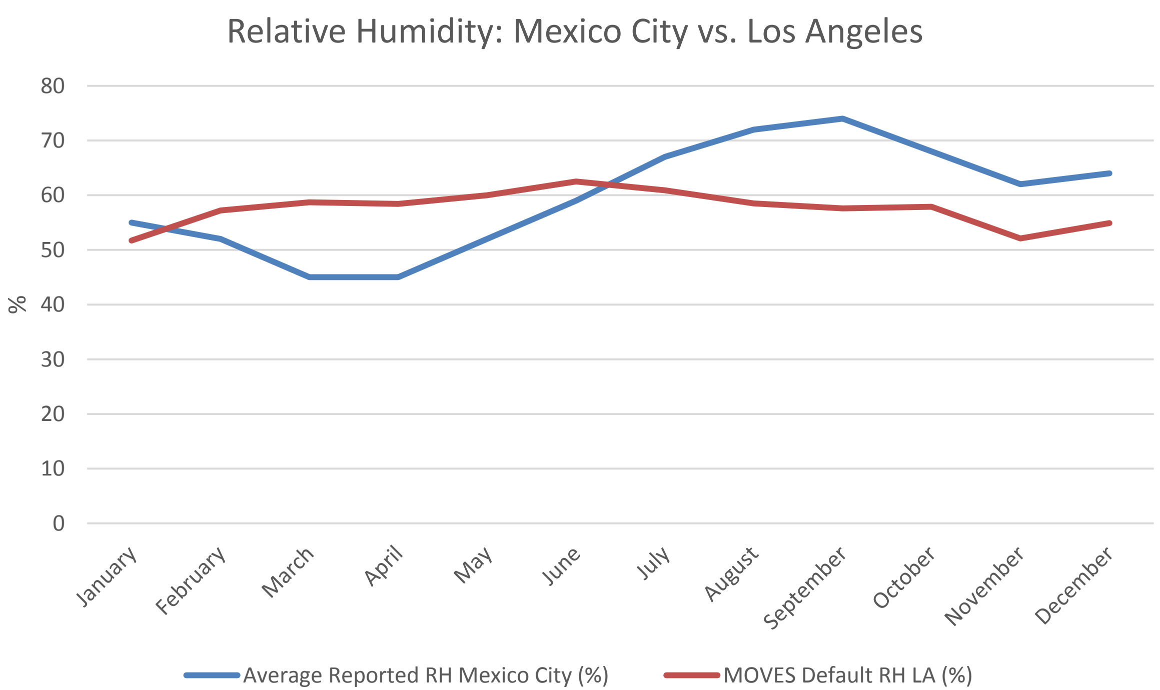
MOVES Modeling Effort

- Adjusted Vehicle Age based on a combination of the following publications:
  - "United States – Mexico Land Ports of Entry Emissions and Border Wait Time White Paper and Analysis Template"; US Department of Transportation – Federal Highway Administration https://www.fhwa.dot.gov/planning/border_planning/us_mexico/
    - **Study also Used MOVES model**
  - "Cash for Clunkers? The Environmental Impact of Mexico's Demand for Used Vehicles"; Davis et al; UC Davis 2011.
  - "Mexico City Vehicle Activity Study Conducted January 25 – February 5, 2004"; Nicole International Sustainable Systems Research, Nicole Davis et al. 2004
  - Resulting distribution was actually close to the Los Angeles vehicle fleet
- Copied Los Angeles weather file over to Denver location
- Obtained fuel samples from Mexico gas stations
  - Fuels data source: Alliance of Automobile Manufacturers.
The survey was calendar years 2011- 2015
(5 years), includes winter and summer samples from January and July.
- Ran model on 4 computers over 2 weeks
- Large volume of data was managed with custom SQL queries

Close Weather Conditions



Relative Humidity



HUMIDITY AND TEMPERATURE CORRECTION FACTORS FOR NOX EMISSIONS FROM SPARK IGNITED ENGINES; SwRI® Project No. 03.10038; October 2003.

Study based on Older Vehicles. In general Higher Humidity Lower NOx "water vapor in the intake will act as a Odiluent for the combustion charge, reducing the flame temperature, and therefore, the reaction rates for forming NO. Second, the diluent will slow the fuel burning rate, moving the average combustion later in the cycle where temperatures are lower due to the expansion cooling. "

Fuel Parameters

- Adjusted distillation curves based on fuel composition:
  - “The distillation characteristics of automotive gasoline containing biobutanol, bioethanol and the influence of the oxygenates”; V. Hönig; Agronomy Research 13(2), 558–567, 2015
  - “Distillation Curves for Alcohol-Gasoline Blends”; Energy Fuels XXXX, XXX, 000–000 : DOI:10.1021/ef9014795; V. F. Andersen, et al.
  - “Vapor Pressures of Alcohol-Gasoline Blends”; Energy Fuels 2010, 24, 3647–3654 : DOI:10.1021/ef100254w; Published on Web 05/21/2010; V. F. Andersen, J. E. Anderson, T. J. Wallington, S. A. Mueller, and O. J. Nielsen

