5. Fuel and Lubricant Technologies

The Vehicle Technologies Office (VTO) supports early-stage research and development (R&D) to generate knowledge upon which industry can develop and deploy innovative energy technologies for the efficient and secure transportation of people and goods across America. VTO focuses on research that industry either does not have the technical capability to undertake or is too far from market realization to merit sufficient industry focus and critical mass. In addition, VTO leverages the unique capabilities and world-class expertise of the national laboratory system to develop new innovations for significant energy-efficiency improvement. VTO is also uniquely positioned to address early-stage challenges due to its strategic public-private research partnerships with industry (e.g., U.S. DRIVE and 21st Century Truck Partnerships) that leverage relevant technical and market expertise, prevent duplication, ensure public funding remains focused on the most critical R&D barriers that are the proper role of government, and accelerate progress—at no cost to the Government.

The Fuel and Lubricant Technologies (FT) subprogram supports early-stage R&D to improve our understanding of, and ability to manipulate, combustion processes, generating knowledge and insight necessary for industry to develop the next-generation of engines and fuels. The primary means for accomplishing this is through the Co-Optimization of Fuels and Engines program (Co-Optima), which is working to identify the critical fuel properties needed to enable advanced engine architectures and emission control systems that optimize engine efficiency and operability, along with scalable and cost-effective low-carbon fuels that have those properties. FT also supports research to promote fuel diversification through the direct substitution of emerging domestic fuel. Increased use of these fuels can promote national energy security and reduce the operation costs for domestic fleets. Additionally, FT projects are researching advanced lubricants that are compatible with future and legacy vehicles and can reduce friction losses in engines, transmissions, and axles, thereby improving fuel economy across the vehicle fleet.

Subprogram Feedback

The U.S. Department of Energy (DOE) received feedback on the overall technical subprogram areas presented during the 2017 Annual Merit Review (AMR). Each subprogram technical session was introduced with a presentation that provided an overview of subprogram goals and recent progress, followed by a series of detailed topic area project presentations.

The reviewers for a given subprogram area responded to a series of specific questions regarding the breadth, depth, and appropriateness of that DOE VTO subprogram's activities. The subprogram overview questions are listed below, and it should be noted that no scoring metrics were applied. These questions were used for all VTO subprogram overviews.

Question 1: Was the program area, including overall strategy, adequately covered?

Question 2: Is there an appropriate balance between near- mid- and long-term research and development?

Question 3: Were important issues and challenges identified?

Question 4: Are plans identified for addressing issues and challenges?

Question 5: Was progress clearly benchmarked against the previous year?

Question 6: Are the projects in this technology area addressing the broad problems and barriers that the Vehicle Technologies Office (VTO) is trying to solve?

Question 7: Does the program area appear to be focused, well-managed, and effective in addressing VTO's needs?

Question 8: What are the key strengths and weaknesses of the projects in this program area? Do any of the projects stand out on either end of the spectrum?

Question 9: Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

Question 10: Has the program area engaged appropriate partners?

Question 11: Is the program area collaborating with them effectively?

Question 12: Are there any gaps in the portfolio for this technology area?

Question 13: Are there topics that are not being adequately addressed?

Question 14: Are there other areas that this program area should consider funding to meet overall programmatic goals?

Question 15: Can you recommend new ways to approach the barriers addressed by this program area?

Question 16: Are there any other suggestions to improve the effectiveness of this program area?

Responses to the subprogram overview questions are summarized in the following pages. Individual reviewer comments for each question are identified under the heading Reviewer 1, Reviewer 2, etc. Note that reviewer comments may be ordered differently; for example, for each specific subprogram overview presentation, the reviewer identified as Reviewer 1 in the first question may not be Reviewer 1 in the second question, etc.

Presentation Number: ft000 Presentation Title: Overview of the DOE Fuel and Lubricant Technologies R&D
Principal Investigator: Kevin Stork (U.S. Department of Energy)

Question 1: Was the program area, including overall strategy, adequately covered?

Reviewer 1:
The reviewer stated yes, all areas were briefly covered. The strategy seeks to displace petroleum based fuels through improved combustion efficiency and reduced engine and vehicle friction.

Reviewer 2:
The reviewer stated that the information regarding the strategy of the fuels and lubricants that can enhance combustion efficiency programs was provided. The strategy includes identifying fuel properties to enable advanced engine and emission control systems that optimize engine efficiency and increase energy security by enabling fuel substitution.

Reviewer 3:
The reviewer commented that the presentation did a good job of identifying the key challenges for the program area (fuels and lubricants) for both light and heavy-duty applications. In addition, the strategy/approach for addressing the identified barriers was adequately covered.

Question 2: Is there an appropriate balance between near-, mid-, and long-term research and development?

Reviewer 1:
The reviewer responded yes, there is an appropriate balance between near-, mid-, and long-term research and development. For lubricants, near term work includes developing drop-in lubricants while long term includes researching new base stocks, additives and methods to measure and predict performance. For fuels, the benefits of high ethanol blends are being studied and new fuel molecules or blends are being studied which are lower carbon footprint than current petroleum fuels and enable more efficient combustion.

Reviewer 2:
The reviewer commented that there was an adequate discussion of today's fuels and that of what is needed in future fuels to help to achieve efficiency goals.

Reviewer 3:
The reviewer stated that the presentation started with two of the most pressing concerns for light-duty vehicles (i.e., knock resistance/octane of gasoline fuel, and low-viscosity lubricants for reducing friction losses). Addressing the aforementioned concerns has the potential to perhaps have the greatest impact on national fuel consumption and expenditure on transportation in the near term. In addition, the overview addressed the looming challenge of balance in gasoline and diesel volume demand, which can have significant implications particularly for the heavy-duty market. The scope of the Co-Optima program covers the mid-to-long term research and development needs.

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer commented that an important issue for the drop-in lubricant for in-use vehicles is the use of lower viscosity oils in engines which were not originally designed for them, figuring out who is taking the risk of introducing them, and motivating a customer to purchase them for only a 2% fuel economy gain. This reasoning has been used for years to help justify the lubricant program, but the path forward is not clearly identified. Lubricant research is important for future engines and vehicles, but I think justifying the program on fuel savings with current vehicles may be a fallacy.

The reviewer observed that the world has changed and petroleum displacement is not nearly as important as it was 5 or 10 years ago. I think the main justification for this research is to minimize supply disruptions, to reduce generation of CO_2, to support development of higher efficiency engines, and to extend the use of natural resources into future generations.

Reviewer 2:

The reviewer noted that the two barriers were identified: a lack of understanding of how fuel properties impact the efficiency of modern engines and in light-duty application; and a lack of fueling infrastructure and compact on-board storage for gaseous fuels.

Reviewer 3:

The reviewer responded yes, the important issues and challenges have been identified. In particular, the most pressing need for gasoline fuel - knock resistance or octane - has been highlighted. Improving the octane of the market fuel is arguably the most cost-effective measure for improving the efficiency and fuel economy of the entire vehicle fleet. As the entire vehicle fleet can benefit from improved fuel octane, the benefit to society in reduced fuel consumption can be substantial.

Question 4: Are plans identified for addressing issues and challenges?

Reviewer 1:

The reviewer observed that Co-Optima is a relatively new program aimed at matching new fuels with advanced combustion regimes with a very broad range of molecules being studied and many down-select gates for the fuels as research becomes more focused.

Reviewer 2:

The reviewer noted that the Co-Optima program will identify the optimal fuel-engine combination to lead to higher efficiency and this will lead to addressing the challenge of how fuel properties effects the efficiency of modern engines.

Reviewer 3:

The reviewer commented that while fuel knock resistance/octane has been rightly identified as the most important fuel property for light-duty vehicles, the plan to address the need for improved fuel knock resistance has not been explicitly addressed. In general, the plan for addressing the challenges identified has been presented at a very high level. It would be beneficial to tabulate the challenges and associated action plans on one slide.

Question 5: Was progress clearly benchmarked against the previous year?

Reviewer 1:

The reviewer noted that the presentation highlighted progress since last year, but details were not given due to breadth of program. Those details were discussed in the individual talks.

Reviewer 2:

The reviewer commented that there was a general discussion about how from 2000 to 2016 there has been a great deal of improvement in fuel economy and downsizing engines and that by having higher octane fuels and higher compression ratios fuel economy can be increased, However, there was not an adequate discussion regarding progress benchmarked against previous year successes.

Reviewer 3:

The reviewer stated no, the overview presentation did not address progress at all.

Question 6: Are the projects in this technology area addressing the broad problems and barriers that the Vehicle Technologies Office (VTO) is trying to solve?

Reviewer 1:
The reviewer observed that VTO is aimed at improving truck and automotive fuel economy and to substitute new fuels in place of petroleum derived fuels. Additionally, this reviewer continued, VTO wishes to maintain air pollution control and to enable the evolution of engines, materials, and vehicles.

Reviewer 2:
The reviewer commented that projects in the Fuels and Lubricants Program area definitely are working towards helping to increase fuel efficiency of engines as well as providing lubricants that can also have a positive impact on fuel economy efficiency.

Reviewer 3:
The reviewer stated yes, the ongoing work described in this overview presentation is directly addressing the goals of improving energy independence by reducing fuel consumption as well as facilitating greater use of biomass based fuels.

Question 7: Does the program area appear to be focused, well-managed, and effective in addressing VTO's needs?

Reviewer 1:
The reviewer commented that the Fuels and Lubricants Program area continues to be extremely well managed by very technically competent managers and has projects that fit well into the VTO portfolio to help increase fuel economy of light,

Reviewer 2:
The reviewer stated yes, the program area appears to be focused, well-managed, and effective in addressing VTO's needs.

Reviewer 3:
The reviewer was a little confused about the divergence of octane and compression ratio. It appears that the efficiency gains of higher compression ratio can be gained both through higher octane as well as by improved engine design. It would be interesting to learn more about and to study design changes that enable higher compression ratio with a fixed octane.

The large multi-laboratory lubricants program did not seem to have an overarching vision, but seemed to be mainly a shot gun combination of the research each laboratory had been doing separately and previously.

The reviewer commented that the presentation talked about the octane index (OI) being a better measure of fuel performance than anti-knock index. But the OI is just a correlation developed after the fact and with an adjustable factor that tunes for different engine types and model years. It is not a fundamental measurement.

The reviewer noted that if program is cut back, I think it would be most important to improve engine efficiency with current lube and fuels portfolios, rather than continuing to develop new fuels.

Question 8: What are the key strengths and weaknesses of the projects in this program area? Do any of the projects stand out on either end of the spectrum?

Reviewer 1:
The reviewer commented that the co-optimization projects are a real strength of the Fuel and Lubricants Program. Pulling together fuels and engines is essential to continuing to increase fuel economy of both gasoline and diesel engines.

Reviewer 2:
The reviewer noted that a key strength of the program is the development of new science relative to fuels and lubricants which will allow continued evolution of engine and vehicle technology. Co-optima is a fresh look at a wide range of fuels and should be considered a strength. Justifying the lubricants program on the development and adoption of a lower viscosity lubricant for in use vehicles is probably a fallacy, but the research is still very important for future engines and vehicles.

Reviewer 3:
The reviewer noted that the strength of the program is that the key challenges facing both light and heavy-duty markets have been rightly identified. The reviewer identified the weakness of the program as focusing on the advanced combustion concepts and thus on projects that are addressing longer term goals. By the time these advanced combustion concepts reach a maturity level ready for industrial considerations, they may no longer be relevant as the same level of efficiency improvement would have been achieved through alternate technology pathways including increased electrification of the powertrain. In addition, while increased energy independence due to use of domestic feedstock has been identified as an opportunity, no clear action plan has been identified to facilitate adoption and introduction of biomass based fuels in the market.

Question 9: Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

Reviewer 1:
The reviewer commented that program seeks to develop more efficient research and screening methods and models, both to speed up the rate of research and learning and also to discover underlying science.

Reviewer 2:
The reviewer noted that the co-optimization projects represent an extremely innovative method of how to address the issues of increasing fuel economy by looking at a complete systems approach of both the engine and the fuel interaction.

Reviewer 3:
The reviewer stated yes, the projects do represent innovative ways to approach the technical challenges identified. However, for the fuels projects, the emphasis is on longer term solutions which may never come to fruition due to the substantial challenges associated with engine controls and aftertreatment that are currently considered out of scope. Shifting the balance more towards some of the near-to-mid-term solutions may be better for achieving VTO's goals of reduced petroleum consumption and greater energy independence.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
The reviewer observed that the program has a large number of partners including large auto and truck companies, Tier 1 suppliers, universities, small businesses, government laboratories, trade organizations, fuel and chemical companies, lubricant and additive manufacturers, and instrument manufacturers. The participation of all these diverse groups ensures that research will be directed in the most useful manner.

Reviewer 2:
The reviewer noted that through the work in the Fuels Working Group within the United States Driving Research and Innovation for Vehicle Efficiency and Energy (U.S. DRIVE) organization and through Co-Optima monthly conference calls, the program is actively involved with partners that will add to the value of the projects within the program.

Reviewer 3:
The reviewer stated that the program area has engaged partners in industry (automotive and energy) and academia. In addition, the program area is fostering greater collaboration between the participating national laboratories.

Question 11: Is the program area collaborating with them effectively?

Reviewer 1:
The reviewer noted that the program does a good job of collaborating within the restraints of funding, proprietary

Reviewer 2:
The reviewer stated yes, the program area has a very good relationship with the partners that work in the program and uses their input very effectively.

Reviewer 3:
The reviewer stated yes, the program area is collaborating effectively with project partners. However, there is room for improvement in interaction with stakeholders, in particular for the Co-Optima program. The monthly stakeholder conference calls serve the purpose of apprising stakeholders of the various projects and are much appreciated. However, the stakeholder calls are not necessarily the most effective means for seeking stakeholder feedback. One potential option could be to set up a website for stakeholders where all the review presentations are posted and stakeholders have the options of providing written feedback.

Question 12: Are there any gaps in the portfolio for this technology area?

Reviewer 1:
The reviewer stated that there are no obvious gaps in the program. There is an appropriate balance between fuels and lubricants and between near-term and far-term development.

Reviewer 2:
The reviewer noted that the Fuels and Lubricants Program area projects do not have any apparent gaps that need to be addressed.

Reviewer 3:
The reviewer stated that as advanced combustion concepts are investigated, it would be beneficial to take into consideration the variations in properties of market fuels. Testing fuel blends representative of the extreme ends of the market fuel spectrum would provide valuable information about the robustness of the various combustion concepts. Also, as the project results are reported, especially for projects focused on biomass based fuel components, it would be beneficial to include assessment of the Analysis of Sustainability, Scale, Economics, Risk, and Trade (ASSERT) team (techno-economic analysis) in the project reports.

Question 13: Are there topics that are not being adequately addressed?

Reviewer 1:
The reviewer commented that the fuels and lubricant topics that were discussed were adequately addressed.

Reviewer 2:
The reviewer stated that it would be nice to know more about how engine design interplays with compression ratio, so that compression ratios continue to increase, even in the absence of octane increase. It would be nice to know if there is a better or more fundamental way of evaluating octane or cetane than those currently used. However, the reviewer recognized that engine design steps over into proprietary company decisions and that a more fundamental measurement of octane or cetane has already been the subject of much research, with no clear winner emerging.

Reviewer 3:
The reviewer commented that when the project results are reported, especially for projects focused on biomass based fuel components, it would be beneficial to include assessment of the ASSERT team (techno-economic analysis) in the project reports. Assessing the feasibility of combustion concepts or potential new fuel components would help identify the more promising candidates and increase the likelihood of realizing the opportunities identified in the presentation.

Question 14: Are there other areas that this program area should consider funding to meet overall programmatic goals?

Reviewer 1:
The reviewer stated that the program could benefit from continuing to develop closer collaboration and/or joint programs with combustion engines, controls, bio-energy, modeling, and materials. Co-Optima is a good example of this. There is also some work developing new lubricants, additives, and measurements corresponding to new materials being introduced into vehicles, such as plastics and coatings.

Reviewer 2:
The reviewer commented that the program should make sure to continue funding the Co-Optima projects because it is very important to look at engine and fuel interactions.

Reviewer 3:
The reviewer noted that there were insufficient funds to address existing program goals.

Question 15: Can you recommend new ways to approach the barriers addressed by this program area?

Reviewer 1:
The reviewer stated that the modeling of fuels, engines, and materials should continue to bear fruit. The reviewer realizes that a lot of modeling has and is being done, but as computers and computation speed and complexity.

Reviewer 2:
The reviewer observed that currently the program area adequately addresses the barriers. However, if funding is reduced to the fiscal year (FY) 2018 budget request levels this will not be the case.

Reviewer 3:
The reviewer suggested to promote greater use of modeling tools to complement and augment the experimental work, in particular related to the non-linear variation in fuel properties and how that impacts engine combustion.

Question 16: Are there any other suggestions to improve the effectiveness of this program area?

Reviewer 1:
The reviewer suggested that the program continue to engage with other parts of the DOE program and continue to engage with industry and universities. This broad exposure and viewpoint should ensure that the program maintains its relevance.

Reviewer 2:
The reviewer stated that the program is structured very well and is effective as it stands now.

Reviewer 3:
The reviewer suggested that the program evaluate existing projects based on their feasibility and likelihood to impact production technologies and re-allocate funding accordingly. Some of the current projects purportedly have the potential to deliver large efficiency gains but are extremely unlikely to be incorporated into

automotive applications due to controls, aftertreatment, and reliability concerns. It would be better to fund projects that may have a smaller benefit but greater likelihood of influencing technology in production.

Project Feedback

In this merit review activity, each reviewer was asked to respond to a series of questions, involving multiple-choice responses, expository responses where text comments were requested, and numeric score responses (*on a scale of 1.0 to 4.0).* In the pages that follow, the reviewer responses to each question for each project will be summarized: the multiple choice and numeric score questions will be presented in graph form for each project, and the expository text responses will be summarized in paragraph form for each question. A table presenting the average numeric score for each question for each project is presented below.

Table 5-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
ft023	Polyalkylene Glycol (PAG) Based Lubricant for Light- and Medium-Duty Axles	Arup Gangopadhyay (Ford Motor Co.)	5-13	3.10	2.80	3.00	3.10	**2.94**
ft024	A Novel Lubricant Formulation Scheme for 2% Fuel Efficiency Improvement	Q. Jane Wang (Northwestern U.)	5-17	3.40	3.20	3.50	2.90	**3.25**
ft025	Improved Fuel Economy through Formulation Design and Modeling	Gefei Wu (Valvoline)	5-21	3.25	3.25	3.75	3.38	**3.33**
ft037	Co-Optimization of Fuels and Engines (Co-Optima)—Overview	John Farrell (NREL)	5-25	3.25	3.45	3.30	3.40	**3.38**
ft047	Advanced Lubricant Technology—Surface and Lubricant Interactions	Oyelayo Ajayi (ANL)	5-33	3.38	3.13	3.75	3.38	**3.30**
ft048	Advanced Lubricant Technology—Technology Innovation, Design, and Synthesis	Lelia Cosimbescu (PNNL)	5-37	3.10	3.30	3.50	3.40	**3.29**
ft049	Lubricant Effects on Combustion and Emissions Control	John Storey (ORNL)	5-41	3.70	3.70	3.50	3.40	**3.64**
ft050	Power-Cylinder Friction Reduction through Coatings, Surface Finish, and Design	Arup Gangopadhyay (Ford Motor Co.)	5-46	3.50	3.40	3.60	3.50	**3.46**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
ft051	Co-Optimization of Fuels and Engines (Co-Optima)—Fuel Property Characterization and Prediction	Robert McCormick (NREL)	5-50	3.50	3.75	3.50	3.63	**3.64**
ft052	Co-Optimization of Fuels and Engines (Co-Optima)—Topic 7 - Fuel Kinetics and Its Simulation	Matthew McNenly (LLNL)	5-54	3.36	3.50	3.43	3.29	**3.43**
ft053	Co-Optimization of Fuels and Engines (Co-Optima)—Fuel-Property Impacts on Spark Ignition Efficiency, Part 1: Research Octane Number, Sensitivity, and Heat of Vaporization	Jim Szybist (ORNL)	5-60	3.75	3.75	3.50	3.63	**3.70**
ft054	Co-Optimization of Fuels and Engines (Co-Optima)—Fuel-Property Impacts on Spark Ignition Efficiency, Part 2	Chris Kolodziej (ANL)	5-64	3.33	3.58	3.33	3.33	**3.46**
ft055	Co-Optimization of Fuels and Engines (Co-Optima)—Multimode Lean Spark Ignition: Experiments and Simulation	Magnus Sjoberg (SNL)	5-69	3.40	3.70	3.40	3.30	**3.54**
ft056	Co-Optimization of Fuels and Engines (Co-Optima)—Exploratory Advanced Compression Ignition Combustion Tasks	John Dec (SNL)	5-73	2.67	2.83	3.00	2.33	**2.75**
ft057	Co-Optimization of Fuels and Engines (Co-Optima)—Emissions, Emission Control, and Sprays	Todd Toops (ORNL)	5-76	3.70	3.40	3.40	3.40	**3.48**
ft058	High-Efficiency Cost-Effective Natural Gas Engine	Alexander Freitag (Bosch)	5-80	3.00	3.25	3.38	3.13	**3.19**
ft059	High BMEP and High Efficiency Micro-Pilot Ignition Natural Gas Engine	Jeffrey Naber (Michigan Technological Institute)	5-83	2.33	2.83	2.17	2.83	**2.63**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
ft060	Single-Fuel Reactivity Controlled Compression Ignition Combustion Enabled by Onboard Fuel Reformation	Ben Lawler (Stony Brook U.)	5-86	2.88	3.25	3.13	3.00	**3.11**
ft061	Methods to Measure, Predict, and Relate Friction, Wear, and Fuel Economy	Steve Gravante (Ricardo)	5-90	3.20	3.00	3.30	3.00	**3.09**
Overall Average				**3.28**	**3.35**	**3.36**	**3.26**	**3.32**

Presentation Number: ft023
Presentation Title: Polyalkylene Glycol (PAG) Based Lubricant for Light- and Medium-Duty Axles
Principal Investigator: Arup Gangopadhyay (Ford Motor Co.)

Presenter
Nikolaus Jost, Ford Motor Co.

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that the author had selected a quite unique approach to formulating axle lubricants by using polyalkylene glycol (PAG) base stocks.

Reviewer 2:
The reviewer stated that the approach and strategy presented appear to be adequate to provide information to meet the barriers identified.

Reviewer 3:
The reviewer commented that while the overall approach is reasonable, better planning might have obviated some of the setbacks encountered. In particular, according to this reviewer, project planning seems to have lacked a well thought out screening sequence including literature searching and screening tests for such properties as toxicity and foaming.

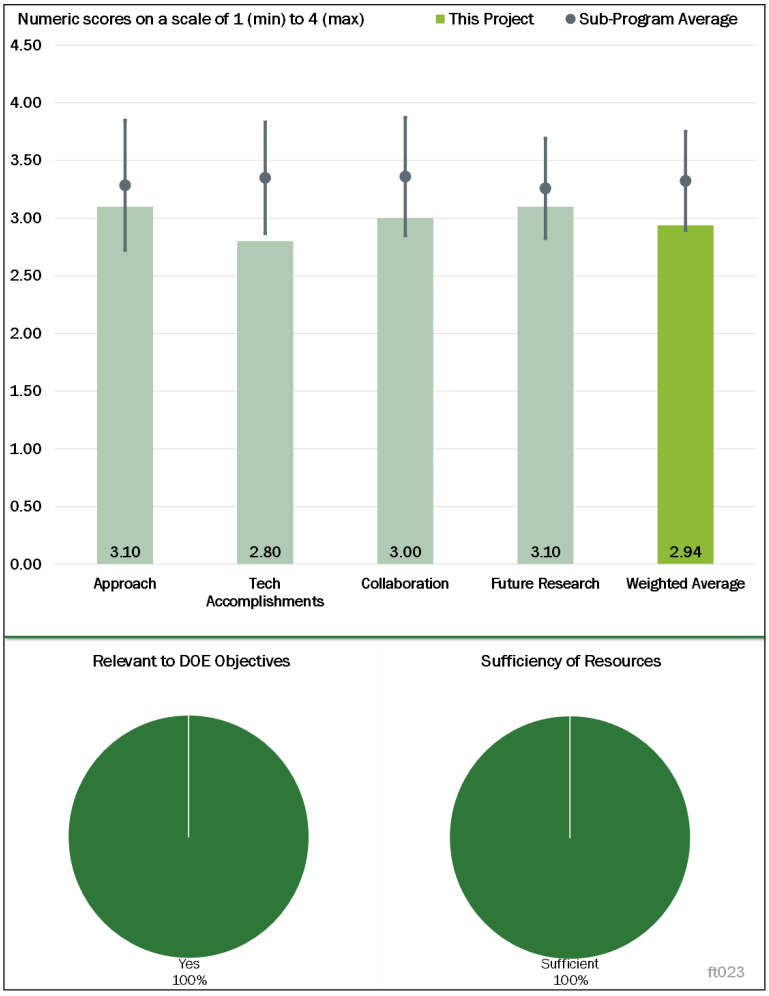

Figure 5-1 - Presentation Number: ft023 Presentation Title: Polyalkylene Glycol (PAG) Based Lubricant for Light- and Medium-Duty Axles Principal Investigator: Arup Gangopadhyay (Ford Motor Co.)

Reviewer 4:
The reviewer commented that the project has continued to encounter some surprises along the way, such as toxicological issues and foaming, and that although the project team has diligently addressed all the issues they have encountered, these issues have certainly hampered the progress considerably. The reviewer believes that many of these issues can be prevented by implementing a rigorous bench screening protocol, and strongly recommended inclusion of the following property evaluation as a minimum on each candidate before doing any performance testing: demulsibility; foaming and aeration tendencies; haze, additive drop out, and/or precipitation (usually requires several weeks of storage stability testing at various temperatures of interest); and regulatory issues (e.g., toxicology).

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that while the project has shown the PAG family to have interesting and useful properties, progress towards the end goal has been severely hampered by unpleasant surprises, and as a result, the latest candidate formulation is essentially at the starting block.

Reviewer 2:
The reviewer said that progress is being made despite some setbacks in the testing.

Reviewer 3:
According to this reviewer, the author reported on the project's technical progress by providing details identifying all the reformulations that were carried out. The reviewer stated that the lessons learned from the data collected were well summarized. The reviewer noted that the author was forced to change the base fluid for safety and toxicology requirements, which impacted and slowed down progress.

Reviewer 4:
The reviewer commented that technical accomplishments have not been very good to date. The reviewer added that there have been several failures of some of the formulations, including significant scoring on both drive and coast side of the ring and pinion gears; a cloudiness showing evidence of a precipitate; and a base fluid change required for safety and toxicological requirements. The reviewer noted that there are now some promising wear scar test results but it still needs to be determined whether the fuel economy impacts can be delivered using the new oil formulations.

Reviewer 5:
The reviewer commented that lubricant formulations have demonstrated significant efficiency improvements and passed a number of the tests, but other properties present obstacles that may or may not preclude their ultimate use with modifications to the formulations, particularly with regard to the precipitate formation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer praised the project lead for having put together a very good group of partners and collaborators including Dow Chemical, Argonne National Laboratory (ANL) and testing service companies to provide input and guidance to the project.

Reviewer 2:
The reviewer commented that the collaboration between Ford and ANL seems to be working well; however, it is not clear if the third partner, Dow, is as engaged as they need to be. The reviewer added that Dow needs to proactively advise the project on the chemical nature of the base fluids and their potential consequences in terms of bench properties. The reviewer stated that the team has also correctly pointed out the absence of an additive partner as a critical issue, and that this matter should be addressed urgently because an additive partner can help a lot by advising on appropriate bench testing prior to any performance testing.

