

# UNDERSTANDING LUBRICANT REQUIREMENTS OF HYBRID-ELECTRIC VEHICLES

Dean B. Clarke, Infineum USA

API Detroit Advisory Panel – Dearborn, MI April 2014

Performance you can rely on.



# Outline



- Background
- Tear Down Inspection Results
- Field Testing Toyota Camry Hybrid Taxis in NYC
- Summary/Conclusions



# Background



- Hybrid electric vehicle options have grown rapidly in recent years
- Infineum has launched a research program to understand lubricant requirements of hybrid electric vehicles
- First phase: engines from a 400K mile 2006 Toyota Prius and a 264K mile 2009 Toyota Camry Hybrid in taxi service inspected for hardware distress or other unusual features
- 2<sup>nd</sup> phase: Lubricants with varying rheological and performance properties were tested in a NYC fleet of 2012 Toyota Camry Hybrids



# Toyota Prius 400K Mile Engine Had Cleanliness Issues



## Non-Hybrid Reference Vehicle

2005 Cadillac Deville  
GM 4.6L Northstar V-8 Engine  
Service: Limousine in NJ  
200K miles; 10K-15K mi ODI  
ILSAC GF-5 SAE 5W-30



## 2006 Toyota Prius

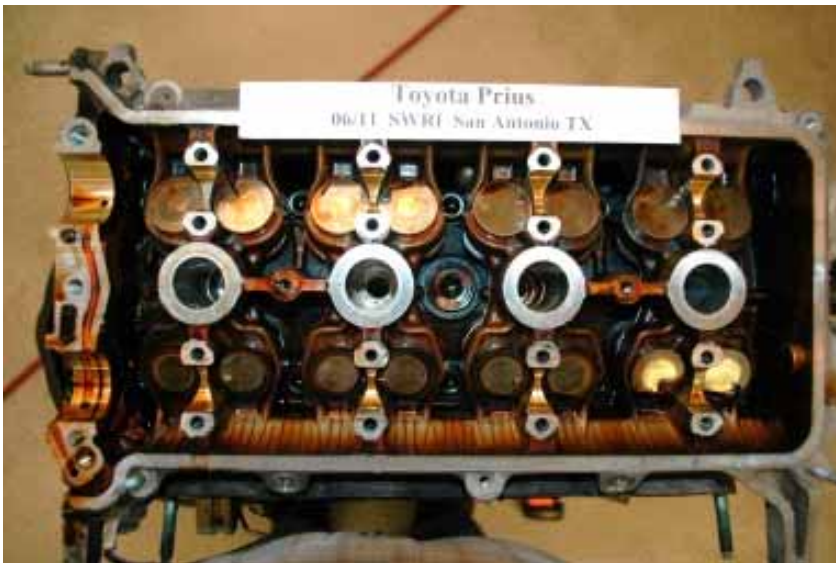


1.5L L-4 Engine  
Service: Taxi Winnipeg, Manitoba  
400K miles; 3.7K-5K mi ODI  
ILSAC GF-4 SAE 5W-30

# Toyota Prius Cleanliness Poor but Low Wear Observed



**Cylinder Head Prius**



**Cylinder Head Cadillac**



- Cadillac engine at lower mileage was cleaner
- But wear on Prius was only slightly worse than for the Cadillac (surprisingly low wear for 400K miles)
- Crankcase intake manifold deposits found to be carbonaceous with primarily polycyclic aromatics

## Another Toyota Hybrid Taxi Engine Was Inspected



- Vehicle: 2009 Toyota Camry Hybrid
- Engine: 2.4 Liter 4 cylinder
- Miles: 264K
- Use: Taxi in New York City
- Operation: Two 12 hr shifts, 7 days/week for 3 years
- Oil: ILSAC GF-5 5W-30 (but Toyota recommends 5W-20 for 2009 Camry Hybrid)
- ODI: Every 10 days or ~2,700 miles
- End of life: Performing well; removed engine block for inspection



