

# Lubricants Activities

George Fenske, Layo Ajayi, Nicholas Demas

Robert Erck, and Cinta Lorenzo-Martin

Argonne National Laboratory

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# Overview

## Timeline

- Project start date FY 11
- Project end date FY 16
- Percent complete 20%

## Budget

- Total Project Funding \$1200K
  - DOE Share \$1100K
  - Contractor Share\* \$100K
- FY 11 \$600K
- FY 12\* \$500K

\* in-kind contributions

\* Incremental support for start of new projects

## Barriers

- Fuel economy improvement via lubricants and tribology
- Emissions – maintain or reduce impact of lubes on after-treatment devices
- Lube compatibility with alternative fuels
- Lubricating alternative (non-traditional) materials
- Alternative lube stocks (bio-based)

## Partners

- MIT – Lube Consortium
- Vehicle and Engine OEMS
- Component OEMs
- Lubricant Suppliers
- Additive Suppliers
- DOD/TARDEC
- Small Businesses, Academia
- DOE Vehicle Systems



# Overview/Relevance - Role of Lubricants (and Tribology) in Fuel Economy

## ■ Lubrication Facts:

- 250+ million vehicles on the road.
- 3 million-million ( $3 \times 10^{12}$ ) miles driven by vehicles.
- 12-14 MBBL/day petroleum used for on-road vehicles.
- **10-15% of fuel used consumed by engine and driveline friction losses.**
- **1.1 to 1.7 MBBL/day of petroleum lost to parasitic friction.**
- A 10% reduction in engine friction will save 1.2 billion gallons of fuel per year.
- 1.2 billion gallons of automotive lubricant sold per year in US.

## ■ Goals of Lubrication Activities: DOE initiated a Lubricant Program to develop lubrication science and technologies that reduce parasitic friction losses in vehicles (e.g., engines and drivelines) and improve fuel economy.

- **Next Generation Lubricants:** Develop advanced lubricant system (lubricant and engineered surfaces) to reduce parasitic friction losses by 50% and increase fuel economy by 5-7% in **NEW** vehicles.
- **Legacy Vehicle Lubricants:** Develop advanced lubricants (base fluids and additives) to reduce parasitic friction losses by 10% and increase vehicle economy by 1-2% for **EXISTING** vehicles.

## ■ The following information provides a broad overview of lubrication projects, and highlights of several projects on validation and additive development.



# Milestones

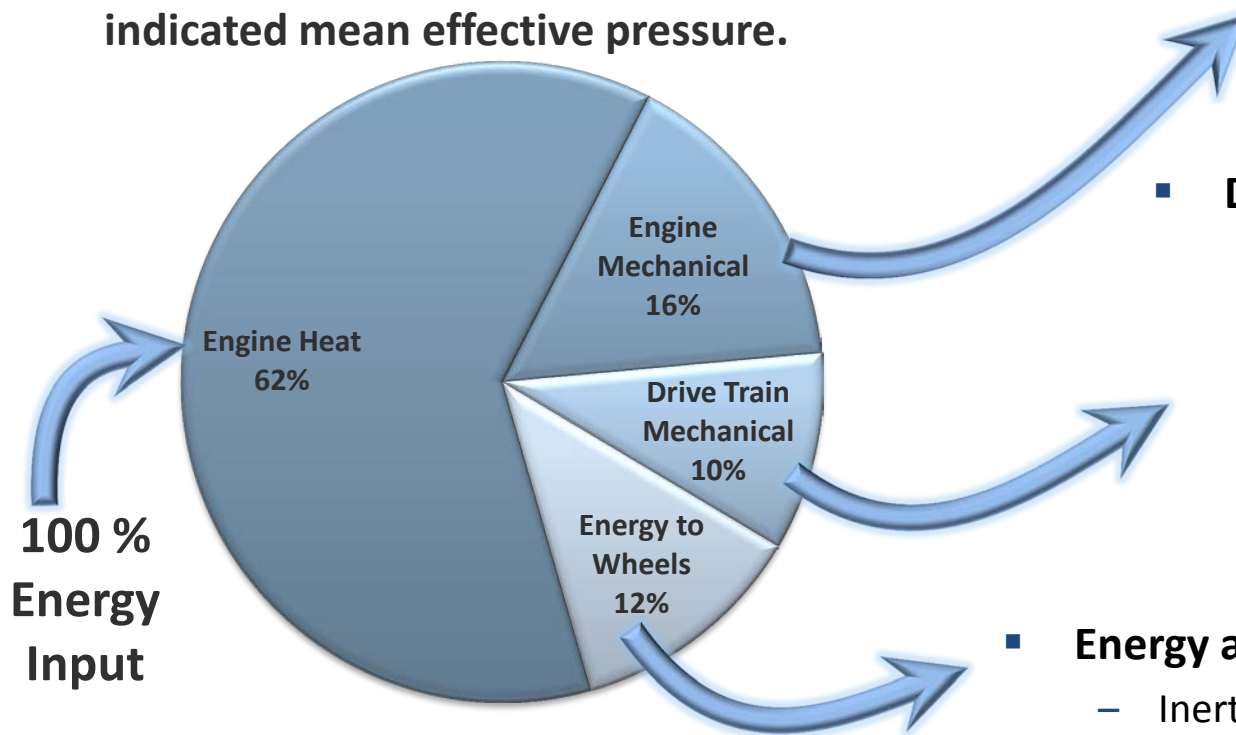
- **Milestones fall into program- and project-specific milestones.**
- **Major Program Milestones:**
  - FY 11: Open solicitation on lubrication **(completed)** – 4 new projects selected for award.
  - FY 12: Develop/concur on multiyear program plan **(in progress)** – establish goals and targets; identify barriers and potential solutions/approaches.
- **Project Specific Milestones (select milestones – not all-inclusive):**
  - FY 12: Lab-Engine Validation: Establish team and identify approach to improve fidelity of lab-based data as applied to engines (in progress).
  - FY 12: Develop test protocols for accurate prediction of vehicle performance (in progress).
  - FY 12: Phenomenological Investigation of Tribo-Films: Characterize structure and composition of protective tribofilms using advanced surface analytical techniques (in progress).
  - FY 12: Innovative Lubricant Formulations: Design and synthesize functionalized layered, core-shell nanoparticles with controllable dissolution properties (in progress).