Reviewer 3:
The reviewer remarked that a strong collaborative team was established, but no additive supplier was invited to join this project, and that the lack of additive technology may have impacted progress of this project.

Reviewer 4:
The reviewer said that an additive company would be a good addition. DOW may not have enough expertise to fully formulate oil.

Reviewer 5:
The reviewer found that the presentation did not make clear how active the collaborations are within the project; rather it listed "collaborators" for specific defined tasks. The reviewer noted that two of the project participants shown are clearly just (testing) service providers while a third, ANL, is also shown firstly as conducting tests, as well as providing expertise which may amount only to analysis of the test results for tribofilm and friction reduction mechanism. The reviewer commented that the main collaborator with the principal organization (Ford) is Dow Chemical, which is not accepting DOE funding and is responsible for the formulation of the lubricant packages; further, it is not clear how active its role is in planning, screening, candidate selection and formulation rather than merely being responsive.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer found that the work plan clearly outlines the issues that need to be resolved, but added that the plan should include finding an additive partner as a high priority.

Reviewer 2:
The reviewer commented that this is one of the unique projects where the authors are actually planning to explore optimization of candidate formulations. The reviewer also noted that several critical performance tests are being planned: moisture corrosion resistance; shock loading; and Ford axle wear and efficiency and vehicle fuel economy testing.

Reviewer 3:
The reviewer suggested adding some testing to show how PAG behaves if contaminated with water.

Reviewer 4:
The reviewer stated that the proposed future work appears satisfactory, but with only 4 months left in FY 2017 it is unclear if all the future work and remaining challenges can be met.

Reviewer 5:
The reviewer observed that the principal investigator (PI) expects to have the project back on schedule by this summer and has made some progress that appears to make that feasible, but it is still not clear that the planning and coordination/collaboration is adequate to prevent the recurrence of similar setbacks.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer remarked that optimization of driveline fluids, especially axle fluids, remains one of the few areas that has not received sufficient attention from the industry, and that, therefore, the project team should be complimented for providing the much-needed attention to this area. The reviewer noted that optimization of axle fluid can offer measurable efficiency gains to support the overall DOE goals of reducing petroleum consumption.

Reviewer 2:
The reviewer found that, based on proposed project structure, this project definitely supports overall DOE objectives.

Reviewer 3:
The reviewer commented that the objective of this project, to reduce petroleum consumption by improving fuel economy and to reduce energy dependence by using non-petroleum based lubricants, definitely supports the overall DOE objective of petroleum displacement.

Reviewer 4:
The reviewer responded yes, reduction of axle friction could significantly enhance overall efficiency, and the project has goal of overall 2% fuel economy improvement, due to reduction of axle friction.

Reviewer 5:
The reviewer said that the project could save petroleum due to efficiency improvements if successful.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that, between Ford and ANL, the project has enough resources on the primary performance aspects of the projects; however, the project could benefit from the addition of a skilled formulation resource (potentially from an additive partner.)

Reviewer 2:
The reviewer commented that the authors do not discuss and include in their budget money contributed by DOW Chemical and ANL.

Reviewer 3:
The reviewer observed that, according to the presentation, only 12% of the DOE's funding has been spent and, with only a few months left in the project, it is not clear how the balance of the $350,000 can be used.

Reviewer 4:
The reviewer stated that the project budget of $700,000 appears reasonable for the work done. The reviewer noted, however, that no explanation is recorded for why only approximately $42,000 of the $350,000 DOE share had been used by FY 2016, with the project shown as 75% complete by the time the presentations were prepared.

Presentation Number: ft024
Presentation Title: A Novel Lubricant Formulation Scheme for 2% Fuel Efficiency Improvement
Principal Investigator: Q. Jane Wang (Northwestern University)

Presenter
Q. Jane Wang, Northwestern University

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer stated that the authors have provided a clear and focused vision of their project, listing all potential technical barriers that must be overcome to address DOE goals.

Reviewer 2:
The reviewer noted that the approach seeks to simultaneously develop enhanced friction modifiers, wear reduction additives (nanoparticles), and shear thinning viscosity modifiers, and integrate them into formulations with each other so that all three critical properties are addressed jointly. The reviewer observed that the project uses novel approaches, particularly for the heterocyclic friction modifiers, which align on the surfaces so as to adsorb on them, thus substantially reducing asperity caused friction.

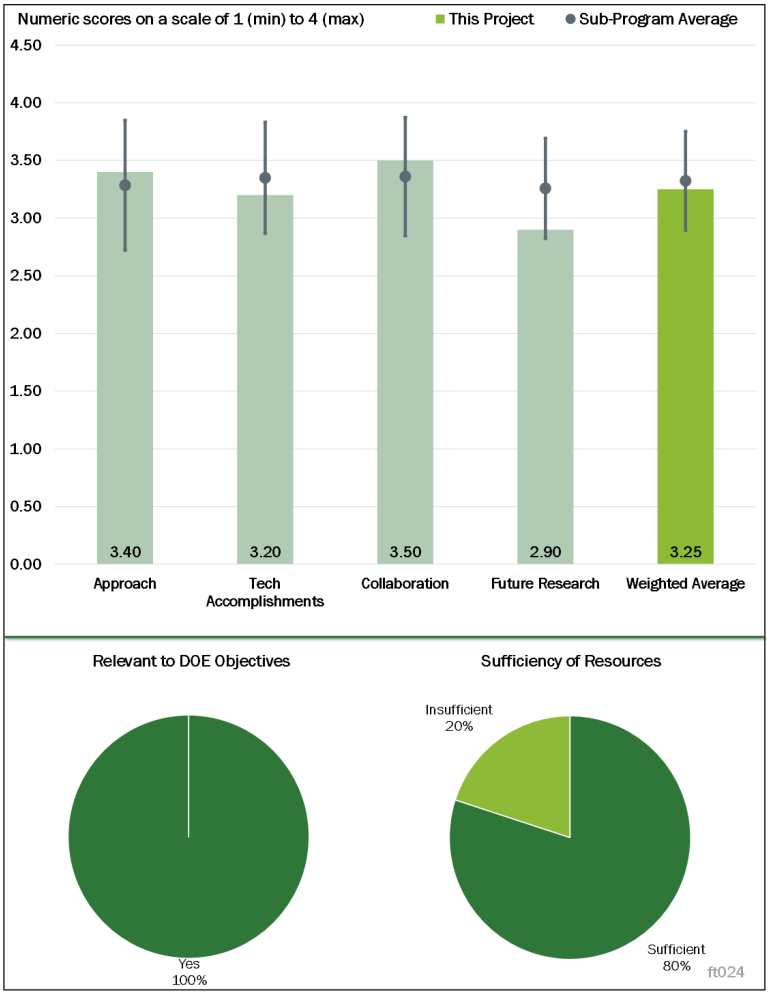

Figure 5-2 - Presentation Number: ft024 Presentation Title: A Novel Lubricant Formulation Scheme for 2% Fuel Efficiency Improvement Principal Investigator: Q. Jane Wang (Northwestern University)

Reviewer 3:
The reviewer remarked that the overall project approach seems valid, and that the scope is targeting both hydrodynamic and boundary lubrication by using friction, viscosity and nanoparticle additives. The reviewer noted that friction modifiers will be used to reduce boundary lubrication friction, and that nanoparticles are theorized to impact both boundary and hydrodynamic, and, the reviewer speculated, mixed lubrication, as well. The reviewer recommended that careful stribeck mapping be used to understand how nanoparticles affect each lubrication regime.

Reviewer 4:
The reviewer commented that the project team has done quite a bit of bench evaluation, which shows some interesting and encouraging results for the friction modifier (FM) and viscosity modifier (VM) candidates; however, the issue is that this project is operating in a very mature industry, and as such there is an extensive array of existing technologies against which these candidates must compete. The reviewer further stated that the project team has neither the access to the large number of existing technologies, nor to the relevant

formulations, nor the background in the testing required to prove out their candidates. The reviewer highly recommended that the team seek an additive company partner to conduct the requisite testing in the relevant formulation space. The reviewer added that, given the secretive nature of the additive industry, this will not be an easy task; but that nevertheless it is the only way to prove that this project is creating value.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that work to date has successfully identified candidate FMs, nanoparticles (NPs), and VMs utilizing the mechanisms discussed in Question 3, narrowed the selection field, and demonstrated the success of each in accomplishing the respective objectives, even demonstrating synergies by combining them in oil formulations. The reviewer noted that modeling toward the actual efficiency and fuel efficiency (FE) goal was not discussed.

Reviewer 2:
The reviewer said that progress is being made to a sufficient level.

Reviewer 3:
The reviewer stated that the project team has done everything that they can do to progress the project; however, they need an additive partner to conduct the testing to show that these candidates are better than the existing range of additive technologies.

Reviewer 4:
The reviewer commented that nanoparticles have shown significant wear reductions in this effort; however, further investigation should be conducted to understand the mechanisms for this enhancement. The reviewer noted that nanoparticles can act in several different fashions, depending on their functionalization, chemistry, material properties, charge, etc., and that the utmost importance would be the investigation of a tribofilm. The reviewer stated that, if generated by nanoparticles, chemistry, morphology, material properties and thickness should all be documented. The reviewer observed that, on Slide 8, PAO4 was shown to have even a lower coefficient of friction than a fully formulated 5W30 oil under the ball on flat rotational test in boundary lubrication. The reviewer commented that this seems very unlikely, as neat PAO4 under boundary lubrication is a very poor lubricant without any friction or wear modifiers to prevent steel on steel contact; however, the proposed friction modifiers show a rather large reduction from this test.

Reviewer 5:
The reviewer remarked that the researchers should be congratulated on the successful frictional/wear bench testing of novel classes of organic, metal free, boundary lubrication effective FM (i.e., alkyl cyclenes). The reviewer noted that, in their presentation, the authors did not attempt to optimize concentration of C18 cyclopropane (C18 cyc), or C12 cyc additives blended into 100% synthetic base stocks (PAO 4). The reviewer observed that all bench testing was carried out with additives present at 1% wt. concentration level, potentially missing the "sweet" performance point at lower or higher concentration levels offering superior FE and exceeding DOE set goals. The reviewer further stated that progress with di-block copolymers utilized as VMs is difficult to judge without a side by side performance comparison to standard olefin copolymer VM structures (including commercially available di-block polymers.) The reviewer inquired about the following: the uniqueness of the currently tested VM structures; whether patent literature has been checked in detail; why the intellectual property (IP) application was planned but not submitted; why only one concentration level (8% wt.) of di-block polymers was examined; whether a structure of NP was examined; whether any of these additives contain metals, and if so, what type of metals (e.g., boron); the NP size examined in bench tests and how these NPs were dispersed (dissolved) in PAO; and if boron reduces the efficiency of aftertreatment

catalysts. The reviewer pointed out that no progress is reported on suppressing lubricant aeration problems, yet this goal was listed in the 2015 presentation. The reviewer questioned whether it is still going to be pursued.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that a well-balanced team of technical collaborators is contributing to this project, including a specialty chemical industry representative (Ashland), National Renewable Energy Laboratory (NREL), and an Original Equipment Manufacturer (OEM), General Motors (GM).

Reviewer 2:
The reviewer commented that Slide 22 describes the roles of the project collaborators and reflects considerable interaction between them, and that interaction between representatives during the actual presentation further confirmed this.

Reviewer 3:
The reviewer stated that the project has a good mix of auto OEM, oil formulator, national laboratory, and university partners, and that all invested parties seem to be fulfilling their respective obligations.

Reviewer 4:
The reviewer commented that there is good evidence of close cooperation between Northwestern University (NU), ANL, and Ashland. The reviewer noted that, to date, GM appears to be acting as a validator of results, but the reviewer would hope to see GM play a more direct role in the future, in terms of engine testing.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer noted that the team has documented the future tasks but has not outlined the strategies for accomplishing these tasks; for instance, it is not clear how they will develop an "optimized oil" based on these additives unless they have access to the core additive components. The reviewer further noted that one of the candidates they are considering, nanoparticles, is well-known to have stability issues in the oil, i.e., a tendency to drop out over time, and this should be included in the future work.

Reviewer 2:
The reviewer said that some testing to look at the long-term impact of shear thinning would be beneficial, especially because this is a newer molecule for friction modification.

Reviewer 3:
The reviewer commented that planned industrial tests are not defined in detail, and that, surprisingly, no engine dynamometer testing is proposed to be included as a part of proof of the performance for novel chemistries. The reviewer questioned why this was the case, and also wondered what GM's contribution to this project is, beyond assessing bench testing results.

Reviewer 4:
The reviewer noted that the project is due to be completed within 3 months from the AMR meetings, and that the slides as prepared earlier show 80% completion with a few remaining knowledge gaps to be filled in, i.e., more severe testing, final optimal formulations to be chosen, as well as some additional variations of the FM concept to be tested.

Reviewer 5:
The reviewer observed that the project will address the huge barrier of synthesizing novel fully formulated lubricants, and indicated that interest from an oil formulation company should help determine commercial viability. The reviewer stated that the project is lacking some of the fundamental work to understand the mechanisms behind the performance enhancements of the novel additives, and suggested the addition of more thorough posttest analytics.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that, based on a well-planned project structure, this project definitely supports overall DOE objectives.

Reviewer 2:
The reviewer commented that the project is attempting to improve fuel efficiency through lubricant redesign, which aligns well with the DOE objective.

Reviewer 3:
The reviewer observed that friction reduction aims at 2% efficiency improvement, which translated to increased fuel economy.

Reviewer 4:
The reviewer said that it should save petroleum in both new vehicles and legacy vehicles due to efficiency improvements if successful.

Reviewer 5:
The reviewer commented that targeting all lubrication regimes is a good approach to achieve the overall DOE objective, and that the technical approach seems feasible in achieving this goal.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that the project appears on track for successful completion, with all DOE funding having already been received by the participants.

Reviewer 2:
The reviewer observed that the project is nearing completion and has been running on schedule and budget without delays.

Reviewer 3:
The reviewer stated that the project needs an additive supplier partnership to conduct real-world testing on the additive chemistries developed by the team.

Reviewer 4:
The reviewer commented that the budget expenses were not clearly described, e.g. amount of money spent in 2016 or 2017.

Presentation Number: ft025
Presentation Title: Improved Fuel Economy through Formulation Design and Modeling
Principal Investigator: Gefei Wu (Valvoline)

Presenter
Gefei Wu, Valvoline

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

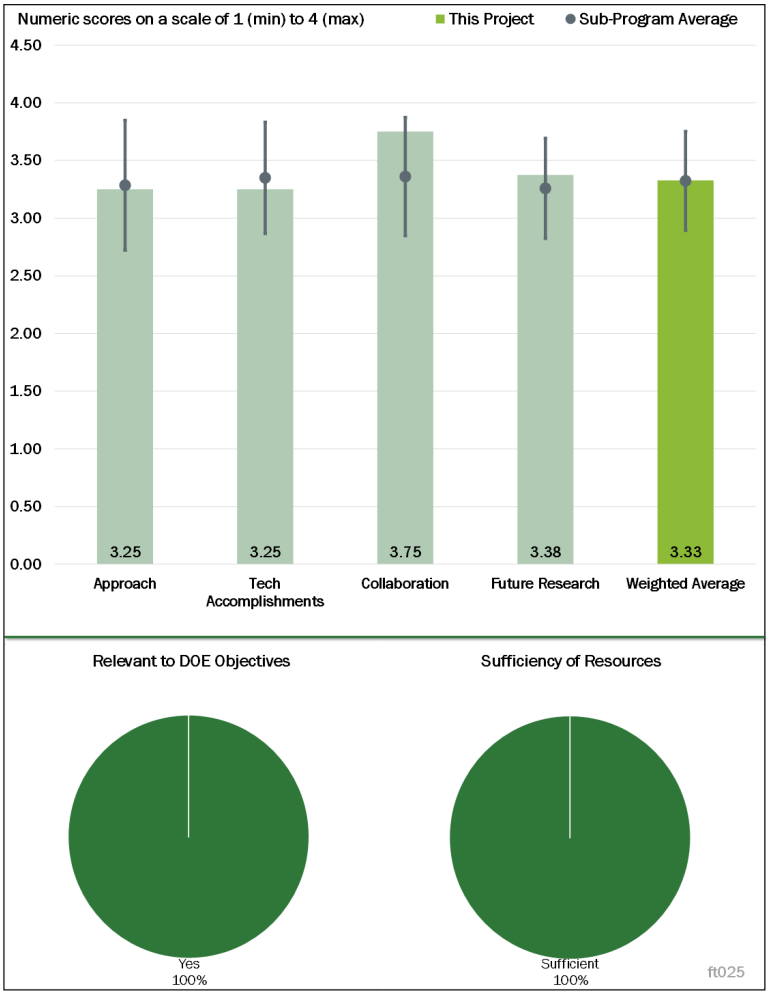

Figure 5-3 – Presentation Number: ft025 Presentation Title: Improved Fuel Economy through Formulation Design and Modeling Principal Investigator: Gefei Wu (Valvoline)

Reviewer 1:
The reviewer remarked that it is a unique program proposing to examine FE in heavy-duty (HD) transport vehicles. The reviewer noted that the program is planning to address a holistic approach by testing three types of fluids: engine oil performance in an ISL 8.9L FE verification engine; axle oil efficiency; and transmission fluid in Society of Automotive Engineers (SAE) #2 test.

Reviewer 2:
The reviewer commented that the project seeks to develop fuel savings through a new engine and axle lubricant, with at least a 2% overall improvement and a 2,000-hour durability test in a medium-duty diesel engine. The reviewer remarked that these targets are rather modest, and appear to be directed at short term, real world development rather than at a totally new discovery.

Reviewer 3:
The reviewer praised the project, from bench tests all the way to field testing.

Reviewer 4:
The reviewer observed that the project started with the formulation of candidate engine and axle oils for evaluation, then joined a modeling effort with full engine testing for fuel economy validation. The reviewer commented that this approach is a very conventional and effective way to demonstrate potential fuel-efficient products.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer commented that the technical target has not been fully reached, and noted that overall testing has been delayed due to discrepancies between Valvoline proprietary modeling and actual results obtained from dynamometer testing. The reviewer stated that the project summary does not provide the expected fundamental knowledge to the technical community, because the contributors do not share critical information regarding changes made in their formulation approaches of any new candidate fluids tested, i.e., engine oils, transmission fluids or axle fluids. The reviewer indicated that using the labels Oil 1, Oil 2, and so on is not sufficient. The reviewer further commented that no baseline fluids description or kinematic viscosity data were listed for any engine, axle, or transmission tests performed, and that no information was given regarding how in-house Valvoline models used to predict FE performance were developed. The reviewer indicated that the authors quote the IP document filed (14548850), claiming advantages of silicone oil as a part of engine oil formulation, but questions whether this approach was used to formulate currently assessed candidate fluids. The reviewer noted that silicone may severely impact durability and performance of aftertreatment catalysts, and stated that it is not clear that testing of exhaust catalyst exposure to silicone containing oils was carried out or is planned in the future.

Reviewer 2:

The reviewer commented that the program did not meet the fuel savings target with the first round of lubricants, and Valvoline reformulated and retested at their own expense, which shows real commitment. The reviewer noted that the authors are evaluating against a 15W-40 oil as a baseline and switching to 5W-30 and 5W-20, and that gear oil remains at 75W-90, but with improved additives. The reviewer remarked that a 2% improvement goal seems to be readily reachable, but the durability requirement may be very challenging in a diesel engine.

Reviewer 3:

The reviewer remarked that it is good to see multiple reformulations in response to test results, and noted that the project achieved the 2% goal on dynamometer tests. The reviewer observed that there were weather delays on J1321 testing, but the project is still moving forward.

Reviewer 4:

The reviewer observed that the technical accomplishments seem to be running on schedule, but the results are somewhat mixed. The reviewer commented that modeling seemed to over-predict the actual fuel economy gains demonstrated in engine tests. According to the reviewer, the speaker noted that zinc in zinc dialkyldithiophosphate poisoned the catalyst, where it is actually the phosphorous content. The reviewer believes this was just a misspoken statement, as the speaker is very knowledgeable in the field. This reviewer would like to know more details on the selection of the baseline engine and axle oils, and whether they were FE approved oils. The reviewer noted that, on Slide 7, there was a recalculation of fuel economy based on carry-over effect, and cautioned that the speaker should be careful when doing this to carefully quantify the hysteresis before recalculation. This reviewer observed a test progression as follows to track carry-over: baseline to candidate oil to baseline to candidate oil. The reviewer further remarked that the additional candidate oil test at the end would require additional funding, but may be important to establish a trend.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer complimented the project for its excellent collaboration with major commercial entities in the heavy-duty mobility sector.

Reviewer 2:
The reviewer remarked that Valvoline had a tight collaboration with Cummins and NREL that provided test hardware components and fuel economy testing performed in this project, and noted that the group also subcontracted J1321 testing, which will be finished shortly. The reviewer noted that Valvoline also has great connections with additive manufacturers needed to formulate fuel efficient candidate oils.

The reviewer noted that contributors include Valvoline (as lead), NREL, Transportation Research Center, and additive suppliers (i.e., Afton, Ovonic, Infimum, and Lubrizol).

Reviewer 3:
The reviewer commented that the program team includes Cummins as the engine supplier, 4 additive companies to support oil formulation, and NREL for 2,000-hour durability tests, and indicated that it seems like a very comprehensive team. The reviewer was unable to get a sense of how much new, research technology was being used in the oils, however, and how much was just re-formulation of commercially available additives and base oils.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer remarked that future research follows the project plan and is appropriate for completing this project.

Reviewer 2:
The reviewer suggested that the project might be able to minimize delays in SAE J1321 testing by working with multiple partners from different locations.

Reviewer 3:
The reviewer noted that, due to missing expected performance levels, additional testing on reformulated engine oil fluids will be carried out and Valvoline will cover all expenses. The reviewer commented that no clear definition of proposed vehicle testing is given, however, and questioned what baseline fluids will be used to establish expected improvements in FE.

Reviewer 4:
The reviewer commented that the project is nearing its conclusion and fuel economy gains have been demonstrated, a comparative fuel economy test will be conducted before the end of the project, and engine durability testing will be done as well. Additionally, the reviewer noted that further durability and tear down testing will be completed next year to quantify fuel economy retention. The reviewer remarked that it would have been better to have some of this durability testing mixed in with the fuel economy testing, considering the candidate oils are low-viscosity lubricants which could lead to wear issues, but the proposed durability testing seems to be comprehensive.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer remarked that the work being performed by an oil formulator is a good approach to keep the fuel-efficient candidates within the realm of commercial possibilities, and thus, this project has a high potential to deliver commercially viable, fuel efficient engine and axle lubricants.

The reviewer stated that, based on reported project structure, this project definitely supports overall DOE objectives.

Reviewer 2:
The reviewer commented that the goal of achieving real world fuel economy improvements through the introduction of drop-in lubricants with demonstrated durability is very relevant to DOE's mission of reducing petroleum consumption, although the targeted gain is rather modest and may not provide sufficient incentive for commercially developing the oil as a drop-in. However, according to the reviewer, the research could also support the development of future engines, through identification of potential problem areas, and could support the development of future lubricants, through the identification of friction and wear reducing additives and additive blends.

Reviewer 3:
The reviewer noted that the project demonstrated a 2% reduction in multiple phases of testing.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer commented that resources seem sufficient to complete the project as long as funding is maintained and as long as Valvoline is willing to re-do portions of the research at their expense if performance targets are not met.

Reviewer 2:
The reviewer stated that there is a good balance with the PI's company's funding level.

Reviewer 3:
The reviewer observed that this project has been running on schedule and budget for multiple years, and can be expected to continue this performance until project conclusion.

Reviewer 4:
The reviewer noted that, with current and possible future delays, no clear definition of future costs is given.

Presentation Number: ft037
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Overview
Principal Investigator: John Farrell (National Renewable Energy Laboratory)

Presenter
John Farrell National Renewable Energy Laboratory

Reviewer Sample Size
A total of 10 reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer stated that the approach was excellent.

Reviewer 2:
The reviewer stated that the overall approach of the Co-Optima program, which is focused on fuel properties that optimize engine performance and allow the market to define the best means to blend and provide the fuels, is very good and should help to address DOE barriers and meet the goals of the VTO.

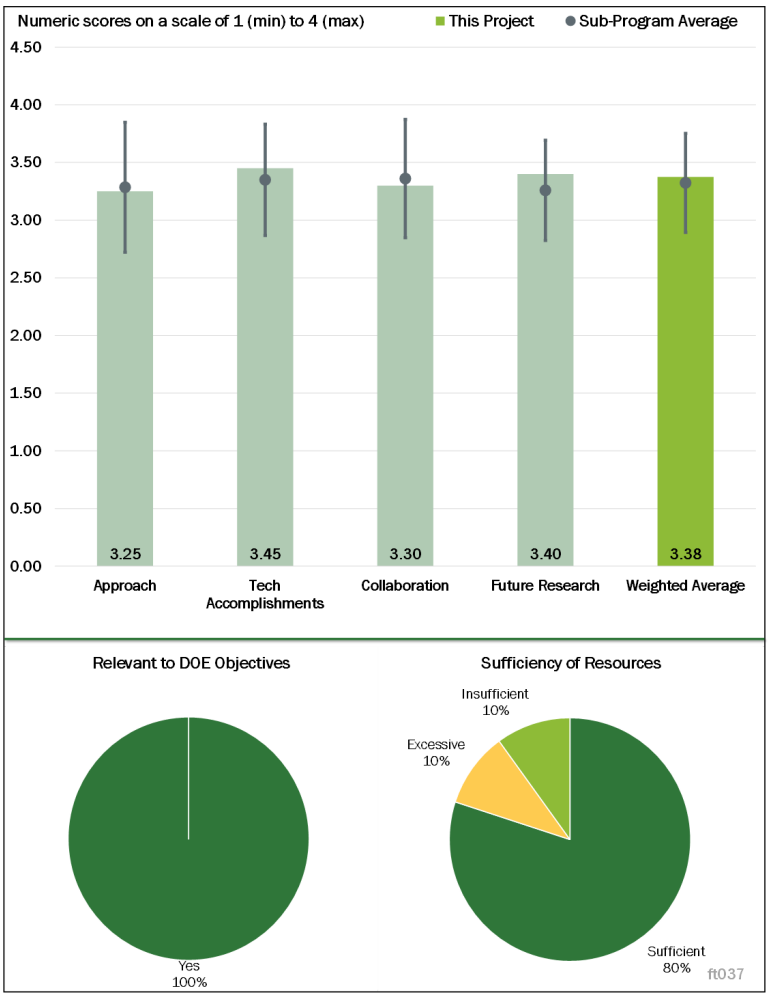

Figure 5-4 - Presentation Number: ft037 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Overview Principal Investigator: John Farrell (National Renewable Energy Laboratory)

Reviewer 3:
According to the reviewer, conceptually, the approach of developing fundamental information on fuel property effects on efficiency, performance, and emissions of a variety of engine combustion platforms is excellent, and that information will be very valuable input to industry for their individual market decisions for the future. The reviewer also commented that the ongoing sharing of results with, and obtaining input from, a wide range of stakeholders is noteworthy, although industry could benefit from more detailed discussion of results in a timely manner. The reviewer voiced concern that, although the basic premise of Co-Optima was the co-optimization of fuels and engines, full-time kinetically-controlled advanced combustion light-duty has disappeared from the slides and appears to have been replaced by "multi-mode spark ignition/advanced compression ignition (SI/ACI)." The reviewer commented that, if this observation is true, the potential benefits of full-time ACI operation would be mitigated/lessened by reverting to SI and likely the fuel choice would be driven by SI requirements, so contrary to the stated overarching goal of Co-Optima, it would not truly be co-optimizing engine design and fuel properties. The reviewer added that, if this decision has been made, rather than inadvertently left off the slide, it is unclear what the basis was, i.e., was this driven by technical results, input from specific stakeholders, or other factors? The reviewer noted that the Merit Function is discussed throughout all of the presentations, suggesting that it will play a key role in the selection of candidate components; it is critical that the SI Merit Function be validated in multi-cylinder SI engines that are

representative of those that are likely to be introduced into the market in the near future. Further, the reviewer stated that the Merit Function has been portrayed as only relating to SI engine efficiency, a key, but not the sole, technical criteria for assessing candidates. The reviewer suggested that other performance aspects, such as emissions, including toxics, need to be assessed, as well as other aspects such as production viability, infrastructure compatibility and costs to stakeholders. The reviewer contended that because these are intended to be fundamental studies and measurements, they should also include more hydrocarbons, rather than just oxygenates, to make the learnings more robust.

