Fuel blending guide for ethanol emissions effect

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Abstract

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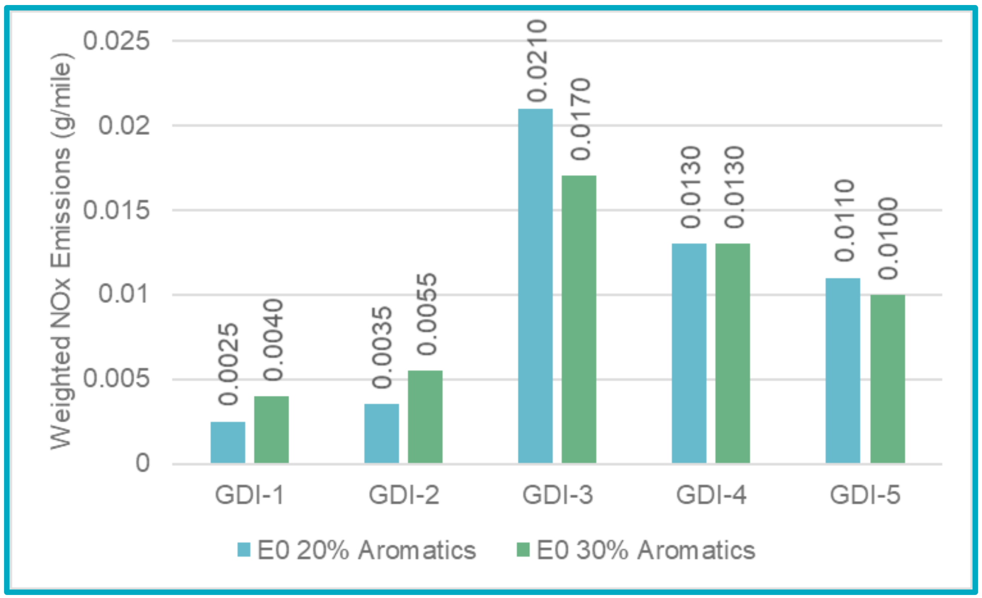
This Blending Guide Study identifies sound practice for acquiring or blending fuels for studies of emissions changes in response to fuel composition or specification changes in the marketplace, emphasizing studies examining ethanol effects. Four recommendations for future market fuel studies represent a departure from many prior approaches. First, fuels expected in the market should be used. For most efficient use of resources, effects resulting from a change of ethanol level should be evaluated by employing only fuels with the ethanol levels of interest and with hydrocarbon (BOB) compositions that are expected in the market at those ethanol levels. In this way measurement effort is not devoted to fuel formulations that may never enter commercial use, and nonlinear blending effects are addressed directly by the study fuels themselves. Second, fuel composition should be used to define fuels. For precise fuel description, measures of fuel composition are unambiguous and are preferable to properties that are determined using standardized protocols. Third, influence of vehicle technology merits higher recognition. Vehicles used in a study should be well characterized with regard to their powertrain technology and control strategy so that emissions effects can be projected reliably to a fleet. Fourth, driving schedules should mimic on-road use. During emissions testing, vehicles should be operated in a real world fashion and environment if the intent is to predict emissions inventory. A step-by-step approach supports these recommendations, and two example emissions study approaches (for E10 to E15 splash blend, and E10 vs. E20) are presented.

Background and Motivation

- *Differences in fuel blending approaches, vehicle technology, driving schedules, and study structure contribute to substantial differences between results of many fuel effects studies.*
- *Multivariate studies require a substantial count of fuels and test runs to have statistical significance.*
  - *Interpolative or extrapolative models can be applied to predict emissions using assumed or measured market fuel properties.*
  - *Sometimes models are misinterpreted by considering only a single variable, or by adopting the study fuel composition directly.*
- *Splash blends are not representative as study fuels except where the market fuel itself is splash blended. (e.g. some current E15).*
- *An economical approach to examining effects of fuel changes is to use fuels truly representative of the current or future market fuels.*
  - *Blending guide presents an approach for identifying these fuels and employing them in such a study.*
  - *Changes of ethanol content in gasoline, and resulting fuel composition changes, are emphasized*