Distillation Curve

- Based on literature increased RVP, decreased T50, T90, increased E200 and E300 with increasing ethanol and MTBE. Accounted for volumetric dilution with ethanol/MTBE

Distillation Fraction	25	50	90
Conventional Gasoline	133	190	306
E5.7 Splash Blend	129	166	302
15% MTBE Splash Blend	133	182	305

- Extensive modeling effort for all pollutants. Ran model on 4 computers over 2 weeks

MOVES Modeling Run Matrix

- Modeled Emissions with Meteorology approximating Mexico City (using Los Angeles weather data)
- Modeled Altitude approximating Mexico City (using Denver, Colorado location with 5,500 ft /1670m elevation) and compared to sea level (Los Angeles)
- Modeled Mexican Gasoline, Mexican Gasoline Adjusted for Ethanol 5.7% Blend and Mexican Gasoline adjusted for 15% MTBE blend.
- For fuel blends with Ethanol and MTBE modeled average RVP and maximum RVP fuels
- This produced a total of 10 cases
- Plus one sensitivity on Year 1986 vehicle for vehicles which do not have Onboard refueling vapor recovery system (ORVR)

1	Mexico Gasoline	Sea Level
2		Altitude
3	Ethanol: AVG VP 5.7	Sea Level
4		Altitude
5	Ethanol: Max VP 5.7	Sea Level
6		Altitude
7	MTBE AVG VP	Sea Level
8		Altitude
9	MTBE Max VP	Sea Level
10		Altitude
	Vehicle Age Sensitivity	

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Mexico Moves Modeling Results by Pollutant

- Data provides "trend" indications
- In this fuel set comparing each run altitude increases VOC and THC, reduces NOx and NO2. Very consistent with literature
- In the ethanol set, the vapor pressure had no effect (actually lower emissions for the Maximum VP data)

Emissions (tons/year)

Fuel Scenario		**Volatile Organic Compounds**	**Total Gaseous Hydrocarbons**	**Oxides of Nitrogen (NOx)**	**Nitrogen Dioxide (NO2)**
Mexico Gasoline	Sea Level	802	812	846	75
	Altitude	856	870	822	72
E: AVG VP 5.7	Sea Level	842	852	885	79
	Altitude	911	918	860	76
E: Max VP 5.7	Sea Level	837	838	842	73
	Altitude	911	908	819	70
MTBE AVG	Sea Level	805	811	832	74
	Altitude	864	865	809	71
MTBE Max	Sea Level	810	814	807	70
	Altitude	873	872	785	67

VOC Emissions Breakout by Process

Fuel Scenario		Crankcase Running Exhaust	Crankcase Start Exhaust	Evap Fuel Leaks	Evap Fuel Vapor Venting	Evap Permeation	Refueling Displacement Vapor Loss	Refueling Spillage Loss	Running Exhaust	Start Exhaust	Grand Total
		Emissions (tons/year)									
Mexico	Sea Level	2	5	85	152	34	2	8	144	370	802
	Altitude	2	5	85	158	34	41	17	144	370	856
E: AVG VP 5.7	Sea Level	2	5	85	165	65	3	9	148	361	842
	Altitude	2	5	86	184	65	55	17	142	356	911
E: Max VP 5.7	Sea Level	2	5	86	170	65	3	9	142	356	837
	Altitude	2	5	85	176	65	52	17	148	361	911
MTBE AVG	Sea Level	2	5	87	159	35	2	8	142	365	805
	Altitude	2	5	87	167	35	45	17	142	365	864
MTBE Max	Sea Level	2	5	83	157	35	2	8	139	378	810
	Altitude	2	5	83	167	35	47	17	139	378	873

- Looking at VOC breakout
  - "Start Exhaust" is the largest emissions source but it is slightly lower for ethanol blends than for MTBE and current gasoline.