# Another Toyota Hybrid Taxi Engine Was Inspected: 2009 Toyota Camry Hybrid at 264K miles



## Non-Hybrid Reference Vehicle

2005 Cadillac Deville  
GM 4.6L Northstar V-8 Engine  
Service: Limousine in NJ  
200K miles; 10K-15K mi ODI  
ILSAC GF-5 SAE 5W-30



## 2009 Toyota Camry Hybrid

2.4L L-4 DOHC Engine  
Service: Taxi NYC  
264K miles; 2.7K-3.5K mi ODI;  
stop-go drive cycle with ~50% engine  
usage  
ILSAC GF-5 SAE 5W-30

- **Avg sludge and varnish similar but non-hybrid had a slight edge**

# Toyota Camry Hybrid Front End vs. Reference



## Non-Hybrid Reference Vehicle

2005 Cadillac Deville  
GM 4.6L Northstar V-8 Engine  
Service: Limousine in NJ  
200K miles; 10K-15K mi ODI  
ILSAC GF-5 SAE 5W-30



## 2009 Toyota Camry Hybrid

2.4L L-4 DOHC Engine  
Service: Taxi NYC  
264K miles; 2.7K-3.5K mi ODI;  
stop-go drive cycle with ~50% engine  
usage  
ILSAC GF-5 SAE 5W-30



# Toyota Camry Hybrid Field Test Lower End vs. Reference



## Non-Hybrid Reference Vehicle

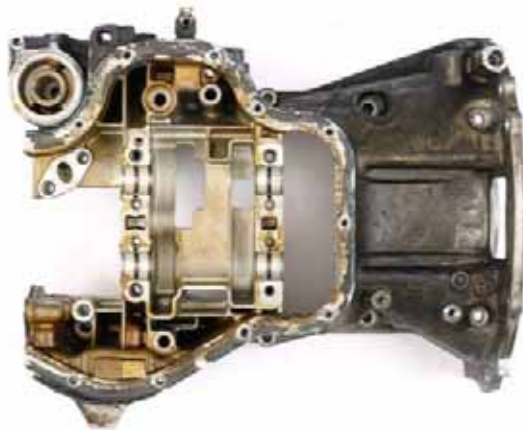
2005 Cadillac Deville  
GM 4.6L Northstar V-8 Engine  
Service: Limousine in NJ  
200K miles; 10K-15K mi ODI  
ILSAC GF-5 SAE 5W-30



Lower end with oil pan built in



Lower End  
Stiffener Assembly



Separate oil pan



## 2009 Toyota Camry Hybrid

2.4L L-4 DOHC Engine  
Service: Taxi NYC  
264K miles; 2.7K-3.5K mi ODI;  
stop-go drive cycle with ~50% engine  
usage  
ILSAC GF-5 SAE 5W-30