Observations on fuel effects

- *Increasing ethanol level in finished gasoline is typically accompanied by changes in the gasoline blending component (BOB).*
  - *For market fuels, reduction in aromatics, to maintain a constant AKI, is usual.*
  - *Emissions effects are driven by the BOB changes as well as the ethanol level.*
- *Aromatics are known to contribute to changes in emissions*
  - *For PM, this is usually an increase.*
  - *For other emissions species, vehicle and cycle choice can affect the observed change.*



Data from Yang et al. (2019) for five GDI vehicles on two fuels using the weighted LA-92 cycle. Distance-specific emissions vary between vehicles operated on two zero ethanol fuels with different aromatic levels.

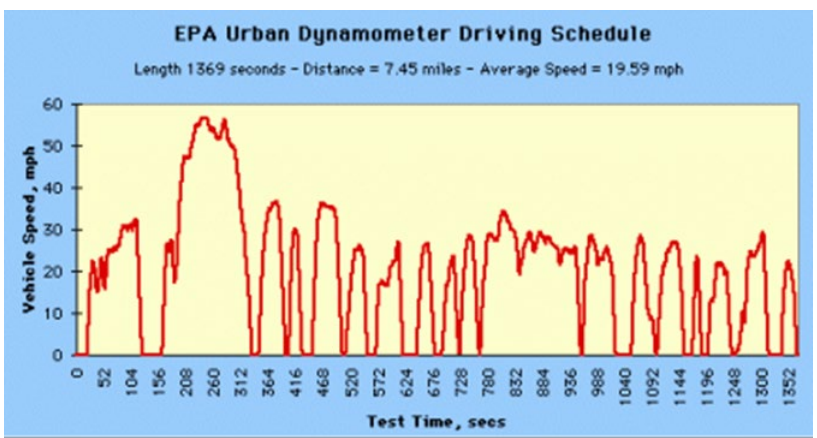
Recommendations of Guide - 1

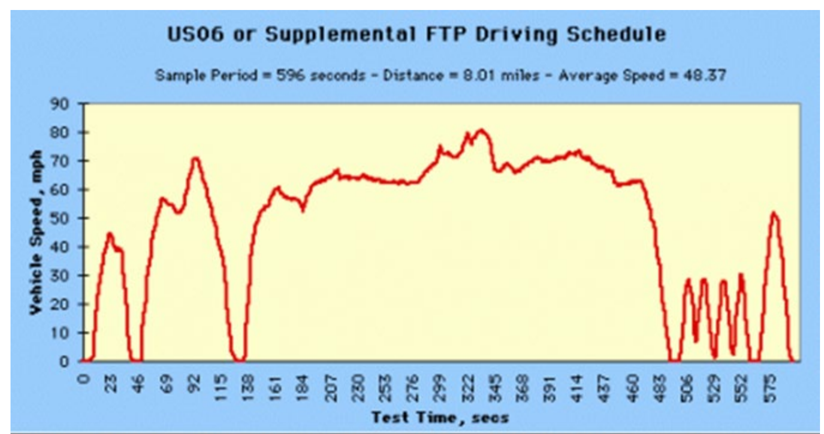
- ***Fuels expected in the market should be used.***
- Evaluate effects resulting from a change of ethanol level by employing only fuels with the ethanol levels of interest.
- Use hydrocarbon (BOB) compositions that are expected in the market at those ethanol levels.
- Represent each ethanol level using either one fuel, with a representative hydrocarbon composition, or by a suite of fuels with a distribution of hydrocarbon compositions that reflect expected market variability in composition.
- Do not devote measurement effort to fuel formulations that may never enter commercial use.
- Rely on the study fuel behavior to address nonlinear blending effects.