Reviewer 4:

The reviewer commented that the scope of this project is very aggressive and sets out to provide strong tools to the industry to optimize systems for improvements in fuel consumption. Further, the reviewer commented that the goals of the program are very strong and address an industry need. The reviewer was impressed by the project's very unique approach, by the central fuel hypothesis and the approach to identifying the key properties, rather than specific blends that can be used to optimize performance. The reviewer voiced skepticism that the approach would work, but indicated that the initial results seem to be supporting that it is heading in a good direction. The one barrier that the reviewer indicated was not clear is how to address the fuel effects on emission control systems, as mentioned on Slide 4. In the reviewer's opinion, the propensity to form particulates and create hydrocarbon species in the exhaust that aftertreatment systems are capable of reducing, and the impact of exhaust temperature, are important factors that may allow for emissions control optimization; otherwise the optimized engine system may need to be operated in a less efficient manner to meet emissions control requirements. The reviewer noted that there was no emphasis on the durability impacts of the fuels on the engine system, for example, their wear characteristics for injectors and ring packs, which again lead to the combined system efficiency.

Reviewer 5:

The reviewer commented that the overall plan for Co-Optima is sound, well-conceived, and is being executed well, from a research standpoint, although it may not be fair to make this observation only on this presentation. The reviewer wondered about the "big picture" issue of engine manufacturers and fuel providers, adding that if the objective is to move toward a description of fuel properties that are optimal for efficiency and/or fuel economy, it seems likely that the engines using these fuels will need to be designed and operated in a somewhat uniform way. The reviewer questioned whether engine manufacturers would get on board with this, as typically they want to have their own proprietary designs and features, and may not want to conform to the idea of a common design.

Reviewer 6:

The reviewer noted that the presentation is an overview rather than an actual project, so it is difficult to comment, but added that Co-Optima overall seems well designed, particularly with the revised decision point approach to Thrust I. The reviewer cautioned that an important concern is that the results of Thrust I will become available just as automakers have completed the phase in of corporate average fuel economy (CAFE) standards to 2025, so that the major efficiency improvements contemplated for a period of 15 years will have already been accomplished.

Reviewer 7:

The reviewer commented that fuel-engine co-optimization provides the potential of achieving additional engine efficiency by up to 15%, and that the project is well-designed, feasible, and integrated with other efforts. The reviewer wondered why this project considers renewable fuels only, and explained that blendstock for oxygenated blending (BOB), which will consist of at least 70% of the future fuels, should also be included in the Co-Optima program.

Reviewer 8:

The reviewer commented that, in view of the reduced level of funding going forward, a reasonable approach has been undertaken to adjust the Co-Optima program's goals and research priorities. The reviewer added that,

unlike 2016, it is encouraging to see that in addition to defining goals, metrics have been specified to assess the success/completion of the project. The reviewer stated that, while the overall approach is reasonable, the fuel economy targets currently specified appear to be too optimistic. The reviewer elaborated, saying that the work being conducted under the Co-Optima program has a lot of value, and in order to avoid the pitfall of being gauged against extremely ambitious targets, the fuel economy targets should be revisited and revised to more reasonable numbers. The reviewer stated that, at present, it is somewhat unclear how the merit function and the Co-Optimizer will be used to drive or facilitate change in market fuel and consequently realize the opportunities identified as benefits of the Co-Optima program, and that providing a clear vision of the use of the Co-Optimizer would help further establish the value of the Co-Optima program.

Reviewer 9:

The reviewer commented that, if the Governing Hypothesis is used as a surrogate for the approach, it assumes that higher engine efficiency is needed for some of the advanced combustion regimes. The reviewer questioned whether really impressive efficiencies had not already been demonstrated for several advanced combustion regimes with market fuels. The reviewer suggested that the barriers to those concepts were limited operating range, transient control, cold operation, combustion noise, high hydrocarbon (HC) and carbon monoxide (CO) emission, cold exhaust temperature, mode switching, complexity, cost, and other factors. The reviewer stated that from this overview presentation one does not get the impression that Co-Optima will focus on these barriers, but instead will continue to pursue high engine efficiencies, primarily while expanding operating range. The reviewer observed that having a single-issue program will probably not prove to be successful, and questioned whether there will be more effort devoted to removing these other barriers in the detailed presentations to follow. The reviewer stated that vehicle fuel economy is a complex function of vehicle characteristics, engine speed-load characteristics, and drive cycle, and questioned how the fuel economy goals presented in Slides 2 and 3 were arrived at, and what assumptions were made. The reviewer noted that the x-axis on the figure in Slide 3 is taken as the time a lab demonstration is targeted to be made, and questioned whether the Lab demo will include all the barriers mentioned above, or whether it will just focus on increased fuel efficiency. The reviewer suggested that the challenge presented in bullet #1 on Slide 24 is really the primary challenge for Co-Optima, and questioned how Co-Optima proposes to address it; without that, the reviewer questioned whether having a timeline like in Slide 3 has any meaning.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer commented that the group has done a lot of excellent work in a very short timeline, and they should be commended for their efforts.

Reviewer 2:

The reviewer stated that the project made significant progress.

Reviewer 3:

The reviewer said that great progress is being made.

Reviewer 4:

The reviewer commented that there has been some significant progress to date, but the extent of the collaborations is such that it will take a significant effort to manage, between gathering inputs, prioritizing all of the inputs, and the logistics of working with such a cross-functional group. The reviewer stated that there has already been excellent work in making this working group function and setting a strong path forward. The reviewer noted that the progress to date on the merit function for SI engines, data gathered to validate the central fuel hypothesis, and initial stages of the Co-Optimizer tool has been excellent.

Reviewer 5:
The reviewer noted that this program is large, highly collaborative, and has a lot of moving parts, which requires a great deal of coordination. According to the reviewer, the program must overcome a lot of inertia to get going, but it seems that this is starting to happen now.

Reviewer 6:
The reviewer noted good progress in Tier 1 and Tier 2 screening and down-selection of fuel component candidates for Thrust I. The reviewer commented that the statement is made about accomplishments in the ASSERT and Market Transformation, but those detailed results have yet to be shared externally, and the authors need to get that information out. The reviewer stated that the authors need to conduct testing in multi-cylinder engines representative of the range of GDI technology that will be in the market place in the near future, to validate that the theoretical, calculated Merit Function is applicable.

Reviewer 7:
The reviewer stated that in 2016-2017, multiple projects under Co-Optima made substantial progress. In particular, according to the reviewer, the progress made in the following areas was very encouraging: refinement of the Merit Function for Boosted SI engines; nonlinear blending of fuel properties and down-selection of promising fuel components; simulation toolkit; and spray characterization and particulate emission studies.

Reviewer 8:
The reviewer commented that this question is best directed toward the component parts of the overall Co-Optima program, rather than the overview, but noted that some significant improvements have been made at the overall program level, such as considering potential synergies between Thrust I and 2, by using similar fuels for boosted SI and gasoline compression ignition. The reviewer noted that testing of the central fuel and engine hypotheses has progressed, merit functions have been refined and high-level fuel screenings and tier 2 selections have been completed.

Reviewer 9:
The reviewer observed that the overview of the co-optimization project identified ten major accomplishments which will help move the overall project towards helping to address the barriers identified in the presentation.

Reviewer 10:
The reviewer opined that the progress made on the Merit function is good, and the engine test programs at Oak Ridge National Laboratory (ORNL) and NREL that address boosted SI engines are making reasonable progress; however, the overall Co-Optima program is making slow progress towards DOE goals.

The reviewer questioned how the Co-optimizer is envisioned to work, and whether, as a result of various stakeholders exercising it, there will be various fuels then in the market place, all having roughly the same Merit function score but different fuel properties and molecules. The reviewer questioned whether that will work.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that the scope of collaboration for this project is very impressive, and that it appears to have an excellent representation of critical industry partners. The reviewer noted that the project takes advantage of the strengths of various national laboratories and universities, and the Advisory Board has some very strong industry experts that are ensuring good technical direction. The reviewer further noted that the number of partners also ensures that there are not strong biases or technical interests that influence the conclusions.

Reviewer 2:
The reviewer commented that overall this program is highly collaborative and involves many sub-projects, institutions, people and capabilities.

Reviewer 3:
The reviewer praised the collaboration and coordination in the overall co-optimization project as being excellent, and noted that the effort includes an industry led advisory group, as well as collaboration with multiple DOE laboratories, and several academic institutions, which will help to continue to focus the effort to successfully address the barriers.

Reviewer 4:
The reviewer stated that the overview includes collaboration with a multiplicity of DOE laboratories and other research institutions, as well as other stakeholders.

Reviewer 5:
The reviewer commented on the excellent collaborations among national laboratories, universities, and industries, and noted that the partners are full participants and well-coordinated.

Reviewer 6:
The reviewer commented that increased collaboration between the participating national laboratories has been one of the strengths of the Co-Optima program. In addition, the reviewer found that a concerted effort has been made to schedule and update stakeholders with periodic updates. The reviewer found that the Stakeholder Listening Day in January 2017 helped foster further interaction between the Co-Optima team and pertinent stakeholders including OEMs, the energy industry, and regulatory agencies such as the U.S. Environmental Protection Agency and California Air Resources Board. The reviewer encourages further involvement of the retail and infrastructure stakeholders.

Reviewer 7:
The reviewer found that the collaboration between all the labs and universities is very good.

Reviewer 8:
The reviewer noted that collaboration is predominantly within the national laboratory community, and it looks like there is much better coordination of the R&D activities within the national laboratories. The reviewer stated that various mechanisms and forums have been held to get input from various external stakeholders, which is very valuable, but probably should not be characterized as "collaboration." The reviewer commented that dissemination of detailed technical information on a timely basis is needed for stakeholders to truly understand and assess the results, and noted that the monthly teleconferences are ok, but topics are rotated and do not permit extensive presentation or discussion of results. The reviewer said that there is frequent mention of reports that are being drafted, but those never seem to be released.

Reviewer 9:
The reviewer commented that working more closely with energy companies and refining stakeholders would enable the team to look for more value-added pathways. For instance, some of the fuels being looked at could be co-produced in the refinery and be a win-win for the auto and oil companies.

Reviewer 10:
The reviewer noted that Co-Optima's collaboration between labs is excellent, but that there is a lack of university input and little to no industry input into their programs except after the fact.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer commented that the R&D work makes sense; however, it seems that important decisions and recommendations will be based on merit function calculations, so it will be very important to determine under which conditions and which boosted SI engine platforms the merit function is valid, and that appears to be missing in the plans. The reviewer suggested that the inclusion of hydrocarbon candidates (even those that are petroleum-derived, but not necessarily viable for biologic production processes) in the studies would greatly increase the robustness of the fundamental R&D.

Reviewer 2:
The reviewer found that the path forward for the project is well defined and has a strong approach, but had reservations regarding whether the aftertreatment and emissions control impacts, based upon fuel properties, are being sufficiently addressed in the merit functions and tools.

Reviewer 3:
The reviewer observed that the proposed future research in the Co-Optima program, including completing the merit function development and initiating a more focused ACI research approach for medium and heavy-duty applications, will continue to move the project towards a successful completion.

Reviewer 4:
The reviewer commented that future research is outlined in the presentation and is logical and well thought out.

Reviewer 5:
The reviewer found that the future work is very well planned in a logical manner, by incorporating appropriate decision points.

Reviewer 6:
The reviewer noted that the proposed future research is in line with the Co-Optima program's goal to help develop advanced compression ignition combustion concepts that are targeted at providing high efficiency and low emissions solutions for both light and heavy-duty applications. The reviewer stated that, as the outputs of the Co-Optima program are supposed to be low technology readiness level (TRL) technologies, barriers to proposed technology and alternate pathways are not relevant.

Reviewer 7:
The reviewer questioned when the fuel property values (research octane number [RON], sensitivity, HoV, flame speed, etc.), or range of values, for the eight candidate fuels to achieve a Merit function score greater than E10 Premium will be published. The reviewer recommended that a majority of the project's resources be spent on the first two bullets on Slide 26 for the light-duty gasoline fleet, and noted that even though the efficiency gains are only modest, the implementation risks are low, while the consumer benefits are very large, due to the sales volume. The reviewer commented that, on the other hand, a majority of resources can be spent on bullet #3 on Slide 26, with the understanding that risks are very high while benefits are also high. The reviewer questioned whether both approaches can be pursued in the future, given the budget and resource constraints.

Reviewer 8:
The reviewer remarked that some additional work on the formation (quantity and morphology) of particulate matter with the different fuels would be beneficial.

Reviewer 9:
The reviewer found that, other than the overall plan, future research was not laid out.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that yes, this project supports the overall DOE objectives of petroleum displacement, and noted that the project is very well designed to improve engine efficiency and better use of renewable fuels.

Reviewer 2:
The reviewer commented that this project has a high probability of success in identifying opportunities for fuel consumption improvements of engine systems, because it is taking a total system optimization approach to determining how to optimize the fuels and engine systems in order to recognize fuel economy gains. The reviewer noted that the Co-Optimizer tool will be valuable to the industry, for improving powertrain efficiencies.

Reviewer 3:
The reviewer found that the work performed in the Co-optimization of fuels and engines is definitely supportive of the DOE objective of petroleum displacement. The reviewer noted that the projects include increasing fuel economy in both light-duty and heavy-duty applications as well as research to help diversify the fuels resource base.

Reviewer 4:
The reviewer indicated that the improvement of existing engine combustion technologies, identification of desirable fuel properties, and development of new biofuels are all expected to contribute to DOE's goal of petroleum displacement.

Reviewer 5:
The reviewer found that improvement of engine efficiency and incorporation of bio-components in fuel blends support DOE's objectives.

Reviewer 6:
The reviewer noted that the project aims at maximizing efficiency of fuel and engine technology, which would greatly increase fuel economy.

Reviewer 7:
The reviewer noted that the project's end goals are to displace petroleum consumption by 30%.

Reviewer 8:
The reviewer concluded that yes, the project does support the overall DOE objectives of petroleum displacement.

Reviewer 9:
The reviewer said that the project should save petroleum in new vehicles due to efficiency improvements and biofuels if successful.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer found that there are sufficient resources for the project to achieve the stated milestones in a timely fashion.

The reviewer noted that this project has a very large scope and requires a large number of resources, which are necessary to meet the stated goals, and added that the project has a high potential for success at the projected resource levels.

Reviewer 2:
The reviewer stated that overall resources for the co-optimization project appear to be adequate.

Reviewer 3:
The reviewer commented that project resources appear adequate at this time for this level of planning, but may need to be extended or otherwise adjusted as the project progresses.

Reviewer 4:
The reviewer found that resources are sufficient for now, but wondered what the impact of likely budget cuts will be, i.e., will the cut be spread out and affect all of the projects, or will there be certain projects or aspects of projects that are dropped entirely?

Reviewer 5:
The reviewer commented that resources appear to have been sufficient up to this point; however, budget cuts seem imminent for 2018, and that would affect program progress.

Reviewer 6:
The reviewer stated that it is not possible for the project to achieve the stated goals with the resources allocated under the 2017-2018 budget proposal, and noted that additional resources are required to support the ongoing work, in particular for the near term boosted SI engine technology. The reviewer noted that, while the improvement of the boosted SI engine technology may only lead to modest gains in engine efficiency, due to the sheer size of the vehicle fleet that employs such engines, the potential gains for society in terms of lower fuel consumption and cost savings are substantial.

Presentation Number: ft047
Presentation Title: Advanced Lubricant Technology—Surface and Lubricant Interactions
Principal Investigator: Oyelayo Ajayi (Argonne National Laboratory)

Presenter
Oyelayo Ajayi, Argonne National Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer noted that this sub-project is focused on developing rapid methods capable of predicting the impact of friction reduction technologies on engine related fuel economy and wear. The reviewer commented that the methods of prediction will be both empirically and analytically based and will require a lot of coordination between various labs and contributors, due to the complexity of the overall list of proposed tasks.

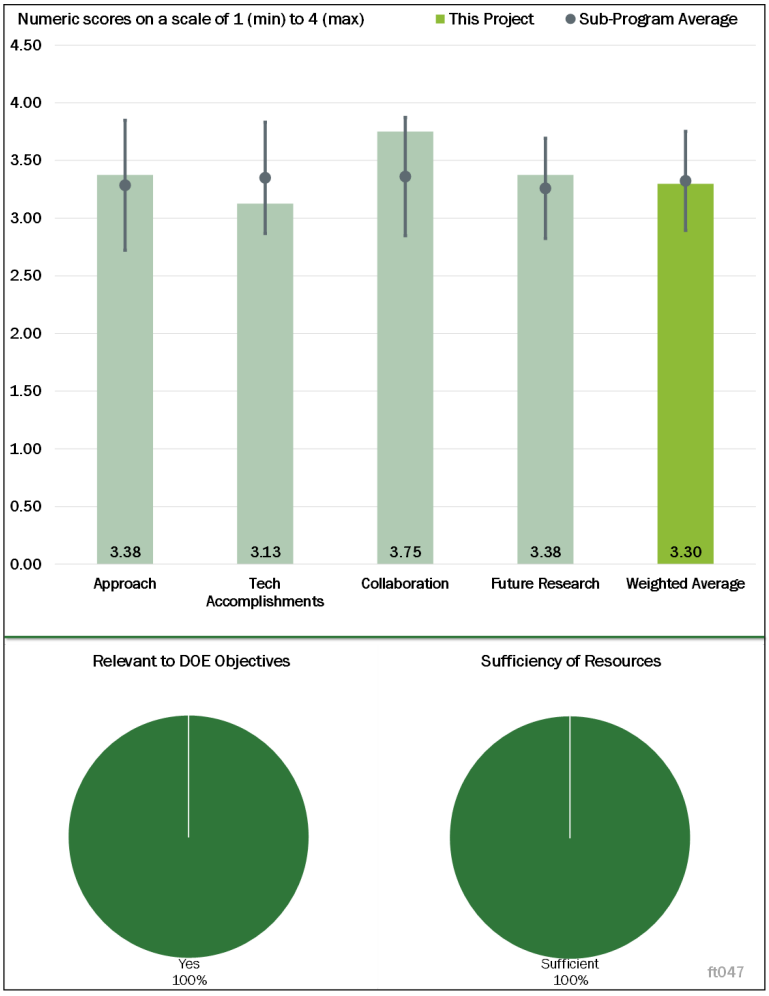

Figure 5-5 - Presentation Number: ft047 Presentation Title: Advanced Lubricant Technology—Surface and Lubricant Interactions Principal Investigator: Oyelayo Ajayi (Argonne National Laboratory)

Reviewer 2:
The reviewer stated that the project seeks to study surface and lube interactions through test methodology; film characterization; and models for wear and scuffing, nonferrous materials, and effect of soot. The reviewer commented that the baseline is 5W30 GF5, but it was unclear if this was FM or non-FM oil. The reviewer further remarked that the project does not verify results in vehicle or engine tests, so targets need to be very clear, but they were not.

Reviewer 3:
The reviewer found that, overall, this is a very well-developed project, with many moving parts and different technologies that have the potential for overlap and optimization. The reviewer remarked that one area that needs to be further developed is the characterization of tribochemical films. The reviewer noted that Slide 10 shows the use of energy-dispersive X-ray spectroscopy (EDAX) to quantify chemical properties of films, but, according to the reviewer, this method is far from optimal to understand the film. The reviewer went on to say that, typically, EDAX is used as a qualitative quick test to demonstrate evidence, and then methods such as X-ray photoelectron spectroscopy are used to quantify chemical percentages as a function of tribofilm depth. The reviewer praised the use of X-ray diffraction to determine crystallinity, or lack thereof, and indicated that nano indentation and nanoscratch testing should be done carefully as well, although a conventional nano indenter can have a hard time quantifying thin tribofilms even at the nanoscale. This reviewer suggested cross

sectioning the tribofilms and indenting various positions of the tribofilm to develop a relationship of tribofilm hardness as a function of depth, claiming that this approach would eliminate the potential effects of substrate material.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer remarked good progress to date.

Reviewer 2:
The reviewer expressed surprise that a summary slide describing proposed variables to be included as a part of a rapid bench testing protocol was not presented. The reviewer indicated that testing parameters used as an optimized approach to examining the most severe conditions for frictional contacts and wear contacts in IC engines cover many ranges, and need to be wisely selected. The reviewer elaborated, saying it would be important to contrast two protocols mimicking DI diesel versus GDI engine conditions. The reviewer noted that results collected for five commercial application programming interface (API) GF5 fluids did use standard bench testing conditions, and indicated that it would be of great value to the technical community if ANL has developed a unique rapid performance testing protocol. The reviewer asked what the repeatability or reproducibility of coefficient of friction data reported were, and suggested that the authors include SD bars on all the experimental data graphs in the future. The reviewer noted that compatibility testing of AW additives with a non-ferrous alloy included only two types: Bronze alloy 600 and A380 Al alloy, and questioned why these specific alloys were selected, and why no were presented for copper (Cu) and lead. The reviewer further questioned whether these are the most commonly used overlays for bearings; how stable the suspension of selected carbon black CB (R250R) in a base oil was; and whether CB (R250R) resembles GDI soot or diesel soot from the perspective of particle size distribution and surface chemistry.

Reviewer 3:
The reviewer commented that it looks like the project team has a good start on test methods and surface analysis and need to begin tying things together. The reviewer added that baselines and targets need to be better established.

Reviewer 4:
The reviewer praised the great progress thus far, even though it is early in the project, and noted that every task seems to be well developed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said excellent collaboration among the multiple labs. This should continue and be a model for other work.

Reviewer 2:
The reviewer commented that a well-balanced team of technical collaborators is contributing to this project: specialty chemical industry representatives, national laboratories, and OEMs. The reviewer added that this sub-project will require a lot of coordination between various laboratories/contributors due to the complexity of the overall list of tasks proposed.

Reviewer 3:
The reviewer stated that there was very good collaboration with industry for used oils, additives, and used engine parts, and that the program is a multiple lab partnership, with each lab working on its specialties. The

reviewer criticized the lack of a grand vision for the overall project, which consisted of the individual labs continuing what they had done previously.

Reviewer 4:
The reviewer complimented the project as an excellent example of multiple organizations working well with each other; however, the reviewer added, there seems to be some uncertainty regarding what exactly the overall project goal is and how to obtain it.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer commented that the results from future plans can provide significant understanding of the role of lubricant components in reducing friction and protecting hardware, although some of the tasks may be too challenging to provide expected answers within the planned time frame.

Reviewer 2:
The reviewer found that there was a good plan for moving forward. The reviewer indicated that several items need to be further developed, but added that it seems this work will be done as the project proceeds, although the information was not conveyed in the presentation. The reviewer observed that below the tribofilm, there was a plastic deformation, and the tribofilm was sputtered away, but no subsurface analysis was proposed. The reviewer suggested the use of a Focus Ion Beam Scanning Electron Microscope (FIB-SEM) to look deeper, until pristine substrate is reached, as there could be severe subsurface damage, grain deformation or cracks that should be quantified.

Reviewer 3:
The reviewer said please add more extreme temperatures to the testing protocol to better represent real world conditions.

Reviewer 4:
The reviewer stated that the goals seem unclear, e.g., 2% or 4% fuel economy improvement, 25% or 40-50% total engine friction reduction, and expressed surprise that the project team could not project what viscosity oil would be needed to achieve this. The reviewer commented that, overall, the project seems to have a shotgun approach, which may be appropriate, but needs to be very carefully managed to meet deliverables and targets.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that, based on the proposed structure of detailed tasks, this project definitely supports overall DOE objectives.

Reviewer 2:
The reviewer found that improving fuel consumption and reducing engine friction losses support the DOE goal of petroleum displacement.

Reviewer 3:
The reviewer stated that this ground-up approach has the potential to yield the DOE set project metrics.

Reviewer 4:
The reviewer commented that it should save petroleum in both new vehicles and legacy vehicles due to efficiency improvements if successful.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that all proposed resources are needed to make this project successful.

Reviewer 2:
The reviewer stated that, although it is early on in the project, the resources seem to be allocated properly and the project is progressing on schedule.

Reviewer 3:
The reviewer commented that, at planned funding levels, resources would be sufficient; however, if funding is reduced, the project will have to be re-planned to provide the most relevant results on a timely basis.

Presentation Number: ft048
Presentation Title: Advanced Lubricant Technology—Technology Innovation, Design, and Synthesis
Principal Investigator: Lelia Cosimbescu (Pacific Northwest National Laboratory)

Presenter
Lelia Cosimbescu, Pacific Northwest National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer stated that the authors have provided a clear and focused vision of their sub-project, listing all potential technical barriers that need to be overcome to address DOE goals. The reviewer noted, however, that there is no clear indication of how new candidate fluids will be formulated and tested. The reviewer questioned whether the approach is to totally reformulate GF5 type fluids, which would mean running and passing API required engine tests, or whether new base stocks, additives, and VM will be treated as "add-on" technologies.

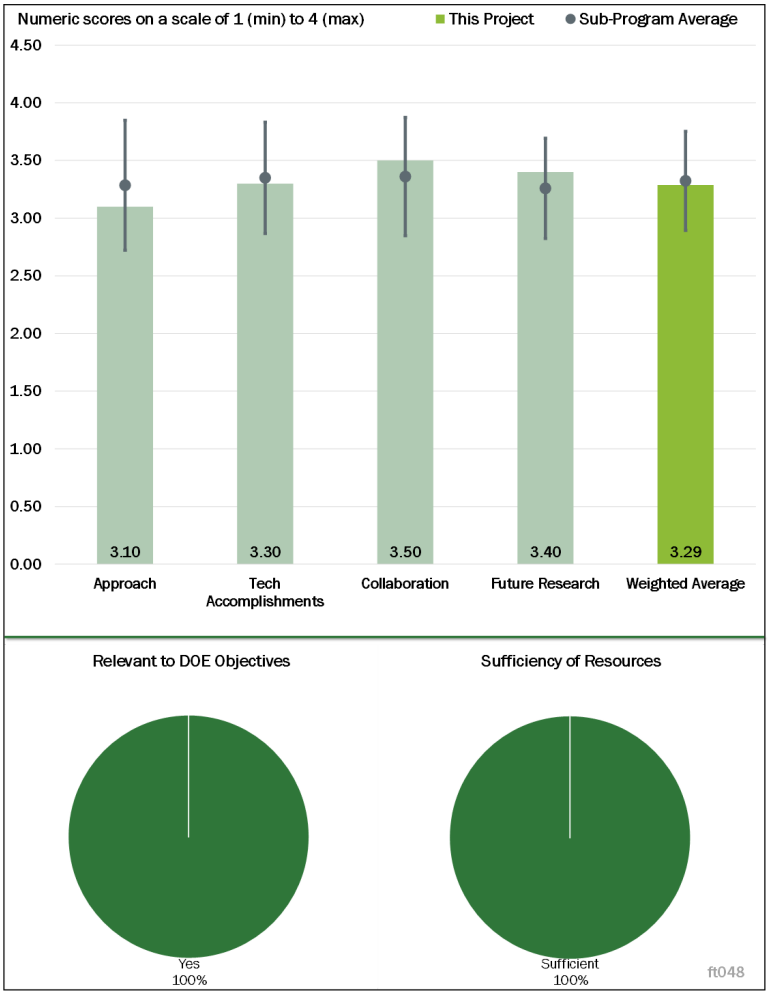

Figure 5-6 - Presentation Number: ft048 Presentation Title: Advanced Lubricant Technology—Technology Innovation, Design, and Synthesis Principal Investigator: Lelia Cosimbescu (Pacific Northwest National Laboratory)

Reviewer 2:
The reviewer stated that, overall, the project was well organized, considering the number of partners, although the large team of collaborators may have led to some lack of focus. The reviewer suggested that perhaps coatings should be a different project.

