5. Fuel and Lubricant Technologies

To strengthen national security, promote future economic growth, support American energy dominance, and increase transportation energy affordability for Americans, the Vehicle Technologies Office (VTO) funds early-stage, high-risk research. This research will generate knowledge that industry can advance to deploy innovative energy technologies to support affordable, secure, reliable, and efficient transportation systems across America. VTO leverages the unique capabilities and world-class expertise of the National Laboratory system to develop new innovations in electrification, including advanced battery technologies; advanced combustion engines and fuels, including co-optimized systems; advanced materials for lighter-weight vehicle structures and better powertrains; and energy efficient mobility technologies and systems, including automated and connected vehicles as well as innovations in connected infrastructure for significant systems-level energy efficiency improvement. VTO is uniquely positioned to address early-stage challenges due to its strategic research partnerships with industry (e.g., the U.S. DRIVE and 21st Century Truck Partnerships) that leverage relevant technical and market expertise. These partnerships prevent duplication of effort, focus DOE research on the most critical research and development (R&D) barriers, and accelerate progress. The partnerships help VTO focus on research that industry does not have the technical capability to undertake on its own—usually because there is a high degree of scientific or technical uncertainty or it is too far from market realization to merit sufficient industry emphasis and resources. At the same time, VTO works with industry to ensure there are pathways for technology transfer from government to industry so that Federally-supported innovations have an opportunity to make their way into commercial application.

The Fuel and Lubricant Technologies (FT) subprogram supports early-stage R&D to improve our understanding and ability to manipulate combustion processes, fuel properties, and catalyst formulations, generating the knowledge and insight necessary for industry to develop the next generation of engines and fuels for light- and heavy-duty vehicles. As a result, co-optimization of higher-efficiency engines and high performance fuels has the potential to improve light-duty fuel economy by 35% (25%from advanced engine research and 10% from co-optimization with fuels) by 2030 compared to 2015 gasoline vehicles. The subprogram supports cutting-edge research at the National Laboratories, in close collaboration with academia and industry, to strengthen the knowledge base of high-efficiency, advanced combustion engines, fuels, and emission control catalysts. The FT subprogram will apply the unique facilities and capabilities at the National Laboratories to create knowledge, new concepts, and research tools that industry can use to develop advanced combustion engines and co-optimize with fuels that will provide further efficiency improvements and emission reductions.

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
ft037	Co-Optimization of Fuels and Engines (Co-Optima)	Robert Wagner (ORNL)	5-5	3.25	3.38	3.63	3.13	**3.34**
ft067	Multi-Mode (MM)/Multi-Mode Compression Ignition (MMCI): Fuel Property Characterization and Prediction	Gina Fioroni (NREL)	5-10	3.70	3.60	3.50	3.50	**3.60**
ft069	MM: Fuel Property Impacts and Limitations on Combustion - Spark Ignition Focus	James Szybist (ORNL)	5-15	3.50	3.60	3.50	3.20	**3.51**
ft070	MM: Autoignition in MM/Advanced Compression Ignition (ACI) Combustion, Part 1	Magnus Sjoberg (SNL)	5-19	3.10	3.50	3.40	3.20	**3.35**
ft071	MM: Autoignition in MM/ACI Combustion, Part 2	Dean Edwards (ORNL)	5-24	3.38	3.63	3.38	3.50	**3.52**
ft072	MM: Autoignition in MM/ACI Combustion, Part 3	Chris Kolodziej (ANL)	5-28	3.50	3.50	3.38	3.38	**3.47**
ft073	Co-Optima Emissions and Emissions Control for Spark Ignition /ACI Multi-Mode Combustion	Josh Pihl (ORNL)	5-32	3.67	3.67	3.50	3.33	**3.60**
ft074	MM: GDI Sprays	Lyle Pickett (SNL)	5-36	3.67	3.50	3.50	3.33	**3.52**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
ft075	MM: Fuel Kinetics	Scott Goldsborough (ANL)	5-39	3.25	3.00	3.25	3.00	**3.09**
ft076	Advanced Numerics and Modeling.	Matthew McNenly (LLNL)	5-42	3.50	3.30	3.40	3.40	**3.38**
ft077	Heavy-Duty Mixed-Controlled Compression Ignition (MCCI): MCCI and Ducted Fuel Injection, Part 1	Charles Mueller (SNL)	5-46	3.63	3.50	3.25	3.25	**3.47**
ft078	Heavy-Duty MCCI: MCCI and Ducted Fuel Injection Part 2	Christopher Powell (ANL)	5-50	3.38	3.13	3.38	3.25	**3.23**
ft079	Expanding the Knock/Emissions/Misfire Limits for the Realization of Ultra-Low Emissions, High-Efficiency, Heavy-Duty Natural Gas Engines	Dan Olsen (Colorado State University)	5-54	2.83	3.33	3.17	3.33	**3.19**
ft080	Fundamental Advancements in Pre-Chamber Ignition and Emissions Control for Natural Gas Engines	Brad Zigler (NREL)	5-58	3.75	3.50	3.75	3.50	**3.59**
ft081	Direct Injection 4.3 L Propane Engine Research, Development, and Testing	Brad Zigler (NREL)	5-615-63	3.00	3.00	3.50	3.00	**3.06**
ft082	High-Performance Fluids and Coatings for Off-Road Hydraulic Components	George Fenske (ANL)	5-63	3.13	3.38	3.13	3.00	**3.23**
ft083	Efficient, Compact, and Smooth Variable Propulsion Motor	James Van de Ven (University of Minnesota)	5-67	3.38	3.38	3.25	3.38	**3.36**
ft084	Individual Electro-Hydraulic Drives for Off-Road Vehicles	Andrea Vacca (Purdue University)	5-71	3.13	3.13	3.25	3.25	**3.16**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
ft085	Hybrid Hydraulic-Electric Architecture for Mobile Machines	Perry Li (University of Minnesota)	5-75	3.38	3.25	3.25	3.13	**3.27**
ft086	On-Demand Reactivity Enhancement to Enable Low-Temperature Combustion of Natural Gas	Will Northrop (University of Minnesota)	5-79	3.50	3.17	3.50	3.17	**3.29**
Overall Average				**3.38**	**3.37**	**3.39**	**3.26**	**3.36**