**Relevance: What is the magnitude of frictional losses? More energy is lost to friction than is delivered to the wheels - approximately 10% in engine and 5% in the drivetrain (1.1-1.7 MBBL/day)**

- Frictional losses are heavily dependent on a number of factors – most notably driving cycle.
- Friction mean effective pressure ( FMEP - friction horsepower normalized to displacement) ranges from 4% (max load/speed) to >50% (idle) of the indicated mean effective pressure.



#### ▪ Engine Mechanical Losses

- Pumping work
- Overcoming Friction
  - Rings and piston skirt
  - Valve train
  - Bearings & seals
- Accessories

#### ▪ Drive Train Mechanical Losses

- Overcoming friction
  - Transmission
  - Differential
  - Bearings & seals
- Coasting and idle work
- Braking work

#### ▪ Energy at Wheels

- Inertia, rolling resistance, air resistance, gravity (grades)



# Program Progress: Identified goals, issues, targets; barriers and program approach to develop advanced energy conserving lubricants

- One-on-one meetings with stakeholders to identify current status, critical issues, goals, targets, and barriers to the development of lubricants that reduce parasitic losses and improve fuel economy.
- Developing multiyear program plan (MYPP); draft due out in June will be vetted by stakeholders – late FY 12.
- **Goals** – Multiple goals, including high level goals identified for NEW and LEGACY vehicles on reducing parasitic friction losses by 10-50%, resulting in fuel economy gains of 1-5%.
  - VSATT modeling effort will provide detailed support for analysis and goals.
- **Issues identified**
  - Fuel economy (lubricant formulation – basestocks and additives)
  - Emissions – lowering limits on beneficial additives that degrade after-treatment systems
  - Alternative fuels – compatibility of lubricants with diluted fuel
  - Vehicle weight – lubricants compatible with non-traditional materials
  - Biobased lubricants – improving performance of bio-derived lubricant base fluids
  - Engineered surfaces – impact of advanced surface textures on lubrication regimes
  - Cost and time to develop advanced lubricants