Sensitivity: Older Vehicles

- Sensitivity on Year 1986 vehicle for older vehicles without Onboard refueling vapor recovery system (ORVR)
- No significant difference in VOC emissions behavior

Emissions (tons/year)		
Fuel Scenario	**Elevation**	**VOC MY 1986 and Older Vehicles**
Mexico	Sea Level	17.7
	Altitude	18.5
E: AVG VP 5.7	Sea Level	19.5
	Altitude	20.7
E: Max VP 5.7	Sea Level	19.6
	Altitude	20.6
MTBE AVG	Sea Level	18.0
	Altitude	18.9
MTBE Max	Sea Level	18.5
	Altitude	19.4

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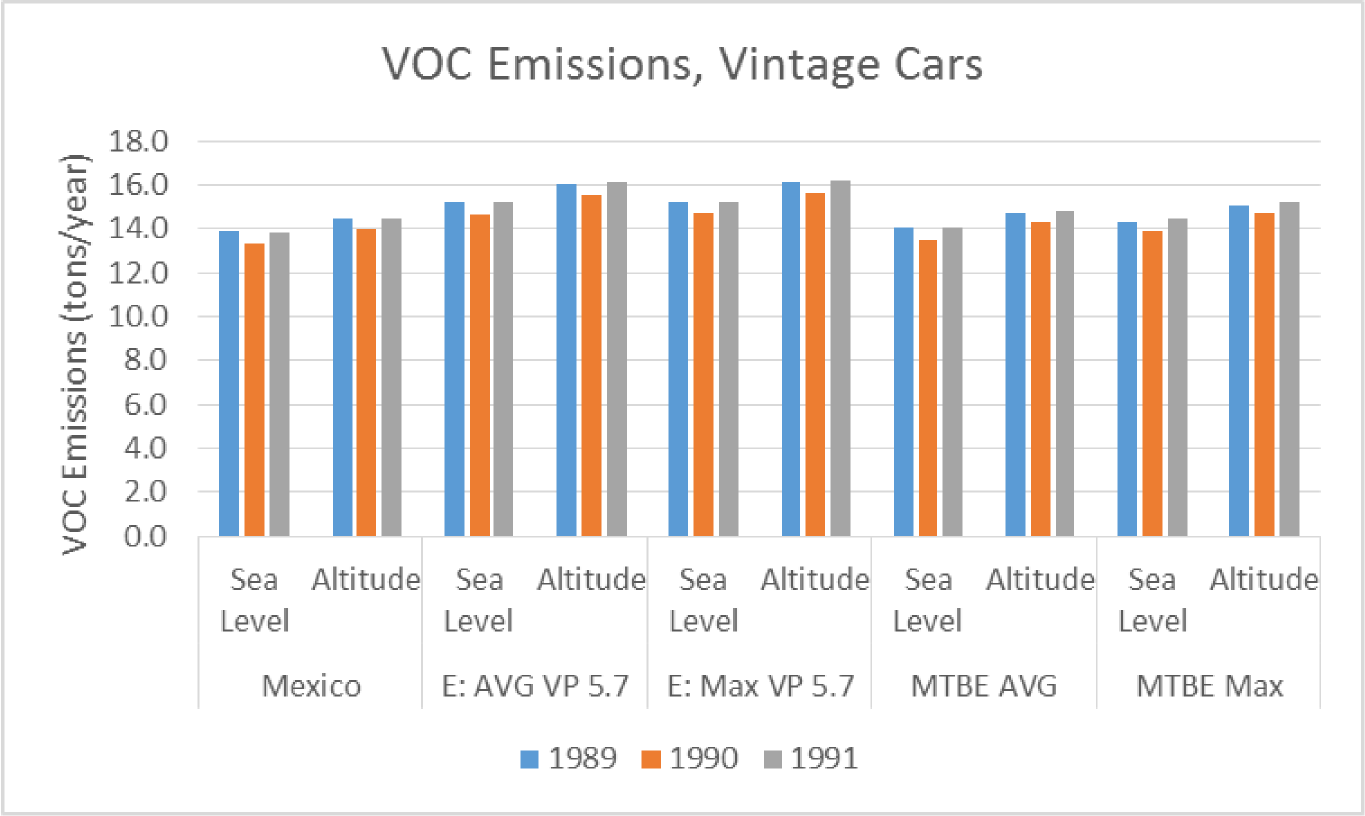
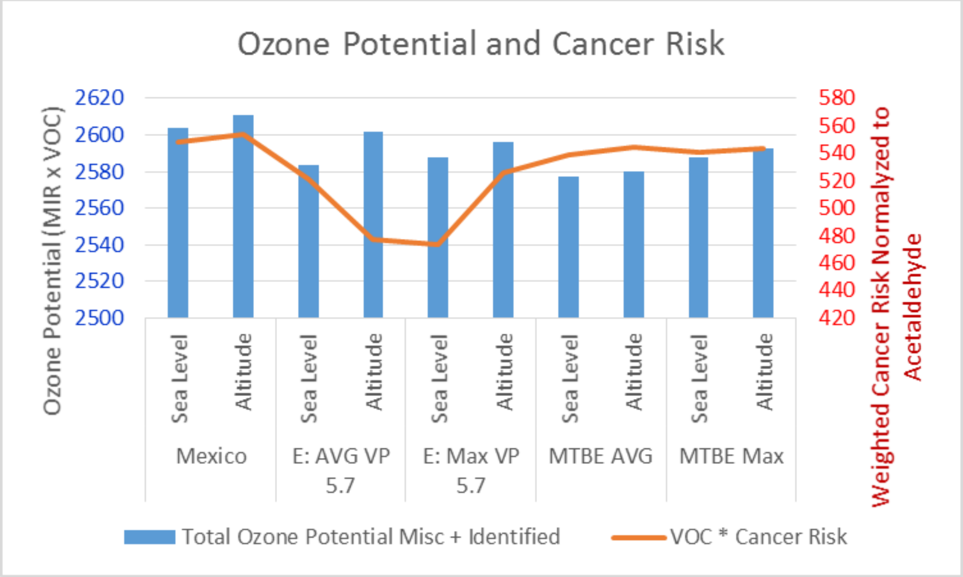
Sensitivity: Older Vehicles