- ***Fuel composition should be used to define fuels.***
- Composition varies widely, and properties alone are insufficient to define a fuel's behavior.
- Fuel composition is unambiguous, whereas several fuels blended with diverse compositions may satisfy the same set of properties.
- Detailed hydrocarbon analysis (DHA) of fuels has become more reliable and rapid, permitting the grouping of molecular species by type, weight or expected influence.
- Use of composition to govern blending and fuel characterization avoids interference of non-linear blending effects on values of study parameters.
- Standardized protocols (defining properties) are not necessarily governed by the same chemistry, physics or time constants as the processes occurring in real-world injection, combustion, catalysis, adsorption and permeation.
- Certain fuel properties, such as octane numbers, will continue to govern formulation of market fuels sold at the pump.

Recommendations of Guide - 2

- ***Influence of vehicle technology merits higher recognition.***
- Vehicles used in a study should be well characterized with regard to their powertrain technology and control strategy.
- Port Fuel Injection or Gasoline Direct Injection is too coarse a classification to use alone.
- The vehicle cohort may be characterized by numerical descriptors, such as power to weight ratio, or engine power density, to appreciate the vehicle interaction with fuels at different loads and speeds. (See Stein et al, 2013)
- More thorough classification supports statistical analysis of vehicle-to-vehicle differences and defines the applicability of results from each vehicle for application to the on-road fleet.
- Involvement of automobile manufacturers or powertrain experts is beneficial in study planning and data interpretation.
- ***Driving schedules should mimic on-road use.***
- Vehicles should be operated to mimic their real-world on-road use and environment as closely as possible if the intent is to predict emissions inventory.
- Practically, it is recommended that data gathered from vehicles includes operation at idle, light to medium load, and near full load, because modern engine controls will manage combustion differently in these circumstances.
- At least a researcher should employ a low power cycle such as the FTP, a high power cycle such as the US06, and, if possible, a segment of wide open throttle (WOT) acceleration.



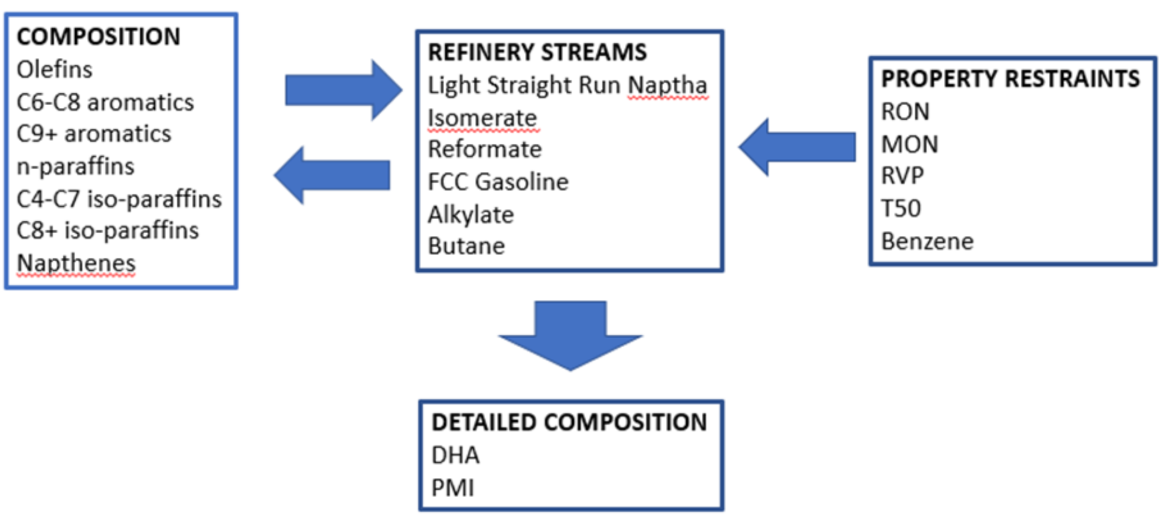


Cycle figure source: https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules

Determining Representative Fuel Properties

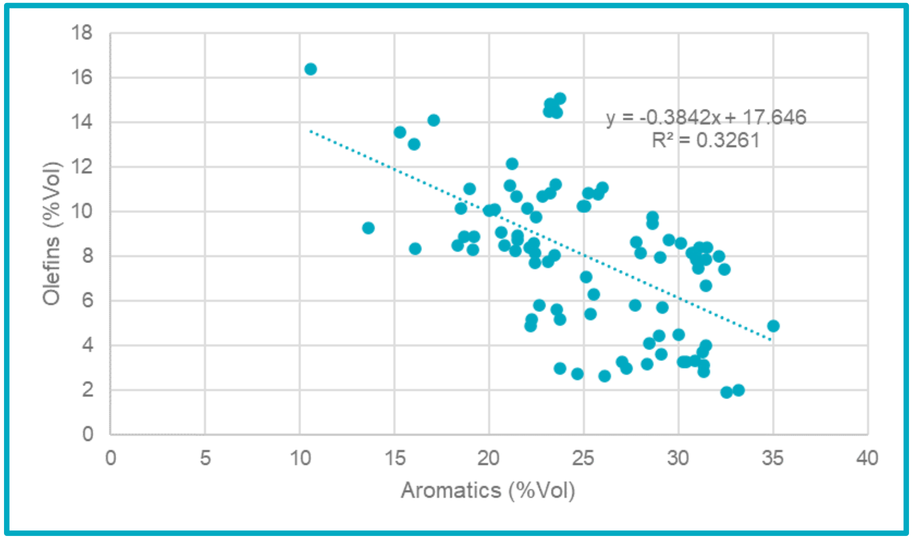
- ***Influence of vehicle technology merits higher recognition.***
- A baseline suite of fuels is used to represent variation in the composition of market fuels. The baseline fuel BOB compositions vary within this suite. One fuel may be used.
- Target fuel formulation requires projection or estimation of the most likely distribution of future market parameters.
- Typically target fuels would not exist in the marketplace and would need to be blended to satisfy composition.

- ***Refining practices play a major role in defining target fuel composition***
- Customary blends contain least value streams that meet fuel specification.
- Input from refiners and blenders should be sought.

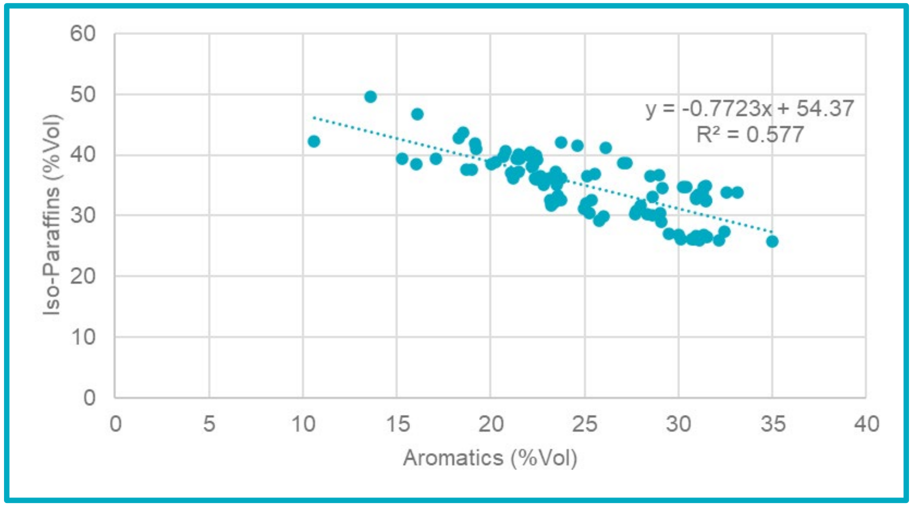


Detailed Hydrocarbon Analysis

- ***Texas summer fuel study provides good insight and valuable data***



Olefin content varies widely and shows a weak trend with aromatics for E10 Texas study (ERG, 2017) regular gasoline.