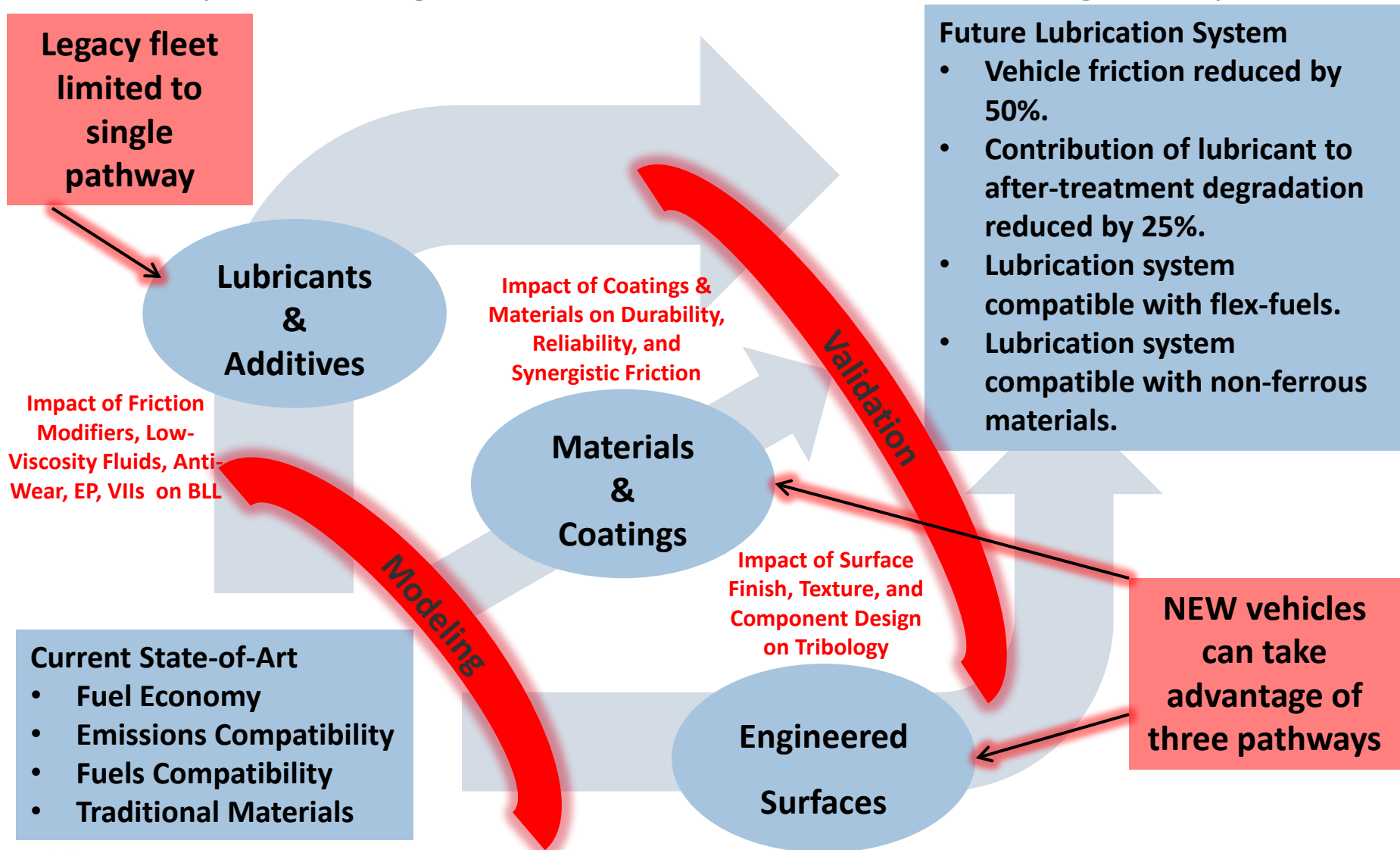


# Program Progress: Identified goals, issues, targets; barriers and program approach to develop advanced energy conserving lubricants

- **Barriers** to achieving goals and targets identified:
  - **Inadequate data and predictive tools:** ability to predict impact of advanced technologies on fuel economy, impact of alternative fuels on lubricant performance, interaction of additives and chemistry with ferrous and non-ferrous materials, information on mechanical efficiency of accessories.
  - **Limited basestocks and additive formulations (one size may not fit all):** friction modifiers often compete against antiwear additives; introduction of advanced concepts (e.g., turbocharging, cylinder deactivation, bifuels, etc.) with different performance requirements; compatibility with advanced materials, coatings, and engineered surfaces; compatibility with emission systems; backward compatibility; engine vs. driveline systems; alternative fuels.
  - **Validation is limited:** poor fidelity between benchtop tests with well-defined configuration and controlled environments to complex, integrated systems (engines, drivetrains) with widely varying operational cycles; poor extrapolation of science-based models to engineered continuum models/simulations.
  - **Cost to develop and certify advanced lubricants is time consuming and expensive:** changing certification requirements – cost to develop a new engine sequence protocol in excess of \$5M, and lengthy (up to 6 years). Sequence tests are expensive (\$100K/run).



