Effect of Fuel Composition on PM Emissions

LEV III Workshop
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HONDA
The Power of Dreams

Overview

- Particulate Matter (PM) is a significant concern.
- Recent efforts to reduce PM focus on engines, not fuel.
  - Current LEV III proposal: 10mg → 6mg → 3mg/mi
- Honda theorized that better fuel specifications could reduce PM.
  - This was confirmed by research and testing.
- Honda's PM Index can lead to fuel specifications which reduce previously unaccounted variations in PM measurement

Background

- Fuel formulation can have a profound effect upon tailpipe emissions of particulate matter (PM).
- This effect is not directly addressed in CaRFG3 market fuel specifications or in the proposed CaRFG3 certification fuel specifications, although some regulated properties (e.g. T_{90}) do affect PM emissions.
- The fuel effect on PM is also not addressed in the current CaRFG3 predictive model.

Proposed CaRFG3 Certification Fuel Specifications

Fuel Property	Limit	Test Method
RVP	6.95 psi	TBD
T50	214 oF	TBD
T90	312 oF	TBD
Total Aromatic Hydrocarbons	24 vol. %	TBD
Olefins	7.4 vol. %	TBD
Total Oxygen	3.5	TBD
Sulfur	8 ppm by wt.	TBD
Benzene	0.74 vol. %	TBD
Ethanol	10 vol. %	TBD

Source: CARB's "Preliminary Discussion Paper," February 2010

Pollutants Included in Predictive Model

Pollutant Predictions	**Units**
Oxides of Nitrogen (NOx)	gm/mile
Exhaust Hydrocarbons (HC)	gm/mile
Evaporative Hydrocarbons (HC)	Percent Change (Candidate Fuel Relative to Reference Fuel)
Exhaust Potency-Weighted Toxics (PWT)	mg/mile
Evaporative Benzene	mg/mile
Exhaust CO (Adjustment Factor for Oxygen)	gm/mile

Source: "California Procedures for Evaluating Alternative Specifications for Phase 3 Reformulated Gasoline using the California Predictive Model," August 2008

“PM Index” Concept

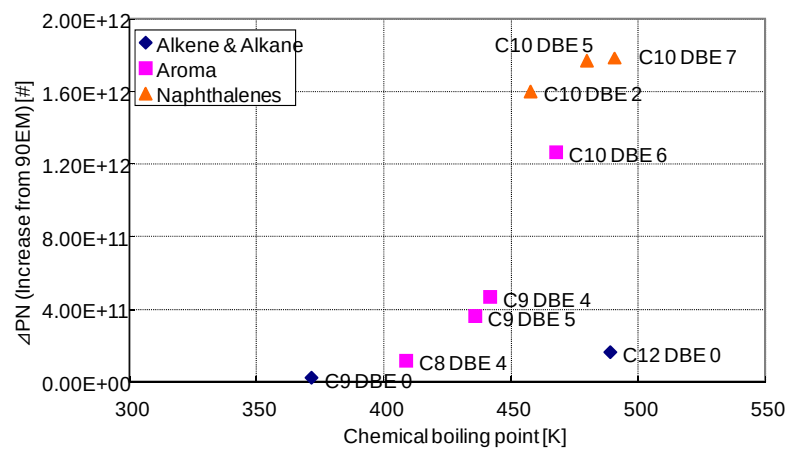
- Over the last year, Honda has been working on a model that can predict trends in tailpipe PM emission levels based on fuel properties. We call this model the “PM Index.”

- Overview of the development work:
  - Pure hydrocarbons were added to an Indolene base fuel at nominally 10% by weight; i.e., each test fuel consisted of the base fuel spiked with one hydrocarbon.
  - PM emissions were measured over the NEDC cycle for each fuel. PM number (in place of PM mass) was used as the metric to improve accuracy at lower PM emission levels.

- PM emissions were determined to primarily be a function of the DBE* and vapor pressure of the fuel components:

$$PM\ \ Index = \sum_{i=1}^{n}\left(\frac{DBE_i + 1}{V.P(443K)_i} \times Wt_i\right)$$

- This research, and subsequent test results, will be presented at SAE in October. (2 papers)

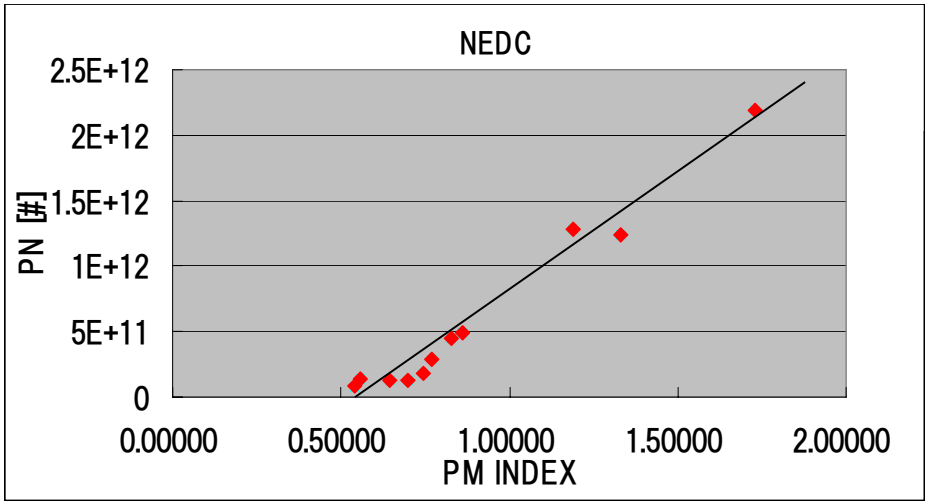


Example of test fuels, in this case arranged by BP, DBE, and PM number increase from the base fuel.

