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
- 2nd 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

<table>
<thead>
<tr>
<th>Cylinder Head Prius</th>
<th>Cylinder Head Cadillac</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Cylinder Head Prius" /></td>
<td><img src="image2" alt="Cylinder Head Cadillac" /></td>
</tr>
</tbody>
</table>

- 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

2009 Toyota Camry Hybrid
2.4L L-4 DOHC Engine
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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

### Parameter Comparison

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

- Cadillac at 200K miles had highest rated cleanliness
- Camry Hybrid at 264K miles was a close 2\(^{nd}\) 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 2nd Land pieces
- The Prius fared best on Top Groove, Top Land, and 3rd Land
- The Cadillac fared best on 2nd Groove and 2nd Land
Piston Comparison

- 12-15% of the 2nd 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 1st 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

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

• 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

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

- Boosters 1 and 2 designed for improved cleanliness
- 3 units tested per oil
• 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.
• Data logger multi-day averaging revealed an MPG credit with reduced HTHS
• 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
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