Improve Fuel Economy through Formulation Design and Modeling

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Overview

Timeline

- Budget Period 1: Sep 2013 to Dec 2014
  - 100% completed
- Budget Period 2: Jan 2015 to Dec 2015
  - in progress
- Budget Period 3: Jan 2015 to Sep 2015

Budget

- Total Project Funding:
  - DOE share: $593,869
  - Valvoline share: $601,924
- Budget Period 1 Funding:
  - DOE share: $168,634 (all received)
  - Valvoline share: $190,202 (actual $215,858)

Barriers

- Reduce vehicle energy loss due to friction
- Maintain anti-wear performance of low viscosity lubricants
- Mitigate poisoning of emission catalysts

Partners

- Cummins Inc,
- National Renewable Energy Laboratory

Valvoline.

Relevance and Project Objectives

Target level of performance:

- Engine oil fuel economy improvement (~2%)
- Axle oil fuel economy improvement (~0.5%)
- Whole system – greater than 2 % by SAE J1321
- Durability Penalty – None, no detriment seen to component life at 2,000 hours tear down after field test

Objective for Budget Period 1:

- Complete formulations of two candidates each for engine oil and axle oil.
- Use bench tests and proprietary modeling work to predict fuel economy performance and meet the target level.
- Develop multiple formulae of transmission fluid for SAE#2 test.

Milestones

Title/Description	Planned date	Actual Date	Verification Method	Comments/progress/deviation
1.A. Engine Oil Candidate 1: PC-11 Candidate, 5W-30, FE>2%, **Go/No-Go**	3/30/2014	3/14/2014	modeling	Modeling result show 2.04% FE improvement
1.B. Engine Oil Candidate 2: Bio-base, Special Chemistry, PC-11 Candidate, 5W-20, FE>2%, **Go/No-Go**	9/30/2014	9/29/2014	modeling	Modeling result show 2.12% FE improvement
1.C. Axle Oil Candidate 1 : J2360 Approved, 75W-90, FE>0.5%, **Go/No-Go**	3/30/2014	3/28/2014	modeling	Modeling result show 0.61% FE improvement
1.D. Axle Oil Candidate 2: J2360 Approved, 75W-90, Special Chemistry, FE>0.5%, **Go/No-Go**	9/30/2014	9/26/2014	modeling	Modeling result show 0.73% FE improvement
2.E. Transmission Fluid: Meets TES 295 Performances with Lower Viscosity	6/30/2015		SAE #2 Test	finished formulation and bench tests
2.F. NREL ISL 8.9L Engine FE Verification Test, FE>2%	3/30/2015		Engine lab testing	Delayed due to DI update
2.G. Axle Oil Efficiency Verification Test, FE>0.5%	6/30/2015		Axle rig test	In preparation
2.H. SAE J1321 FE Test of all oils, DOE Metrics and Analysis, Overall FE>2%, **Go/No-Go**	9/30/2015		Class-6 truck Track test	
3.I. Engine Durability Tests: SLT B Engine Evaluation Test of both Engine Oils	9/30/2016		Engine lab testing	
3.J. FE Retention and Durability Test of All Oils, Components Tear Down	9/30/2016		Field test	

Approach/Strategy

- Run formulation design metrics to meet rheological performance - - Combination of best ingredients from different suppliers.
- Run tribological bench top tests (MTM, HFRR, Four-ball, EHD) to pick the best candidate.
- Use proprietary modeling work to predict Fuel Economy performance.

FY 2014 Accomplishments: Formulation and Modeling

Engine Oil:

- Baseline: CJ-4 15W-40, commercially available on the market.

- Candidate 1: PC-11 candidate, 5W-30, HTHS ~ 3.0. Formulation was finalized. The oil had been tested by OEM.
The modeling work shows a 2.04% FE compared with the baseline. A milestone was logged on March 16, 2014.

- Candidate 2: 5W-20, HTHS~2.9, with bio-base oil and friction modifier. Compared with the candidate 1 engine oil, this oil has higher VI, lower friction and lower traction. Formulation was finalized.
The modeling work shows a 2.12% FE compared with the baseline. A milestone was logged on September 29, 2014.

FY 2014 Accomplishments: Formulation and Modeling

Axle Oil:

- Baseline: J2360 approved 75W-90, commercially available on the market.

- Candidate 1: J2360 approved 75W-90. The formulation was decided. The chemistry has been proved by field test.
Modeling work showed a 0.61% FE under conditions of New European Driving Cycles. A milestone was logged on March 28, 2014.