Tradeoff between iso-paraffins (including alkylate) and aromatics (including reformate) for Texas study E10 regular gasoline. Defining aromatics suggests an alkylate content.

Example of Blending Guide Decision - 1

- ***Fuel Composition Example – E10 Versus E20 Market Fuel***
- Identify appropriate E10 and E20 projected fuel compositions that would be expected at the pump.
- One study fuel (E10) has an established BOB composition.
- The planner contacts refiners and experts and seeks opinions on the most likely makeup of the E20 BOB in comparison to E10 BOB of interest. For simplicity, the following fractions are sought:
  - Olefins
  - C6-C8 aromatics
  - C9+ aromatics
  - n-paraffins
  - iso-paraffins
  - Napthenes
  - Ethanol (known)

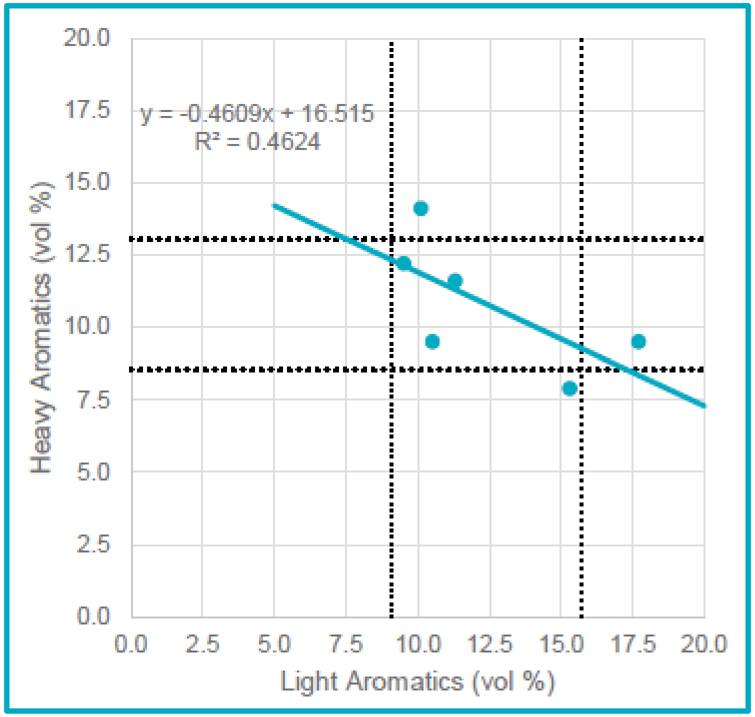
Component	E10-1	E10-2	E10-3	E10-4	E10-5	E10-6	E10-Ave
Olefins	7.5	13.0	10.8	8.0	12.8	14.8	11.2
C6-C8 aromatics	10.1	11.3	15.3	17.7	10.5	9.5	12.4
C9+ aromatics	14.1	11.6	7.9	9.5	9.5	12.2	10.8
n-paraffins	15.5	7.6	16.7	15.3	12.9	10.6	13.1
iso-paraffins	34.8	39.8	31.0	33.8	38.7	34.6	35.5
Napthenes	8.1	6.9	8.3	5.7	5.5	8.4	7.2
Ethanol	9.9	9.8	10.0	10.0	10.1	9.9	10.0

Component	E20-1	E20-2	E20-3	E20-4	E20-5	E20-6	E20-Ave
Olefins	6.9	11.5	10.0	8.0	10.8	12.6	10.0
C6-C8 aromatics	8.1	8.3	10.3	12.7	6.5	6.5	8.7
C9+ aromatics	10.2	6.6	4.9	6.8	5.5	8.8	7.1
n-paraffins	14.4	10.1	16.7	16.1	11.5	10.9	13.3
iso-paraffins	31.7	35.6	30.0	30.8	38.2	32.8	33.2
Napthenes	8.7	7.9	8.3	5.7	7.5	8.4	7.8
Ethanol	20.0	20.0	19.8	19.9	20.0	20.0	20.0

