

Particulate Matter (PM) Emissions from Low Greenhouse Gas Engine Technologies

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Outline

- Background
 - LEV III PM standards
 - Test cycles (FTP and US06)
- Vehicle Testing Overview
- Test results
 - FTP and US06 emissions
 - Variability
- Next Steps
- Summary

LEV III phase-in of FTP PM standards

3 mg/mi	2017	2018	2019	2020	2021
Percent of Vehicles	10	20	40	70	100

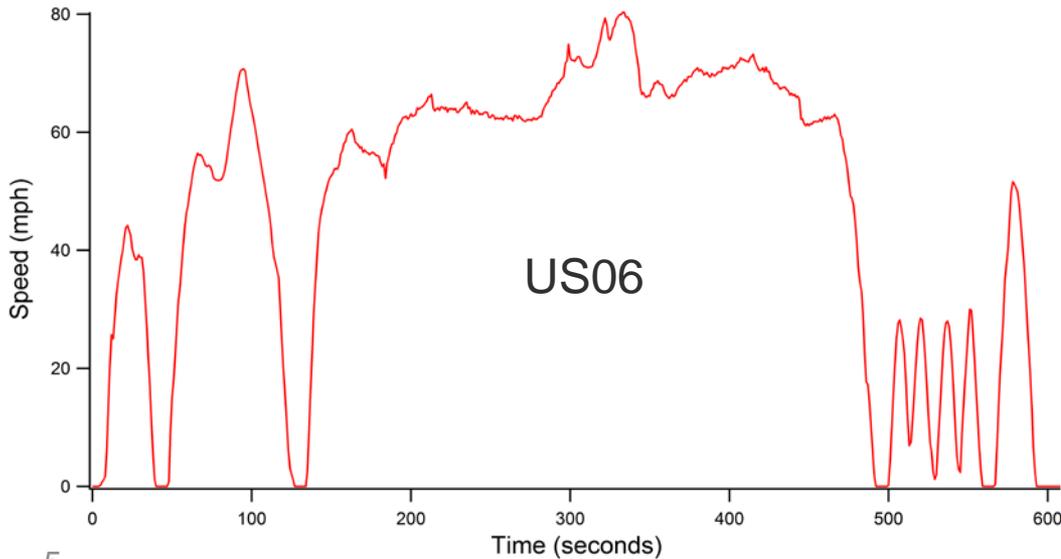
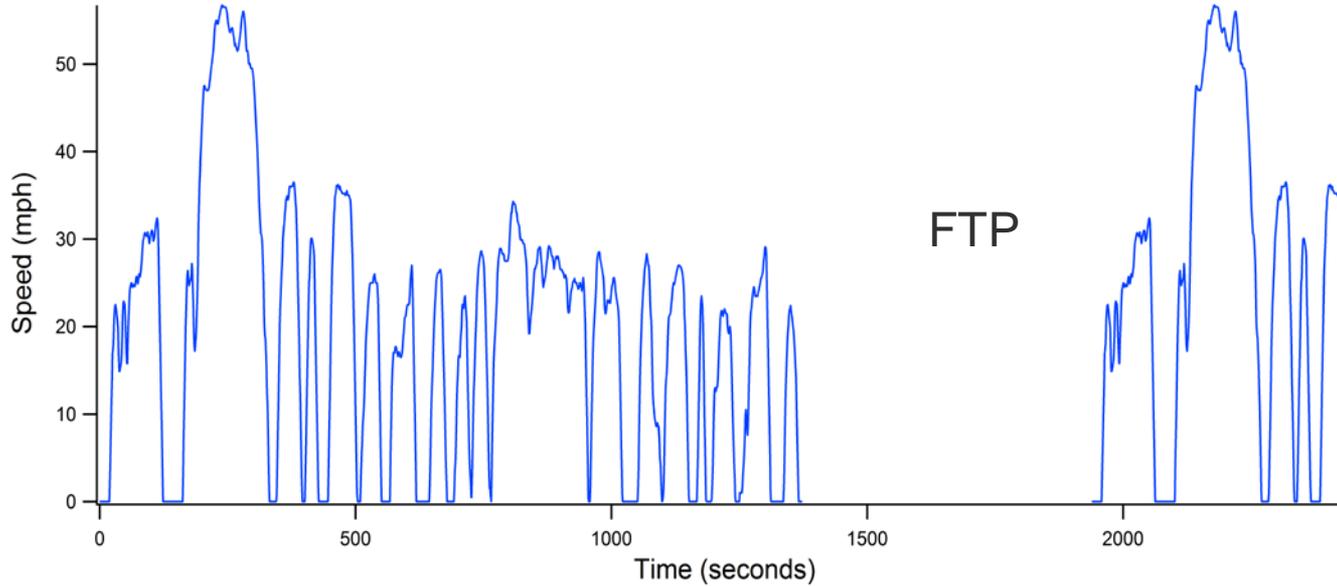
1 mg/mi	2025	2026	2027	2028
Percent of Vehicles	25	50	75	100