Reviewer 3:
The reviewer commented that it was a little unclear as to what test was run to generate the data on Slide 10. The reviewer stated that, as shown on Slide 11, the AW candidates of aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), and zirconium dioxide (ZrO_2) are all potentially abrasive particulate if not harnessed correctly, and it would be interesting to understand how these particles are formed and functionalize to control the particle performance. The reviewer observed that two of three seem to be abrasive in nature, which does not seem surprising, but one seems to have some promise, and that understanding the mechanisms behind the AW performance benefit is crucial to optimizing these lubricants.

Reviewer 4:
The reviewer found that the slides and presentation are very sketchy for a major scale project such as this. The reviewer commented that the project is shown as consisting of three thrusts, with Thrust I appearing intended to inform Thrust II, yet the very short presentation focuses almost solely on Thrust II, with no mention of how the results from Thrust I (which was the subject of a separate presentation) have informed Thrust II. The reviewer stated that the project is both examining hybrid base fluids, which it says could address rheology, friction and wear without additives, and examining enhanced additives, but it is not clear why the investigations of the two are presented as alternatives rather than examining optimal combinations of the two, i.e., which properties each can best address and how the two can work together to address properties. The reviewer observed that the project also includes an investigation of coatings for reduced friction and wear, but says it will do so for the purpose of eliminating stringent requirements of lubricants (Slide 6) rather than examining the best lubricants for use with such additives, for maximum feasible and cost justified friction reduction. The reviewer noted that this appears to be different, per a bullet on Slide 24.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer stated that there were many moving parts with the partners, but that early on technical accomplishments seem to be on schedule, except for multifunctional VII. The reviewer commented that the results seem promising thus far, with interesting work and conclusions drawn from the multifunctional base fluids. The reviewer would especially like to see the shear stability results once available, and noted that there is high potential for the newly developed multifunctional base fluids to be more shear stable.

Reviewer 2:
The reviewer observed that the multifunctional colloidal additives showed impressive performance on the bench test, but there still is some concern about potential issues when the surface agent breaks down.

Reviewer 3:
The reviewer commented that the project was still in its early stages when the slides were prepared, but has demonstrated some early progress in down-selecting which candidate base fluids and additives to pursue and which not to pursue. The reviewer observed that some base fluids investigated were determined to be possibly viable as additives, rather than base fluids. The reviewer found that the initial results on VN coatings were also achieved with promising indications, and the results indicate substantial promise, but the presentation is too sketchy and unclear to confirm substantial progress toward the goals.

Reviewer 4:
The reviewer questioned how the proposed ester chemistry differs from the commercial ester chemistry currently used in Mobil 1 brand, and asked whether Mobil 1 fluid is going to be used as a comparison baseline to achieve proposed performance goals. The reviewer also questioned how the overall stability of colloidal dispersions of molybdenum disulfide, Cu, Al_2O_3, SiO_2, ZrO_3 additives was tested, what the particle size of these dispersions was, and whether they effect the color of the lubricants tested. The reviewer further asked how the 20% improvement in FE over API GF-5 baseline oil will be examined, i.e., bench testing alone or engine testing. Additionally, this reviewer inquired about the viscosity grade of the baseline API GF5 fluid selected for this Thrust II project to be used as a "poor" reference fluid.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that this project joins three national laboratories and several industry partners to investigate a full, ground-up, tribological approach, and that it will take careful coordination among all parties, of which this group is very capable.

Reviewer 2:
The reviewer remarked that there is a well-balanced team of technical collaborators contributing to this project, from the national laboratories and academia, and that this sub-project will require a lot of coordination between the various labs and contributors, due to the complexity of the overall list of tasks proposed.

Reviewer 3:
The reviewer stated that there are many partners, but overall the project seemed well coordinated.

Reviewer 4:
The reviewer commented that the presentation at the meeting included contributions from various team partners, indicating substantial and appropriate collaboration, but that the answers were somewhat different from the project participants, indicating that collaboration is less than perfect. The reviewer noted that no vehicle or engine makers are included as project collaborators. The reviewer pointed out that Slide 24 states that the participants work closely with vehicle OEMs to evaluate coatings, but that they are "unlikely to disclose their testing platforms." In the reviewer's opinion, this seems questionable and unfortunate, considering that they participate openly in other projects, but the actual meaning of that phrase is not altogether clear.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer remarked that, although early on in the project, the progression of work seems to be well planned, and it will be interesting to track the progress of this project over time.

Reviewer 2:
The reviewer stated that the VN coating testing sub-proposal is quite vague and needs to be rewritten, to provide clear direction of potential benefits of this technology versus implementation of novel base stocks+ additive technologies.

Reviewer 3:
In the reviewer's opinion, this project is too broad, and it would be nice to see more focus on the oil formulations for drop-in, for example, to achieve goals. The reviewer commented that coatings seem to be on a good forward path, but questioned the interactions of the coatings with the optimal lubricants. The reviewer stated that it makes sense to perform early tests using base oil/commercial formulations, but this needs to progress to compatibility with potential future formulations.

Reviewer 4:
The reviewer commented that the future work identified in Slide 17 will be useful but, as presented, it furthers the appearance that the "project" is actually a combination of different approaches and examinations, with the hope that one or more of them will provide a solution, rather than an integrated program, either within Thrust II or with Thrust II incorporating results from Thrust I.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
According to the reviewer, based on a well-planned project structure, this project definitely supports overall DOE objectives

Reviewer 2:
The reviewer commented that the project targets a 4% FE improvement from friction reduction, which would be a major source of petroleum displacement.

Reviewer 3:
The reviewer noted that several potential replacement candidates were presented.

Reviewer 4:
The reviewer stated that a ground up technical approach is vital for the successful implementation of novel base stocks, additives, and surface modifications, and the compilation of such technologies could greatly increase fuel efficiency by reducing frictional losses.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that $985,000 for Thrust II is an appropriate level of resources, more so because a 25% friction reduction resulting in a 4% FE improvement is targeted. It is not clear to the reviewer, however, why Thrust II does not command a greater share of the overall $3 million budget for the 3 thrusts, because the core of the work is in Thrust II and it involves a multiplicity of approaches.

Reviewer 2:
The reviewer stated that resources seem to be properly allocated, and that, with such a large project, they are doing well to stay on budget and mostly on schedule.

Reviewer 3:
The reviewer stated that all proposed resources are needed to make this project successful.

Reviewer 4:
The reviewer commented that resources are more than sufficient if the project becomes a bit more tightly focused on fewer candidate formulations.

Presentation Number: ft049
Presentation Title: Lubricant Effects on Combustion and Emissions Control
Principal Investigator: John Storey (Oak Ridge National Laboratory)

Presenter
John Storey, Oak Ridge National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that the approach identified in the project that includes in-depth characterization of particulate matter (PM), HCs and fuel economy to better understand lubricant effects is proving to be excellent and should successfully address the barriers identified.

Reviewer 2:
The reviewer remarked that the project is looking at how lubricants contribute to PM and low-speed pre-ignition (LSPI) and are critical to enabling future efficiency increases.

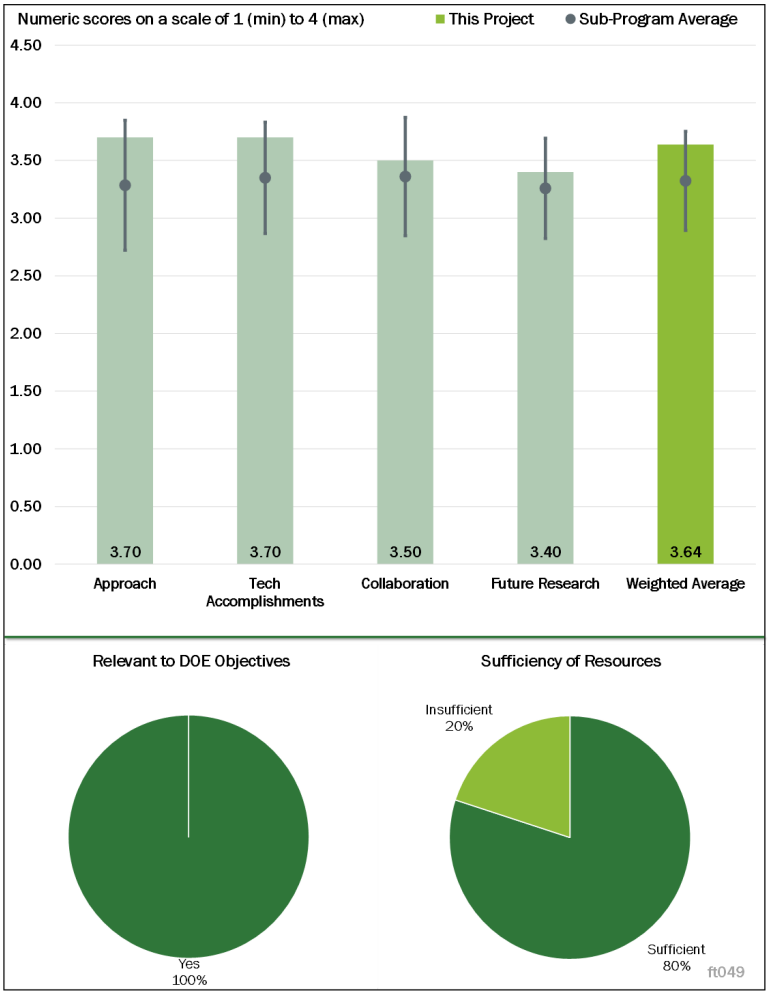

Figure 5-7 – Presentation Number: ft049 Presentation Title: Lubricant Effects on Combustion and Emissions Control Principal Investigator: John Storey (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer praised the work as being very interesting and relevant, and said it will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer thanked the project managers for the support of this project and efforts, and appreciated that they are open to some coaching support and advice from reviewers. The reviewer added that there is important research going on in this project that needs to continue. The reviewer suggested looking at the impact of wear testing with these thinner weight oils, as the project is focused on fuel economy and involves testing with oils. The reviewer stated that, even though fuel economy improvements could be shown with thinner weight oils, the challenge is really with the engine wear over time with these oils, and this is a more relevant challenge to study. On Slide 9, the reviewer questioned whether the oil used in the study was new or had been sheared down with a break in procedure. The data made the reviewer wonder if there were light ends evolving during the testing. The reviewer added that the Nowack volatility of the oil can be determined very easily, and is typically a value to rate oils; also, the distillation curve of the oil may help to explain why there was an increase in PM mass, either from the light ends or from the high volatility oil. The reviewer remarked that it was very interesting that all the oils behave the same way,

as shown in the chart on Slide 19, and asked whether we can conclude that the SPI issue is not a function of oil ignition quality. The reviewer also questioned whether it is the Sequence 6 D test that is referenced on Slide 21, saying that it was noted by the American Society for Testing and Materials (ASTM) number and by a Sequence test, but the reviewer wanted to confirm. The reviewer commented that on Slide 26 and during the presentation, it was mentioned that Boron in oil would be evaluated. The reviewer did not think that this metallic additive could be used because of emissions control devices, and asked for the presenters to confirm and let the reviewers know.

Reviewer 4:

The reviewer commented that this work and the stated objectives are a positive step forward in contributing to the understanding of lubricant effects on combustion and emissions control. The reviewer stated that work in developing an understanding and correlation of lubricant properties to PM characteristics is important, and provides information to advance the understanding of how to optimize the choice of lubricants to be compatible with emissions control. The reviewer stated that the impact on LSPI is also contributing in a similar fashion. The reviewer added that the fuel economy study is interesting, and using several vehicles to get better statistical information is excellent, but it will be challenging to conclude the impact on fuel economy, because there are so many different factors and powertrain designs that have an impact on fuel economy. The reviewer stated that it will be important not just to evaluate the fuel economy over a sample of vehicles, but to identify some of the key vehicle characteristics (i.e. oil temperature, overhead design, oil consumption rate) that directly impact the fuel economy, and to develop correlations against the modal fuel economy, with the goal of providing models that can allow for system optimization. Overall, the reviewer found the project to be well designed, with all of the elements fitting well together into a central scope and goal. The reviewer commented that the work is feasible, the deliverables are realistic, and it will provide useful information to the industry.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer commented that it seems that a lot of progress was made this year and the work is on track to deliver against the stated milestones. Further, the results seem to have strong conclusions and there is sufficient statistical confidence over multiple experiments.

Reviewer 2:

The reviewer commented excellent progress to date.

Reviewer 3:

The reviewer commented that technical accomplishments have been excellent thus far, and the project has developed and employed engine-based test stands and vehicle tests to explore the emissions and fuel economy impacts of lubricants. The reviewer stated that the work performed this year has allowed the project to meet several milestones and be on track to complete others in the future.

Reviewer 4:

The reviewer stated that the work is directly relevant and needs to be prioritized and accelerated; this will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer thanked the project managers for the support of this project and efforts, and appreciated that they are open to some coaching support and advice from reviewers. The reviewer suggested that the authors try to accelerate the accomplishments of the work, forego the LSPI work on the oil, focus on the fuel, and let the oil industry uncover these issues. The reviewer also recommended conducting a test with the low-viscosity oils, and a bad fuel, to determine the impact of the fuel and the oil viscosity grade. The reviewer expressed skepticism about a

finding of the Sequence 6D test to the vehicle fuel economy; however, the work is important to highlight that the test does not accurately account for real world results, and to show the difficulty in measuring small impacts of oil on FE.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that the project has pulled together an excellent set of collaborators and partners, including national laboratories, OEMs, lubricant manufacturers and academia.

Reviewer 2:
The reviewer suggested that it might be helpful to review these data with someone from the oil industry, to help focus some of the testing on the oils, and to help explain the data so that it is of more value. The reviewer added that the data on Slide 9 could use further inspection of the oil, and perhaps a DOE set of oils to determine if the effect is from the Nowack volatility or from the oil viscosity itself. The reviewer suggested that it would be helpful for the project managers and engineers to attend one of the oil industry programs that teaches the background of engine oil technical specifications; this would help to provide the researcher with additional technical training and technical background, and networking with technical contacts in industry.

The reviewer found that, overall, there is a good mix of collaborators on the project, and they can help to guide the research with appropriate technical questions.

Reviewer 3:
The reviewer stated that there is an impressive collaboration among multiple labs, and there also appear to be good industry collaborations and input from vehicle manufacturers. The reviewer voiced surprise, however, that there is not more direct collaboration with a fuel or oil industrial partner. The reviewer noted that Driven Racing Oil is involved and that they are providing samples, but stated that this seems like a very small subset of this industry that is supplying the component at the heart of this project.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer noted that the project has identified proposed future research that will address the remaining challenges identified by the presenter. The reviewer found that there has been an excellent use of input from the partners in the project to provide guidance into the future research.

Reviewer 2:
The reviewer made multiple suggestions for the proposed future work. The first suggestion is to test the oils that were used in the PM evaluation and provide these data to help explain the test data already collected. Specific to the LSPI work, the reviewer recommended minimizing the majority of the work on the oil, and accelerating the work on the thinner weight oil and bad fuels. This, the reviewer explained, will help to show if the mechanism of the oil or the fuel, or both together, is causing the issue. The reviewer noted that there is great need to study the fuel effect, so this work needs to be pulled ahead. The reviewer observed a need to understand why boron can be used in oil, as the reviewer thought this was not allowed for emission control devices; if this is not an issue for the devices, then this is important work that should be completed. The reviewer recommended an LSPI test with the boron containing oils as well.

Reviewer 3:
The reviewer found that the proposed future research is on-track to deliver against the stated objectives, although there was not much in the planning about decision points, which is partially due to the nature of the

project, which is more of a survey and developing critical functions. The reviewer suggested that the authors address on Slide 26 is the fact that future work depends on funding levels, and there may need to be a mechanism to set priorities. The reviewer noted that this mechanism may exist, but there may have been insufficient time to include it in this review.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that emissions problems could prevent more efficient lubricants so this project meets the goals as an enabler for better lubricants.

Reviewer 2:
The reviewer found the work to be very interesting and relevant, and directly related to fuel economy improvements from today's and tomorrow's (near term) vehicle technology, which focuses on displacing petroleum. The reviewer commented that it is important to make sure that there is adequate understanding of the test methodology for measurements of the metrics, and that there is understanding of the impacts of thinner weight oils, as well as LSPI on engine technology that improves fuel economy. The reviewer indicated that this research will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer thanked the project managers for the support of this project and efforts, and appreciated that they are open to some coaching support and advice from reviewers. The reviewer stated that there is important research going on in this project that needs to continue.

Reviewer 3:
The reviewer commented that the goals of this project will guide the industry in determining the properties that will drive more efficient use of lubricants, and that understanding the emissions properties will guide efficient burning of the fuel to meet emissions requirements. The reviewer noted that the fuel economy vehicle measurements show the potential benefits of new lubricants to reduce the fuel consumption of existing vehicles as well as those being developed.

Reviewer 4:
The reviewer found this project to be extremely relevant to the DOE objective of petroleum displacement, as a major component of the project is to develop and demonstrate vehicle-based protocols to screen lubricants for improved fuel economy, which will directly impact the petroleum displacement objective.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer indicated that the budget for this project appears to be adequate for the project to complete milestones.

Reviewer 2:
The reviewer stated that this is significant and relevant work that needs to be completed. The reviewer voiced concern that this work might not be completed with the proposed budget cuts, and emphasized that this work is relevant for current and near-term propulsion systems.

Reviewer 3:
The reviewer commented that it seems that the national laboratories' capabilities and expertise are being well utilized to meet the stated objectives. The reviewer questioned the vehicle testing and evaluation, however, as being able to get a large enough sample to capture all of the variations and properties of different vehicles

available on the market can be challenging. The reviewer suggested that there is a potential opportunity to widen the scope of that work, although a reasonable balance is being applied here to get valuable work with a reasonable utilization of resources.

Presentation Number: ft050
Presentation Title: Power-Cylinder Friction Reduction through Coatings, Surface Finish, and Design
Principal Investigator: Arup Gangopadhyay (Ford Motor Co.)

Presenter
Arup Gangopadhyay, Ford Motor Co.

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that the project is working on a comprehensive set of approaches to reduce friction, and that the methodology is well-designed and logical. The methodology included a study of relevant variable for coating deposition, a detailed characterization of the coatings and performance evaluation of the coatings.

Reviewer 2:
The reviewer found the project had a well-designed project plan addressing a unique approach to develop and understand an impact of protective coating porosity and oil film interactions.

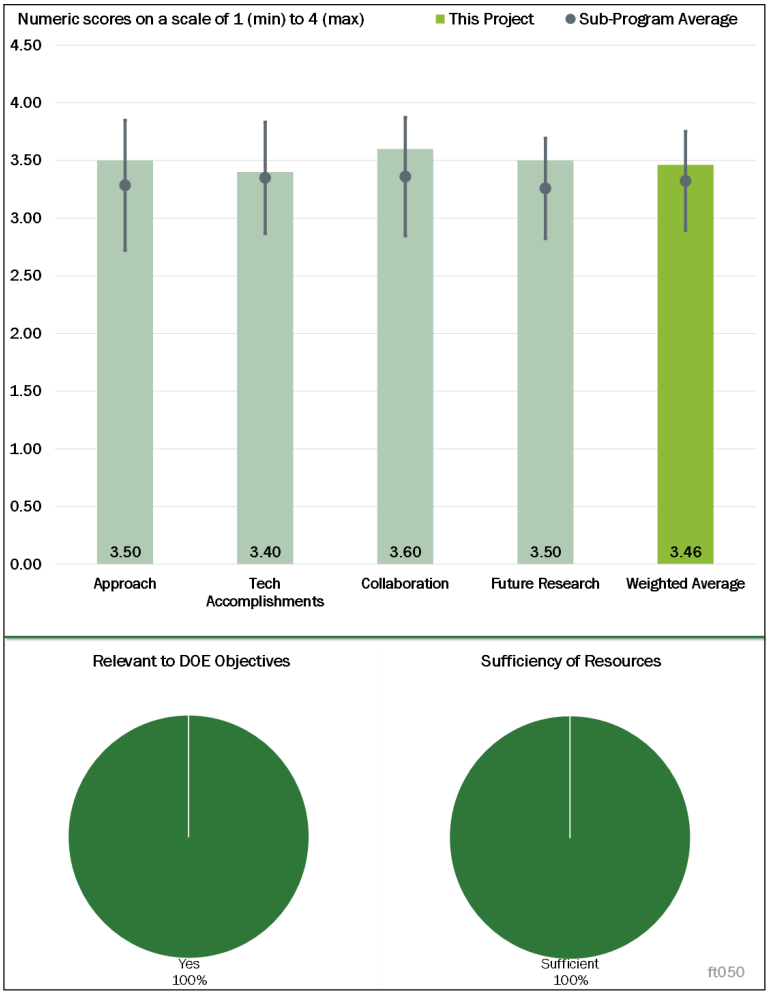

Figure 5-8 - Presentation Number: ft050 Presentation Title: Power-Cylinder Friction Reduction through Coatings, Surface Finish, and Design Principal Investigator: Arup Gangopadhyay (Ford Motor Co.)

Reviewer 3:
The reviewer commented on the good technical plan and collaboration with coating suppliers, and noted that deposition feasibility, then bench testing, all the way to chassis dynamometer testing was very complete.

Reviewer 4:
The reviewer remarked that the PI has considerable experience with the proposed technology of plasma transfer wire arc (PTWA) coatings, and noted that the proposed project will allow for variability of porosity of these coatings and will proceed with quantifying their tribological performance. The reviewer commented that porosity seems to be adequately characterized and monitored; evaluation of coatings seems to be sufficient as well, and it will be interesting to see how ANL proposed coatings will be implemented alongside the PTWA coatings. This reviewer has many questions as to the commercial viability of the ANL proposed coating and if that was considered in Ford's approach.

Reviewer 5:
The reviewer commented that the approach is logical and systematic for completing research, and is likely to result in project completion. The reviewer found that the project has a good mix of bench and engine tests with final verification on a chassis dynamometer, and addresses fuel economy benefits and evaluation of wear. The reviewer noted that long term durability is not demonstrated. The reviewer commented that the project combines three technologies to achieve results: porous cylinder liner; low friction piston rings; and low viscosity lubricant.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer stated that there has been overall good progress after some delays in setting up a new wear testing laboratory, and good development of the PTWA process and coating characterization protocol.

Reviewer 2:
The reviewer commented that there has been good progress in achieving a consistent porous coating and determining the optimum amount of porosity. In addition, friction reductions have also been demonstrated for polished crankshaft, piston ring coating, and PAG oil. The reviewer noted that the next phase will be to combine these technologies and evaluate total improvements.

Reviewer 3:
The reviewer noted that coating deposition method, characterization and initial assessment of the frictional properties have been completed, and that friction reduction benefits in bench and full scale motored rigs have been demonstrated.

Reviewer 4:
The reviewer stated that good technical progress is being made, and it is good to see a very well-planned testing strategy. The reviewer questioned why the authors selected API GF5 5W-20 (low viscosity grade) oil as a baseline for their studies. Since PAG base stocks offer unique challenges in overall performance of engine oil lubricants, the reviewer suggested that the authors reconsider using another futuristic GF-6 formulation based on conventional synthetic base stocks to optimize their novel coatings performance and achieve DOE target goals.

Reviewer 5:
The reviewer commented that the project is an interesting study of different bar stocks to use with PTWA coatings. The reviewer stated that it looks as though the 7% PTWA liner with DLC ring has very similar performance to the normal production ring for higher u*V shown on Slides 11 and 12, and commented that this would make sense as the lubrication condition moves away from boundary. The reviewer noted that the data are on two separate plots with different scales, so it is difficult to see. The reviewer stated that Slide 11 does not successfully demonstrate a clear performance trend with varying percentages of PTWA coatings, and it seems as though the lower concentration tested is detrimental to performance. This reviewer would recommend further benchtop tribological studies with varying PTWA porosity and thorough post-test analytical data to understand the mechanisms governing the performance.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented on the excellent collection of real, production auto suppliers who are each contributing in their respective areas of expertise, and who should have a good chance of commercially developing and releasing these technologies, if warranted. The reviewer stated that the coating and honing companies, in particular, appear to be very competent.

Reviewer 2:
The reviewer noted a very good collaboration with important partners in this area.

Reviewer 3:
The reviewer stated that, given the large number of collaborators, coordination among partners can be quite challenging; however, the project team has continued to make good progress, indicating that coordination among the partners is going well.

Reviewer 4:
The reviewer observed that it seems several partners acting as suppliers are providing the hardware components necessary to demonstrate the chosen technologies. The reviewer noted that ANL's nanocomposite coating seems promising as well, but it will be interesting to see how it plays in the future progress of this project, as it is a separate thrust area to the primary PTWA coating technology.

Reviewer 5:
The reviewer commended the authors on the impressive list of collaborating organizations that are contributing to this project, but questioned why there no lubricant additive supplier included in any activity, as additive supplier can offer key technical knowledge regarding formulating approaches.

The reviewer also requested clarification of the distinction between contributions from collaborating organizations and from supplier organizations.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer stated that the key steps to complete the project have been well documented.

Reviewer 2:
The reviewer commented that several detailed and realistic future testing strategies are identified, including friction reduction on motored cranktrain rig with PTWA coated blocks (at various porosity levels); friction reduction on motored cranktrain rig with PTWA coated blocks with low friction rings; friction benefits on pressurized single cylinder friction rig; and friction benefits of piston skirt and ring nano-composite coatings against PTWA coated liner in laboratory bench rigs. The reviewer noted that there is also an impressive plan to conduct durability examinations in engines and vehicles.

Reviewer 3:
The reviewer commented that future work is following the project plan as written and is logical to achieve overall deliverables.

Reviewer 4:
The reviewer observed that the group has a large go/no-go decision point rapidly approaching, as they move from benchtop validation of the PTWA coating technology to rig testing. The reviewer expressed hope that this will elucidate some of the mixed performance results demonstrated in benchtop tribological testing. The reviewer noted that both friction and wear/durability performance will be quantified over the next year to year and a half.

Reviewer 5:
The reviewer stated that we really need to see the fired engine testing benefits, eventually progressing to chassis testing.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer replied yes, based on a well-planned project structure, this project definitely supports overall DOE objectives.

Reviewer 2:
The reviewer originally surmised that the porous coating might be hard to control or expensive; however, after reviewing the coating and honing supplier websites, the reviewer was impressed by their apparent competence. The reviewer added that the project will stimulate further interest in this approach to an oil retention bearing surface, if results add up as it appears they will.

Reviewer 3:
The reviewer found that preliminary results appear to support the reduction of petroleum usage.