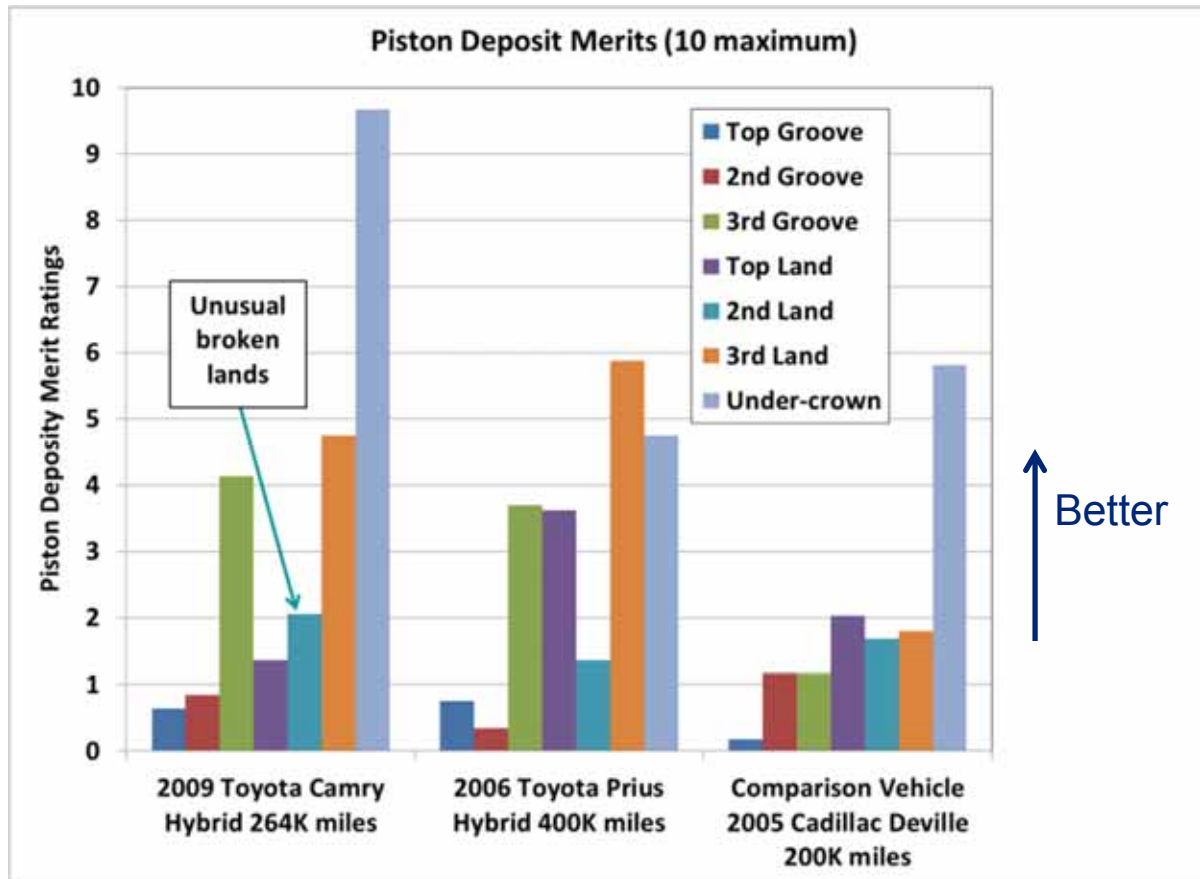
# Sludge/Varnish and Deposits Summary



<u>Parameter</u>	<u>2009 Toyota Camry Hybrid 264K miles</u>	<u>2006 Toyota Prius Hybrid 400K miles</u>	<u>Comparison Vehicle 2005 Cadillac Deville 200K miles</u>
Oil Drain Interval (miles)	2.7K – 3.7K	3.7K – 5K	10K – 15K
Lubricant Used	ILSAC GF-5 SAE 5W-30	SAE 5W-30 ILSAC GF-4	ILSAC GF-5 SAE 5W-30 (but different than that used in the Toyota Camry Hybrid)
<b>Total Average Cleanliness Merits (10 = best)</b>	<b>9.45 sludge (very light); 7.65 varnish (light-med amber lacquer)</b>	<b>8.93 sludge (light); 3.49 varnish (med-heavy; dark amber lacquer)</b>	<b>9.67 Sludge (very light) 8.32 Varnish (light amber lacquer)</b>

- Cadillac at 200K miles had highest rated cleanliness
- Camry Hybrid at 264K miles was a close 2<sup>nd</sup> in cleanliness
- Toyota Prius at 400K miles significantly worse
- Limousine service for Cadillac less severe than taxi service

# Piston Deposits and Condition Summary



- The Camry fared best on 3rd Groove and Under-crown but had unusual broken 2<sup>nd</sup> Land pieces
- The Prius fared best on Top Groove, Top Land, and 3<sup>rd</sup> Land
- The Cadillac fared best on 2nd Groove and 2nd Land

# Piston Comparison



2009 Toyota Camry  
New York City 264,425  
Miles

- 12-15% of the 2<sup>nd</sup> Ring Land broken on thrust side of 3 of the 4 pistons
- No broken Ring Lands observed with either the Prius or the Cadillac
- Wear slightly worse in Camry valve train and piston rings than the Cadillac