LEV III phase-in of US06 PM standards

6 mg/mi	2017	2018	2019	2020	2021
Percent of Vehicles	10*	20*	40	70	100

*Vehicles in 2017 and 2018 certified to interim higher standards of 10 mg/mi

FTP and US06 cycles



Trait	US06	FTP
Startup	Hot start	Cold start
Avg speed	48 mph	21 mph
Top speed	80 mph	57 mph
Top accel.	8.4 mph/sec	3.3 mph/sec
Time	10 min	31 min
Distance	8 miles	11 miles
Soak	None	10 min

Testing Overview

- Evaluate the state of current PM emission control technology
- Focus on newer generation of low-GHG emitting vehicles
 - Downsized turbocharged GDI
 - Atkinson cycle GDI
 - Dual PFI/GDI systems
 - Piezo injectors
 - Plug-in Hybrid Electric Vehicles (PHEV)
- Ten vehicles tested to date, more to come

PM results

Vehicle	Engine	Odometer	FTP Avg Mass (mg/mi)	US06 Avg Mass (mg/mi)
2015 Mazda 3	2.0 GDI Atkinson	4,000 miles	1.4	0.6
2016 Honda Accord	2.4 GDI	27,000 miles	0.9	1.3
2014 Ford Fiesta	1.0 GDI turbo	26,000 miles	1.4	1.4
2015 Ford F-150	2.7 GDI turbo	15,000 miles	5.4	3.8
2012 Lexus IS350	3.5 GDI+PFI	40,000 miles	5.9	1.3
2015 Subaru BRZ	2.0 GDI+PFI	15,000 miles	1.0	3.1
2016 Toyota Tacoma	3.5 GDI+PFI Atk.	51,000 miles	0.4	2.3
2013 Chevy Volt	1.4 PHEV PFI	8,000 miles	0.3	0.1
2013 Toyota Prius	1.8 PHEV PFI	25,000 miles	0.1	0.3
2016 Hyundai Sonata	2.0 PHEV GDI	6,000 miles	1.1	1.6

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2015 Ford F-150	2.7 GDI turbo	15,000 miles	5.4	3.8
2012 Lexus IS350	3.5 GDI+PFI	40,000 miles	5.9	1.3
2015 Subaru BRZ	2.0 GDI+PFI	15,000 miles	1.0	3.1
2016 Toyota Tacoma	3.5 GDI+PFI Atk.	51,000 miles	0.4	2.3
2013 Chevy Volt	1.4 PHEV PFI	8,000 miles	0.2	0.1
2013 Toyota Prius	1.8 PHEV PFI			
2016 Hyundai Sonata	2.0 PHEV GDI			

One early generation of dual GDI/PFI engine is high emitting, but other two are low emitting – and their emission profile appears more PFI-like

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PFI hybrids very low emitting



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Most other recent GDI vehicles are in the 1.0 - 1.5 mg/mi range

Real-time PM

- Real-time PM data can indicate where, over the course of a test, PM emissions are occurring
 - Cold start emissions
 - High load transients/acceleration
- Real-time data can also help pinpoint test-to-test differences that can lead to increased variability