Reviewer 4:
The reviewer stated that coatings are becoming vital to lubricated systems as lubricants move to lower viscosities, and the proposed PTWA coating technology could work exceptionally well with these low-viscosity lubricants. The reviewer concluded that there is high relevance overall to reducing friction and increasing fuel efficiency.

Reviewer 5:
The reviewer stated that the project aims to reduce friction by development and use of advanced coatings on engine components, and this goal is directly related to the DOE objective of reducing petroleum dependence; however, the project team is grossly over-estimating the size of the FE benefit that will accrue from this work. The reviewer remarked that the team should be requested to provide a rational basis for their assessment of the benefit.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that the funds allocated for 2017 appear adequate to complete the remaining tasks identified by the project team.

Reviewer 2:
The reviewer replied yes, all proposed resources are sufficient to make this project successfully reach DOE specified goals.

Reviewer 3:
The reviewer commented that resources appear to be adequate to achieve end results, as long as planned funding is maintained.

Reviewer 4:
The reviewer stated that the project team has been performing on budget. In the reviewer's opinion, it is good to see a cost share by Ford to investigate the chosen technology; the strong mutual interest should help the success of this project.

Presentation Number: ft051
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Fuel Property Characterization and Prediction
Principal Investigator: Robert McCormick (National Renewable Energy Laboratory)

Presenter
Robert McCormick, National Renewable Energy Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer found that the work being conducted under this project is critical for establishing the Central Fuel Hypothesis that if pertinent fuel properties that enable higher engine efficiency are identified, then fuels that have those properties will be able to provide the expected improvement in engine performance. To this end, the reviewer commented that this project is generating new information and developing analytical/computational tools to help define the relevant fuel properties for improved engine efficiency.

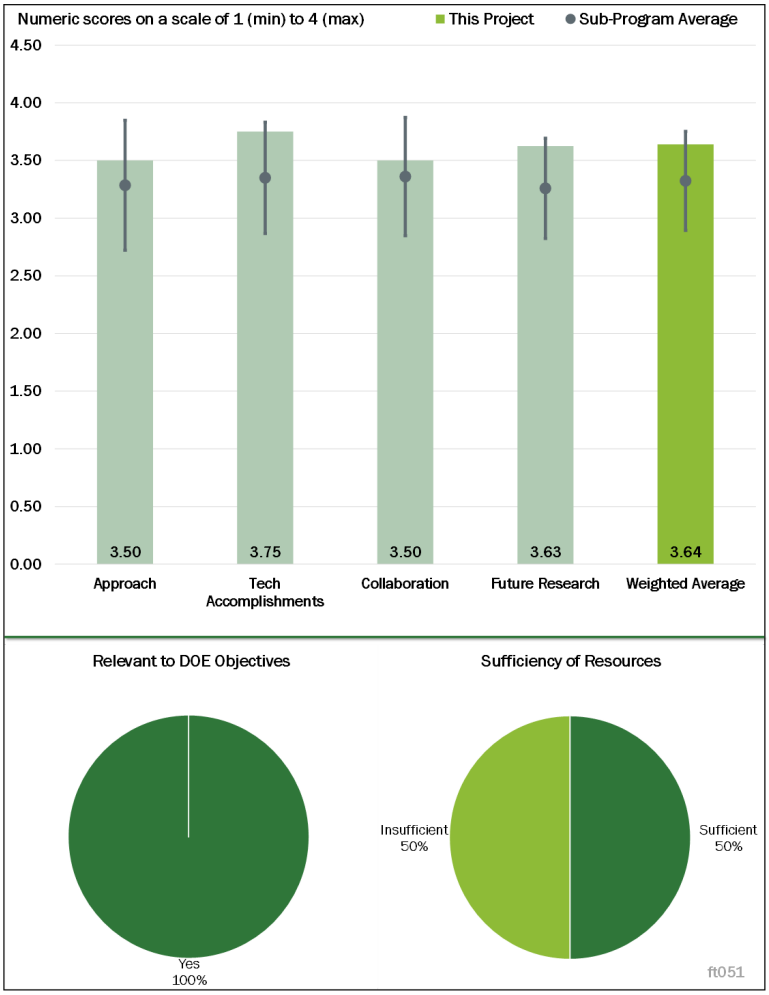

Figure 5-9 - Presentation Number: ft051 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Fuel Property Characterization and Prediction Principal Investigator: Robert McCormick (National Renewable Energy Laboratory)

Reviewer 2:
The reviewer noted that there are a number of different projects contained within the "umbrella" of this presentation topic of "Fuel Property Characterization and Prediction," and each of those has its own merits and debits. The reviewer stated that the overall concept/approach of understanding the impact of fuel properties on engine performance has a lot of merit, and assessment of potential fuel component candidates requires measurement of accurate prediction of the candidates' properties. The reviewer commented that the presentation raises some confusion about the performance characteristics that the Merit Function is developed to address. The reviewer elaborated by saying that in previous Co-Optima presentations, the Merit Function has been proposed as a way to predict the efficiency of SI, boosted engines based on fuel properties; however, in this presentation, the Merit Function comes immediately after the statement of the Central Fuel Hypothesis that "If we identify target values for the critical fuel properties that maximize efficiency and emissions performance ..." Further, the Merit Function has a term for particulate matter index (PMI), but lacks terms for other important emissions components. The reviewer added that this leads to confusion as to whether the Merit Function is solely focused on efficiency, or if it also tries to account for some, but not all emissions. The

reviewer stated that the ultimate key to the value of the Merit Function is validation through comparison of predictions versus actual results in engines that are representative of downsized, boosted production engines. The reviewer commented that the focus of the fuel blend property testing appears to be oxygenates (based on data presented in Slide 9); however, in the spirit of true "Co-optimization" of fuels and engines, hydrocarbon candidates (regardless of whether they are bio-derived or not) should also be included to identify the best potential candidates. In the reviewer's opinion, the work to measure the heat of vaporization of multicomponent mixtures characteristic of "real" fuels has a lot of merit. The reviewer added that the development of small volume testers to measure key properties of fuel components that are not available in large enough quantity for conventional analytical devices (such as Cooperative Fuel Research [CFR] engines for octane determination) would be very valuable. The reviewer stated that the use of those devices for quantitative measurement will require that they have repeatability and reproducibility values consistent with the larger instruments.

Reviewer 3:
The reviewer said that emissions problems could prevent more efficient lubricants so this project meets the goals as an enabler for better lubricants.

Reviewer 4:
The reviewer praised the work as being very interesting and relevant, and said it will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer thanked the project managers for the support of this project and efforts, and appreciated that they are open to some coaching support and advice from reviewers. The reviewer added that there is important research going on in this project that needs to continue. The reviewer did not see flame speed (SL) or PMI in the dataset, and commented that it was part of the merit function. The reviewer questioned whether that is being completed under a different part of the project or perhaps had not been prepared yet in this project. The reviewer commented that the decision point presentation followed the final Co-Optima presentations, and this seemed to help clarify why some factors of the merit function were not addressed. However, the reviewer stated that it is still imperative to look at Flame Speed (SL) and PMI as part of the merit function for the final blended fuels, as there are some effects to be understood with the blended fuels.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer said excellent progress to date.

Reviewer 2:
The reviewer remarked that in 2016-2017, this project made excellent progress towards defining the fuel properties most relevant for increasing engine efficiency, and added that, in addition to generation significant new information on properties of various biomass based fuel components, new analytical and computational tools were also developed to help estimate the properties of finished fuels. The reviewer noted that the fuel property information was used to refine the merit function. The reviewer observed that, because 97% of the light-duty vehicles sold in the U.S. are powered by SI engines, fuels that can help improve engine efficiency even modestly can have a significant impact on the national energy consumption as well as expenditure on transportation. The reviewer concluded that defining properties of the fuel that can enhance engine performance is a critical step towards realizing the DOE goals of reduced energy consumption and petroleum displacement.

Reviewer 3:
The reviewer remarked that lots of work has been completed on predicting fuel component and blend properties, and the ultimate value of the work will need to be validated in tests in representative engines.

Reviewer 4:
The reviewer observed that the presentation demonstrated significant technical accomplishments and was well organized and very detailed. The reviewer really appreciates the attention to detail and the technical team that put this presentation together, and complimented them on a job well done. The reviewer stated that this work will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer commented that there is critical research going on in this project and believes that it needs to continue to support improvements in fuel selection and efficiency in the near term and within the next 10 years.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that there is a good list of collaborators on this program and they are coordinating at a high level, and added that this is demonstrated in the significant work accomplished and the valuable work being completed with a small budget. The reviewer offered praise for this highly efficient team.

Reviewer 2:
The reviewer stated that the collaboration between the various national laboratories and PIs has been excellent and is evident from the improved alignment of activities across various facilities, as well as the significant enhancement of the knowledge base related to properties of various fuel components.

Reviewer 3:
The reviewer remarked that the collaborations for this work that are mentioned on Slide 18 are predominantly within the national laboratories and universities, and no mention is made about collaborations with industry. The reviewer also noted that the Coordinating Research Council (a consortia of energy companies and automakers) is mentioned, but that was for the specific work on diesel fuel surrogate solidification and some heat of vaporization measurements. The reviewer suggested that sharing more technical details with industry and obtaining input on a timely basis (i.e., in developing fuel matrices and test conditions and as the results are obtained) would likely improve the ultimate relevance and potential for commercial deployment.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer noted that the proposed future research, particularly reducing uncertainty of the Merit Function for light-duty (LD) SI engines, as well as relevance of SI fuels for Advanced Compression Ignition combustion concepts, is in line with the goals of the project as well as the DOE goals. According to this reviewer, formalizing the Merit Function and finalizing the most relevant fuel properties for LD SI engines would be a substantial contribution to the existing body of knowledge and this effort should be provided all the support it requires.

Reviewer 2:
The reviewer said that including some non-biofuel streams would be beneficial and is being considered at least. This would help to frame how the biofuels compare to other exotic fuel sources.

Reviewer 3:
The reviewer praised the list of proposed work as excellent, and highly recommended that continued funding be spent on the list of work proposed, as these are critical for the success of this program and future fuels for our current and industry product mix.

Reviewer 4:
The reviewer stated that the proposed future work mostly makes sense, but it is unclear how decisions will be made regarding which work to continue if budgets are reduced. The reviewer recommended including the properties and effects of various hydrocarbon components to improve the value of the work.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that this project supports the DOE objective of petroleum displacement. The reviewer added that it specifically addresses all technical issues involved with the fuels, and validating the technical issues with fuels, thus preparing them to be brought to the market place.

Reviewer 2:
The reviewer commented that engine and fuel combinations that lead to higher engine efficiencies will lead to lower fuel consumption.

Reviewer 3:
The reviewer responded yes, that clearly identifying and defining the properties of fuels that can help enhance engine efficiency is in line with the overall DOE objective of petroleum displacement.

Reviewer 4:
The reviewer commented that the project should save petroleum in both new vehicles and legacy vehicles due to efficiency improvements if successful.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer commented that resources seem sufficient at the current funding level, but presumably work in some areas will have to be reduced if budget cuts are made, and it is unclear how that prioritization would be done within DOE.

Reviewer 2:
The reviewer stated that there is significant technical work being completed in this program, and expressed surprise at the funding level, considering some of the other AMR projects the reviewer has seen and reviewed, and compared their funding levels. The reviewer complimented the team as being highly efficient and effective, in comparison to some other projects. In the reviewer's opinion, this is such an important project that it should be funded at a higher level and with more resources to ensure that it will be completed.

Reviewer 3:
The reviewer found that the funds allocated to this effort are insufficient and can be expected to impede progress at a critical juncture, which would be unfortunate, especially in view of the progress made over the past year.

Presentation Number: ft052
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Topic 7 - Fuel Kinetics and Its Simulation
Principal Investigator: Matthew McNenly (Lawrence Livermore National Laboratory)

Presenter
Matthew McNenly, Lawrence Livermore National Laboratory

Reviewer Sample Size
A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer found that the effort is well-focused on improving predictive capabilities regarding key fuel properties and is coordinated with a comprehensive and complimentary team.

Reviewer 2:
The reviewer found the overall approach to be very good, and stated that evaluating the impact of fuel properties on ignition and kinetics is a critical aspect of fuel and engine optimization.

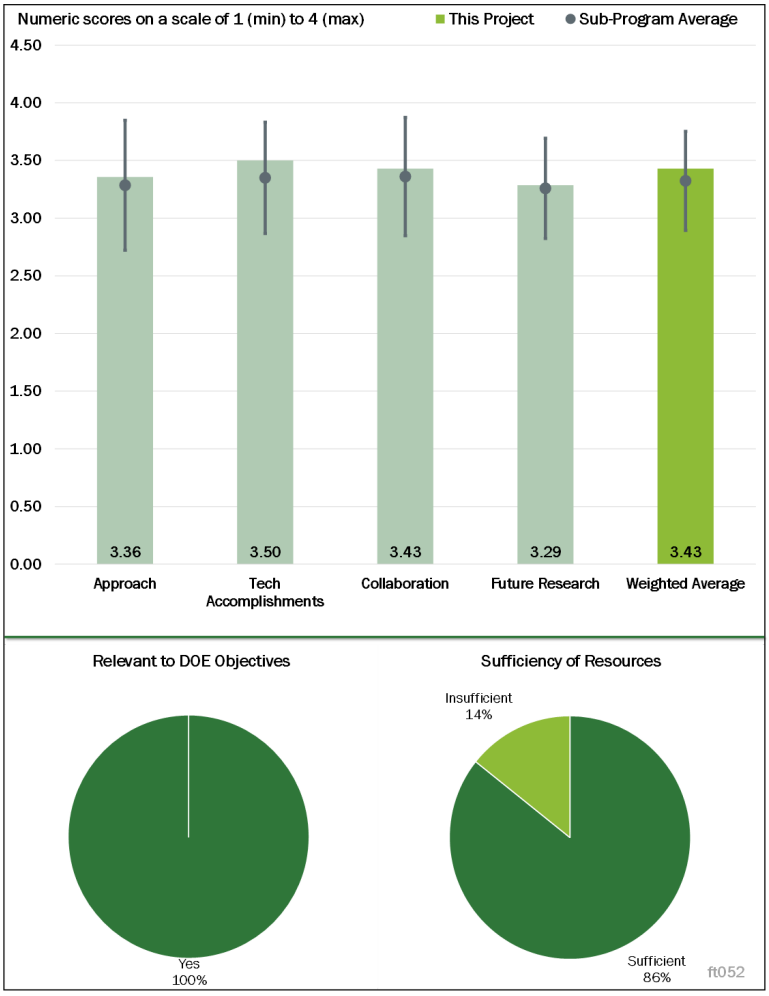

Figure 5-10 – Presentation Number: ft052 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Topic 7 - Fuel Kinetics and Its Simulation Principal Investigator: Matthew McNenly (Lawrence Livermore National Laboratory)

Reviewer 3:
The reviewer indicated that, based upon this review, this appears to be very strong technical work. The reviewer added that if the Co-Optima project is to be successful, then it needs a strong technical understanding of the kinetic properties of the fuels, so that models can be developed to support and guide the merit function and reduce the burden of testing through screening methods via simulation. The reviewer found that the project is well designed and scoped, and praised the goal of addressing the efficiency of finding solutions. The reviewer stated that the project has a very aggressive goal, but expressed concern that there are sufficient resources to complete the work. The reviewer expressed the opinion that the work need not be completed in its entirely to improve the industry knowledge gap, and commented that even sub-sets of this work will be of high value.

Reviewer 4:
The reviewer stated that the approach presented is adequate to provide information to achieve the Topic 7 goals for fuel kinetics and its simulation, and to ultimately eliminate the barriers that need to be addressed.

Reviewer 5:
The reviewer praised the work as being very interesting and relevant, and said it will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer thanked the project managers for the support of this project and efforts, and appreciated that they are open to some coaching support and advice from reviewers. The reviewer added that there is important research going on in this project that needs to continue. The reviewer questioned how the authors will determine if the model properties match the engine results, and asked for evidence that the simplified kinetic model and fuel set matches the engine output for a fully formulated fuel that is multi component. The reviewer also requested that the parameters at the top of Slide 11 be updated in the version of the slides that will be posted on the web.

Reviewer 6:
The reviewer complimented the project on being very well designed, feasible, and integrated with other efforts. The reviewer suggested that Task F2.2.2 should put more effort toward developing a computational fluid dynamics (CFD) model for the Advanced Fuel Ignition Delay Analyzer. The reviewer added that the ignition quality tester (IQT) uses an obsolete injector and the spray model is not very well studied, and was not very confident of using IQT to validate fuel combustion kinetics.

Reviewer 7:
The reviewer commented that development of a kinetic model to rapidly simulate and predict kinetic effects of various fuel properties and blends can be very useful in reducing the research needed for downselection of fuel candidates, as well as impacts with different combustion conditions. The reviewer indicated, however, that much of the actual approach to developing the model is difficult to understand from the presentation and slides.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that there is significant work that has been done in the project to provide fundamental data to support the modeling efforts. While always skeptical of models versus real-world data, the reviewer expressed the view that this effort is worthwhile and will provide a good set of tools for use in fuel selection and optimization for near term and long-term products for the market.

Reviewer 2:
The reviewer found that the technical accomplishments have been adequate to provide information to allow the project to meet FY 2017 milestones and continue to be on track for future milestones. The reviewer added that the project has significantly improved pressure dependence in the kinetic model with work done at ANL in FY 2017, and it has created virtual fuels to test the hypothesis in CFD. The reviewer expressed the view that success in these areas will move the project toward meeting the DOE goals.

Reviewer 3:
The reviewer commented that, considering co-optima relative newness, progress is impressive.

Reviewer 4:
The reviewer stated that the project has made very good progress toward overall project and DOE goals.

Reviewer 5:
The reviewer stated that it appears that excellent progress is being made towards the project goals, information is being provided that is helping to support and validate the Central Fuel Hypothesis, and predictions being

done from the tools which are utilizing the kinetic information developed are showing strong correlation with conducted experiments.

Reviewer 6:
The reviewer remarked that progress is on track.

Reviewer 7:
The reviewer observed that the presentation says that work has been completed predicting blend behavior for high performance blend stocks in base fuels at LD conditions and compared to ethanol blend behavior, but no such results appear to be reported in the slides. The reviewer added that, apart from reporting that various "tools" have been developed, it is not clear from the presentation what work has been completed and what is yet to be done with regard to the model.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that, in reviewing the list of national laboratories involved in the project, it seems that there is a good mix of technical talent in collaboration. Also, it seems that the project has extended to collaborators outside of the government labs, to incorporate additional technical coordination in support of the overall goals.

Reviewer 2:
The reviewer commented that the project has very good coordination and collaboration through the work of four national laboratories and academia; in addition, the project coordinates with the Coordinating Research Council (CRC) which helps bring industry input to the project.

Reviewer 3:
The reviewer remarked on the overall excellent collaboration among national laboratories, and indicated that the project was well coordinated with other activities such as Advanced Engine Combustion (AEC) and CRC.

Reviewer 4:
The reviewer commented that the collaborations described in Slide 6 seem to be very successful and working well to meet the project objectives. The reviewer was particularly impressed with the collaboration with John Dec from Sandia National Laboratories, and the comments that his work was identifying desirable properties of the fuels to optimize efficiency, and was showing some promise in how to blend the fuels to meet those objectives and then demonstrate the expected performance.

Reviewer 5:
The reviewer notes that, apparently, this project has been criticized in the past as needing more collaboration, and agrees that this is still true. The reviewer pointed out that there are many places where researchers are looking at ignition delay/quality and kinetics, including (beyond those already working on this project) Jim Cowart at the Naval Academy, who has an IQT, Josh Bittle at the University of Alabama, who has a Cetane ID, Andre Boehman at the University of Michigan, who also has a Cetane ID, possibly with optical access, and others. The reviewer postulated that perhaps there is room for more extensive collaboration.

Reviewer 6:
The reviewer noted that four labs and 46 organizations are shown as participating in the Task 7 kinetic work, and periodic meetings and conference calls are held. The reviewer stated that the nature of the collaboration to date, however is shown only in Slide 6, which provides only the last names of researchers, not their affiliations; it does identify a breakdown of future work for the four participating labs, but does not do so for work to date.

Reviewer 7:
The reviewer commented that a comprehensive team has been assembled, but, if anything, the team is almost too large, with capabilities perhaps spread too widely. The reviewer stated that it was nice to see a new ignition quality rig brought to the team.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer commented that the future work here is critical to the success of this program, and to providing needed basic fundamental fuel property data for industry. Further, the reviewer noted that this is an outstanding list of future work that will be highly supported by industry. The reviewer stated that this work needs to have sufficient funding for completion because of the relevance and significant need.

Reviewer 2:
The reviewer stated that the proposed future work appears to be adequate and addresses the remaining challenges and barriers.

Reviewer 3:
The reviewer noted that the future work is outlined clearly, and apparently will contribute to understanding by predicting fuel behavior within the co-optimizer tool for different combustion modes, although the explanation of that is not as clear as it might have been.

Reviewer 4:
The reviewer suggested that other collaborators be considered in future work.

Reviewer 5:
The reviewer commented that the future work description should consist of a short set of two or three central outcomes of this part of Optima, not by just showing a distribution of work across the Labs. The reviewer suggested taking a diagram, such as Slide 22, and showing a clear path toward a couple of key outcomes, as it is not quite clear, as currently shown.

Reviewer 6:
The reviewer found that, overall, the future work is well planned. The reviewer did question what the plan is to address the barriers and challenges, however.

Reviewer 7:
The reviewer stated that this work is on track to meeting the stated objectives; the only thing that is not clear, however, is the pathway to mitigate risk. The reviewer commented that it seems there is a very large scope and it is not clear that there are sufficient resources to meet the desired goals. The reviewer added that it appears that the overall Co-Optima project has some mechanisms to manage this, but it would be nice to see that the most critical aspects of the project are able to be met, and that it is clear what the secondary objectives would be if the work takes more resources than allocated.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that the work is relevant to supporting the need to more easily model the impact of fuel properties, in support of petroleum displacement. The reviewer added that the future work here is critical to the success of this program, and to provide needed basic fundamental fuel property data for industry.

Further, the reviewer noted that this is an outstanding list of future work that will be highly supported by industry. The reviewer stated that this work needs to have sufficient funding for completion because of the relevance and significant need.

Reviewer 2:
The reviewer stated that this work has a high potential for success in improving engine efficiency because it is a piece of work which considers total system optimization. The reviewer noted that this specific part of the Co-Optima work is providing fundamental building blocks for modeling efforts and determining the properties of various blended fuels. Further, according to this reviewer, beyond the scope of the Co-Optima work, the integration of the tools and functions gained in this work can be integrated into engine modeling tools for performance predictions, which are critical to the industry in order to run large screening studies and determine system optimums.

Reviewer 3:
The reviewer stated that the project definitely supports the overall DOE objective of petroleum displacement by predicting the impact of fuel properties and bridging the gap of efficient, low-emissions engine knowledge.

Reviewer 4:
The reviewer stated yes, this project supports the overall DOE objectives of petroleum displacement.

Reviewer 5:
The reviewer commented that this project (Task 7) is apparently useful to the overall Co-Optima project, which could result in much higher combustion efficiencies, hence increase fuel economy.

Reviewer 6:
The reviewer replied yes, presuming the fuel and auto/engine organizations will work together, and more efficient fuel-engine systems can be implemented.

Reviewer 7:
Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer found that there are sufficient resources for the project to achieve the stated milestones in a timely fashion.

Reviewer 2:
The reviewer commented that the funds expected to be provided for this project appear to be adequate to complete the planned work.

Reviewer 3:
The reviewer stated that the budget is sufficient for now, but wondered what will be the impact of likely upcoming cuts, and if it will significantly impair progress.

Reviewer 4:
The reviewer found that there is a good level of investment of resources into this work, perhaps not is sufficient to meet all of the desired goals, but it is a good balance to meet a fundamental knowledge gap within the industry.

Reviewer 5:
The reviewer indicated that some of the participating Labs are a bit below the funding level needed to stay dedicated to their tasks; however, they should consider whether some subtasks are really critical or could be consolidated.

Reviewer 6:

The reviewer stated that it seems that this program has sufficient funding for completion; however, it is alarming that for future FYs, the funding will be reduced drastically. The reviewer added that this is important work that will provide fundamental technical support for industry to produce fuel efficient and reduced emissions products, in the longer term. The reviewer further commented that the research provides design tools that will allow for decision making regarding future fuels for engines, and it is imperative that this work be completed with the sufficient funding.

Presentation Number: ft053
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Fuel-Property Impacts on Spark Ignition Efficiency, Part 1: Research Octane Number, Sensitivity, and Heat of Vaporization
Principal Investigator: Jim Szybist (Oak Ridge National Laboratory)

Presenter
Jim Szybist, Oak Ridge National Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer stated that the systematic and thorough experimental approach adopted in this project is crucial for establishing Co-Optima's Central Fuel Hypothesis. The reviewer added that the fundamental studies conducted under this project have helped develop a better understanding of the limits of the most relevant fuel properties for engine efficiency such as Octane Index, Sensitivity, and Heat of Vaporization. In addition, according to this reviewer, the engine experiments being performed as part of this project augment and complement the work being conducted under the Fuel Characterization and Prediction project being led by Bob McCormick.

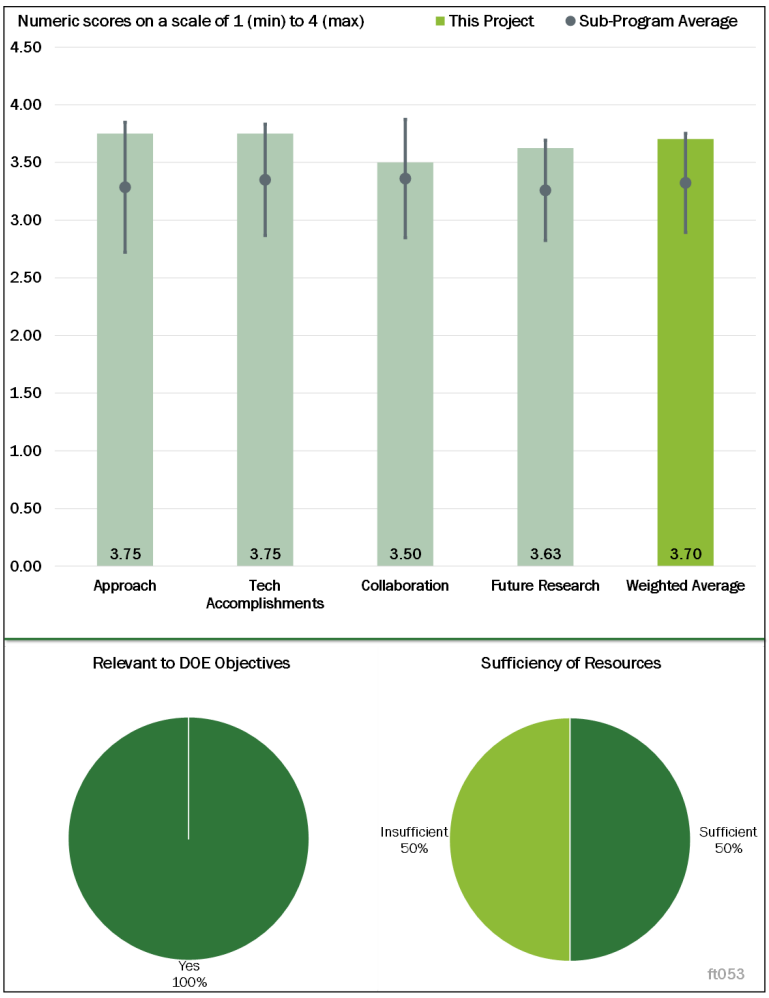

Figure 5-11 - Presentation Number: ft053 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Fuel-Property Impacts on Spark Ignition Efficiency, Part 1: Research Octane Number, Sensitivity, and Heat of Vaporization Principal Investigator: Jim Szybist (Oak Ridge National Laboratory)

Reviewer 2:
The reviewer noted that there are five different projects contained within the umbrella of the topic of this presentation, "Fuel Property Impacts on Spark Ignition Efficiency," and that each of those has its own merits and debits. The reviewer commented that the overall concept/approach of understanding the impact of fuel properties on engine performance and "Co-Optimizing the fuels and engines" has a lot of merit; the focus of the work in this program area is SI combustion, which limits potential "co-optimization" because the engine design is largely defined/fixed. Further, according to this reviewer, the almost exclusive focus of fuel blend component candidates is on those perceived by the DOE researchers to be producible by biofeedstocks, predominantly oxygenates. The reviewer suggested that a more robust, fundamental R&D program that would be of even greater value to fuel producers should also include an understanding of the performance of blends with various hydrocarbon molecule candidates (regardless of whether they can be bio-derived or not). The reviewer commented that the presentation generates some confusion about the performance characteristics that

the Merit Function has been developed to address. The reviewer elaborated that in previous Co-Optima presentations, the Merit Function has been portrayed as a metric for predicting relative SI engine efficiency based on fuel properties; that implies that other metrics are needed and will be used to evaluate other key parameters such as emissions and cold start performance. The reviewer noted that in the current presentation, however, no mention is made that the Merit Function pertains to engine efficiency, and it comes immediately after a statement of the Central Fuel Hypothesis that "If we identify target values for the critical fuel properties that maximize efficiency and emissions performance..." Further, the PMI has a term for PMI, but lacks terms for other important emissions components. This leads to some confusion as to whether the Merit Function alone will be used to assess the potential of the various components in engines or whether the intent is still to include other important engine performance parameters in assessing candidate components. The reviewer commented that the specific approach of coupling engine experiments with modeling and simulation is a good approach. The reviewer added that it will be critical to validate that the Merit Function does correlate very well with efficiencies obtained in SI engines that are representative of what will be in the market in the near future.