Slightly Higher Emissions from Older Vehicles with Ethanol



Potential to Form Ozone and Cancer Risk from E5.7 compared to current gasoline and MTBE in Mexico City

- Slightly Lower Potential to Form Ozone and overall reduced cancer risk



Fuel Scenario	Elevation	Total Ozone Potential Misc + Identified	VOC * Cancer Risk
Mexico	Sea Level	2604	548
	Altitude	2611	554
E: AVG VP 5.7	Sea Level	2584	521
	Altitude	2601	477
E: Max VP 5.7	Sea Level	2587	473
	Altitude	2596	526
MTBE AVG	Sea Level	2577	539
	Altitude	2580	544
MTBE Max	Sea Level	2588	540
	Altitude	2593	544

Recent Research into MOVES and Supporting Fuel Inputs

Important Note on MOVES. Research by "Ethanol Across America":

- Splash blending simply adds ethanol to gasoline. Addition of ethanol to create E10 provides nearly 3 octane point increase to meet minimum 87 octane requirements.
- Match Blending, as done in the EPAct study which forms the fuels basis for MOVES, is when the base fuel prior to splash blending ethanol, is altered to achieve desired outcomes
  - Refineries make a sub-octane gasoline knowing that ethanol will be added later by adding high boiling hydrocarbons. The addition of ethanol increases the fuel's octane above the required octane number.
  - High boiling hydrocarbons and not ethanol are responsible for altered emissions profile
- Corroborated in "Issues with T50 and T90 as Match Criteria for Ethanol-Gasoline Blends"; James E. Anderson and Timothy J. Wallington"; SAE 2014:

  "If match blending is used, it is important to consider the impact of blendstock changes on the measured emissions or performance."
- Therefore MOVES is likely underestimating emissions benefits of ethanol

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Summary

- Literature generally suggest reductions with ethanol for PM, CO, and differing studies on NOx and VOC emissions.
- Emerging literature shows that emissions are <u>often due to adjustments in the gasoline blendstock</u> and not due to ethanol itself.
- Different reactivity of VOCs result in <u>reduced ozone formation when emissions are multiplied by ozone forming potential</u>. Similarly<u>, cancer risk is often shown to be reduced</u> concurrently with a reduction of heavy impact of 1,3 butadiene.

Summary

Chicago MOVES Runs

- MOVES modeling for Chicago shows reduction in PM emissions and VOC between E0 and E10 blends. Literature differs but this is consistent with many scientific publications

Mexico Emulated MOVES Runs

- The MOVES runs for Mexican gasoline, ethanol and MBTE alike show that altitude increases VOC and THC, reduces NOx and NO2. Therefore, our MOVES runs are very consistent with literature
- In the ethanol set, the vapor pressure had no effect (actually lower emissions for the Maximum VP data)
- "Start Exhaust" is the largest emissions source but it is slightly lower for ethanol blends than for MTBE and current gasoline.
- No significant difference in VOC emissions behavior for Model Year 1986 vehicles and older
- Slightly Lower Potential to Form Ozone and overall reduced cancer risk

As explained MOVES is likely underestimating emissions benefits of ethanol due to matchblending of gasoline blendstocks.

In Conclusion

- This research was able to show emissions benefits of ethanol even at low blend levels.
- This research shows that allowing the increase in ethanol's vapor pressure when blended with gasoline does not increase emissions- there is virtually no effect.
- The US is 97% E10 now- even in all mountain areas. There are no driveability problems.
- Mexico vehicles have been compatible with ethanol for decades- and Mexico received many of the Cash for Clunkers vehicles- those vehicles have been running on E10 for years.
- Mexico is a leading automobile manufacturer. Global trend is towards compression ratio, downsized engines.
  - Substantial efforts are underway in US with support from car manufacturers to move towards High Octane Fuels (E25,E30) with ethanol being a cheap form of octane
  - Ethanol blended gasoline in Mexico would support momentum

Supporting Information

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