FTP emissions

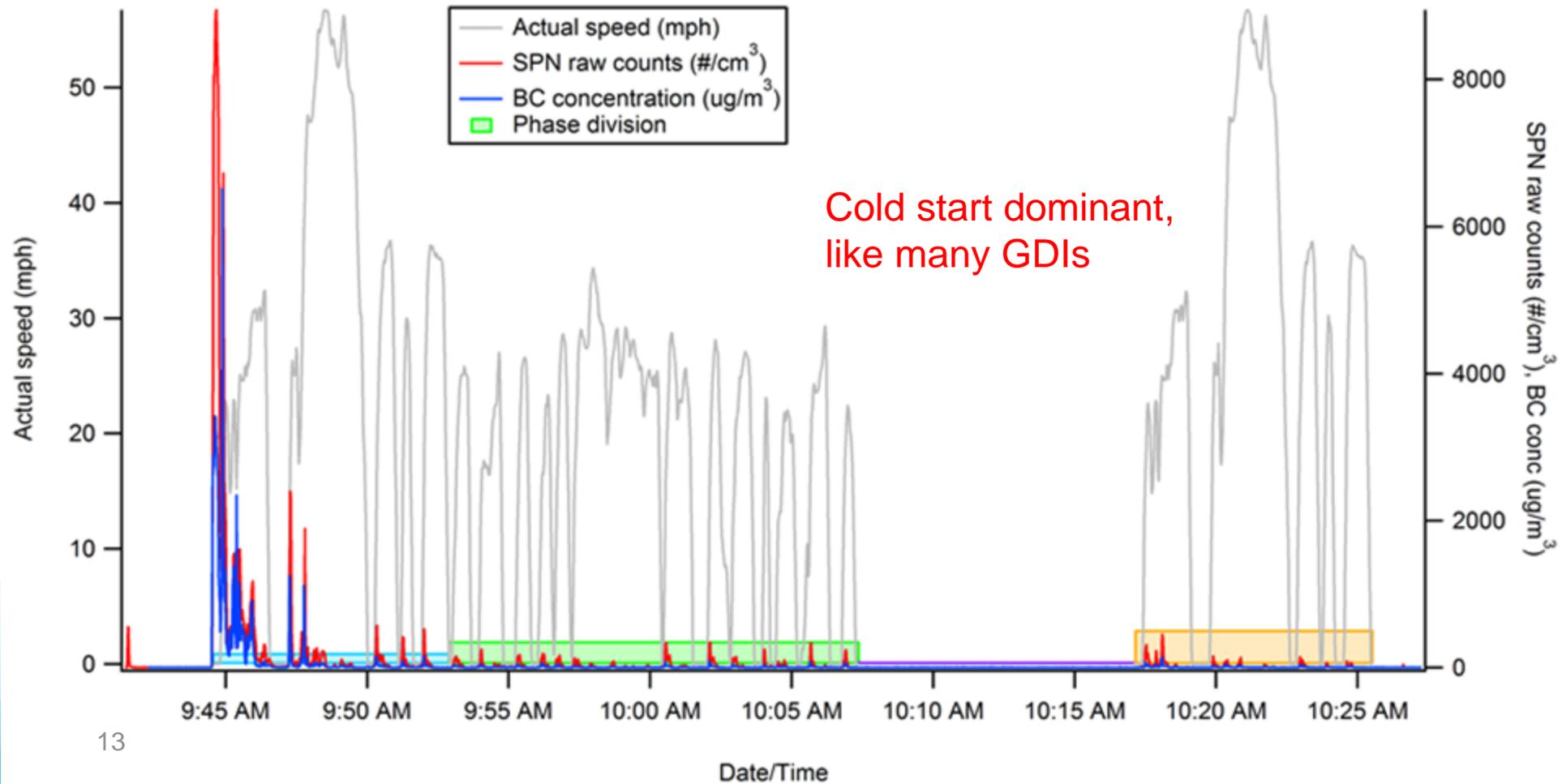
Most GDI vehicles have cold-start dominant emissions

- Fuel/Air less well mixed than PFI
- More impingement on surfaces
- Catalyst light-off strategy