Reviewer 3:

The reviewer praised the work as being very interesting and relevant, and said it will help to support the reviewer's company in producing products that meet not only the current portfolio for today, but also a balanced portfolio for the future. The reviewer stated that the project directly contributes to the understanding of the use of energy in an efficient and clean manner. The reviewer thanked the project managers for the support of this project and efforts, and appreciated that they are open to some coaching support and advice from reviewers. The reviewer added that there is important research going on in this project that needs to continue. The reviewer is in complete agreement with the approach and eagerly awaiting the significantly important results of the project. The reviewer had two questions: whether the material on Slide 8 was CA10-CA90; and, referencing Slide 21, what LFV150 is and how it relates to SPI.

Reviewer 4:

The reviewer liked the quest to quantify how octane could actually be used on drive cycles. The reviewer wished the PI could also develop a correlation to say how it would behave with a newer engine, e.g., downsized and/or higher compression ratio (CR).

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer said great progress to date.

Reviewer 2:

The reviewer commented that, due to the sheer number of light-duty vehicles in the United States powered by SI engines, even modest efficiency gains can go a long way towards accomplishing DOE's overall project goal of displacing petroleum and consequently improving national energy security. Consequently, the reviewer added, the fundamental research being conducted as part of this project to better understand the impact of fuel properties on engine efficiency is critical for achieving a substantial market impact. The reviewer added that excellent progress has been made over the past year, and the constant volume ignition delay experiments and the completion of the engine test campaign evaluating knock propensity of the core Co-Optima fuel matrix were significant achievements. The reviewer stated that continuation of the ongoing efforts, aimed at quantifying and finalizing the ideal fuel properties for enhanced engine efficiency, is crucial for delivering an output that can provide immediate value to the various stakeholders and the society at large.

Reviewer 3:
The reviewer stated that the project has made significant progress and accomplishments so far. The reviewer is looking forward to continued good work in the future, saying that this is the kind of work and research that we are looking for from the industrial perspective that aid us in making critical and necessary design decisions.

Reviewer 4:
According to this reviewer, the projects shows very good technical progress. The reviewer commented that Sluder's experimental results in a multi-cylinder engine coupled with Autonomie vehicle modeling showing that at higher compression ratios (of 11.4) there is still 6% lower fuel economy for a gasoline turbocharged direct injection engine in the US06 drive cycle for E20 blends is very interesting. The reviewer added that the results of the effects of fuel heat of vaporization on load (indicated mean effective pressure) versus intake manifold T are interesting, but assessment/information on the projected actual values of intake manifold Ts in near future production engines would help to put the results in perspective. The reviewer stated that the desire to prove that the Central Fuel Hypothesis is correct seems to be the driver for making the statement on Slide 19 that the "Data validates the Central Fuel Hypothesis," despite the fact that it did not hold for two of the seven fuel blends tested.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer praised the significant collaborations within the national laboratories and within industry, and was pleased by the interactions on this project with the team.

Reviewer 2:
The reviewer stated that the fact that this project involved contributions from nine national laboratories and 13 universities is testament to the excellent level of collaboration and coordination between the various partners. In addition, according to this reviewer, the project leaders did a good job of apprising the various stakeholders of the progress being made in the project through periodic updates during the monthly conference calls.

Reviewer 3:
The reviewer noted that there is some engagement with industry through occasional stakeholder teleconferences, although the collaboration would be significantly improved by more timely release and discussion of detailed results.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer stated that the proposed future research is critical for refining the Merit Function for light-duty SI engines. In addition, according to this reviewer, completing the ongoing work to quantify and finalize the desired fuel properties for improving engine efficiency is critical for providing an output that provides immediate value to the various stakeholders, including society at large, and consequently helps accomplish DOE's goals.

Reviewer 2:
The reviewer expressed full support of the proposed future work for this project, but indicated some concern that with the proposed budget cuts, this work might suffer or not be completed. The reviewer cautioned DOE budget cuts on this particular project, as the issues being addressed will enable further fuel economy and reduced emissions for current vehicles being designed, as well as future short-term engine solutions. The reviewer added that the project is showing some interesting impacts of fuels that have not been known before, and expressed thanks to the researchers for their continued pursuit of this work.

Reviewer 3:
The reviewer commented that the proposed plans look reasonable, but they could be improved by including more fundamental work on hydrocarbon components, to truly identify components that are optimal and commercially realistic for these near future engines.

Reviewer 4:
The reviewer said that to optimize the merit function and see how RON matters, the PI might try partnering with someone familiar with LP optimization in refineries. Adjusting the LP tool to optimize the merit function instead of profit might give some insights.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
In this reviewer's opinion, out of the various Co-Optima activities, this project has perhaps the greatest potential to have an immediate impact on the current production technology, and in the process, achieve DOE's overall goal of petroleum displacement. The reviewer added that, due to the potential of this project to have a positive impact on the society at large, it should be afforded all the support it requires.

Reviewer 2:
The reviewer stated that the project is critical to understanding the role of fuel properties on efficiency. The reviewer added that this is needed so that the various fuel properties can be established by the value of their contribution to efficiency improvements.

Reviewer 3:
The reviewer commented that improved engine efficiency and lower emissions are consistent with DOE objectives.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that resources are currently sufficient, although they may not be sufficient to cover all areas if the budget is reduced.

Reviewer 2:
The reviewer stated that the researchers did not indicate that the funding was not a factor for this project; however, due to the nature of the LSPI work, there may be a need for additional hardware to repair engines and testing equipment for continued testing and longevity of the project. The reviewer recommended making sure that this project has sufficient funding for a successful completion, as the data are relevant and of high value to industry.

Reviewer 3:
The reviewer stated that the resources allocated to this project for 2017-2018 are grossly insufficient, and this project cannot be expected to reach a successful conclusion with the allocated funds. The reviewer added that, as the expected deliverables of this project are extremely relevant for the current and near future production technology, and the success of this project would go a long way in accomplishing DOE's overall goals, this project should be provided all the support possible.

Presentation Number: ft054
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Fuel-Property Impacts on Spark Ignition Efficiency, Part 2
Principal Investigator: Chris Kolodziej (Argonne National Laboratory)

Presenter
Chris Kolodziej, Argonne National Laboratory

Reviewer Sample Size
A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that the approach taken in this project, using engine experiments and simulations to provide information regarding how fuel properties affect engine efficiency, is excellent and will help in addressing the barriers identified in the project.

Reviewer 2:
The reviewer stated that the approach to each of the three (broadly defined) tasks undertaken to date is well explained in the task slides. Moreover, according to the reviewer, the overall "approach," i.e. how the work tasks fit directly into the development and testing of the SI Merit Function and ultimately, the Co-Optimizer, is very clear. The reviewer noted that how the other terms of the Merit Function are being tested and defined is less clear, but this is apparently outside the scope of this task.

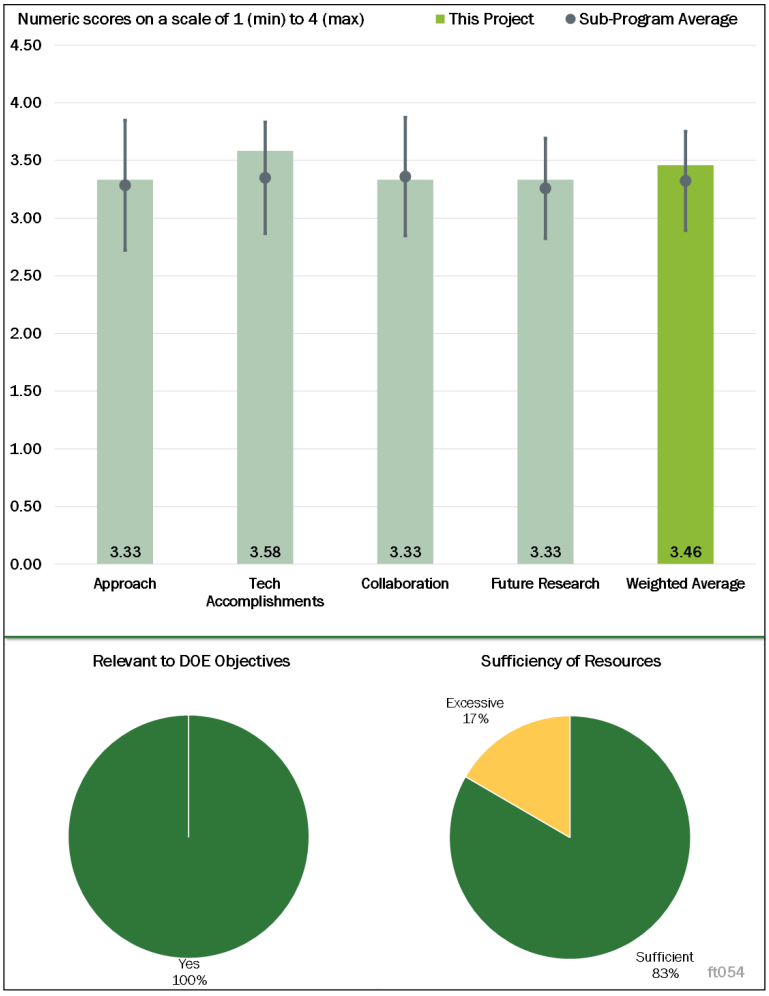

Figure 5-12 - Presentation Number: ft054 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Fuel-Property Impacts on Spark Ignition Efficiency, Part 2 Principal Investigator: Chris Kolodziej (Argonne National Laboratory)

Reviewer 3:
The reviewer commented that the project is well conceived, plays an important role in Co-Optima, and addresses critical technical barriers. The reviewer's only small concern at this point is that collaborations could be expanded to include others with CFR engines and/or modified CFR engines. The reviewer mentioned a group led by Andre Boehman, at the University of Michigan, that has modified a CFR engine to eliminate the carburetor entirely and use a port-fuel injection system and heater upstream of the engine to produce the desired fuel/air mixture at the desired temperature.

Reviewer 4:
The reviewer indicated that, overall, this project is very well designed to better understand the fundamentals of fuel properties on downsized, boosted SI engines, which is important to achieve the overall Co-Optima goals.

The reviewer added that the project is feasible and integrated with other efforts, but stated that one area that can be improved is how to better quantify the fuel effect on low-speed pre-ignition (or superknock).

Reviewer 5:

The reviewer commented that the project approach focuses on fuel property impacts on engine efficiency and on developing models for predicting fuel properties and characteristics for boosted SI engines. The reviewer added that the approach uses the Merit Function to validate the Central Fuels Hypothesis. The reviewer noted that the statement on the barrier does not seem pertinent to this sub-project of Co-Optima. According to this reviewer, all the topics, fuel effects on dilution tolerance, RON and HoV effects, and development of the virtual CFR engine, address downsized boosted engines, which are very pertinent for light-duty OEMs.

Reviewer 6:

The reviewer praised the project's excellent work to understand the effect of various fuel properties on SI engine performance characteristics. The reviewer added, however, that it was not entirely clear from the presentation how the engine performance, like the lean dilution limits and exhaust gas recirculation (EGR) limits, feeds back into the merit function and co-optimizer. The reviewer recognized these to be critical to optimizing the engine efficiency while meeting emissions limits. The reviewer stated that the overall approach is very good, and understanding the performance aspects of critical fuel properties is at the core of this work, and added that this knowledge will be critical to determining the impacts of fuel/engine system optimization. The reviewer liked the fact that uncertainty is captured in the Co-Optimizer tool, and added that it is important that the output is capable of producing distributions and space plots rather single curves, although in that case additional guidance will likely be required to ensure the results can be interpreted. The reviewer commented that one thing that did not come across clearly from the presentation is the approach that is being taken to capture all of the engine efficiency aspects, i.e., the identification and prioritization part, and then a schedule of how those will be addressed. The reviewer commented that perhaps this was part of previous reviews, but it seems an important step to understand the context of where things stand with the current progress.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer stated that the PIs have made significant progress on all 5 tasks.

Reviewer 2:

The reviewer indicated that work to date has been successful in showing the relationship to HoV, as well as intake air, to RON ("equivalent RON") at least for carbureted engines. The reviewer commented that it also has a well-determined relationship of laminar flame speed (LFS) to lean and EGR tolerance. The reviewer added that future research will be facilitated by the development of a "virtual CFR Engine" to predict RON and S, which also provides potentially valuable kinetic information for the Merit Function and Co-Optimizer directly. The reviewer praised the slides and presentation for being very clear.

Reviewer 3:

The reviewer stated that the project's technical accomplishments continue to move the effort toward meeting the DOE goals of petroleum displacement. The reviewer added that accomplishments include validation studies at RON/motor octane number (MON) conditions to show that the CFD setup can capture fuel sensitivity to knock propensity, and a co-optimizer tool for mathematical analysis of fuel cost and engine efficiency has been developed for stakeholder use.

Reviewer 4:

The reviewer stated that everything is completed or on track for completion.

Reviewer 5:
The reviewer commented that all the accomplishments contribute towards understanding the tradeoffs in selecting fuel blends that have high Merit Function scores.

Reviewer 6:
The reviewer commented that the work shows excellent capability of making progress against identifying the parameters of the Merit Function and the development of the Co-Optimizer tool. The reviewer questioned whether a comprehensive set of parameters has been addressed to generate charts like that on Slide 19, and indicated that it is not entirely clear if there is a master list that is being considered as data are available, or if the most critical parameters are being addressed and then other effects will be considered later. The reviewer added that the modeling capability with the virtual CFR engine results was impressive, and the capability of prediction shown on Slide 14 seems very powerful, even beyond the scope of this project. The reviewer stated that only one project milestone is highlighted, and it is very broad, so it is difficult to get a good sense of the planned goals. Overall, the reviewer noted excellent progress, but indicated that it is not clear how the scope is being managed to ensure the Co-Optimizer tool captures the correct trends.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that there is evidence of excellent collaboration between a wide group of partners, and it seems that there is good cross-functional input into the project. The reviewer added that working within the scope of the Co-Optima project, having an advisory board reviewing the direction and gathering industry input are important aspects of this work.

Reviewer 2:
The reviewer stated that the project has excellent collaboration and coordination with nine national laboratories, as well as with Ford and Marathon Oil; the project also is working well with universities and an external advisory board.

Reviewer 3:
The reviewer stated that good collaboration exists among the national laboratories.

Reviewer 4:
The reviewer suggested that the authors consider expanding collaborations to work with other appropriate researchers, but added that budget cuts may make this difficult.

Reviewer 5:
The reviewer observed that, while utilizing a limited number of collaborators, the work to date had obviously done successfully, although most of it has been performed by a single laboratory (ANL) working with a major oil company participant. The reviewer added that NREL is shown as a key collaborator, but mainly for integrating the results of this work into the Co-Optimizer; similarly, reference is made to team of nine laboratories and monthly stakeholder meetings, but that apparently refers to the overall Co-Optima project, not to this task.

Reviewer 6:
The reviewer noted excellent collaboration within DOE laboratories, but hopes this project can create better collaboration with the oil and auto industries.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer commented that it appears that the planned work will continue to provide valuable information about the impact of various fuel properties on SI combustion performance. The reviewer added that the goal of reducing uncertainty in the Co-Optimizer output is important, as is being able to guide the user in how to interpret the output based upon the known uncertainties.

Reviewer 2:
The reviewer stated that the proposed future work is a logical extension of the results achieved to date: applying relationships identified to top Co-Optima fuel blend/BOB compositions; further verification of the virtual CFR engine; and integrating results into the Co-Optima Merit Function.

Reviewer 3:
The reviewer stated that, assuming the funding levels are appropriated, the future research will continue to provide much needed information to address the barriers identified in the project.

Reviewer 4:
According to this reviewer, overall, the future research was very well planned, although one area that can be improved is how to better integrate the results from the five tasks to refine the Merit Function.

Reviewer 5:
The reviewer recommended that the top candidate fuels be tested as soon as possible in a typical downsized boosted gasoline engine.

Reviewer 6:
Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer expressed the view that the Co-Optimizer tool is a good way to show that the combination of fuel properties and their capability to optimize engine performance is an important aspect to improving engine efficiency. The reviewer commented that this system approach has a high probability of identifying a means to improve engine efficiency.

Reviewer 2:
The reviewer stated that, by conducting engine, fuels and combustion experiments, this project provides information as to how fuel blends can help increase engine efficiency, which will definitely support the overall DOE objective of petroleum displacement.

Reviewer 3:
The reviewer commented that this task provides key information for the overall Co-Optima project, which could result in major improvements in engine efficiency, with attendant increases in fuel economy.

Reviewer 4:
The reviewer responded yes, this project supports the overall DOE objectives of petroleum displacement, and added that engine fuels and combustion experiments and simulations are necessary to improve understanding of how fuel blend characteristics can unlock increased engine efficiency.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer expressed the view that, with the project about 60% complete, it appears that resources are sufficient to complete the project as planned.

Reviewer 2:
The reviewer stated that the PIs have sufficient resources to achieve the stated milestones in a timely fashion; for example, the RCF engine has been well modified and instrumented for this project.

Reviewer 3:
The reviewer commented that the work proposed here has a very large potential scope and needs to be refined based upon the available resources. The reviewer added that there are sufficient resources to make a strong advancement of the understanding of fuel properties and develop the Co-Optimizer tool.

Reviewer 4:
The reviewer stated that, as with all DOE projects, the concern is what will happen when expected budget cuts take place, how will cuts affect this project and will it be able to continue moving forward effectively?

Presentation Number: ft055
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Multimode Lean Spark Ignition: Experiments and Simulation
Principal Investigator: Magnus Sjoberg (Sandia National Laboratories)

Presenter
Magnus Sjoberg, Sandia National Laboratories

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer expressed the view that the approach taken, of running both metal and optical engine experiments with CFD modeling, is very good.

Reviewer 2:
The reviewer said that the testing hypothesis is well thought out and critical for future work.

Reviewer 3:
The reviewer commented that the approach adopted in this project not only supports refinement of the Merit Function for LD SI engines, but is also supporting development of diagnostic techniques that can help evaluate and troubleshoot engine operation for mixed-mode combustion regimes. The reviewer stated that it is encouraging to see that the Tier 3 fuels that were primarily intended for direct injection SI engines are also being tested as part of this project, thereby providing a link between the near and long-term efforts. The reviewer added that reviewer feedback from the 2016 DOE AMR was appropriately addressed and used to adjust the technical approach, with the goal of making the project more relevant for production applications. The reviewer indicated that, while the evaluation of particulate emissions is extremely valuable for current and near future production engines, it is not clear if the observed PM emissions were a consequence of the differences in the fuel properties or in the operating procedure. The reviewer suggested that isolating the fuel properties from operating strategy (e.g. fuel injection timing) may provide further insight into engine out PM emissions and how they relate to fuel composition.

Reviewer 4:
The reviewer noted that the researchers combine modeling, metal engine and optical engine experiments to develop a broad understanding of combustion changes due to fuel properties in direct injected spark ignited engines. The tests compared E30, high aromatics, high alkylate, high olefin and high cycloalkane fuels.

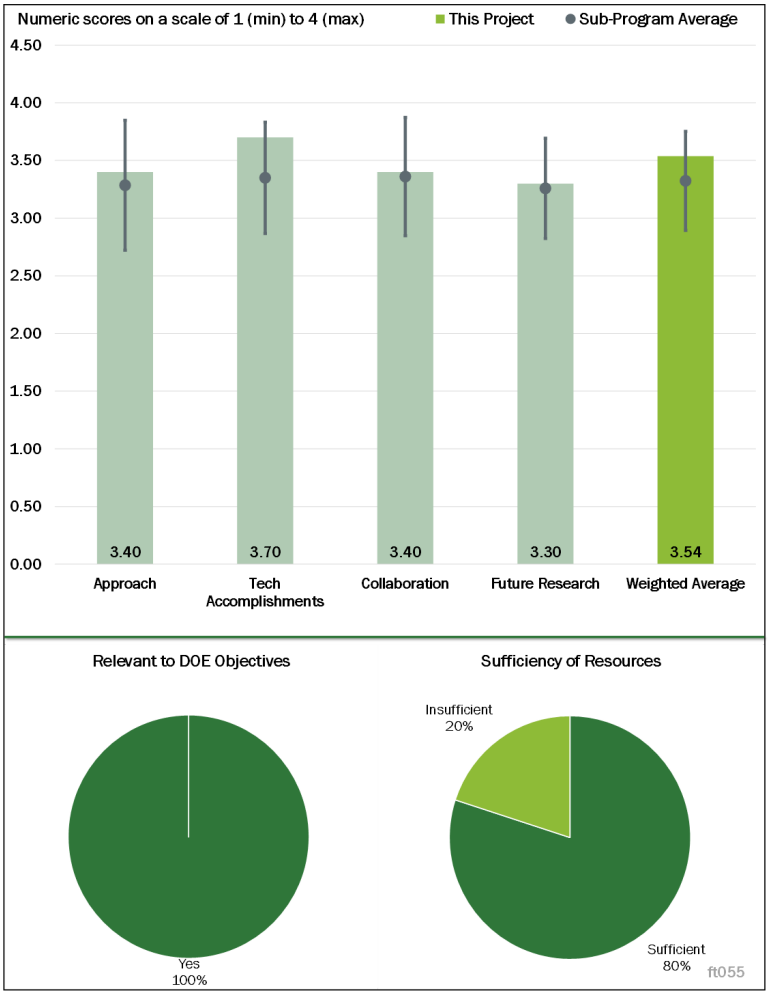

Figure 5-13 – Presentation Number: ft055 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Multimode Lean Spark Ignition: Experiments and Simulation Principal Investigator: Magnus Sjoberg (Sandia National Laboratories)

Reviewer 5:
The reviewer noted that the focus is on boosted advanced spark ignited gasoline combustion, like homogeneous and stratified charge lean combustion, and added that complementing the metal engine tests with optical engine tests and with CFD support at ANL is a good approach.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer remarked excellent progress, and that the PI is doing an excellent job as usual.

Reviewer 2:
The reviewer observed good progress, as demonstrated by completion of measurement of knock limits for five fuels; evaluation of applicability of PM index; and the discovery that pool fires cause E30 blends to have higher PM emissions than PM index predicts. The reviewer commented that this latter discovery has important potential implications for use of gasoline containing higher levels of ethanol than E10.

Reviewer 3:
The reviewer commented that this project has made excellent progress over the past year. In this reviewer's opinion, some of the notable accomplishments of the project include experimental data, in conjunction with CFD results used to refine the Merit Function; development of semi-quantitative wall-wetting diagnostic technique; evaluation of the impact of fuel composition on particulate emissions; and the use of Global Sensitivity Analysis to identify the most influential fuel properties. The reviewer added that the aforementioned accomplishments are in line with the overall goals of the Co-Optima program and have augmented the existing body of knowledge, particularly with respect to LD SI engines.

Reviewer 4:
The reviewer stated that the knock limits of the five fuel types have been related RON and MON at stoichiometry for both steady state and transient conditions. The reviewer added that demonstrating the role of low-temperature heat release for poor performance associated with low sensitivity fuels and determining some of the pitfalls of PMI are significant accomplishments, not to mention the myriad of other accomplishments like examining the wall wetting using E30 and its causes.

Reviewer 5:
The reviewer complimented the PI and team on the amount of relevant progress made this past year, saying that the results on S and knock are very pertinent. The reviewer added that the study on PMI versus soot for both well mixed and stratified designs at two operating conditions is interesting, and the wall wetting aspects of E30 and effect on soot are very pertinent. The reviewer commented on the good progress made on Mixed-mode combustion and transition.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented on the excellent collaboration between participating national laboratories, as well as industry partners. The reviewer added that it is worth noting that coordinating the activities across multiple teams and researchers requires a lot organization and the effort is worth applauding.

Reviewer 2:
The reviewer stated that the national laboratories are collaborating extremely well.

Reviewer 3:
The reviewer noted some collaboration mentioned with industry (GM, Toyota) and some of the other national laboratories (Lawrence Livermore National Laboratory [LLNL] and ANL).

Reviewer 4:
The reviewer complimented the team on good collaboration with the CFD at ANL and links to other ignition work at ANL and SNL.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer commented that the project has made good progress thus far, and continuation of several of the ongoing efforts is encouraged. The reviewer added that, in particular, continued development and use of optical diagnostic techniques in conjunction with CFD modeling is encouraged, as these activities can help develop a fundamental understanding of the underlying physics associated with advanced combustion modes. The reviewer cautioned that, while the scope of work is limited to low TRLs, practical considerations such as aftertreatment requirements and transient controls should be kept in mind while analyzing results and assessing the feasibility of the combustion concepts being proposed.

Reviewer 2:
The reviewer stated that the work plans seem reasonable.

Reviewer 3:
The reviewer stated that the proposed future research makes sense, as it is to finish up and further investigate the work they are doing.

Reviewer 4:
The reviewer suggested that perhaps updating the injectors and playing with injection pressure and timing would show how pool fires can be controlled. The reviewer acknowledged that this adds complexity but it might be interesting for future work.

Reviewer 5:
The reviewer stated that the interaction between an advanced SI engine (e.g., lean strat or multi-mode) and fuel type (say E30) and engine calibration variables like single and double pulsing is complex, and questioned how a Merit Function will be developed for such a situation. The reviewer also asked what would happen if the Merit Functions of an SI boosted engine and an advanced combustion engine predict the need for very different fuels.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that this is exceptional work that couples engine efficiency with emissions, and added that you cannot sell engines that do not meet emissions requirements.

Reviewer 2:
The reviewer stated that the information generated from this program should lead to the development of higher efficiency engines with better fuel economy.

Reviewer 3:
The reviewer commented that the investigations being undertaken as part of this project are in line with the overall DOE goal of petroleum displacement.