# Field Testing Toyota Camry Hybrid Taxis in NYC



- Vehicles: 2012 Toyota Camry Hybrids
- Test Started May 2012 with the first available units
- Plan to test to 200K miles, then inspect selected engines
- 10K mile ODI
- Intermediate samples at 5K and 7.5K miles for 1<sup>st</sup> 2 drains and 7.5K miles only thereafter
- MPG data from vehicle read-out obtained
- Data Logger device recorded drive cycle data
- SAE Viscosity Grade Recommendation for Toyota Camry has reduced:
  - 2001-2008: 5W-30
  - 2009: 5W-20
  - 2010-2013: 0W-20



# Percentage of Miles Driven with Engine Off

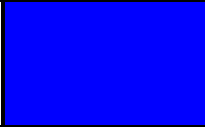

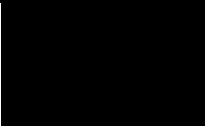





Vehicle	All stop and go short hauls < 2.3 miles	All stop and go short hauls < 10 miles	Stop and go 18-20% + highway 80-82% mix	93-95% highway	100% highway (with variable amount of traffic backups)
2010 Toyota Prius	47.1	45.2	19.2	13.5	1.9
2007 Toyota Camry Hybrid	55.1			12.3	2.8
2012 Toyota Camry Hybrid NYC		61.2			

- 45-61% of miles driven were with the engine off in short haul service
- Engine-off feature saves fuel and engine hours but adds stress of engine start-stop operation