MAZDA 3 on FTP cycle

2015 MAZDA 3
2 liter 4 cyl GDI

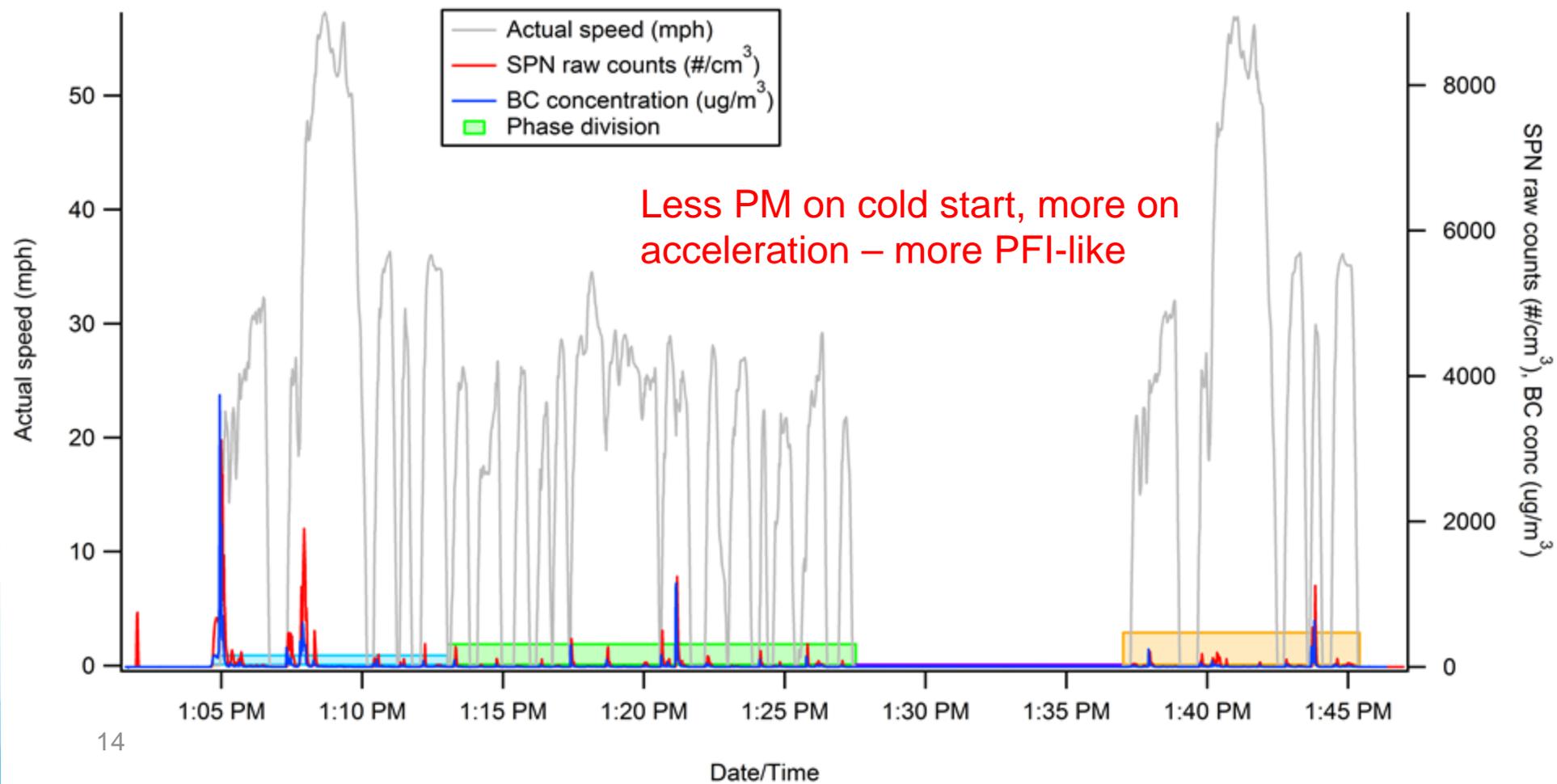
	PM mass (mg/mi)
Total	1.29
Phase 1	5.49
Phase 2	0.21
Phase 3	0.16



Subaru BRZ on FTP cycle

2015 SUBARU BRZ
Engine: 2 liter 4 cyl GDI+PFI

	PM mass (mg/mi)
Total	0.9
Phase	PM mass (mg/mi)
1	1.69
2	0.81
3	0.46



Variability

One of the major concerns expressed with meeting stringent PM standards is variability