Reviewer 4:
The reviewer said that the project should save petroleum in new vehicles due to efficiency improvements if successful.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that the very good progress in meeting milestones suggests that resources have been sufficient.

Reviewer 2:
The reviewer cautioned that the resources allocated to this project may not be sufficient for competing the proposed future work.

Presentation Number: ft056
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Exploratory Advanced Compression Ignition Combustion Tasks
Principal Investigator: John Dec (Sandia National Laboratories)

Presenter
John Dec, Sandia National Laboratories

Reviewer Sample Size
A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

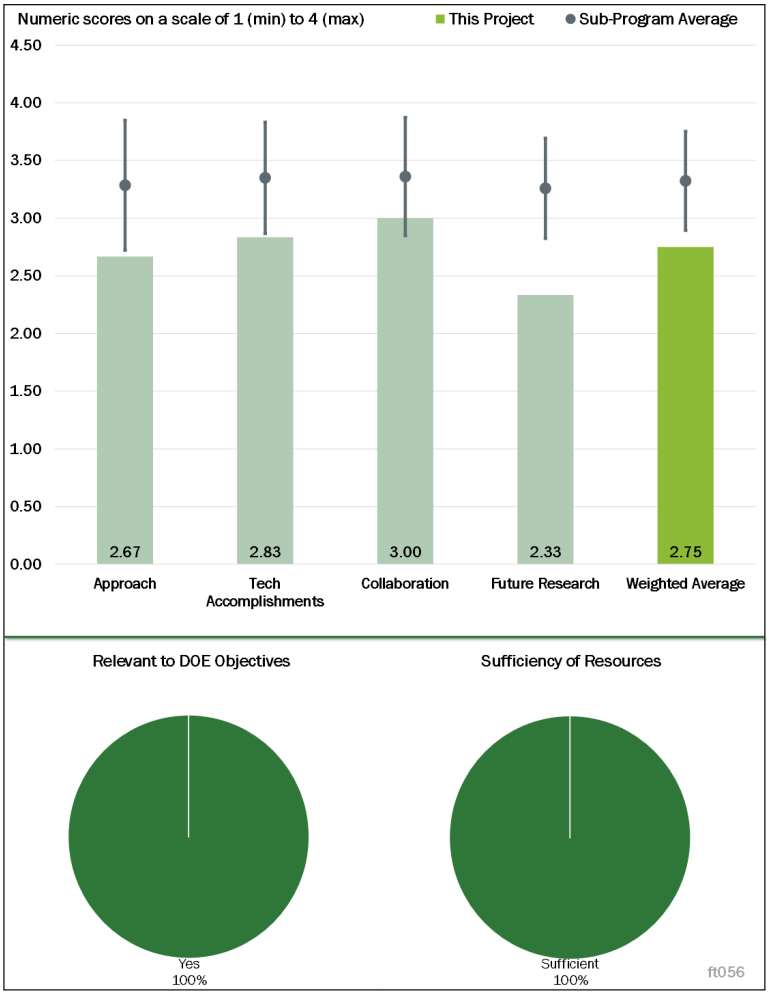

Figure 5-14 - Presentation Number: ft056 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Exploratory Advanced Compression Ignition Combustion Tasks Principal Investigator: John Dec (Sandia National Laboratories)

Reviewer 1:
The reviewer stated that generating data to support the fuel figure of merit is good, and investigating Thrust I SI boosted fuels in ACI engines and processes is good; however, the objectives of many of the ACI studies are too vague, and imply continuing to research a wide range of ACI recipes without a clear end point. The reviewer commented that Optima needs a finite timeframe for delivering data and answers to questions, and added that most of the ACI recipes have a long history already. In this reviewer's opinion, the sub-projects need to have more explicit outcomes and titles regarding questions being answered about fuels and combustion recipes. The reviewer added that the ducted combustion concept is interesting, but does not seem to fit well in the Co-Optima structure; it is more device development, rather than providing data for decision making and policy considerations. The reviewer recommended perhaps continuing it as a separate project.

Reviewer 2:
The reviewer appreciates the authors testing boosted-SI fuels in ACI combustion concepts, as requested in past reviews, and other responses to previous reviewer feedback. The reviewer stated that barriers should include higher fidelity, and the authors should more accurately describe the barriers to low temperature combustion concepts. The reviewer offered the following as examples of barriers: a lack of adequate CA50 control; challenges in transient control; challenges in switching between combustion modes; high combustion noise; high HC and CO emissions; the need for a lean-NO_x exhaust aftertreatment system; challenges in cold operation; limited speed and load range; and low exhaust temperature. The reviewer questioned whether, given this daunting list of challenges, the fuel is really being looked upon to solve all these issues. The reviewer opined that high engine fuel efficiency is the least of the worries; it has been shown numerous times over the past 15 years that the efficiency is very high.

Reviewer 3:
The reviewer stated that the presentation and slides are extremely confusing and difficult to follow. The reviewer commented that the presentation is apparently intended as an overview of various ongoing advanced compression ignition projects, but rather than giving a real overview, explaining the overall thrust of the research and how the different projects relate to each other, it seems to simply pick out what the presenter believes are the most salient features of each of the projects, and presents them outside of the context of other explanations. The result, according to this reviewer, is that both what is shown in most of the slides, as well as the significance of each, is extremely difficult to discern; compounding the problem is that the slides introduce many unfamiliar acronyms without defining or explaining them. The reviewer added that the relationship of the work to the Co-Optima program is especially unclear; further, the response to reviewers' comments slide explains away similar comments from last year, but the author apparently has made no attempt to avoid such problems in this year's slides.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer stated that technical accomplishments cannot be readily discerned from the presentation due to the problems discussed in response to the previous question. The reviewer added that a great deal of data are summarized in graphs and a few conclusions are stated, e.g., RON and MON–S are insufficient to determine reactivity, but what they mean in terms of actual progress is not clear. The reviewer noted that the presenter stated that there might have to be up to five separate Merit Functions rather than a single one, which appears to negate the concept of the Co-Optima program.

Reviewer 2:
The reviewer stated that Co-Optima is relatively new and the data generated are impressive, publications etc.

Reviewer 3:
The reviewer stated that OI and potassium correlations are probably dependent on the engine combustion recipe, and questioned whether we are expecting to develop correlations for each of the known low temperature combustion recipes. The reviewer also asked, by the same token, if we will have a Merit Function for each of the different engine recipes. The reviewer commented that it seems like we need to downselect the low temperature combustion recipe, but questioned who gets to choose the winner.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that collaboration among the national laboratories is very good.

Reviewer 2:
The reviewer commented that various slides do reflect apparent collaboration and interaction between the various labs, in which results obtained by one suggest additional research by another one, but the actual significance is not clear, so that there is little basis for evaluating the quality and relevance of such collaboration.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer questioned whether OEM input has been sought for future ACI work, and whether light-duty OEMs really think reactivity-controlled compression ignition (RCCI) is commercially viable. The reviewer commented that a lot of emphasis is being placed on Low Temperature Gasoline Combustion-Advanced Compression Ignition (LTGC-ACI) and asked whether Light-duty OEMs have given encouragement for this type of work. The reviewer also asked about part-load homogeneous charge compression ignition (HCCI) in a downsized boosted engine that otherwise employs flame propagation combustion.

Reviewer 2:
The reviewer commented that the future research shown in Slide 19 consists of 4 bullets, each of which appears useful, though vaguely stated and without clear explanations as to how such work would proceed from the work referenced in the presentation for 2016, apart from the testing DFI in the optical engine which needs no real explanation.

Reviewer 3:
The reviewer stated that the future research objectives and subjects are mostly too vague and open-ended.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that, overall, Co-Optima can identify more efficient sets (plural) of fuels and engines.

Reviewer 2:
The reviewer commented that the project is intended to research modes of more efficient engine combustion, which would result in higher fuel economy, though much of the presentation is unclear as to how the results presented do this.

Reviewer 3:
The reviewer indicated that the project is relevant, but the emphasis is probably misplaced, per comments in other sections of this review.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer was not sure there is justification for the conspicuously higher investment in ducted combustion within the Co-Optima portfolio, and added that this is not saying anything about the ultimate merit of the idea, but more that Co-Optima is not the best fit for a Cooperative Research and Development Agreement on a specific technology development.

Presentation Number: ft057
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Emissions, Emission Control, and Sprays
Principal Investigator: Todd Toops (Oak Ridge National Laboratory)

Presenter
Todd Toops, Oak Ridge National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer remarked that this is a great project that is needed.

Reviewer 2:
The reviewer commented that there are five projects contained within the "umbrella" of this "Co-Optima Emissions, Emission Control, and Sprays" program, and each has its own merits and debits. The reviewer stated that evaluating the impact of candidate fuel components on injector sprays, emissions, and emissions control is very important to better assess the technical viability of the various candidates. The reviewer commented that it is unclear what the technical basis is for assuming that engine efficiency in the Merit Function is reduced by 0.7% if fuel PMI is less than 1.6, and added that it seems like that would be very dependent on the specific design of the engine and the engine operating conditions. The reviewer pointed out that one emissions aspect that appears to be missing is assessing the formation of toxics such as formaldehyde and acetaldehyde with the component candidates, which are predominantly oxygenates. The reviewer suggested that a robust evaluation of the candidates should include this aspect.

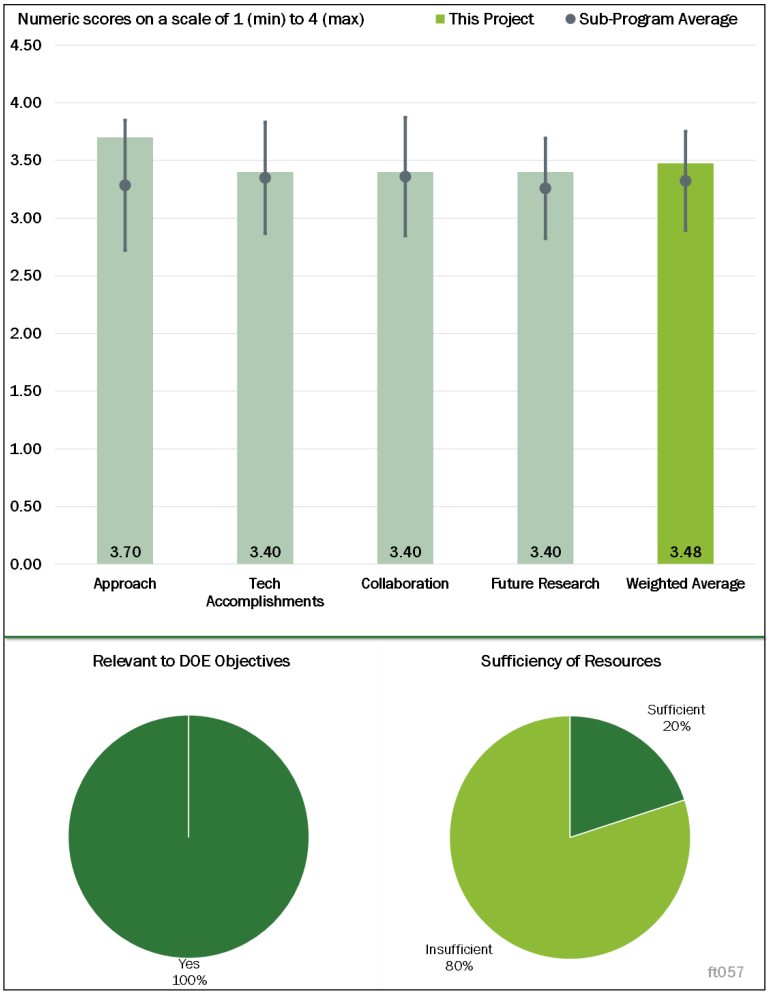

Figure 5-15 - Presentation Number: ft057 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)—Emissions, Emission Control, and Sprays Principal Investigator: Todd Toops (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer stated that engines with improved efficiency cannot be introduced in the market unless they meet stringent emissions criteria, and added that, in view of the importance of emissions criteria, the research being conducted as part of the current project is extremely relevant. The reviewer commented that the investigations being undertaken under this project address some of the most critical aspects of engine development, including fuel spray characterization, emissions, and aftertreatment. The reviewer concluded that the fundamental knowledge being generated here is pertinent to both near and long-term engine technologies.

Reviewer 4:
The reviewer stated that fuel sprays have a major effect on emissions, and found it encouraging that DoE has not forgotten that, and has allocated some of its most sophisticated spray measurement equipment to this task.

Reviewer 5:
The reviewer stated that Co-Optima is proposing eight fuel candidates for SI-intended blendstocks, many of them with oxygenates. The reviewer commented that fuel effects on exhaust aftertreatment performance (both catalysts and particulate filters) are an important part of the Co-Optima project aimed at future downsized boosted SI gasoline engines, especially as the PMI is expected not to correlate for oxygenated fuels. The reviewer added that fuel effects on fuel spray atomization, entrainment, vaporization and penetration characteristics need to be understood.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer said that a lack of funding is holding back some progress but the team is doing very well given the circumstances.

Reviewer 2:
The reviewer observed very good progress in several areas, and commented that the higher than expected PM values relative to PMI values, for fuels containing oxygenates, is very interesting, and suggests that higher levels of ethanol and/or alternative oxygenates may be detrimental. The reviewer stated that this calls into question the validity of the existing PMI term in the Merit Function. The reviewer also noted that the results of catalytic light-off temperatures for pure components are interesting, but we will need to see how that correlates to light-off behavior in blends. The reviewer observed that in some areas, such as the high throughput spray chamber, progress consists of equipment procurement and setup, and that some work apparently was delayed or postponed, such as X-ray studies of baseline fuel under flash boiling and non-flashing conditions in the new high-pressure fuel system.

Reviewer 3:
The reviewer stated that the findings of this project are applicable to current, near future, and long-term engine combustion concepts. The reviewer noted that some of the notable accomplishments include enhancement of optical measurement techniques for characterizing fuel sprays (SNL and ANL), an improved understanding of particulate emissions from oxygenated fuels, cold start performance of oxygenated fuels, and the impact of fuel composition on emissions control and durability.

Reviewer 4:
The reviewer noted that there is a significant amount of information generated from the accomplishments in this study. The reviewer commented that the accomplishments are excellent, however, in the reviewer's opinion, the researchers need more time to analyze and evaluate the data that have been generated.

Reviewer 5:
The reviewer stated that a good amount of work on understanding PM emissions during cold start, silver (Ag) selective catalytic reduction (SCR) catalysts, and catalyst light-off behavior has been accomplished. The reviewer commented that a Merit Function for emissions control or performance is a great idea and should be developed further.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer remarked on the excellent collaboration between the various project partners, and noted that significant effort has been made to coordinate the various activities addressing fuel sprays and emissions, with the objective of ensuring that they complement each other.

Reviewer 2:
The reviewer was impressed with how well coordinated the work between the national laboratories has been.

Reviewer 3:
The reviewer commented that collaboration among laboratories is getting more seamless, but the project needs more involvement from aftertreatment suppliers.

Reviewer 4:
The reviewer observed that while there may be good collaborations between the various national laboratories doing the work in this area, collaboration with industry appears to be very limited, or light. The reviewer noted that collaborations with the External Advisory Board are listed, but those are very infrequent (only a couple of times a year) and tend to be high level. The reviewer commented that the authors also mentioned stakeholder engagements, which presumably include the monthly teleconferences, but topics are discussed on a rotating basis (so not very often for any given area) and tend to be a summary of some results, not a timely in-depth review and discussion of results and near-term plans.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer stated that continuation of the ongoing investigations is vital to the success of both current and future combustion concepts; in particular, improving the fundamental understanding of fuel sprays and particulate emissions is critical for improving engine efficiency, while meeting the stringent emissions requirements.

Reviewer 2:
The reviewer noted that the proposed future research is to continue and finish the outstanding research that has been performed.

Reviewer 3:
The reviewer commented that additional work on low-temperature catalysts is critical for future low-temperature combustion engines and should be expanded.

Reviewer 4:
The reviewer stated that the list of future work (Slides 17 and 22) on PM response to cold start conditions is extremely important, and commented that the Ag-Cu SCR NO_x-catalyst work is very interesting and should be pursued.

Reviewer 5:
The reviewer stated that the future work seems reasonable; however, as mentioned earlier, the authors need to consider the effects of the candidate components on toxics emissions.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that reducing emissions is consistent with DOE goals.

Reviewer 2:
The reviewer commented that the investigations being undertaken as part of this project are crucial for the accomplishment of DOE's overall goal of petroleum displacement.

Reviewer 3:
The reviewer noted that the overall goal of this research is to displace petroleum with biomass based fuels.

Reviewer 4:
The reviewer commented that this project, especially the emphasis on fuel effects on exhaust aftertreatment, is extremely relevant. The reviewer noted that it is assumed that high-octane, high sensitivity fuels (fuel properties, not molecules) will yield high efficiency in SI, downsized, boosted gasoline engines, but what are unknown are the fuel effects on aftertreatment performance, because they are molecule dependent. The reviewer added that it would be a shame to let this project end due to budget restrictions.

Reviewer 5:
The reviewer said that emissions are the biggest threat to improved internal combustion (IC) engines, and that more work should be done on emissions.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer noted that several tasks and milestones, such as catalytic light-off behavior, apparently were delayed, but stated that presumably this was due to insufficient resources, rather than poor project planning. The reviewer added that this will likely become more of an issue if DOE program budgets are reduced for FY 2018.

Reviewer 2:
The reviewer stated that the resources allocated to this project for 2017-2018 are insufficient, and it would be unreasonable to expect timely completion of the proposed work with the funding allotted to this project.

Reviewer 3:
The reviewer suggested that the project scope be expanded to include more exhaust aftertreatment issues, like catalyst efficiencies, and to speed up the pace of work.

Reviewer 4:
The reviewer said that additional work on fundamental combustion is great and useful, but the engines will be illegal without proper emissions controls. This area may be getting shorted on funding because both the advanced combustion engine and fuels groups own it (and disown it as well). The reviewer said please increase the funding or at least do not cut it much if the Trump budget becomes anything close to reality.

Presentation Number: ft058
Presentation Title: High-Efficiency Cost-Effective Natural Gas Engine
Principal Investigator: Alexander Freitag (Bosch)

Presenter
Steve White, Bosch

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that efficiency is to be achieved by high EGR dilution/lean CDI combustion enabled by ammonia (NH_3) generation in catalyst aftertreatment feeding passive SCR. The reviewer stated that hardware was selected from existing systems from diesel engines and installed, and engine combustion modes are being tested.

Reviewer 2:
The reviewer stated that the program is justified based on achieving a 20% increase in efficiency from a stoichiometric natural gas engine by extending lean limit with a high-energy ignition system and with lean / rich cycling of aftertreatment to utilize passive ammonia SCR NO_x reduction. The reviewer commented that the intent of using proven hardware where possible strengthens the project, while not allowing any changes to the base engine weakens it. The reviewer remarked that the base engine is a non-U.S. certified industrial engine and may not be suitable for extreme lean burn operation. It is not apparent to this reviewer that cost savings will be achieved over an active SCR system because two catalysts and a very complex control system will be required. The reviewer added that it is not apparent that fuel savings will be achieved, because rich cycling is needed to generate ammonia for passive SCR, and it is not apparent that technology will function over a wide range of transient operation, duty cycles, and ambient conditions.

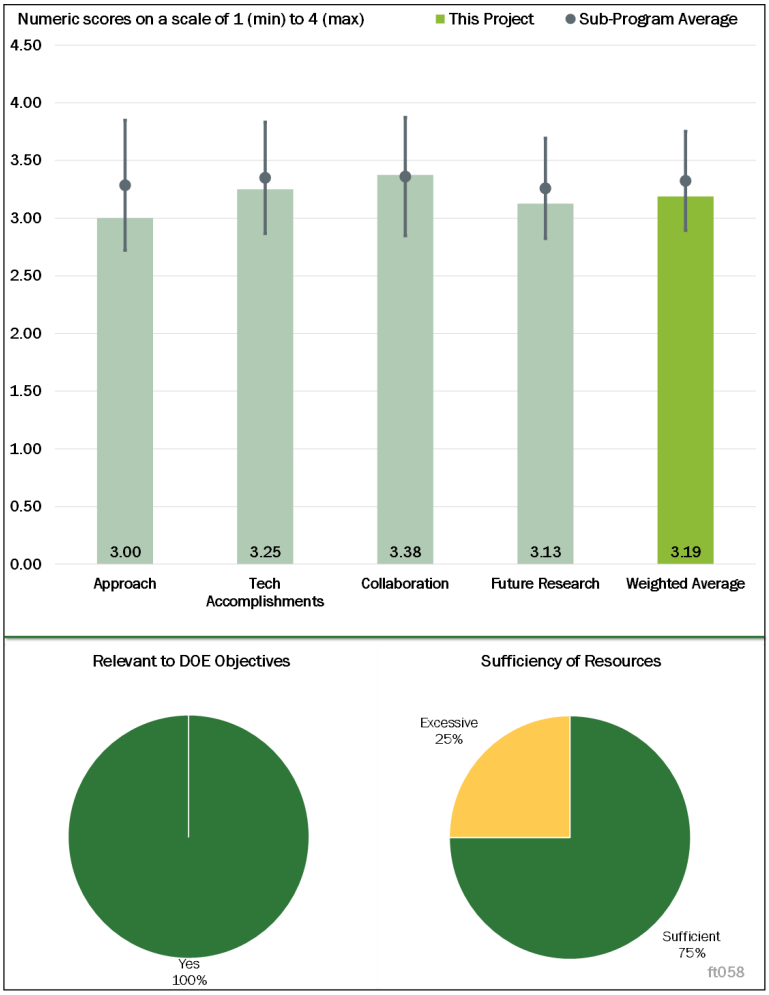

Figure 5-16 - Presentation Number: ft058 Presentation Title: High-Efficiency Cost-Effective Natural Gas Engine Principal Investigator: Alexander Freitag (Bosch)

Reviewer 3:
The reviewer expressed surprise that the project had been funded, as there is a lot of research and work available that has already been done through universities. The reviewer did not see how this project was new and unique and would require DOE funds to be used, and added that it would help if the researchers could further explain how this research work is providing something of R&D value to the area of NG engines. The reviewer commented that it is not clear that the project will meet the goals, and the items that are "out of scope" may need to be used to meet the efficiency targets.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer stated that good progress has been achieved in both hardware configuration and in identifying operating mode for maximum lean operation with adequate rich operation to provide NH_3 to SCR. The reviewer noted that 39% brake specific fuel consumption has been achieved to date, out of a target of 42% (versus base engine of less than 37%).

Reviewer 2:
The reviewer commented that the authors have made good progress in evaluating ignition system improvements, and in EGR and aftertreatment development, and added that they have achieved some efficiency improvements in base engine efficiency, but have not met their goals yet and have not done cycle simulation to determine losses from rich cycling.

Reviewer 3:
The reviewer stated that it looks like this project may not meet the efficiency targets, given the current progress. The reviewer noted that there is a plan to try to work towards the goals, but added that there is uncertainty in meeting the targets, and it seems like there is further process that needs to be made to complete the project, and a little over a year to do this in.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer remarked that Slide 16 shows substantial and appropriate division of research between 3 project partners and 2 suppliers/support organizations.

Reviewer 2:
The reviewer noted that the program included involvement of an OEM engine company and a tier 1 supplier for ignition systems, and that a national laboratory is contributing the aftertreatment technology.

Reviewer 3:
The reviewer commented that there is a good list of collaborators and good coordination with the project.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer stated that the proposed future research is a logical progression of the work to date, so as to bring about successful conclusion of the project.

Reviewer 2:
The reviewer found that there is a good plan for future work to complete this project, but questioned whether the authors are optimizing the aftertreatment size of the three-way catalyst (TWC) and SCR for the project to run lean more often, which will enable the efficiency targets. The reviewer expressed the hope that the authors provide information on the cost of this system to enable the efficiency, and the cost trade-offs.

Reviewer 3:
The reviewer commented that it is not specifically stated, but researchers need to compare this engine concept to an engine running stoichiometric with a three-way catalyst, and to an engine concept of continuously lean

operation with urea SCR NO_x control. The reviewer noted that only then will gains and tradeoffs be clearly demonstrated. The reviewer added that it also appears that the engine and aftertreatment control strategy will be very complex, and it is not clear how far this development will be carried.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that the program is relevant because it promotes the use of natural gas as a fuel and because it seeks to improve engine efficiency while maintaining emissions at the required level. The reviewer added that the project is relevant because it seeks to study a "high risk" advanced concept of engine and emissions control.

Reviewer 2:
The reviewer responded yes, this project is relevant to meeting the DOE objectives of petroleum displacement. The reviewer wondered, however, about the use of natural gas in the United States, and why we would want to work on this project, as there is limited infrastructure to supply natural gas (NG) for vehicles. The reviewer was not sure why this project would be funded, and added that it seems like this kind of research work has been completed before, so it is unclear what is new and unique with this.

Reviewer 3:
The reviewer stated that by enhancing the efficiency of NG engines, this project has the potential to increase their cost-effectiveness and overall deployment as substitutes for petroleum-burning engines. The reviewer added that greater efficiency and reduced use of natural gas is an additional benefit, in terms of overall energy security and greenhouse gas reduction.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that the resources seem adequate to complete the project as planned, providing current funding levels are maintained.

Reviewer 2:
The reviewer expressed the opinion that the resources for the project are excessive, and added that based on projects with which the reviewer has been involved in the past, this could be accomplished for much less. The reviewer added that, given that the base engine hardware was being used for the project and there was no combustion system development, it was a struggle to figure out what the costs of the project are. The reviewer recommended that, if there is some control system development to run the engine and the project, it would be good to highlight that and the developed capability to run the system.

Presentation Number: ft059
Presentation Title: High BMEP and High Efficiency Micro-Pilot Ignition Natural Gas Engine
Principal Investigator: Jeffrey Naber (Michigan Technological Institute)

Presenter
Jeffrey Naber, Michigan Technological University

Reviewer Sample Size
A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

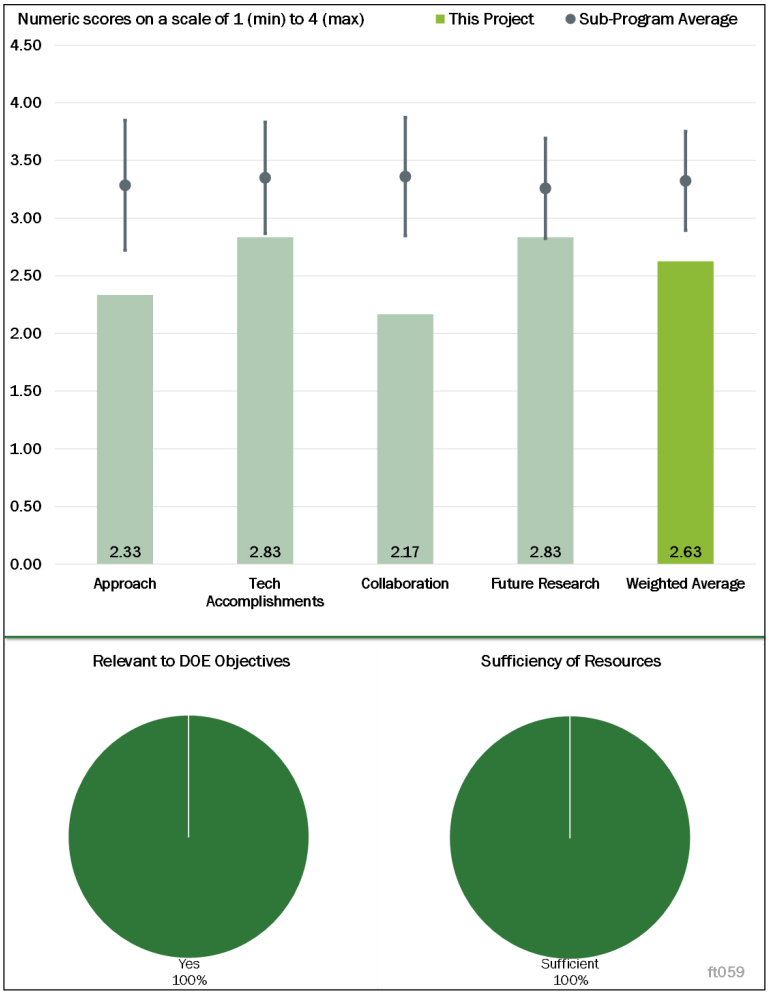

Figure 5-17 – Presentation Number: ft059 Presentation Title: High BMEP and High Efficiency Micro-Pilot Ignition Natural Gas Engine Principal Investigator: Jeffrey Naber (Michigan Technological Institute)

Reviewer 1:
The reviewer commented that this seems like a very detailed study looking at aspects of the project- mixing of the fuels with a micro pilot. The reviewer does not believe that this is new research, and is aware of some that has been previously published. The reviewer recommended checking Penn State work with Andre Boehman, and expressed the hope that this is in the literature review. The reviewer further recommended checking Southwest Research Institute (SwRI) research work. The reviewer suggested looking at the impact of the Cetane number of the fuel on the pilot ignition, by spanning the Cetane number from 40 to 80 with different kinds of fuels. The reviewer also suggested looking at the fuel distillation curve of the pilot injection, and stated that this would be an interesting aspect of the research and would make it more relevant and new. The reviewer also stated that the data for the fuel, shown on Slide 4, should be based on an energy basis of the quantity of the fuel injected; this would make it easier to understand the efficiency improvement and brake mean effective pressure (BMEP) change based on the energy density of the fuel. The reviewer commented that it appears that the authors are just getting started on the engine testing. The reviewer is looking forward to seeing the results of the improved fuel efficiency.