# Identified multiple pathways, approaches to improve fuel economy with improved lubricants and tribological systems



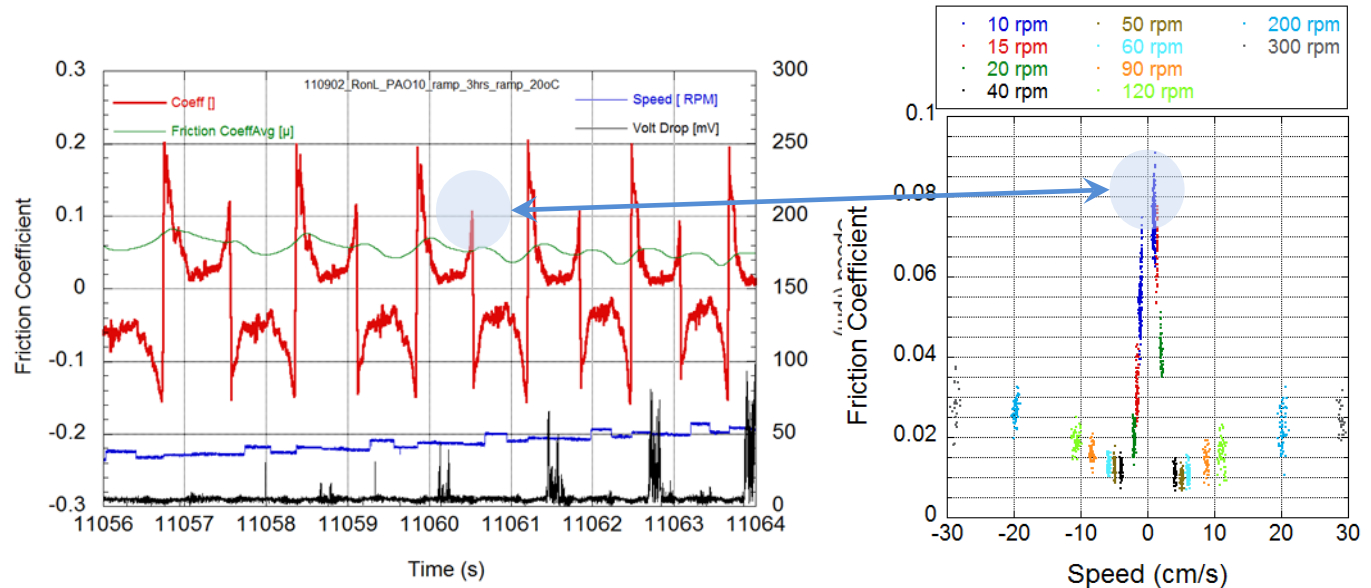
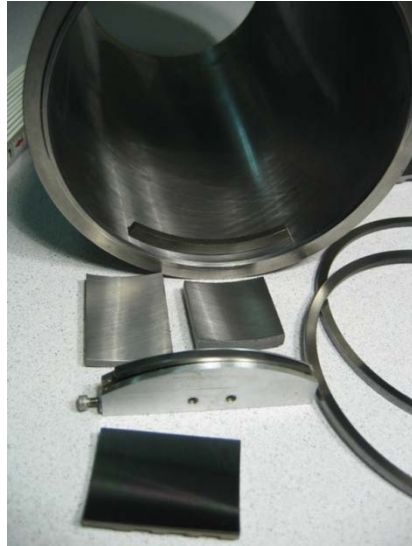


# Projects established to address the development of advanced lubrication concepts

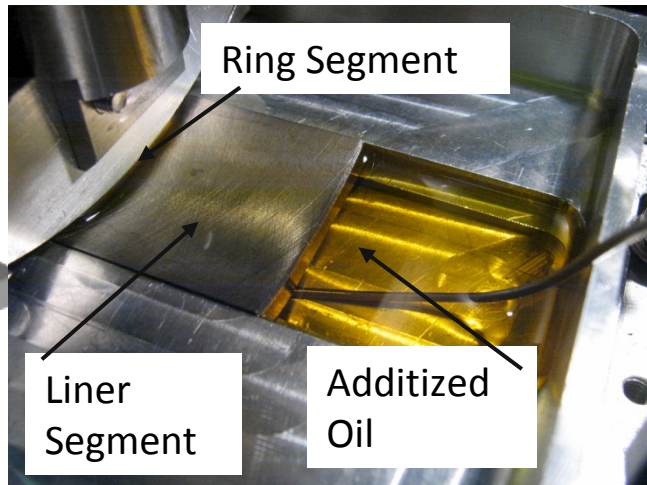
Project	Lead
Novel Lubricant Formulations (New Start)	MIT
Advanced PAG Base Fluids (New Start)	Ford
Ionic Liquids (New Project)	ORNL
Boron-based Lubricant Additives (New Project)	ANL
Lab-Engine Correlation/Validation (Started in FY 11)	ANL
Tribofilm Formation, Structure, Composition, and Performance (FY 12 3rd QTR)	ANL
Self-replenishing Smart Lubricants (FY 12 3rd QTR)	ANL
Industry/Academia Collaborations (ongoing)	ANL



# Progress - Lab-Engine Validation: Developed protocols for high-fidelity database on asperity/boundary friction $\mu_{asp}$ using benchtop rigs



- Utilize reciprocating rig to measure friction (boundary, mixed, and hydrodynamic) on actual component surfaces.
- Provide data on boundary friction coefficient for codes:
  - Temperature effects
  - Tribo-film composition/make-up