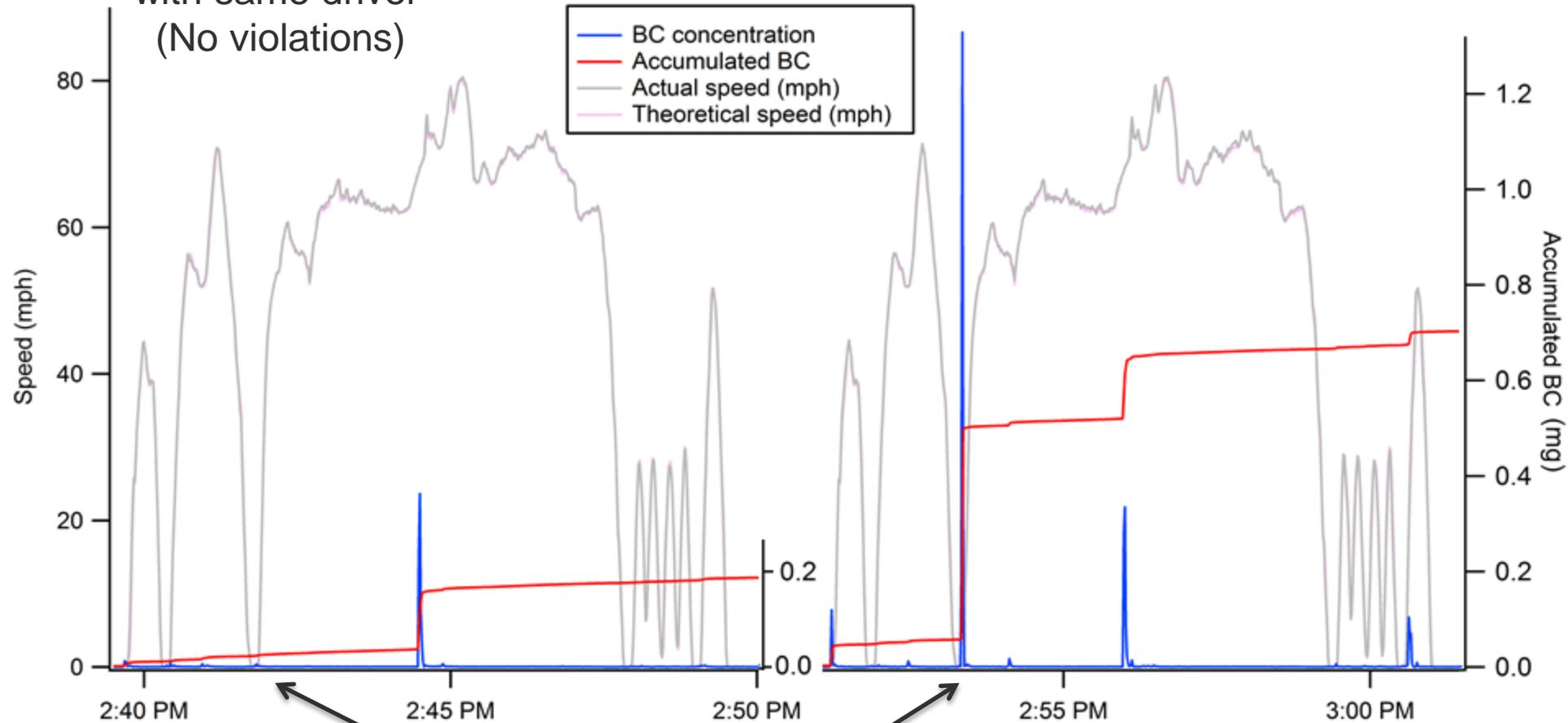
- FTP emissions of GDI vehicles
 - Usually dominated by cold start
 - ➔ relatively consistent from test-to-test
- US06 cycles generally show more variability than FTP cycles
 - No cold start in US06
 - ➔ all PM emissions are from the drive
 - US06 includes higher speed and higher acceleration
 - ➔ more driver dependent