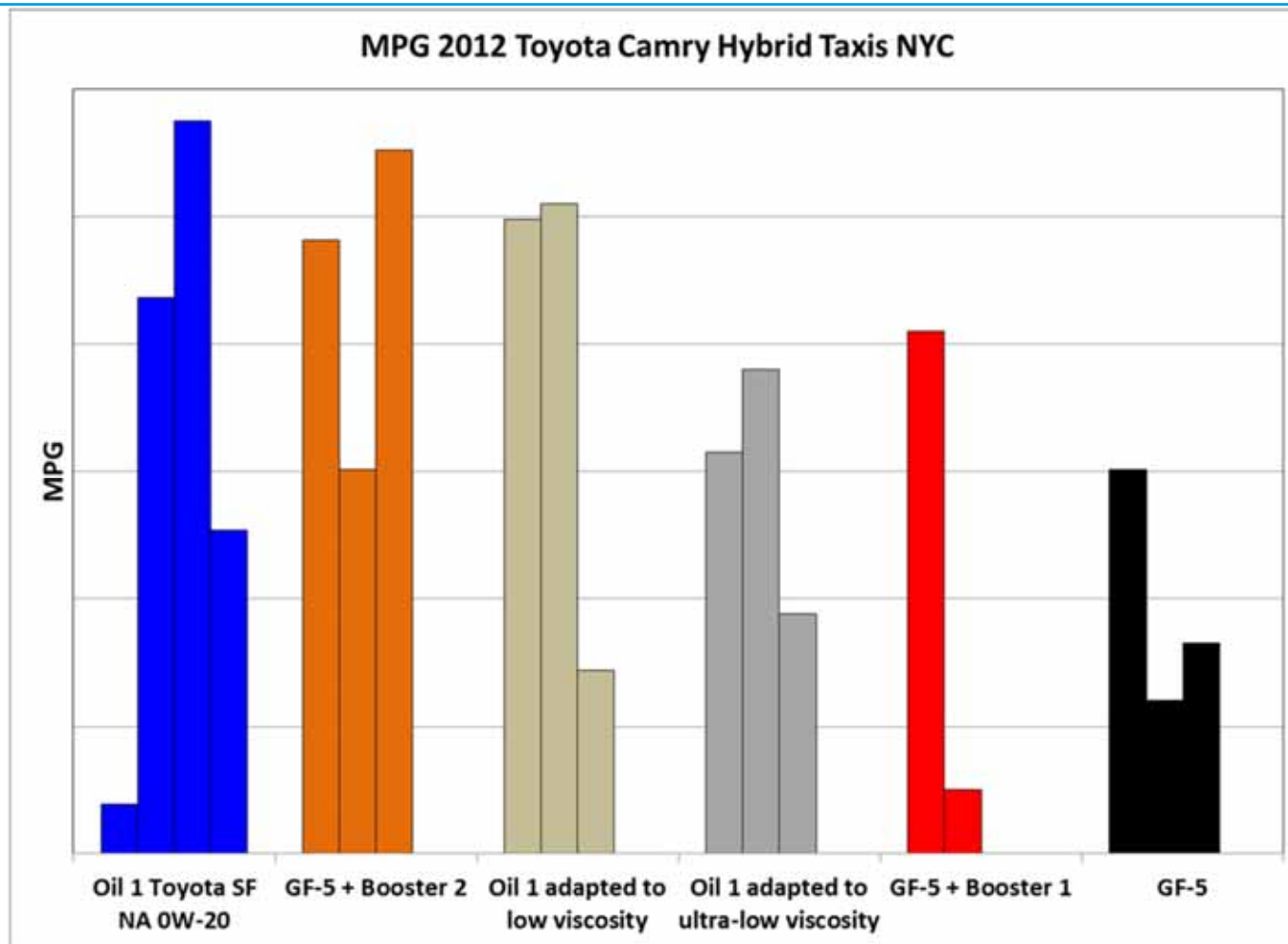
# Field Test Oil Matrix



Oil	Color Code		Description	HTHS (cP)	SAE Vis Grade
1	Blue		Service Fill 0W-20	2.6	0W-20
2	Beige		Oil 1 adapted to low viscosity	2.3	0W-16
3	Black		GF-5	2.6	0W-20
4	Gray		Oil 1 adapted to ultra-low viscosity	2.0	Non SAE J300
5	Red		GF-5 + Booster 1	2.6	0W-20
6	Orange		GF-5 + Booster 2	2.6	0W-20