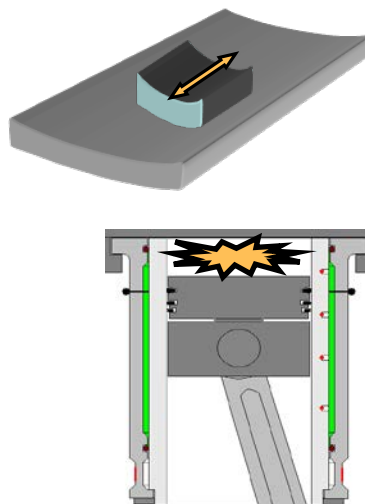
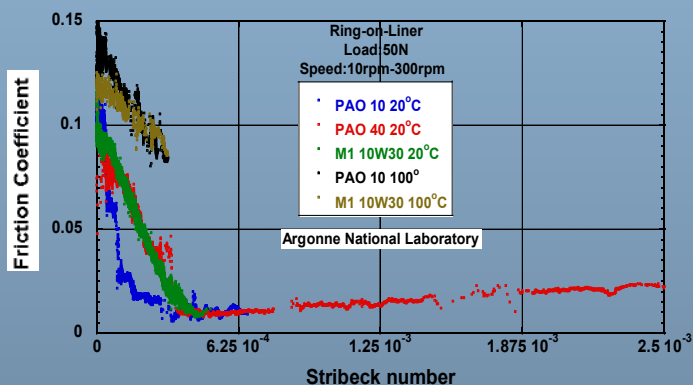
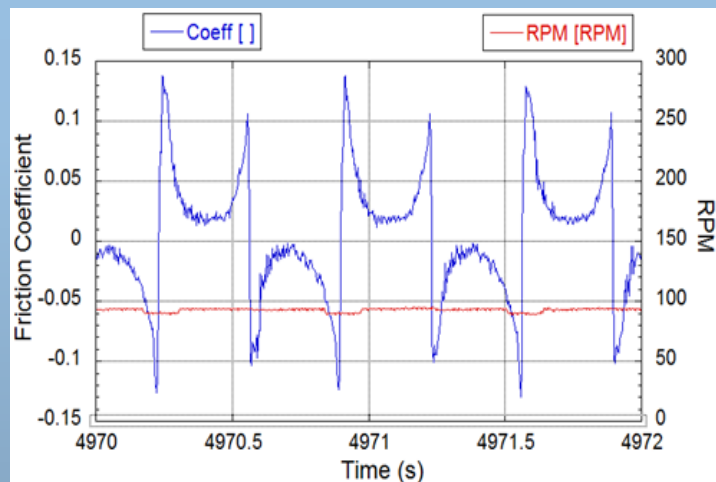




# Progress: Lab/Engine Validation/Correlation Studies

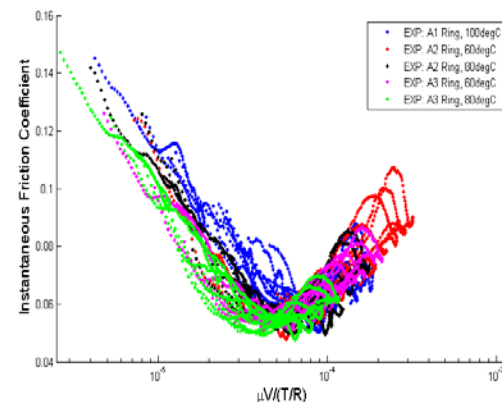
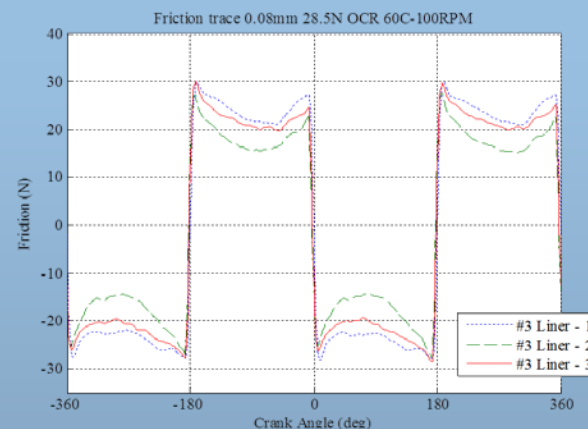
Collaboration between ANL and MIT Lube-Consortium addressing correlation of lab and engine data utilizing Stribeck analysis ( $\eta^*V/L$ ) on benchtop ring-on-liner tests and fired engine with floating liners. Can we obtain meaningful data from benchtop rigs using proper protocols that are transferable to real life (engine/vehicles)?

## Benchtop Ring-on-Liner



Common approach to analyze frictional losses. Work is in progress – **need to address different surface finishes.**