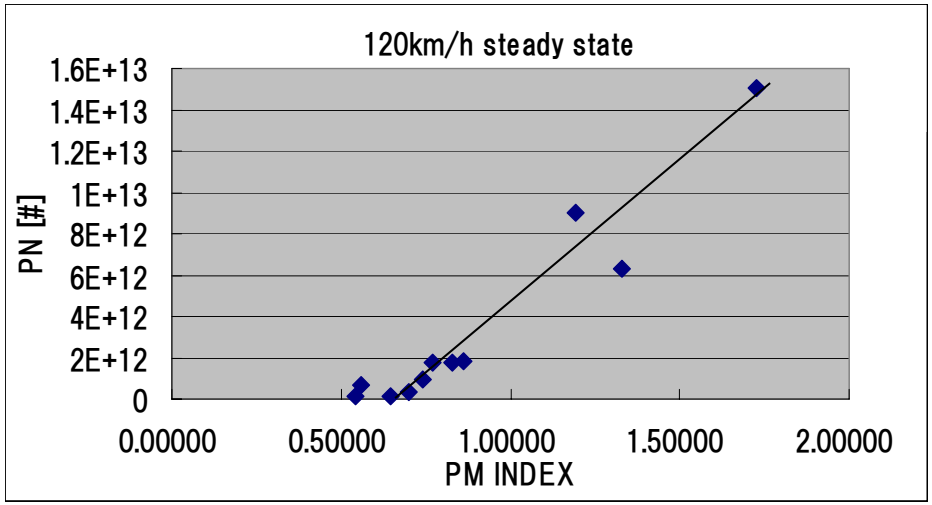
*DBE (Double Bond Equivalent) is essentially an indication of the number of double bonds or rings present in the molecule, and can be easily calculated from the molecular formula.

Confirmatory Tests Performed by Honda

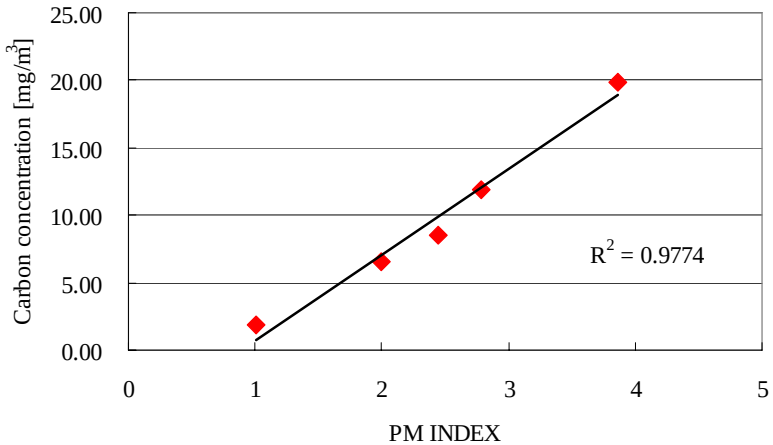
- **EUDC cycle**
- **Test fuels and market fuels**
- **Turbo-charged PFI vehicle**



- **120 km/h steady-state**
- **Test fuels and market fuels**
- **Turbo-charged PFI vehicle**



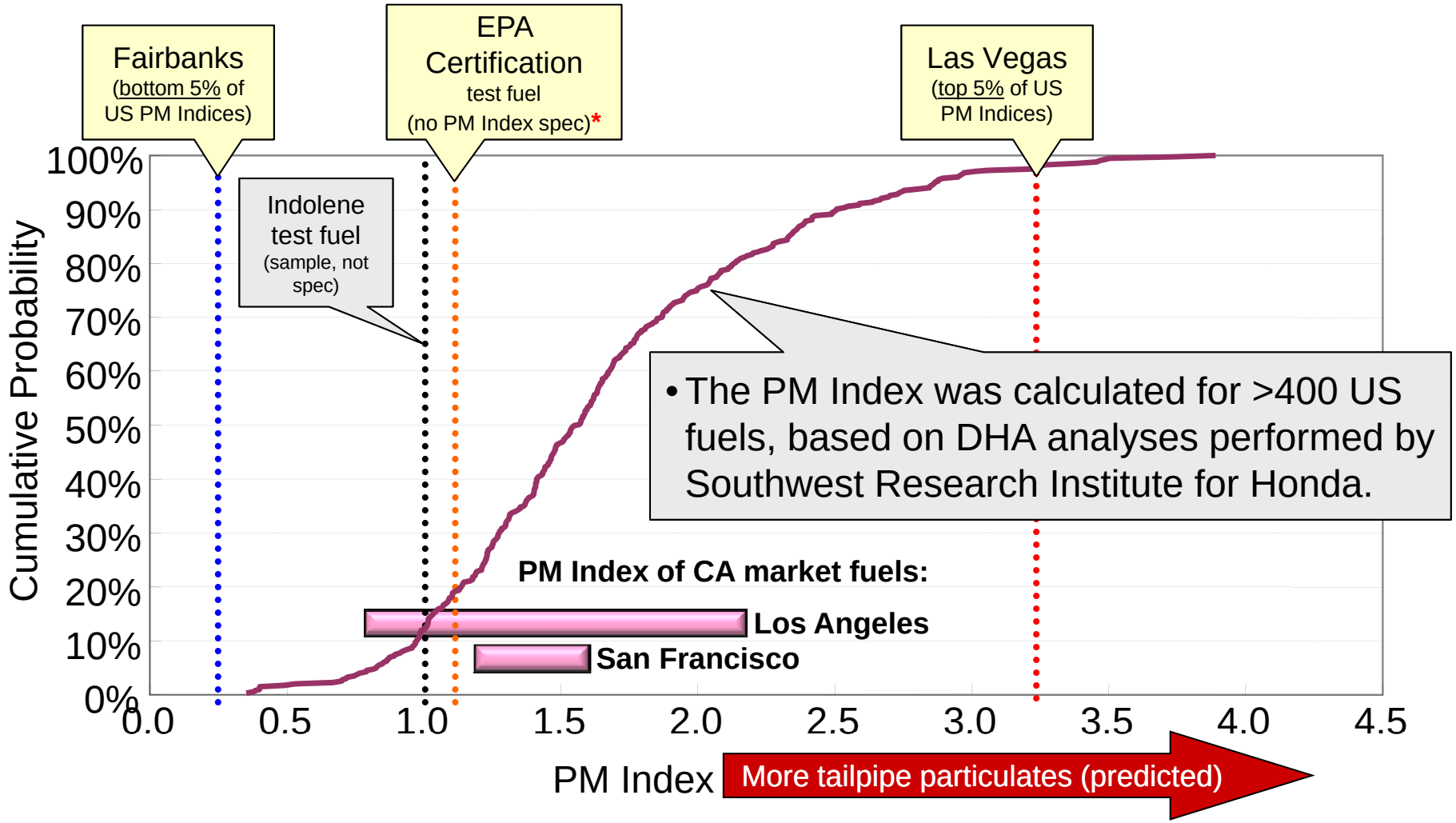
- **Engine bench, 3000rpm @ full load**
- **Market fuels**
- **Normally-aspirated PFI engine**