Variability of FTP and US06

Vehicle	FTP			US06		
	Average Mass (mg/mi)	SD (mg/mi)	COV	Average Mass (mg/mi)	SD (mg/mi)	COV
2015 Mazda 3	1.4	0.18	12%	0.6	0.23	40%
2016 Honda Accord	0.89	0.19	21%	1.3	0.85	67%
2014 Ford Fiesta	1.4	0.25	18%	1.4	0.18	14%
2015 Ford F150	5.4	0.39	7%	3.8	2.07	54%
2012 Lexus IS350	5.9	0.12	2%	1.3	0.05	4%
2015 Subaru BRZ	1.0	0.21	21%	3.1	1.22	40%
2016 Toyota Tacoma	0.40	0.05	12%	2.3	0.98	43%
2013 Chevy Volt	0.32	0.19	58%	0.11		
2013 Toyota Prius	0.12	0.09	71%	0.33	0.08	23%
2016 Hyundai Sonata	1.2	0.33	27%	1.6	1.45	90%
Total average	1.8	0.20		1.6	0.79	

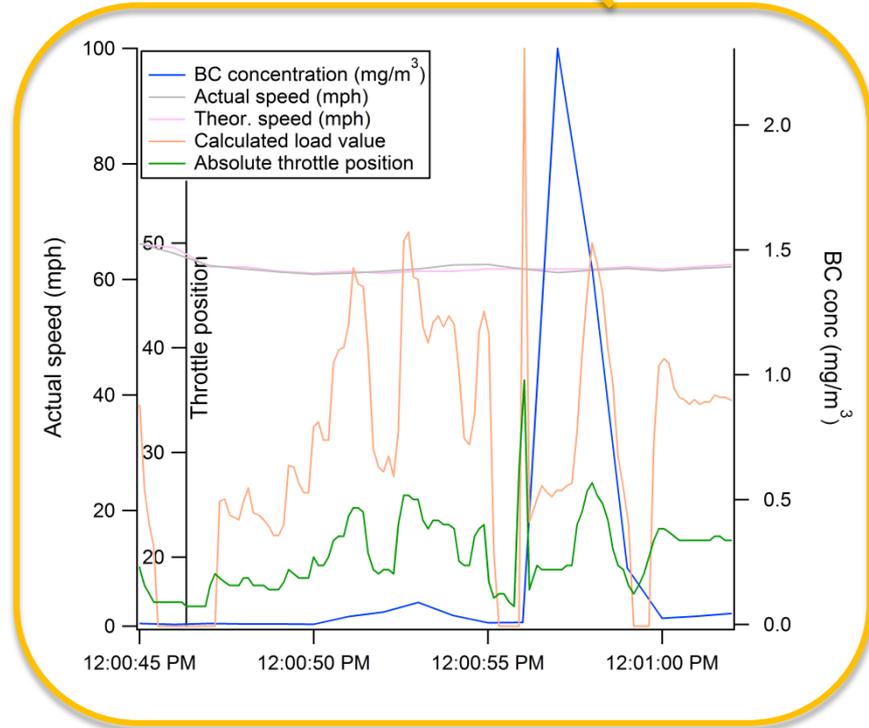
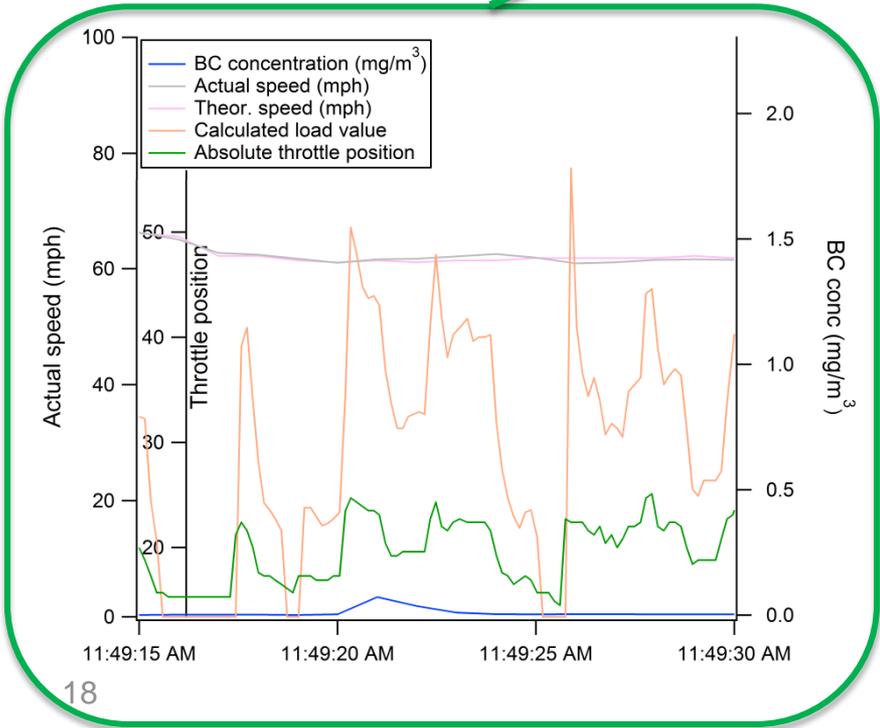
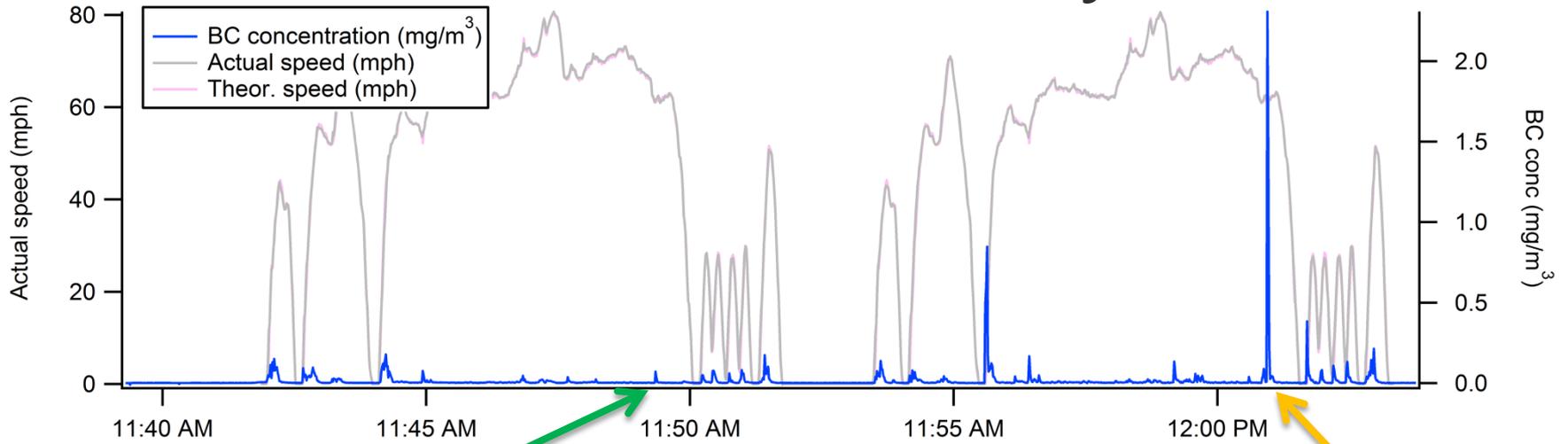
US06 Variability

Consecutive cycles
with same driver
(No violations)



Same part
of trace

US06 Variability



Next Steps

- More Vehicles to be tested
 - 2014 Mercedes CLA
 - 2016 VW Jetta 1.4
 - 2016 Honda Civic 1.5
 - 2016 Toyota Prius
 - 2014 Mini Cooper
- Testing with GPF
 - 2016 Ford F-150 2.7 (~5 mg/mi on FTP)
 - 2015 Chevy Malibu (not yet tested)

GPFs courtesy of MECA

Summary

- FTP emissions
 - Most newer GDIs easily meeting upcoming 3 mg/mi standard
 - Controlling cold start PM emissions appears to be the most critical factor to robustly meet 1 mg/mi
- US06 emissions
 - Most newer GDIs tested are emitting at 25%-50% of the upcoming 6 mg/mi standard
 - Test-to-test variability is significant