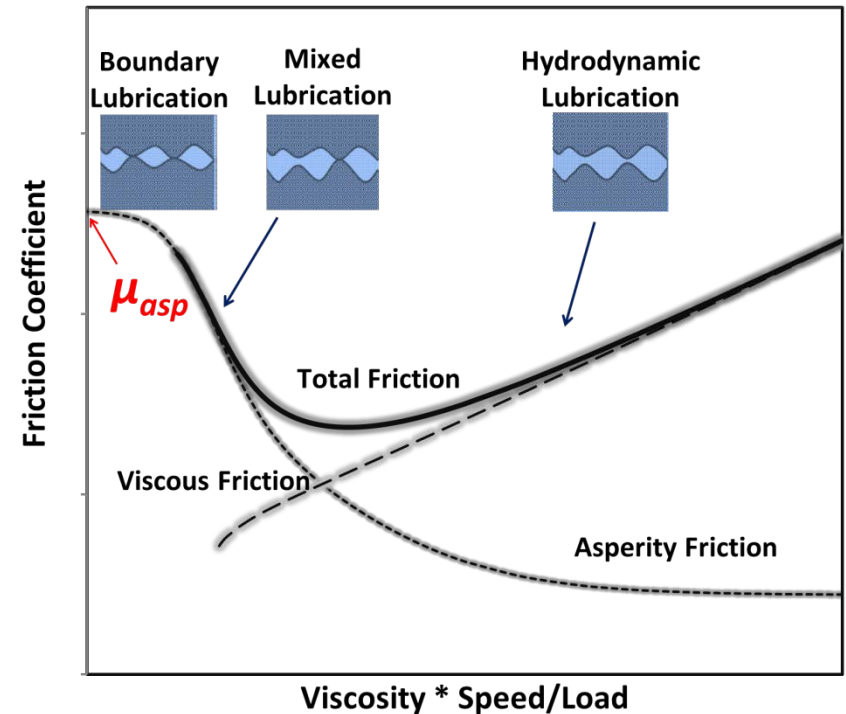
## Floating Liner Engine (MIT)





# Results from lab-engine validation project will be used to provide high-fidelity asperity friction data for FMEP simulation codes VSATT

- FMEP simulation codes require input on asperity friction to model boundary and viscous friction losses.
- Typically the asperity friction is treated as a fixed constant, depending on the component (e.g.,  $\mu_{asp} = 0.08$  for skirt, 0.12 for rings).
- Asperity friction is not a fixed constant – it is affected by temperature, shear rate, and additive chemistry.
- **Lab-scale test configurations and test protocols are being developed to provide asperity friction data.**
- Asperity friction data generated from the Lab-Engine Validation Project will be used as input for FMEP simulation studies.



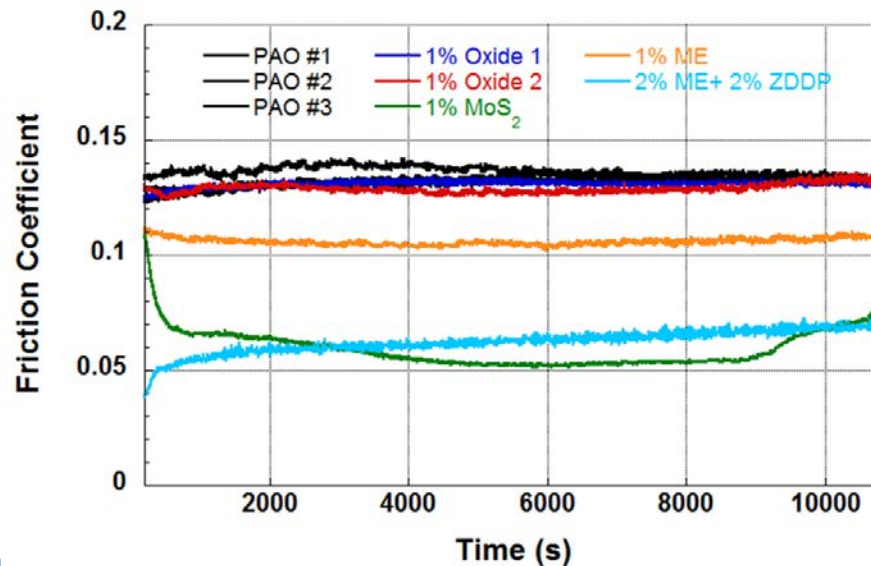
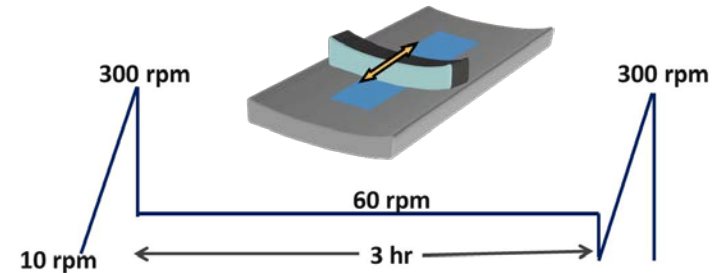
- Lab-scale tests will be performed to develop realistic asperity (boundary) friction data for accurate FMEP prediction.
- $\mu_{asp}$  (as shown in the Stribeck curve) will be determined experimentally for “zero” Stribeck values.



# Progress: Lubricant Additive Studies

Developing common set of test protocols to evaluate frictional behavior of advanced additives (friction modifiers). Using a common set of protocols that (hopefully) replicate engine/vehicle conditions to characterize friction and wear properties of different additives.

- Common test protocols are employed to evaluate frictional behavior of low-friction additives using ring-on-liner configuration.
- Similar approach is under development for ball-on-flat configurations.