- Boosters 1 and 2 designed for improved cleanliness
- 3 units tested per oil

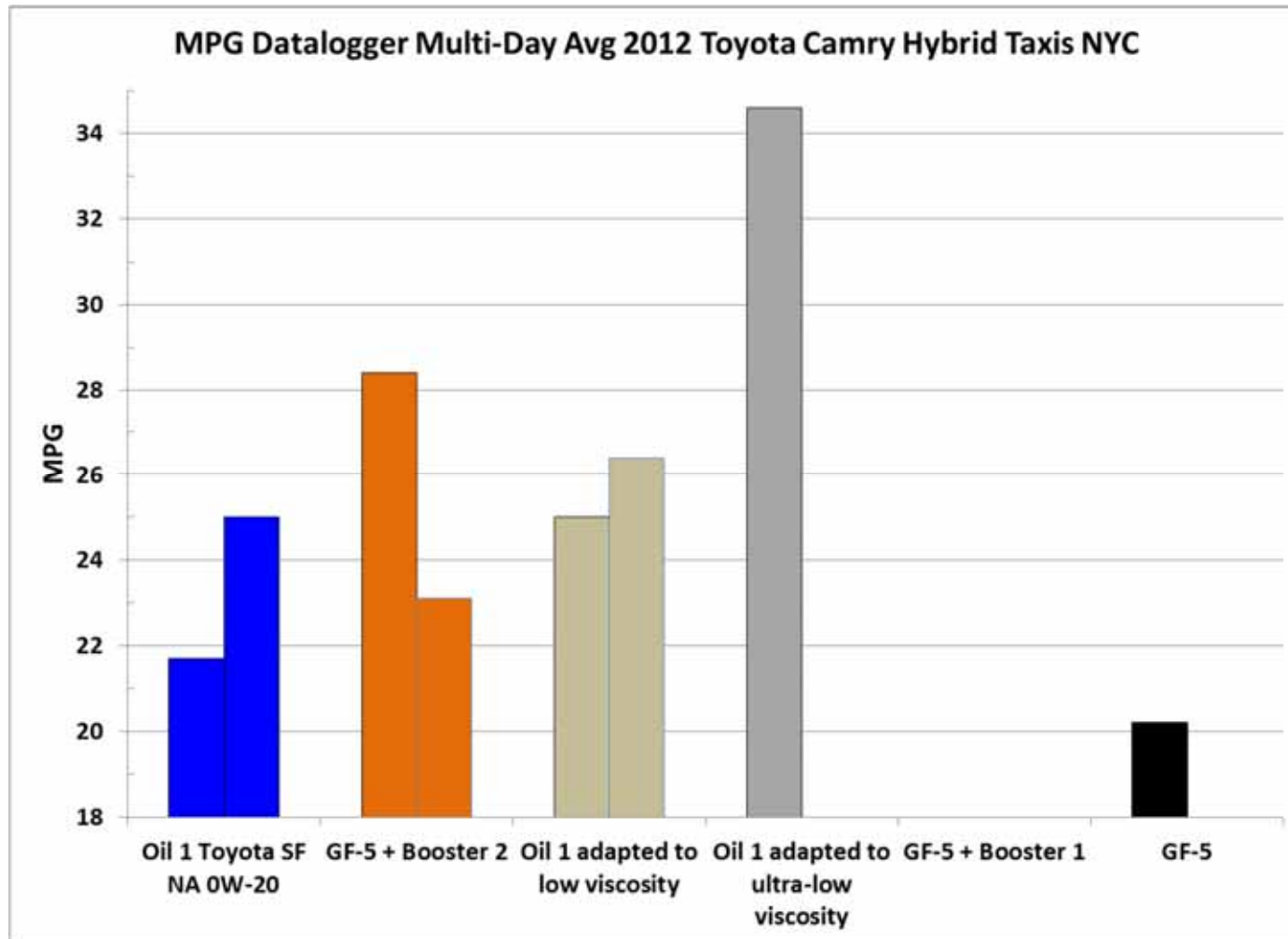
# Measured Fuel Economy Dashboard Readout



- No FE credit when reducing HTHS from 2.6 in the SAE 0W-20 oil (Blue) to 2.3 (Beige) or 2.0 (Grey) oils.