Reviewer 2:
The reviewer commented that, with its high-pressure direct injection (HPDI) 2.0 injector, Westport already has dual fuel (compressed natural gas [CNG] plus diesel) technology in production, and the presentation did not establish how the current dual fuel approach is different than, and superior to, Westport's HPDI 2.0 injection system. The reviewer stated that modern diesel engines are already capable of achieving and exceeding 44% brake thermal efficiency (BTE); thus, it is not clear how the 44% BTE target mentioned in the presentation addresses DOE's goal of reducing fuel consumption. The reviewer noted that stoichiometric fueling is

presented as a positive, as it enables use of a three-way catalyst for exhaust aftertreatment; however, the presentation also mentions ultra-lean operation at low load conditions, and it is not clear how the aftertreatment for ultra-lean conditions will be accomplished without the use of lean aftertreatment systems. The reviewer also noted that use of CNG as the primary fuel has been presented as a benefit, as it provides a lower carbon dioxide (CO_2) and lower cost solution than diesel; however, the use of CNG also implies additional hardware cost due to the need for a second fuel injection system and fuel storage capability. The reviewer stated that it would be beneficial to present a cost-of-operation benefit that also considers the cost of the additional hardware. The reviewer also stated that switching from diesel to CNG should perhaps yield an improvement in CO_2 emissions greater than 10-15%, as mentioned in the presentation.

Reviewer 3:
The reviewer's impression, based on the information provided by the slides and PI, is that this project set up an objective that is too ambitious. The reviewer stated that the major challenges of the NG-diesel dual fuel engine at different loads are different; at low load, it is high HC and CO emissions and thus the engine needs to use a high amount (percentage) of diesel, whereas at high load, it is the high thermal load, due to the thin flame quenching distance. The reviewer expressed the view that the PI did not propose solutions significantly different from the other studies to address these challenges.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that satisfactory progress has been made and the project is in line with the proposed plan. The reviewer noted that accomplishments over the past year included baseline engine testing, combustion vessel modeling, and spray characterization under different operating conditions.

Reviewer 2:
The reviewer stated that, overall, the PIs made decent progress to study NG-diesel dual fuel combustion.

Reviewer 3:
The reviewer commented that, based on the schedule, it looks like the PIs are just getting started with the engine testing, but the program looks like it is almost halfway complete. The reviewer expressed the hope that the PIs can get the data they need to show the improvement by the end of the program, given the challenges. The reviewer added that there is a lot of work to do to make this system work, and that getting control in the system, measuring the fuel injection quantity, and determining the metrics of the energy basis will be challenging.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that Westport is the principal partner and has been supporting the project with CFD modeling, engine hardware, and pertinent test data, and suggested that perhaps Westport can provide additional insights and help make comparisons against their HPDI 2.0 fuel injection system.

Reviewer 2:
The reviewer commented that it appears there is only one partner on this project, and it would be helpful in completing the project to have more than one collaborator who might help and assist in making the project successful, unless the current project sponsors are comfortable with continuing with only the shared responsibilities. The reviewer suggested that it would be nice to see if any of the national laboratories could be consultants, or perhaps Charlie Roberts from SwRI.

Reviewer 3:
The reviewer stated that Westport is the only collaborator, and recommended that the PIs also work with other HD engine OEMs such as Volvo truck, who actually commercialized NG-diesel dual fuel engines for medium-duty (MD) trucks.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer stated that the proposed research is in line with the goals of the project.

Reviewer 2:
The reviewer commented that, overall, the proposed future research is fine, but added that it appears the PIs underestimated the barriers.

Reviewer 3:
The reviewer commented that the future work for FY 2017 and FY 2018 looks interesting and challenging, and expressed the hope that this can all be completed in the next 2 years. The reviewer added that there is quite a bit to do to get the system working.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer responded yes, with abundant NG in the U.S., advancing NG engines will support the overall DOE objectives of petroleum displacement.

Reviewer 2:
The reviewer responded that, yes, this supports the overall DOE objectives of petroleum displacement; however, it was unclear to the reviewer what the future of natural gas is in the United States. The reviewer stated that there is not the infrastructure in place for NG refueling; however, the success of this project could provide the impetus for increased NG locations.

Reviewer 3:
The reviewer stated that displacing diesel with CNG as the primary fuel supports DOE's goal of petroleum displacement; however, the presentation has not clearly established how the work being conducted under this project is advancing the state-of-the-art and surpassing the dual fuel technology already in production.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that there are enough resources to perform the tasks proposed by the PI.

Reviewer 2:
The reviewer commented that resources appear to be sufficient for the proposed scope of the project.

Reviewer 3:
The reviewer noted that this project is only 25% completed, so it is unclear if the resources are sufficient. The reviewer added, however, that it seems that there is a plan in place to complete the program within budget.

Presentation Number: ft060
Presentation Title: Single-Fuel Reactivity Controlled Compression Ignition Combustion Enabled by Onboard Fuel Reformation
Principal Investigator: Ben Lawler (Stony Brook University)

Presenter
Ben Lawler, Stony Brook University

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that this project provides research into one possible concept for controlling advanced combustion, and should provide sufficient information to allow evaluation of the concept. The reviewer added that the concept is using on-board reforming so that a single fuel can be "split" into a high reactive and a low reactive fuel for regulation of RCCI; the fuel is "split" by reforming a portion of it using catalytic partial oxidation.

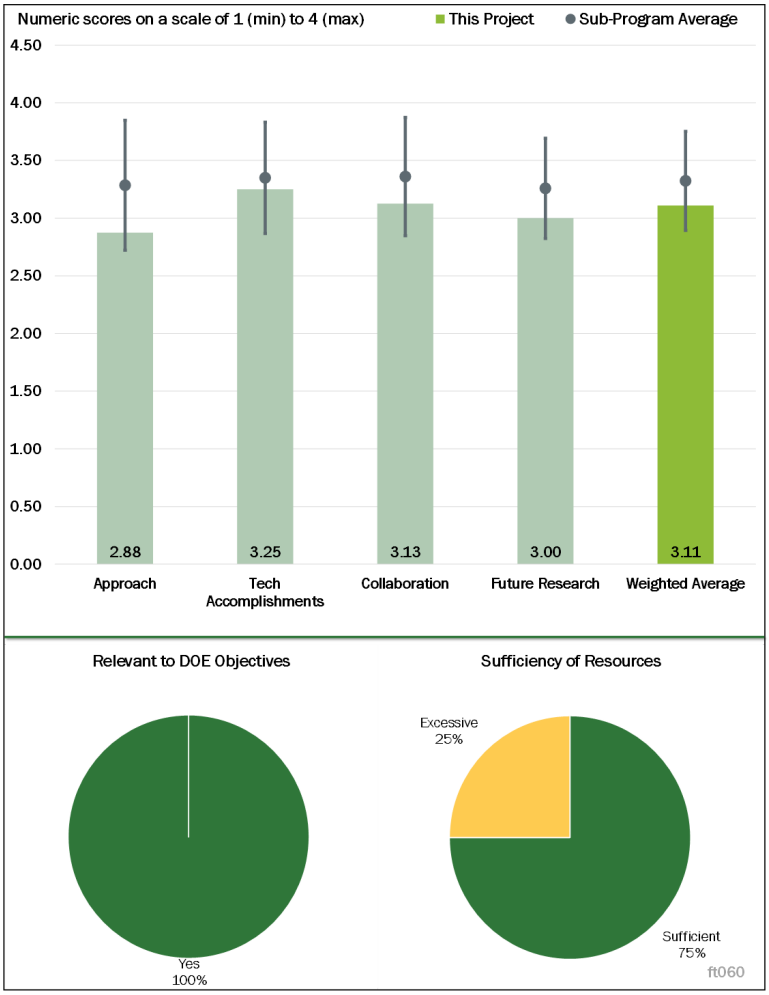

Figure 5-18 – Presentation Number: ft060 Presentation Title: Single-Fuel Reactivity Controlled Compression Ignition Combustion Enabled by Onboard Fuel Reformation Principal Investigator: Ben Lawler (Stony Brook University)

Reviewer 2:
The reviewer commented that the three-step approach outlined is logical, apart from the deferring of the development of the actual on-board reformer, which is outside the scope of the project. The reviewer added that production and characterization of reformate from NG, gasoline and diesel, and subsequent modeling, paves the way for actual testing of a viable parent fuel.

Reviewer 3:
The reviewer commented that, after hearing the presentation, it was unclear what the value of this project was. The reviewer added that there is a lot to be understood on the fuel reforming and the reformer, and this is not a mainstream technology that is being pursued in the industry for application within the next 10 years. The reviewer suggested that what might be better is to understand the types of fuel molecules that provide the reactivity that is needed for a particular flame speed required in the engine for a given condition, or rate of reactivity needed. The reviewer requested clarification on the fuels used in the project, i.e., was it a certification diesel and not a production fuel? The reviewer also inquired about the biodiesel content of the fuel. The reviewer suggested that the PI may need to evaluate better reforming technology, knowing that it will lose energy and becomes an inefficient solution.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that reformate has been produced and characterized, with modeling run on reformate, resulting in down-selection to a single parent fuel (diesel). The reviewer added that the test engine was configured and operational.

Reviewer 2:
The reviewer commented that the researchers have successfully reformed diesel fuel, gasoline, and natural gas with catalytic partial oxidation, and were successful in measuring the reactivity of the reformate as equivalent octane, as measured with a CFR engine. The reviewer stated that this method seems well adapted for this type of measurement, and somewhat novel; unfortunately, the reformate became less reactive than the parent fuel (for gasoline and diesel), resulting in the need for reforming the majority of the RCCI fuel with resulting larger energy loss in the catalytic partial oxidation (CPOX). The reviewer added that, for gasoline and especially for natural gas, the separation of the octanes between the parent fuel and the reformate does not appear to be large enough to allow effective RCCI. The reviewer commented that it appears that enough information has been taken to allow modeling any potential efficiency benefits from RCCI and energy losses from the CPOX process.

Reviewer 3:
The reviewer stated that this project is 50% complete, but seems to still have some technical challenges. The reviewer added that there is a very detailed plan to follow, but some significant technical issues were brought up to address. The reviewer suggested that it would be helpful for the researchers to have a fuel analysis, so that the fuel properties can be used to help to further elucidate the energy content and efficiency of the reformer, as well as the fuel chemistry and reactions. The reviewer commented that it was still not clear why diesel use was chosen over the use of gasoline, as it seems that the gasoline fuel would have been easier to ignite, given its distillation characteristics and lower octane value. The reviewer postulated that this is due to the use of HCCI as the diagnostic, which would indicate that a diesel fuel will have autoignition characteristics. The reviewer referenced other issues noted on Side 12.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that, although the project has only three partners, two of which are essentially subcontractors, the work division is appropriate for the scale and nature of the project.

Reviewer 2:
The reviewer commented that it appears that the reformer technology supplier is well equipped to provide hardware and technology for the project, and inclusion of a university for chemical analysis of the reformate provides an important contribution to the project. The reviewer stated, however, that having no collaborations with engine or auto companies, fuel companies, or tier 1 suppliers weakens the project.

Reviewer 3:
The reviewer noted that there is good collaboration and coordination on the project, but suggested that it might help to have some national laboratory participation in the project so that some of the technical issues can be elucidated with the consultation of experts in the area.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer stated that actual experiments with the parent fuel/reformate mixing in an engine configured to RCCI will proceed after further validation of the CFD model.

Reviewer 2:
The reviewer noted that the project has a very important go/no-go decision point (decision point two) coming in a few months, i.e., can the engine achieve better efficiency operating on a single fuel and its reformate in RCCI than it can operating conventionally? The reviewer stated that this decision needs to be very rigorously evaluated to determine the value of this concept. The reviewer observed that the project does not appear to have additional fuels in the plan, and does not appear to include development of a transient control strategy. The reviewer commented that this is probably appropriate, because this research is definitely exploratory and high risk, and added that any problems with the CPOX, such as coking or catalyst deactivation, also need to be documented.

Reviewer 3:
The reviewer stated that this is a very challenging set of experiments, and it will be hard to model CFD and engine conditions with fuels that are multicomponent. The reviewer suggested using some simple primary reference fuels for some initial tests, and then a multicomponent fuel to show how the models and experiments compare, but added that this is not a trivial task. The reviewer commented that the results will demonstrate how difficult this is for RCCI and control of a system, which is why this technology is very far away from implementation. The reviewer added that, until a system can be demonstrated to use a market multi component fuel, this type of research will be needed to investigate this methodology, and it demonstrates the challenge for OEMs.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that the development of more efficient engine concepts and modification of fuel to make it more compatible with advanced combustion concepts definitely supports DOE's goal of energy efficiency.

Reviewer 2:
The reviewer stated that the project could pave the way for RCCI without the need for storage of two separate fuels on board, assuming an on-board reformer can be designed, and noted that other companies are working on that in hydrogen engine related research. The reviewer commented that this could make RCCI a more viable and attractive option, with its enhanced efficiencies and increased fuel economy.

Reviewer 3:
The reviewer commented that, for this project, if some efficiency gains can be demonstrated, and natural gas can be used, then this would meet the stated goals; however, at present, the project is also using diesel and gasoline, and there are some issues with the efficiency in the system. The reviewer responded yes to this question, but added that it was a stretch to do so.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer commented that resources appear to be sufficient to complete the project if funding levels are maintained.

Reviewer 2:
The reviewer noted that there is a lot of money being spent on this project by the DOE, and expressed the view that it is imperative that several national laboratories be involved to support in consultation, to make sure that the value in this project is accomplished in support of the project goals. The reviewer expressed uncertainty about the project's ability to meet it stated goals, and noted that there seem to be a lot of resources involved in the work.

Presentation Number: ft061
Presentation Title: Methods to Measure, Predict, and Relate Friction, Wear, and Fuel Economy
Principal Investigator: Steve Gravante (Ricardo)

Presenter
Steve Gravante, Ricardo

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that combining a benchtop test, rig test, modeling and simulation to develop a tool to predict system changes seems feasible, and noted that the PIs are using established experimental tests and models to help mitigate some risk.

Reviewer 2:
The reviewer commented that the project took a very interesting and unique approach to developing methods capable of predicting the impact of friction reduction technologies on engine fuel economy and wear, and noted that the methods of prediction are supposed to be both empirically and analytically based.

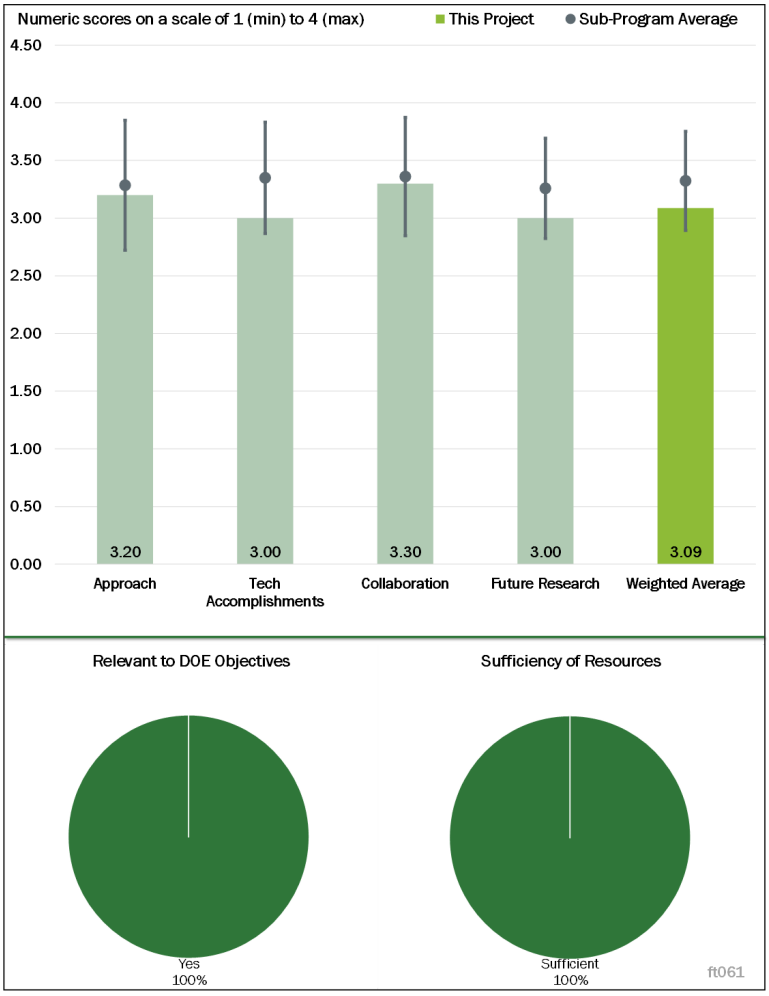

Figure 5-19 - Presentation Number: ft061 Presentation Title: Methods to Measure, Predict, and Relate Friction, Wear, and Fuel Economy Principal Investigator: Steve Gravante (Ricardo)

Reviewer 3:
The reviewer liked the linkage to real engine friction measurement.

Reviewer 4:
The reviewer stated that the project seeks to correlate bench measurements of friction and wear to various motored single cylinder engine tests, and develop correlations which can be used to predict potential effects of new technologies. The reviewer noted that the project uses a matrix of oils and materials to evaluate viscous and boundary friction and wear, and the expected deliverable is an empirical model which can relate basic lab measurements to engine friction and wear. The reviewer observed that the project is developing a methodology, not proving or selecting improvements for power cylinder rings and skirt.

Reviewer 5:
The reviewer expressed a number of reservations about this project. The reviewer stated that there has been a good deal of prior work done by the project leader's own company in the last 5-6 years, and added that this project should have described the current state-of-the art, and explained how the project would advance the

current state-of-the-art, but this has not been done. The reviewer commented that, as such, it is difficult to know if the current project is justified in the base case. The reviewer noted the limited amount of engine testing envisioned in this project, using very few test oils, and engine hardware that is not representative of the prevalent engine designs in the U.S. market, and concluded that it is unlikely to yield models that are sufficiently reliable or relevant to the U.S. market.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer noted that the test oils, hardware and test matrix have been finalized; however, the main body of the work which involves actual engine testing has not begun.

The reviewer questioned what the kinematic viscosity of synthetic OIL C which is currently being used in all studies is. The reviewer found it surprising that the authors selected not to summarize and present their experimental data collected on the original matrix of eight (8) oils, as it was proposed and tested during the 2016 program's presentation. The reviewer noted that it is advisable that technical knowledge gained from DOE sponsored programs be shared and communicated to the general public. The reviewer added that the proposed approach to separate out the impact of lubricant changes on engine friction and fuel consumption realized through other components, e.g., main bearings and valve train, has not been fully developed and reported.

Reviewer 2:
The reviewer noted that the coating of piston skirts and rings with friction reducing materials was unsuccessful, so the researchers formulated a third motor oil to develop their procedures and correlations. The reviewer observed that the results in Slide 12 also indicate that DLC and honing variations have been or will be evaluated. The reviewer added that it also appears that the authors have developed a fairly simple method for quantifying wear; however, the researchers admit that it will not work on surfaces with durable tribofilms, so it may not be applicable to all situations.

Reviewer 3:
The reviewer noted good progress, and expressed the hope that the experimental portion will stay on track.

Reviewer 4:
The reviewer stated that it seems there is some correlation between the project team's lab-scale test correlations, but noted some deviation that should be investigated further. The reviewer commented that the authors developed a good way to quantify wear on complex geometries by focusing on how surfaces change relative to the deepest valleys; white light interferometry has a sensitivity to surfaces with an oil film or tribological film, thus surface preparation becomes critical. The reviewer state, however, that this approach can only be quantitatively used for bare metal surfaces.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that a well-balanced team of technical collaborators are contributing to this project.

Reviewer 2:
The reviewer commented that the program includes Ricardo, ANL, ElectroChemical Associates (EMA), Isuzu, ZYNP, and Infinium, so that all aspects of the engine industry relative to power cylinders have been included. The reviewer noted that bench tests were conducted at both ANL and EMA for ring and liner friction and wear.

Reviewer 3:
The reviewer commented on the good use of an industry partner.

Reviewer 4:
The reviewer observed that no apparent issues with respect to coordination among the partners have emerged.

Reviewer 5:
The reviewer observed that the PI has had some issues receiving parts on schedule and having the parts surface prepped for testing; however, the reviewer found this understandable when dealing with novel coatings. This reviewer would recommend focusing only on proven technologies to prevent schedule delays, as the focus of this project is to develop a tool to predict fuel efficiency, not increase the technical readiness level of novel coatings/additives.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer expressed the hope that this project is successful, and stated that often the linkage between friction reduction agents and actual engine efficiency is not determined. The reviewer stated that, if successful, this could greatly enhance the ability to introduce these agents to manufacturers.

Reviewer 2:
The reviewer noted that there is still a lot of work to be conducted in the final year of the project's period of performance, and commented that the work seems to align with the logical progression to develop a model for fuel economy predictions.

Reviewer 3:
The reviewer stated that the future work is well described; however, future work constitutes the main body of the work, and it is difficult to predict what new barriers might be encountered and how the team will resolve them.

Reviewer 4:
The reviewer observed that the authors are planning a very long list of tests to be carried out within the next 6 months: perform motored and fired friction tests; perform long-term wear measurements to obtain wear rate coefficients; develop a model-of-a-model for fuel economy predictions; and demonstrate that the model can be exercised over a real-world usage profile to quantity fuel economy benefits for the different oils considered in this project. The reviewer added that other theoretical case studies can or will be performed, and offered the example of quantifying wear over a reference usage profile and demonstrating that trade-offs between fuel economy and durability can be understood prior to any field or durability testing. The reviewer stated that it is unrealistic that all these activities can be carried out in timely fashion. The reviewer also questions why there were no technical publications or presentations given on this work over the duration of this project, which started in 2015 and is funded at a $1.3 million level.

Reviewer 5:
The reviewer noted that the authors admit that their results will not be universally applicable to different engines or new technologies, but that successful results can be applied as a methodology to develop further correlations for different engines and technologies. The reviewer commented that correlation of motored engine tests and models to bench tests is highly dependent on local temperatures and temperature distributions in an engine, and, unfortunately, temperatures change based on operating condition and viscous and boundary friction. The reviewer stated that there is a lot of "noise" in this system, and a robust correlation will probably not be reached. The reviewer also found that the number of variables being exercised and the range over which

they are being exercised are also not broad enough to develop a broad correlation procedure. The reviewer commented that the presentation also states that they might not be able to complete modeling if Isuzu does not supply the required information, and questioned why this was not worked out ahead of time.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that, based on the well-planned project structure, this project definitely supports overall DOE objectives.

Reviewer 2:
The reviewer commented that the development of laboratory methods, models, and correlations to predict real world fuel economy changes supports DOE energy efficiency goals.

Reviewer 3:
The reviewer stated that the ability to predict performance based on hardware, lubricant and coating, material is a lofty goal; however, as technology advances, it seems to enter more into the realm of possibility. The reviewer commented that Ricardo's approach could be adopted for other systems if successful, which would be a huge accomplishment and very worthwhile.

Reviewer 4:
The reviewer stated that the availability of reliable models for FE and wear can be helpful in reducing barriers to adoption of advanced FE technologies; however, the critical issue here is the reliability and credibility of such models. The reviewer commented that the current project does not instill much confidence in the reliability and credibility of the models that might come out of this work.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer stated that all the projected aspects of the work seem to be well resourced.

Reviewer 2:
The reviewer commented that all the proposed resources are needed to make this project successful.

Reviewer 3:
The reviewer stated that the resources appear adequate to complete the project, providing that funding level is maintained.

Reviewer 4:
The reviewer found that the team has been allocating resources appropriately as they come to the end of their project period of performance, and they provided good cost sharing; however, they had some schedule issues that are being corrected presently.

Acronyms and Abbreviations

ACI	Advanced compression ignition
AEC	Advanced Engine Combustion
Al_2O	Aluminum oxide
AMR	Annual Merit Review
ANL	Argonne National Laboratory
API	American Petroleum Institute
ASSERT	Analysis of Sustainability, Scale, Economics, Risk, and Trade
ASTM	American Society for Testing and Materials
BOB	Blendstock for oxygenated blending
CFD	Computational fluid dynamics
CN	Cetane number
CPOX	Catalytic partial oxidation
CR	Compression ratio
CRC	Coordinating Research Council
Cu	Copper
DOE	U.S. Department of Energy
E10	10% ethanol blend with gasoline
E20	20% ethanol blend with gasoline
E30	30% ethanol blend with gasoline
EDAX	Energy-dispersive X-ray spectroscopy
EGR	Exhaust gas recirculation
EMA	ElectroMechanical Associates
GDI	Gasoline direct injection
HCCI	Homogeneous charge compression ignition
IQT	Ignition quality tester
LLNL	Lawrence Livermore National Laboratory
LSPI	Low-speed pre-ignition

MON	Motor octane number
NH_3	Ammonia
NO_x	nitrogen oxides
NP	nanoparticles
NREL	National Renewable Energy Laboratory
NU	Northwestern University
OCP	Olefin copolymer
OEM	Original equipment manufacturer
OI	Octane index
ORNL	Oak Ridge National Laboratory
PAG	Polyalkylene glycol
PAO	Polyalphaolefin
PI	Principal investigator
PM	Particulate matter
PMI	Particulate matter index
PTWA	Plasma transfer wire arc
RCCI	Reactivity-controlled compression ignition
RON	Research octane number
SD	Standard deviation
SI	Spark Ignition
SiO_2	Silicon dioxide
SwRI	Southwest Research Institute
TRC	Transportation Research Center
TRL	Technology readiness level
U.S.	United States
U.S. DRIVE	United States Driving Research and Innovation for Vehicle Efficiency and Energy
VM	Viscosity modifier
VN	Vanadium nitride

VTO	Vehicle Technologies Office
ZrO_2	Zirconium dioxide