- Candidate 2: J2360 approved 75W-90. It will have field-proven chemistry plus Valvoline's proprietary technology. Compared with the candidate 1 axle oil, this oil has higher VI, higher thermal conductivity and lower churning loss. The formulation was developed.
Modeling work showed a 0.73% FE under conditions of New European Driving Cycles. A milestone was logged on September 26, 2014.

FY 2014 Accomplishments: Formulation and Modeling

Transmission Fluid:

- Baseline: TES 295 Fluid, commercially available on the market.

- Candidate: meets TES 295 performance, but has better efficiency performance.

Multiple additive suppliers have provided DI packages. Formulations with different types of base oil combination have been carried out. Bench tests of HFRR and MTM using clutch paper material as friction surface have been used for selecting the final formulae to do SAE #2 tests. Four candidates have been selected for SAE #2 test.

Response to Previous Year Reviewers' Comments

This project is a new start

Collaborations and Partnerships

Cummins – Supportive Project Partner

- Input on engine oil property requirements
- Engine testing procedure

National Renewable Energy Laboratory – Project Partner

- Engine oil FE verification testing

Transportation Research Center, Inc. – Sub-Contractor

- J1321 test

Suppliers of Lubricant Components

- Afton
- Evonic
- Infineum
- Lubrizol

Remaining Challenges and Barriers

- DI package updates with PC-11 requirements
  - the PC-11 timeline has not been finalized
- Testing facility schedule conflicts
  - delays may happen
- Discrepancy between modeling and dyno testing
  - reformulation may be needed and it takes time

Proposed Future Work for Budget Period 2

- For engine oil the next step is to run NREL ISL 8.9L Engine Fuel Efficiency verification test. Improvement of around 2% against the baseline is anticipated.

- For axle oil the next step is to run axle efficiency verification test and do reformulation if necessary. Greater than 0.5% improvement against the baseline is anticipated.

- For transmission fluid preparation of multiple candidates for SAE #2 tests is underway. Candidate will be picked after comparison of multiple properties with base line.

- Conduct SAE J 1321 test for the system of the aforementioned three types of lubricants at the Transportation Research Center Inc. in East Liberty, OH. Greater than 2% total fuel efficiency is expected.

Summary

All milestones were reached in Budget Period 1 (FY 2014)

- Two engine oil candidates have been developed and modeling work showed they meet the target FE improvements of greater than 2%. Tribological bench tests showed the Candidate 2 has better wear and friction performances than the baseline.

- Two axle oil candidates have been developed and modeling work showed they meet the target FE improvement of greater than 0.5%. MTM tests showed that both candidates have lower friction than the baseline under most testing conditions.

- Four transmission fluids have been developed for SAE#2 test.

Technical Back-up slides

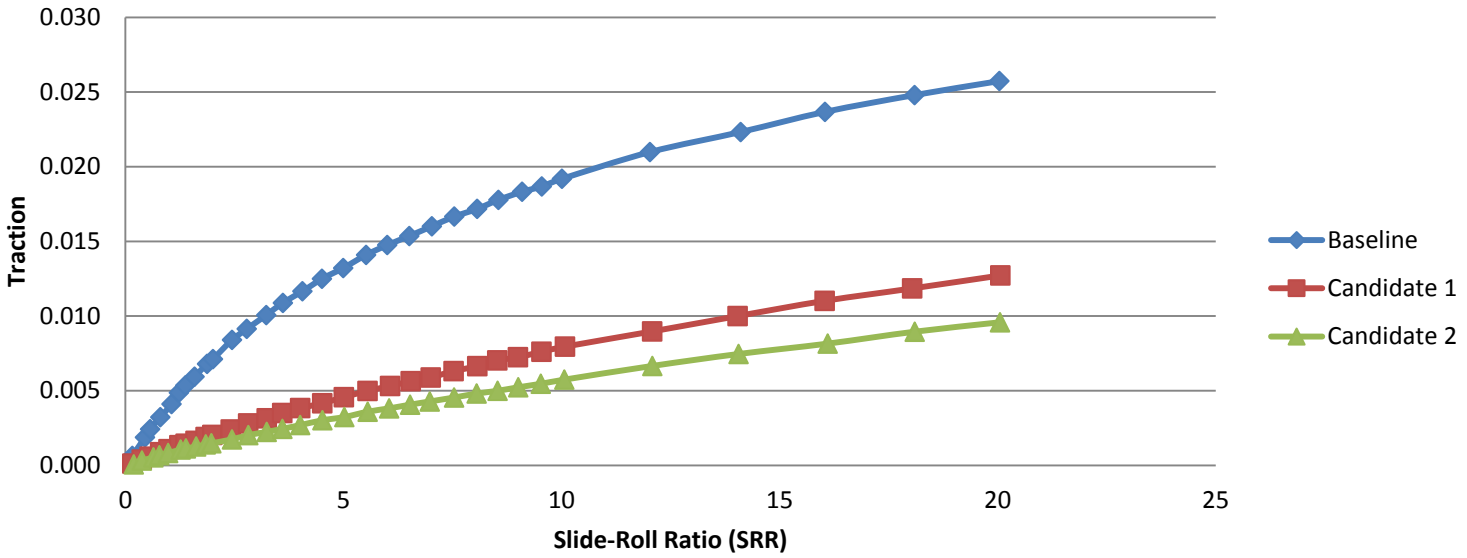
Property of Engine Oil Candidates and Their Baseline