- PM Index correlated well with PM number <u>and</u> mass.
- The correlation held regardless of engine technology and cycle.

Testing Performed at SwRI – Background

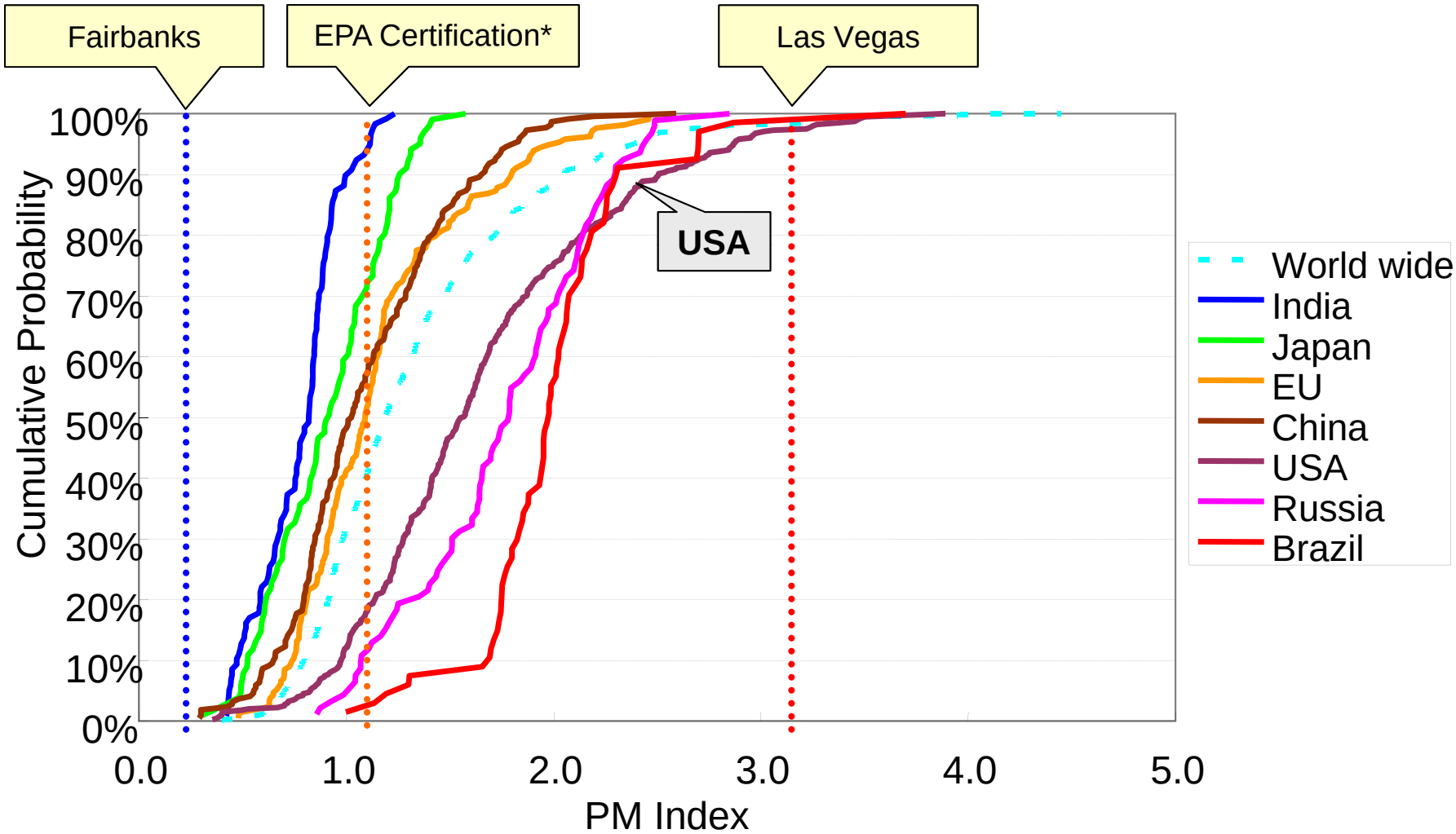
- Three test fuels were chosen, based on the range of PM Indices calculated for US market fuels. The Fairbanks and Las Vegas fuels were retrieved from the market in drum quantities.



* Since there is no PM Index specification, certification fuel from different suppliers, or a different batch from the same supplier, will have different characteristics and a different PM Index.

Testing Performed at SwRI – Background

- PM Index of the test fuels compared to the distribution of PM Indices worldwide.
- Note that the US has the widest range of PM Indices, and also some of the highest values.