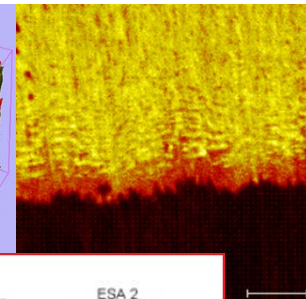
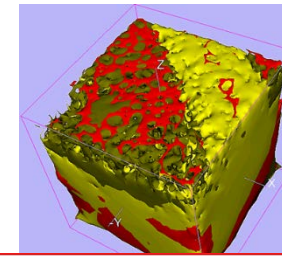
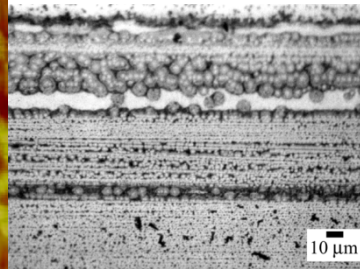
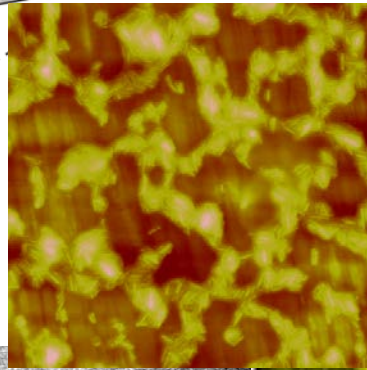
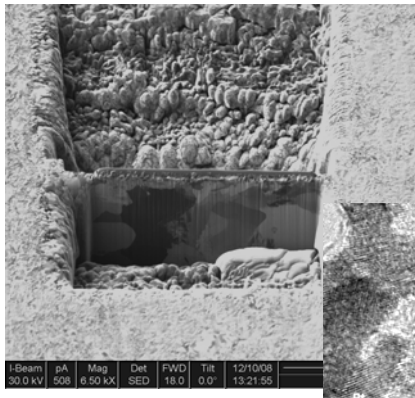
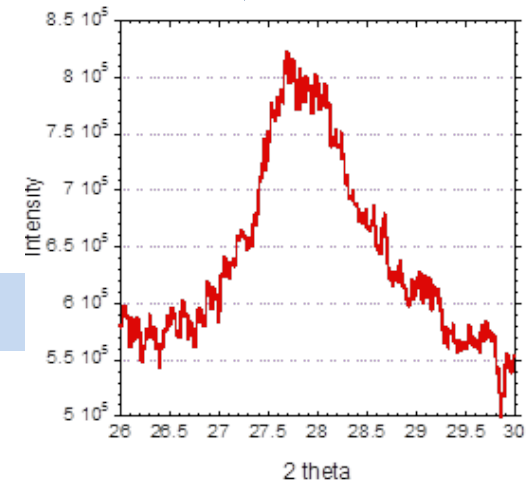
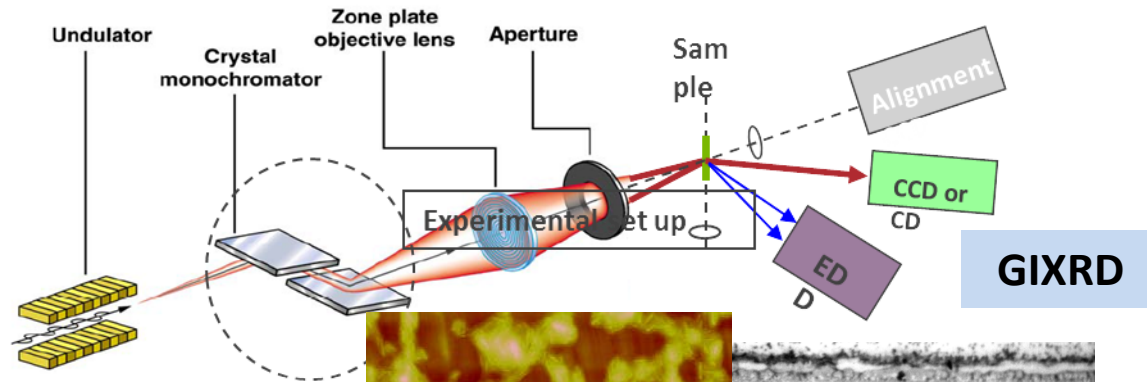


- Comparison of nanoparticulate additives and chemical additives show significant impact on friction response.
- Characterization of surfaces is in progress to determine differences in surface finishes and formation of tribofilms.