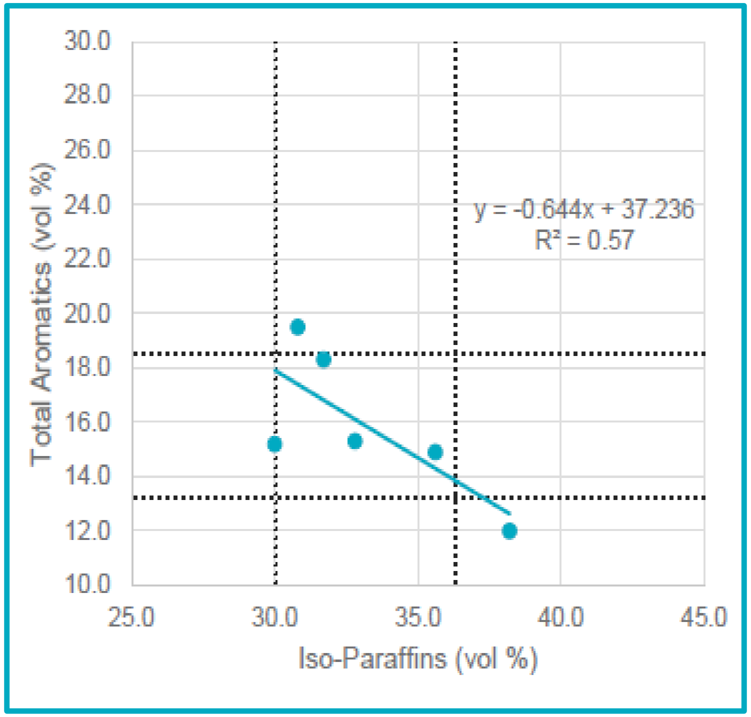
Six hypothetical E10 fuel compositions representing the current market and six corresponding hypothetical E20 fuel compositions recommended by refiners and blenders

Example of Blending Guide Decision - 2

Examples of examining the twelve fuels to reduce the number of variables for fuel blending



Relationship between light and heavy aromatic concentrations for the six E10 fuels. Data from ERG (2017)



Relationship between total (light plus heavy) aromatic concentrations and iso-paraffins for the six E20 fuels

Example of Blending Guide Decision - 3

Options for the study for consideration based on available resources and the tradeoff with vehicle count, cycle count and repeat run count.

- If two E10 and two E20 fuels are considered, aromatics are the target secondary variable.
  - Aromatics vary substantially for the six fuel sets.
  - Aromatics are known to be implicated in PM production.
  - Choices exist between weights of heavy and light aromatics.
  - E10 Total Aromatics Average: 23.2%, Standard Deviation: 2.43%
  - E20 Total Aromatics Average: 15.9%, Standard Deviation: 2.67%
- A reasonable possibility is to use four fuels;
  - E10 fuels with total aromatic content of 21.4% and 25.0%
  - E20 fuels with total aromatic content of 13.9% and 17.9%
- Additional solutions exist for larger suites of fuels
- Heavy to light aromatic split is based on the six fuel compositions for each ethanol content
- Remaining composition takes into account the ethanol and aromatic content

References & Acknowledgements

References

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> Stein, R., Anderson, J. and Wallington, T., "An Overview of the Effects of Ethanol-Gasoline Blends on SI Engine Performance, Fuel Efficiency, and Emissions," SAE Int. J. Engines Vol. 6, 2013, doi:10.4271/2013-01-1635.

> ERG (2017), Eastern Research Group, 2017 Summer Fuel Field Study, https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/582177149010-20170831-ergi-2017SummerFuelFieldStuday.pdf

The complete blending guide and a webinar are available.
https://www.transportenergystrategies.com/2020/08/20/a-fuel-blending-guide-for-ethanol-identifying-sound-practices-for-acquiring-or-blending-fuels-for-studies-of-emissions-changes/

Funding for development of the blending guide was provided by the Urban Air Initiative.