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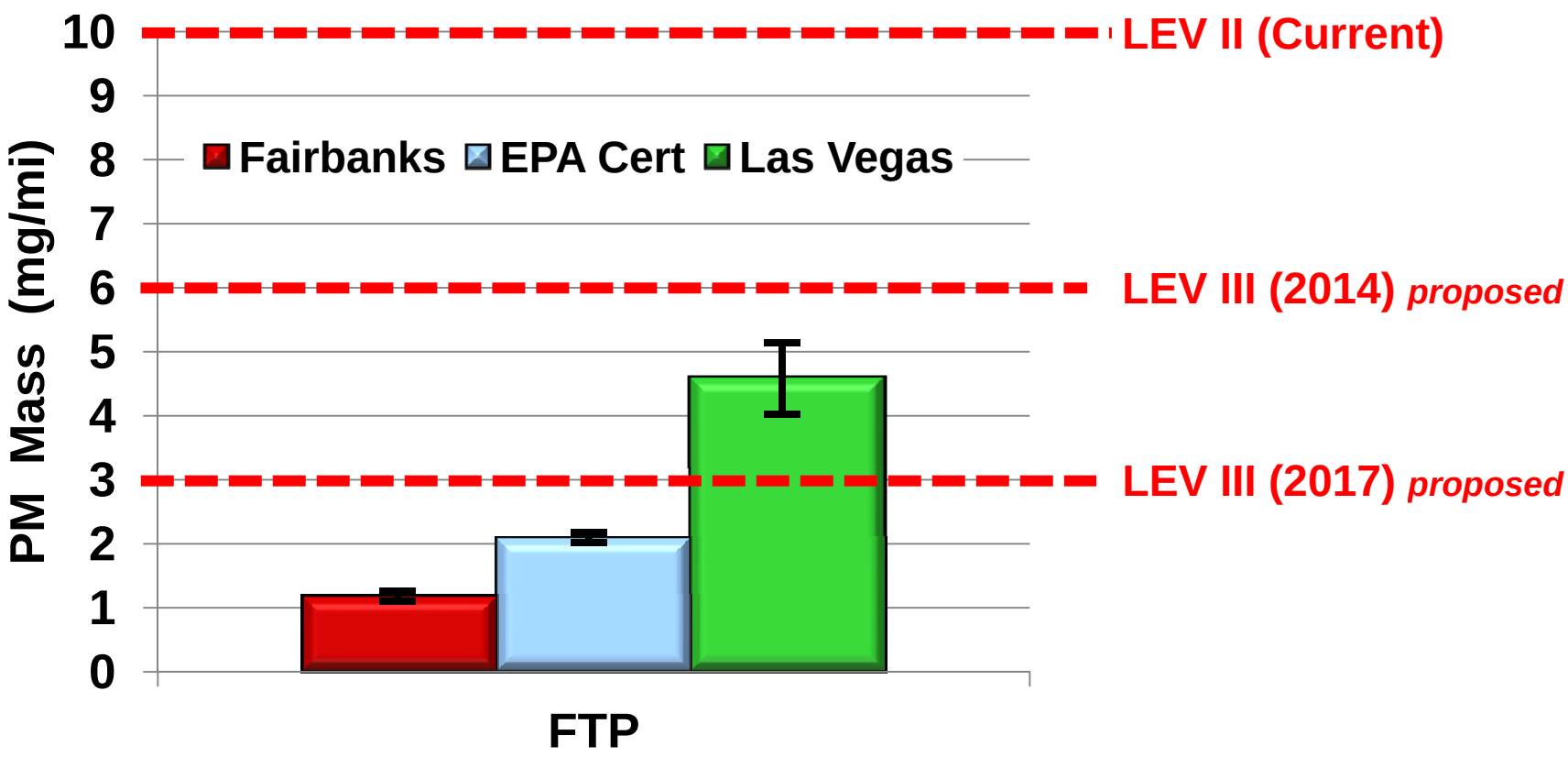
SwRI Testing – PM Mass Results

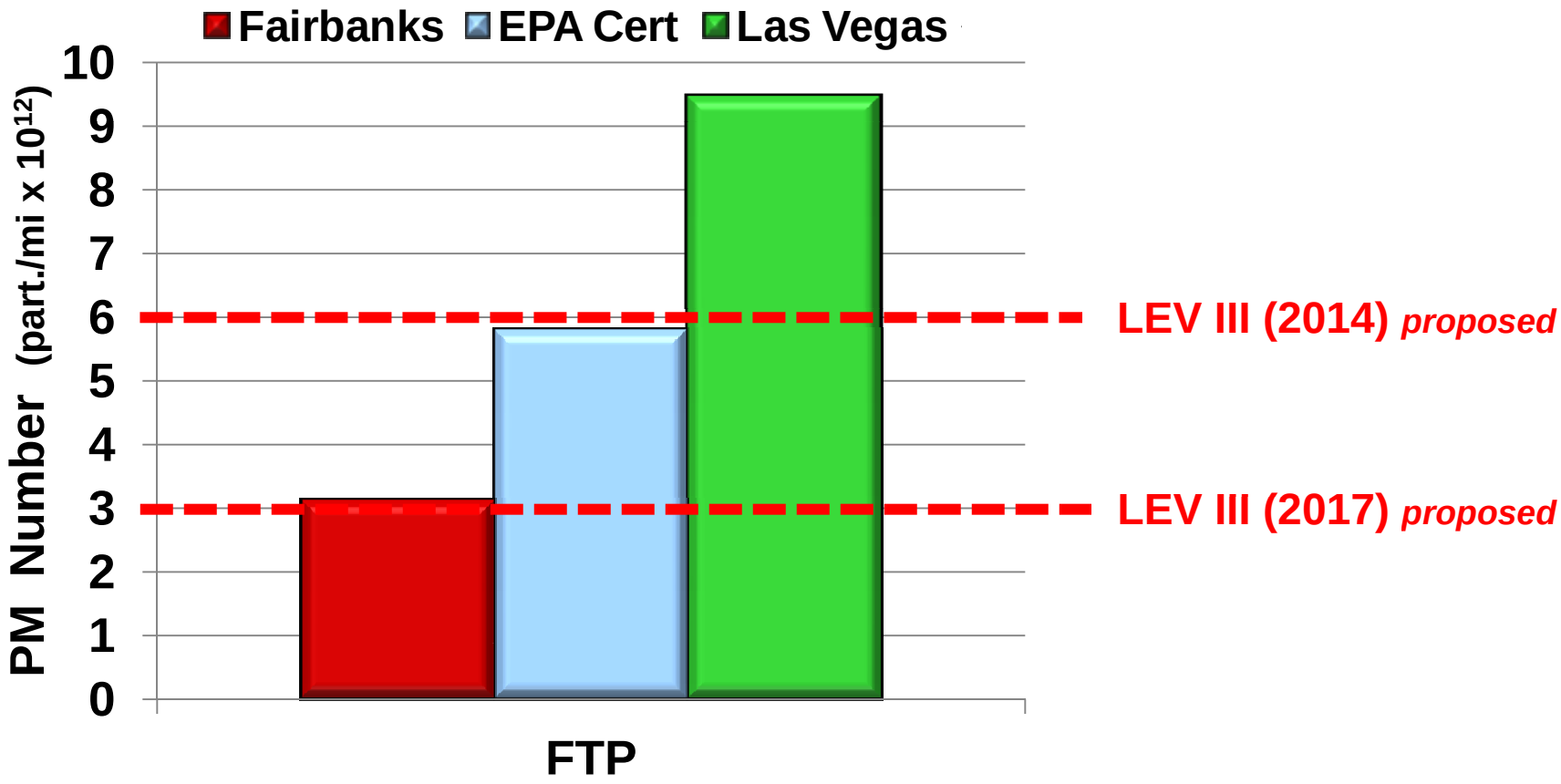
- Factor of 4 difference in FTP PM mass emissions between Fairbanks fuel and Las Vegas fuel.
- Variations in the PM Index of the cert fuel can make the difference between a pass and a fail.