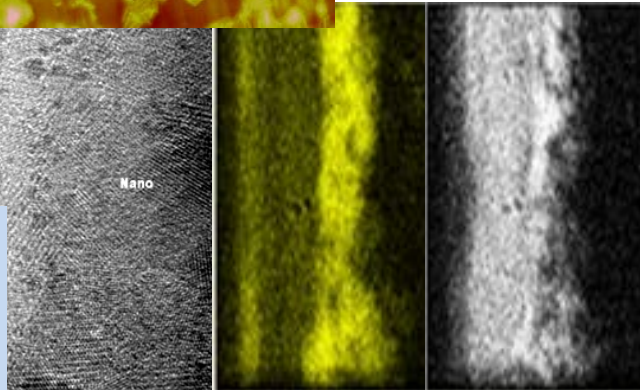




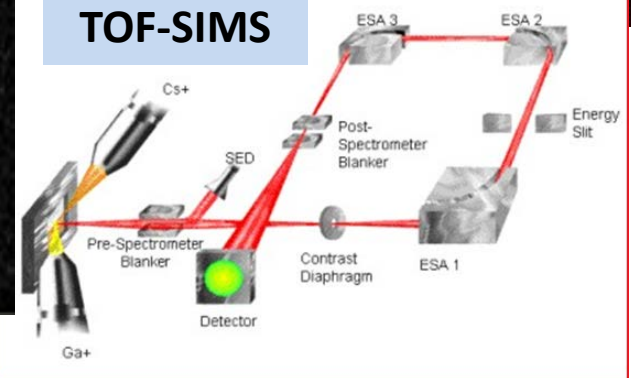
Progress: X-rays, electrons, and ion beams shed light on the chemistry and structure of tribo-films; provide insight on active friction mechanisms; and can be correlated with (low or high) friction



**Focused Ion Beam Spectroscopy (FIBS) / TEM**



**TOF-SIMS**





# Work closely with academia and small businesses to evaluate tribological properties of innovative additives

- Utilize common benchtop protocols to characterize the friction and wear properties of innovative additives under development by academia and industry.
- Perform tests to evaluate not only friction and wear behavior of their additive, but also the impact of additive on lubricant viscosity.
- Tests performed with unformulated, formulated, and partially formulated fluids often show strikingly different response – indicating a competition between different chemically active additives and the need to work with additive/lubricant OEMs to formulate their additive into a total package.
- Will perform preliminary characterization studies to determine if the additives are chemically active, or are mechanically altering the surface.
- Preliminary tests often lead to follow-on, more detailed studies through work for others, CRADA agreements
- Work normally performed under nondisclosure agreement (NDA) arrangements and thus are not provided here.





# Collaborations and Coordination

- MIT – member of MIT Lubrication Consortium – includes vehicle and component OEMs and lubricant OEM.
- Vehicle and Engine OEMs – FMEP modeling, benchtop testing, and additive technology.
- Component OEMs – Mahle – supply stock and advanced liners and rings for experimental studies.
- Lubricant Suppliers – supply basefluids, partially formulated, and fully formulated lubricants.
- Additive Suppliers – supply commercial and advanced additives.
- DOD/TARDEC – collaboration on fuel efficient lubricants (engines and transmissions).
- Small Businesses, Academia – novel additives – synthesis and characterization.
- DOE Vehicle Systems Program – FMEP modeling.





# Proposed Future Activities

- Remainder FY 2012
  - Issue draft MYPP for comment.
  - Finalize lab protocols to develop high fidelity data boundary friction data using Stribeck analysis – extrapolate back to zero Stribeck number.
  - Continue FIBS-TEM structure/chemistry characterization of tribofilm formation.
  - Initiate projects on fuel dilution, and self-replenishing smart additives.
  - Kick-off Boron-Based Lubricant Additive Project.
- FY 2013
  - Role out MYPP at Lubrication Workshop (early FY 13).
  - Lab-Engine Validation – continue studies on the impact of surface finish on Stribeck analysis. Apply engine friction models to lab-scale friction data.
  - Start population of boundary friction database for different additive/lubricant combinations and temperatures.
  - Characterize tribofilms of unformulated, semi-formulated, and fully formulated tribofilms. Determine differences in structure and composition.
  - Continue collaborations with industry/academia on innovative technologies.





# Summary

- Working closely with DOE Office of Fuel and Lubricants to evaluate the impact of lubricants on fuel economy and to develop program to establish goals and targets, identify barriers to achieving targets, and establish projects to develop approaches and solutions to improve fuel economy of new and legacy vehicles with advanced lubricants. A MYPP will be developed and rolled out later this year.
- Established a project to improve the fidelity of lab-based tests for engine and vehicle environments. Project involves a collaborative effort with MIT Lubrication Consortium. Preliminary efforts are focusing on developing test protocols and data analysis procedures to analyze lab and engine data using a common Stribeck approach. The data analysis approach will be applicable to other efforts/projects on advanced lubricants.
- A FIBS-TEM technique was developed for analysis of the structure and chemistry of thin (100 nm thick) tribofilms formed on sliding surfaces. A series of tests on different tribofilms suggests a strong connection between structure and friction. Additional tests are in progress to confirm these findings. If successful, this will provide an insight on future formulation of innovative additives.