ASTM	Property	Candidate 1	Candidate 2	Baseline
ASTM D 445	KV @ 100C (cSt)	9.6	8.56	15.42
ASTM D 445	KV @ 40C (cSt)	55.19	46.09	117.68
ASTM D 2270	Viscosity Index	159	165	134
FE Improvement by modeling (%)		2.04	2.12	n/a

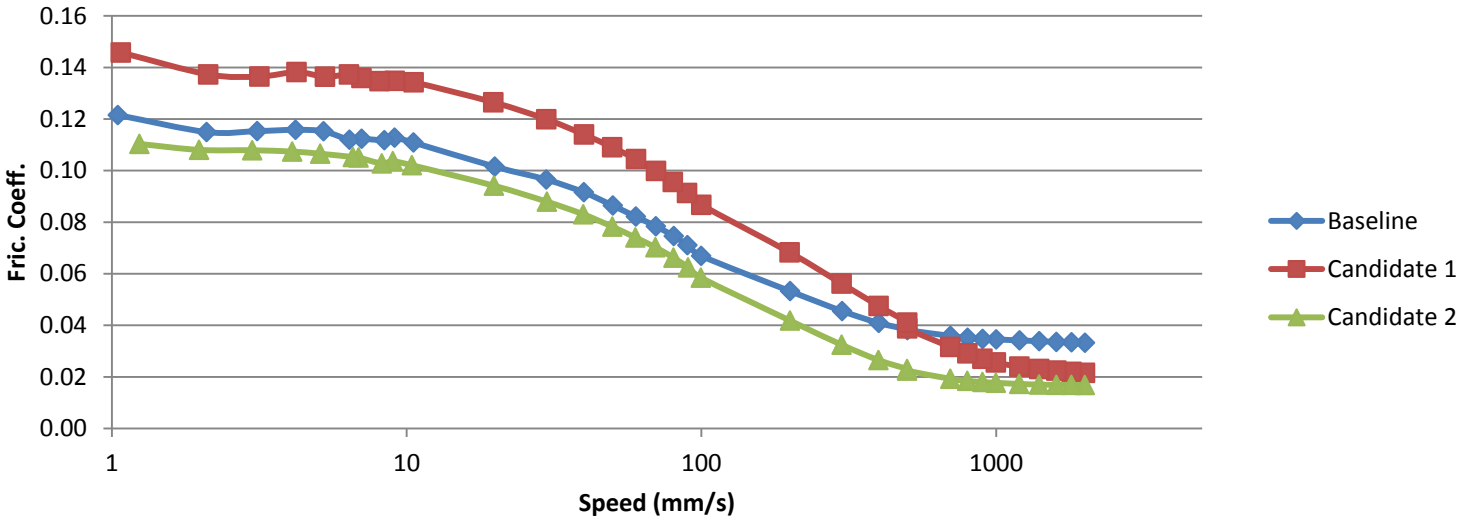
HFRR and 4-ball Wear Test Results of Engine Oil Candidates and Their Baseline

HFRR: 1.25GPa, 20HZ, 40°C for 10 minutes, 125°C for 2 hours				ASTM D 4172: 4-ball
	friction @40°C	friction @125°C	Wear on Ball(μm)	wear on ball (μm)
Candidate 1	0.128	0.13	178	549
Candidate 2	0.127	0.095	151	470
Baseline	0.13	0.13	161	527

MTM Traction vs SRR for Engine Oils



MTM Stribeck Curves for Engine Oils



Valvoline.

Property of Axle oil candidates and their baseline

ASTM	Property	Candidate 1	Candidate 2	Baseline
ASTM D 445	KV @ 100C (cSt)	15.63	15.47	15.28
ASTM D 445	KV @ 40C (cSt)	92.21	90.15	104.39
ASTM D 2270	Viscosity Index	181	182	154
FE Improvement by modeling (%)		0.61	0.73	n/a