- Test vehicle: 2009 2.0L GDI, LEV2 ULEV (not a Honda product)

SwRI Testing – PM Number Results

- FTP PM number emissions from Las Vegas fuel >3x higher than those from Fairbanks fuel.
- Variations in the PM Index of the cert fuel can make the difference between a pass and a fail.



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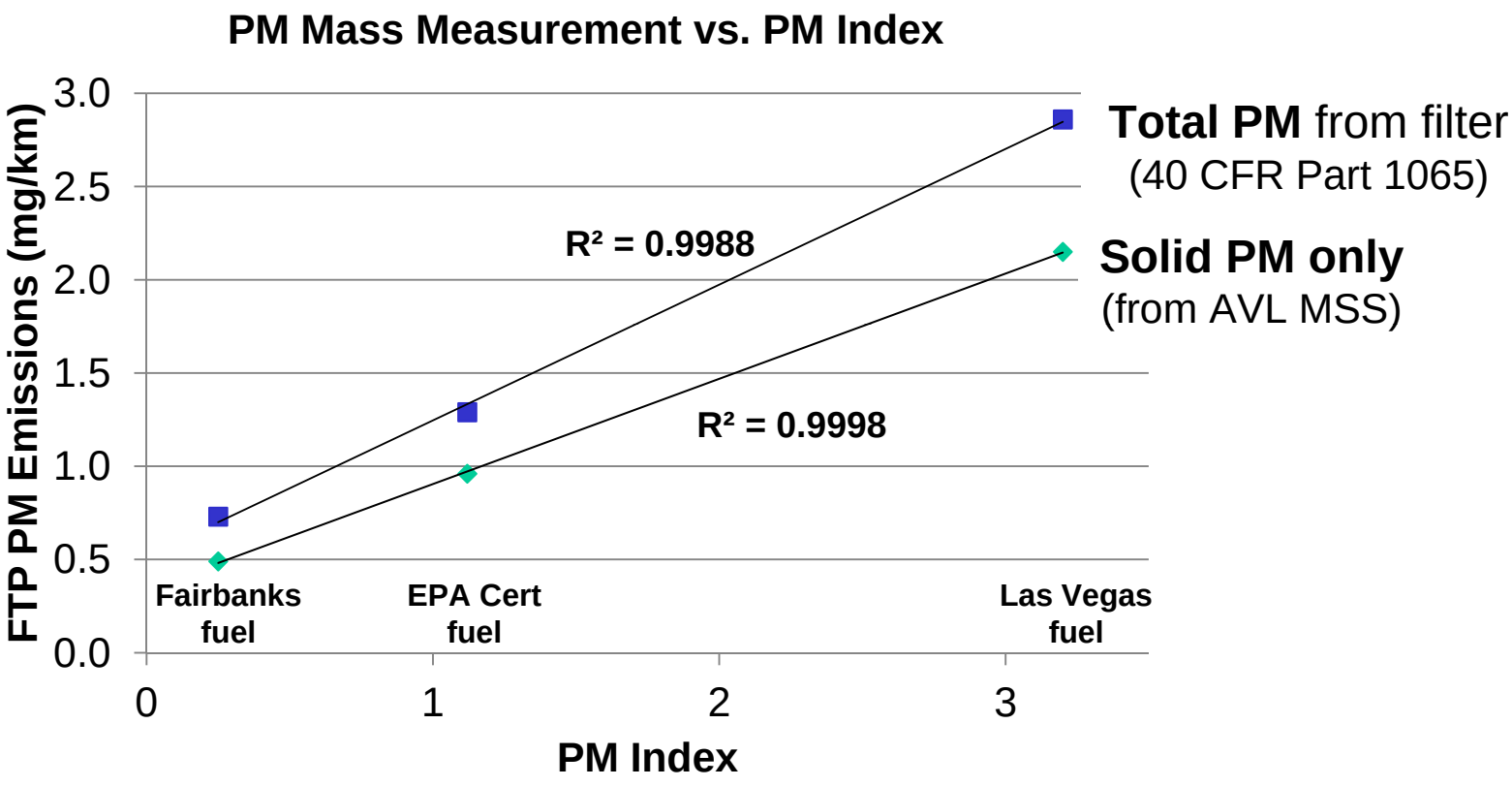
SwRI Testing – Correlation with PM Index