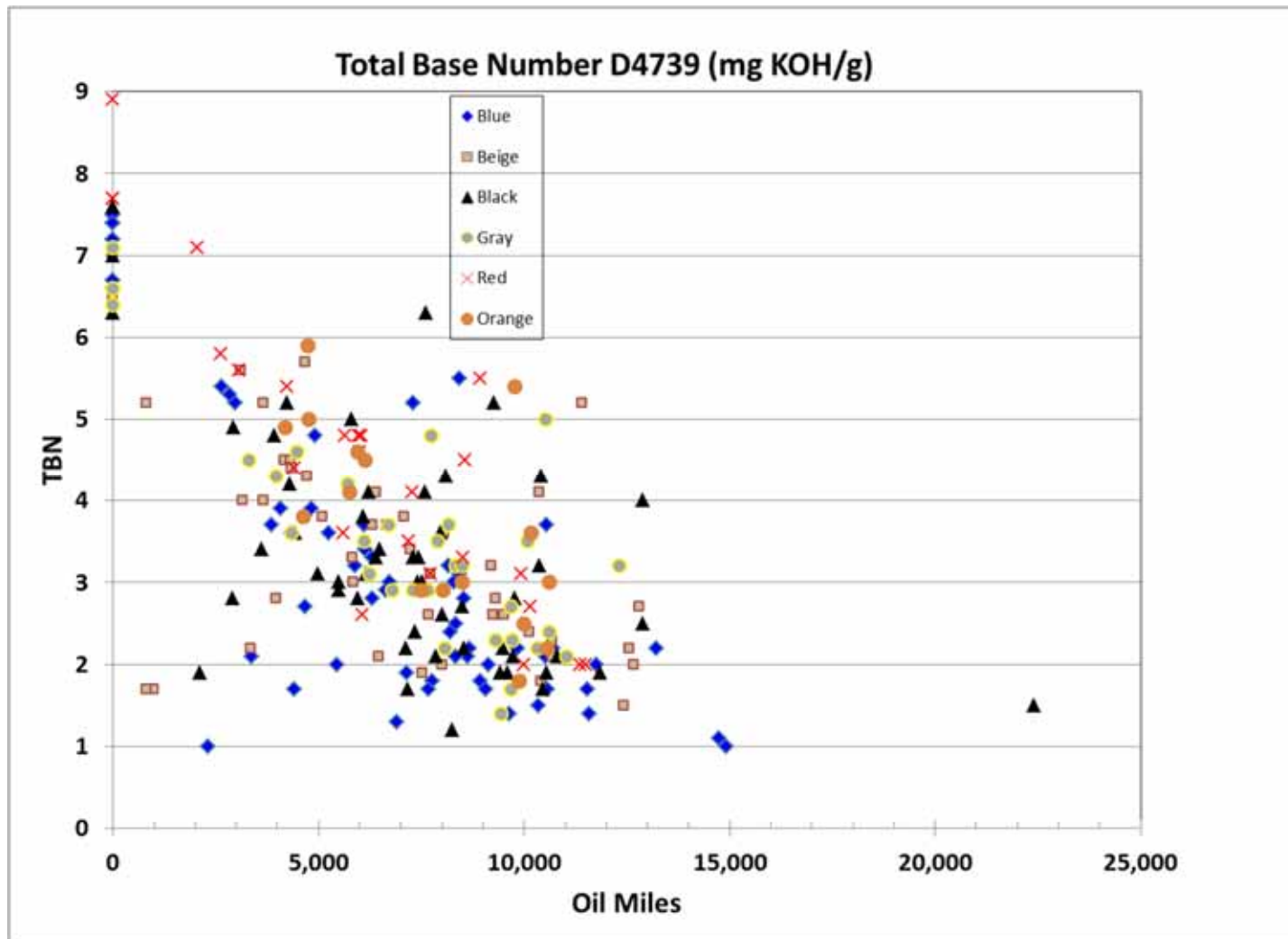


# Measured Fuel Economy with Data Logger



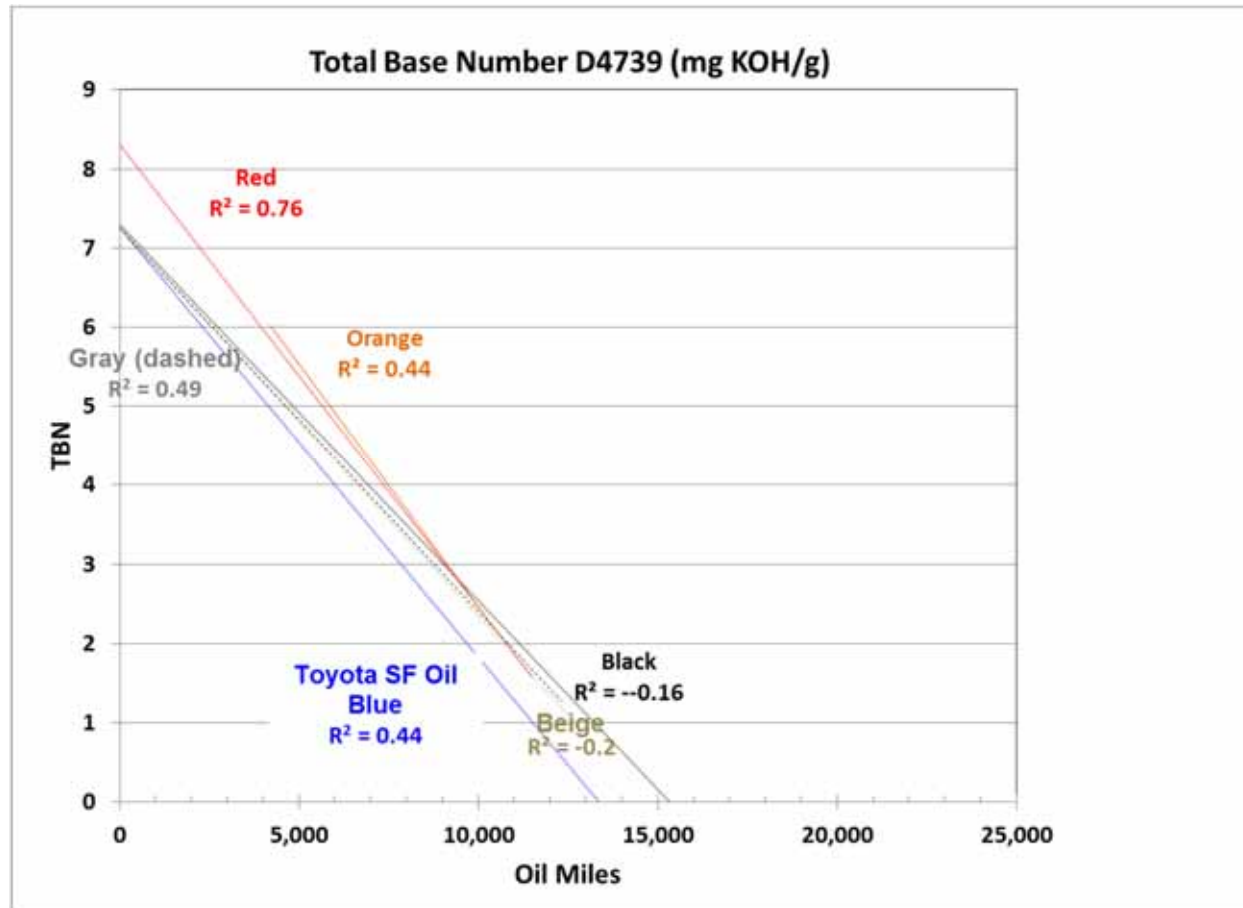
- Data logger multi-day averaging revealed an MPG credit with reduced HTHS

# Used Oil Analysis – Total Base Number



- TBN depletion is evident

# Used Oil Analysis



- TBN depletion is similar for all oils
- No disadvantage observed relative to Toyota Service Fill N. America oil
- TAN all < 4.5 mg/g; Water detected at 0.1-0.2% in only 7% of samples
- Fuel dilution negligible

# Interim Inspections at 100K Miles



## Unit with GF-5 Black oil SAE 0W-20



- Cylinder head decks looks clean after 100K miles
- Will inspect again after 200K miles

# Summary/Conclusions



- Infineum inspected hybrid gasoline vehicles using GF-4 and GF-5 lubricants which were generally in reasonable condition after relatively high mileage (>250,000 miles)
- There were some notable differences:
  - Engine cleanliness issues (carbon/varnish) were discovered in a 2006 Toyota Prius taxi after 400K miles
  - A 2009 Toyota Camry Hybrid after 264K miles had improved cleanliness but unusual broken 2nd land pieces in the pistons
- A field test of engine oils in 2012 Toyota Camry Hybrid taxis in NYC is in progress aimed at improved cleanliness and probing the effect of reduced HTHS
  - Interim results at 100K miles show lack of carbon/varnish or engine distress even at 2.0 HTHS
  - Early results show higher fuel economy as engine oil HTHS is reduced from 2.6 to 2.0 HTHS
  - Final tear down inspection will reveal if HTHS can be reduced and cleanliness improved

# Acknowledgements



Jeff Sellers - SwRI

John Lowsky, John Zalewski, Ray Seiz, and Mike Madalian - Infineum USA

Jai Bansal – Infineum USA

Ruby A. – NYC taxi fleet

Infineum USA – for permission to publish and present the study