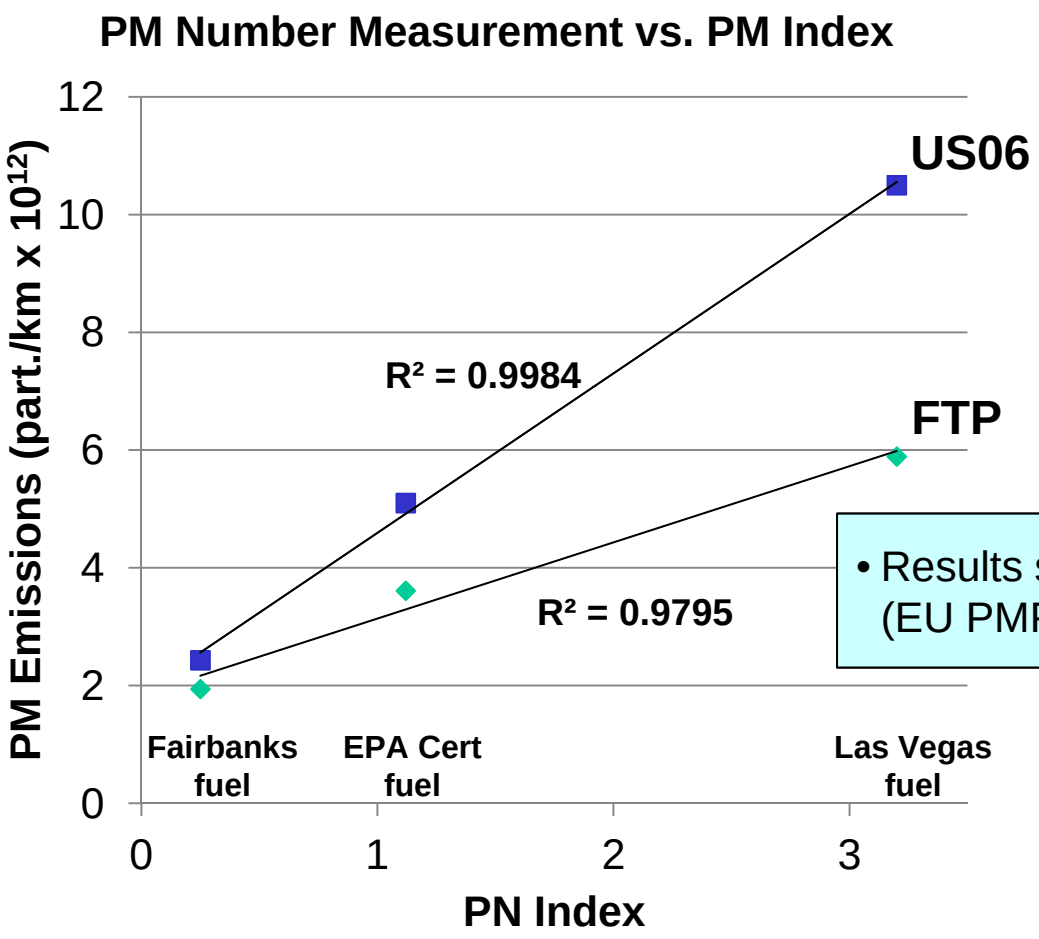
PM Mass



- Excellent correlation between PM Index and actual (measured) PM mass emissions.

SwRI Testing – Correlation with PM Index

PM Number



- Results shown are for solid PM > 23nm. (EU PMP-type measurement.)

- Good correlation also achieved between PM Index and actual (measured) PM <u>number</u> emissions.

Summary & Recommendations

- Fuel formulation can have a **significant** effect upon tailpipe emissions of particulate matter (PM).
- The "PM Index" provides a method by which tailpipe PM emission trends can be predicted, based on fuel composition.

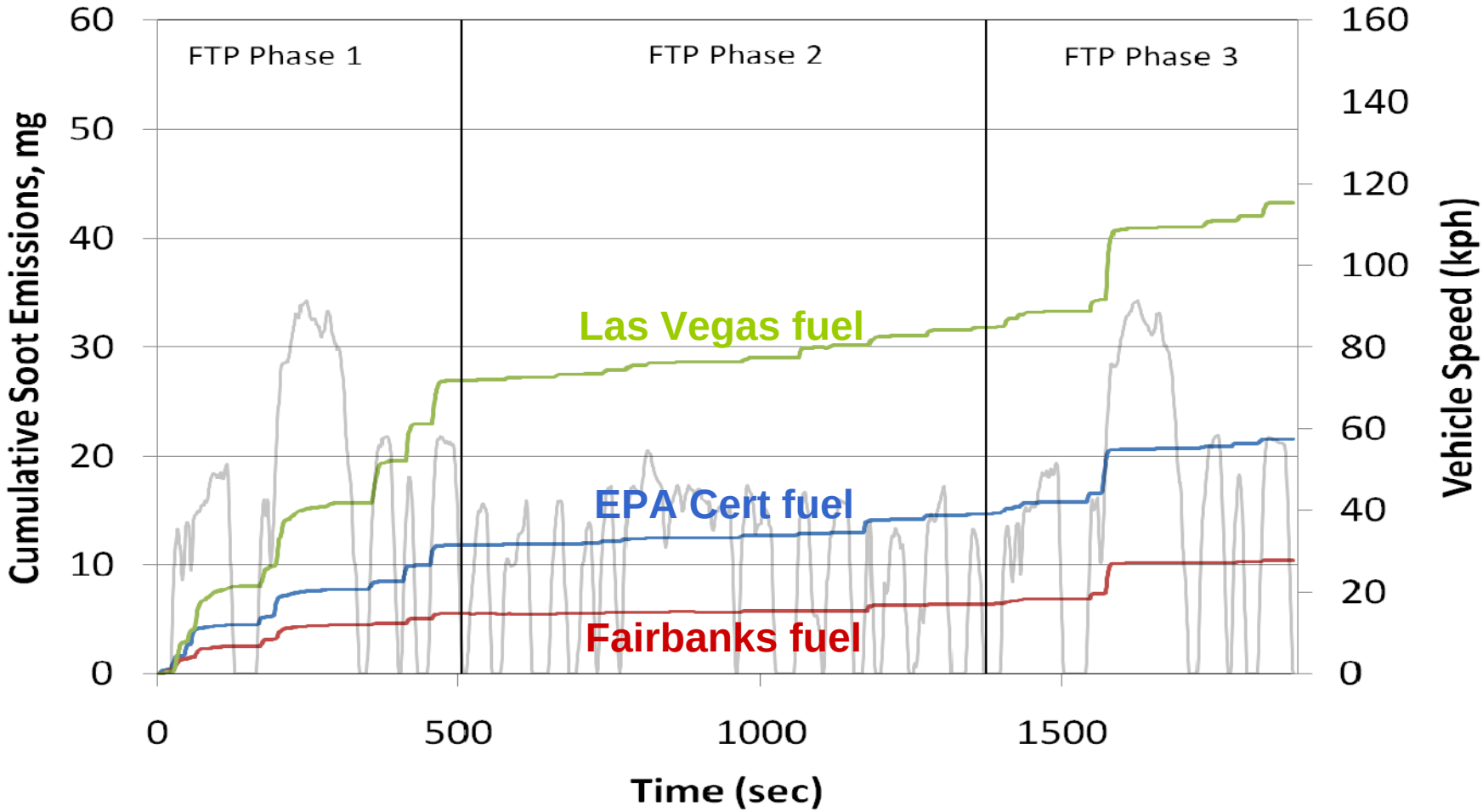
Recommendations:

- Control the Certification Fuel:
  - The CaRFG3 certification fuel specification should include the PM Index (or similar).
- Control the Market Fuel:
  - Market fuel specifications (including the CaRFG3 predictive model) should also include the PM Index. Improvements to market fuel specs will affect real-world PM emissions.

Backup Slides

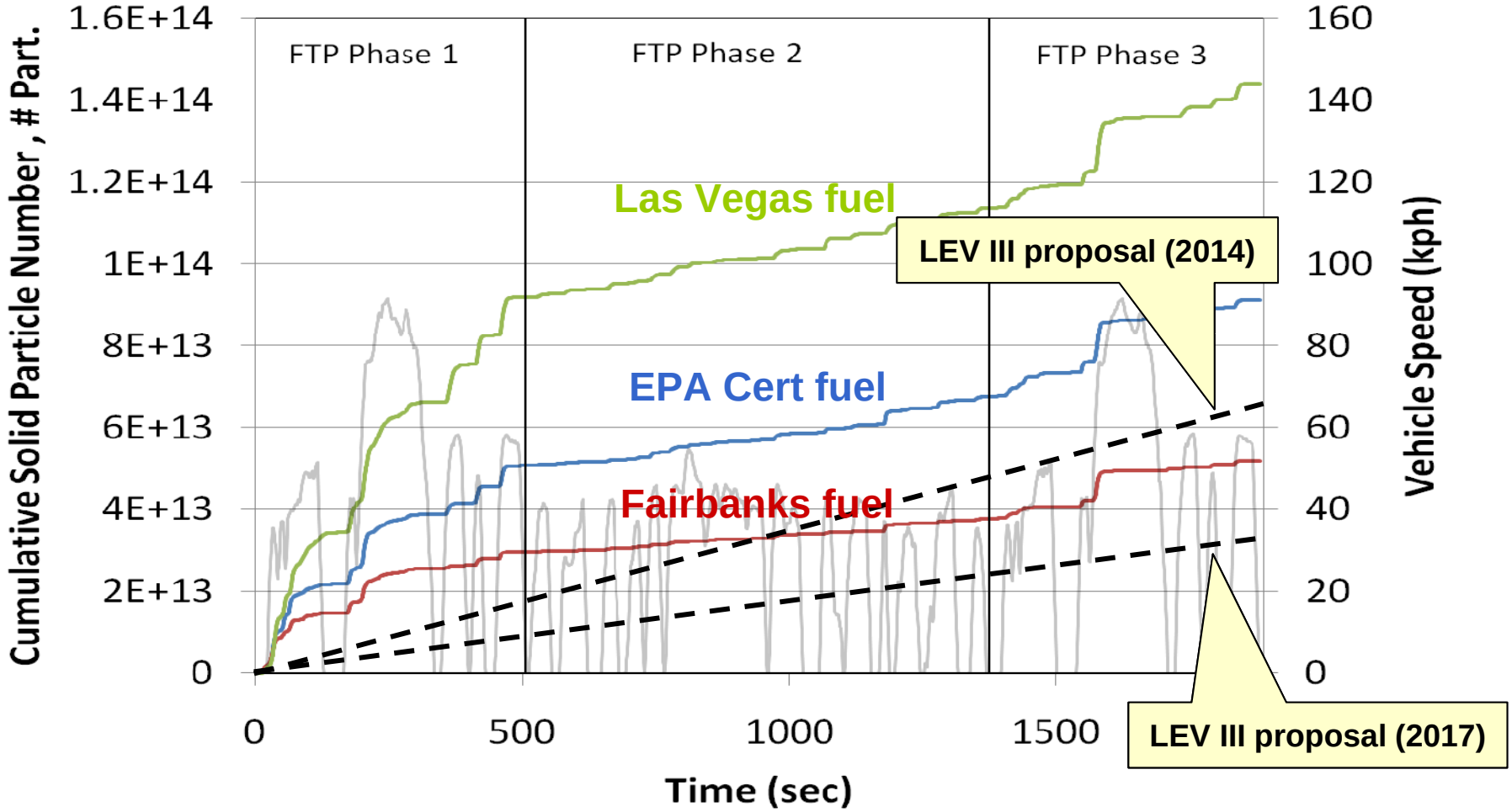
PM Mass – Cumulative Emissions

FTP



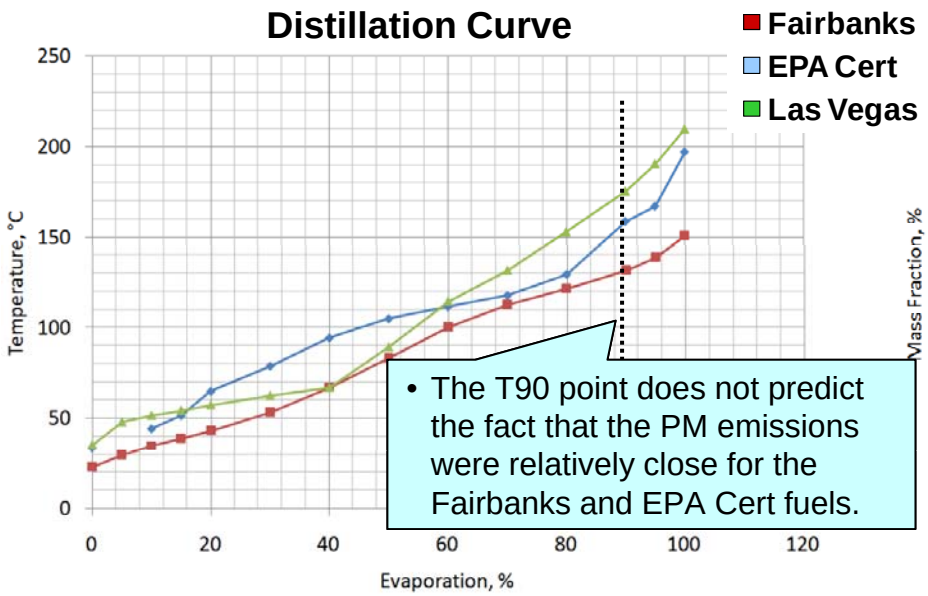
Solid PM Number – Cumulative Emissions

FTP

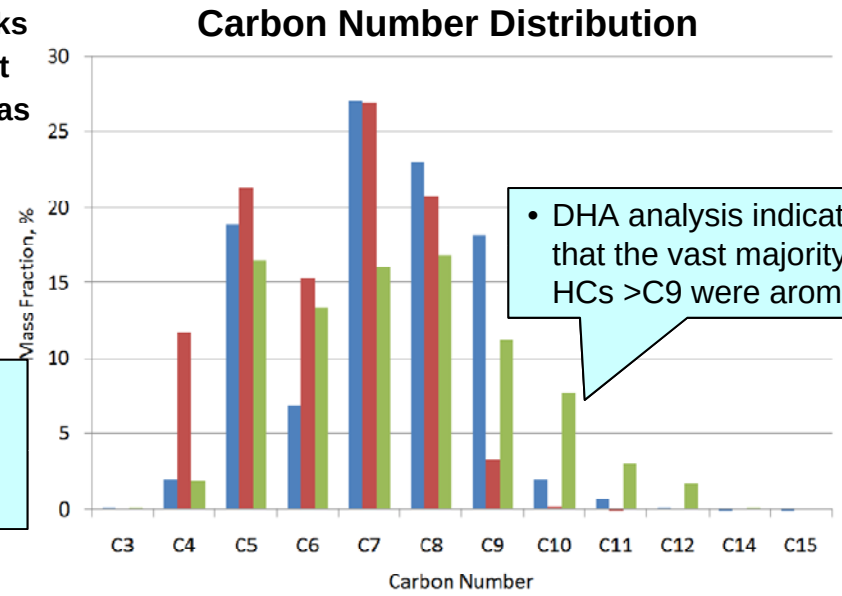


- Control of PM emissions throughout Phase 1 of the FTP (not just the cold-start period) is critical.

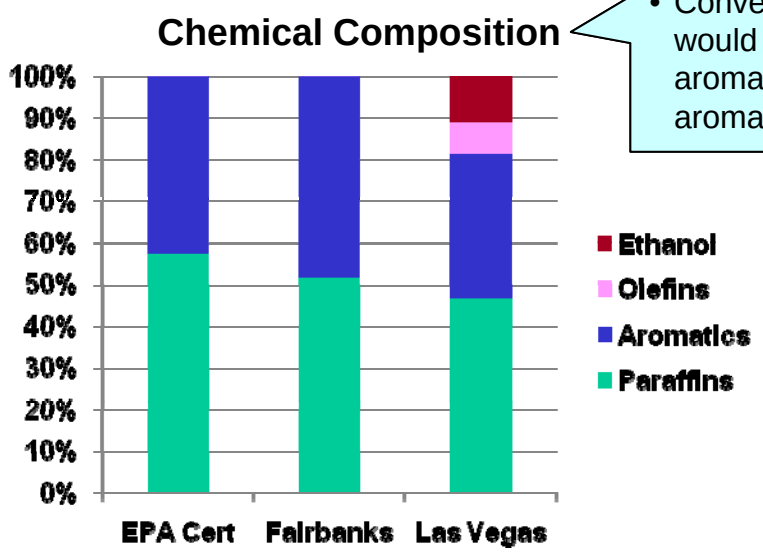
Other Test Fuel Properties



- The T90 point does not predict the fact that the PM emissions were relatively close for the Fairbanks and EPA Cert fuels.



- DHA analysis indicated that the vast majority of HCs >C9 were aromatic.



- Conventional wisdom for PM emissions: The Las Vegas fuel would be relatively low (10% ethanol content and moderate aromatic level) and the Fairbanks fuel relatively high (high aromatics). Actual results were the complete opposite.

- It is difficult to judge the PM-producing potential based only on these traditional properties; assumptions are conflicting.
- Honda's "PM Index" is a better predictor.