Presentation Number: ft037
Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima)
Principal Investigator: Robert Wagner (Oak Ridge National Laboratory)

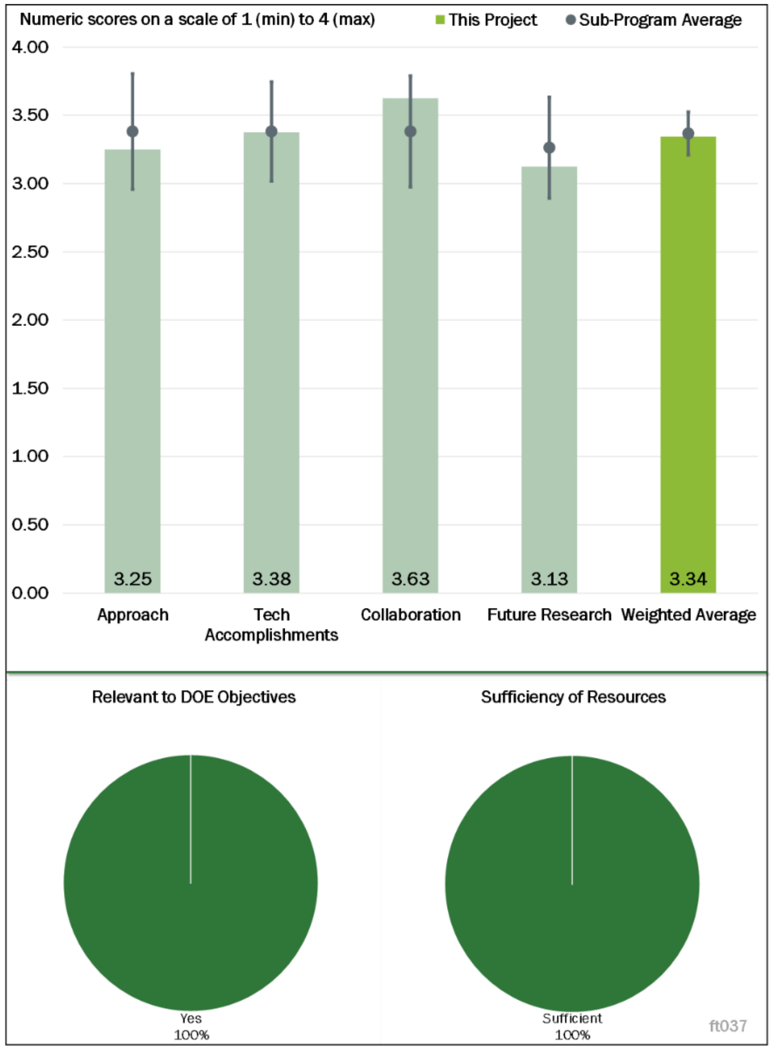

Figure 5-1 – Presentation Number: ft037 Presentation Title: Co-Optimization of Fuels and Engines (Co-Optima) Principal Investigator: Robert Wagner (Oak Ridge National Laboratory)

Presenter

Robert Wagner, 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 and well-planned.

Reviewer 1:

Overall, the reviewer found the approach to this work to be excellent. The very broad and challenging task of co-optimizing engines and fuels has, overall, been broken down into sensible work packages and efforts. The reviewer stated that the suggestions below are not criticisms of the current approach, but rather suggestions for improving upon and/or expanding upon the very good approach that is in place.

The first suggestion from the reviewer was to improve the communication of how the various efforts are interconnected and/or progressing. Given the overall scope, the reviewer proposed that a visual or graphical way of communicating how the various efforts are interconnected to one another and/or have evolved with time would be very helpful. This would allow the broader research community to better understand what Co-Optima is doing and what it has achieved. (And it may also provide insight for areas of future work.) The second suggestion from the reviewer was to assess interactions and/or blending behavior of key fuel constituents. While the reviewer does not disagree with the approach to focus on identifying critical fuel properties (it is probably the best you can do for such a complex problem), the reviewer thought that it would be advisable to also assess the extent to which fuels with similar properties behave similarly or differently when blended. Many examples of unexpected interactions have been observed in the past (e.g., so-called antagonistic blending of ethanol with regards to octane rating). The reviewer stated that simple, quick screening of the candidate fuels blended with common constituents in market fuel would be an outstanding first step. This could be simple engine experiments that evaluated the properties that had been identified as being critical.

The third suggestion from the reviewer was to ensure that engine and fuel limits are given equal treatment as property optimization. The reviewer noted that the presenter acknowledged, for the spark-ignition work, that limits such as emissions, material compatibility, and low-speed pre-ignition and stochastic pre-ignition are not included in the merit function, but did emphasize that these were important issues. More can be done to identify and communicate the tradeoffs and constraints for not only the spark-ignition work, but also all of the Co-Optima work. To say this differently, when the overall results are communicated and suggestions are made, it needs to be clear that the "optimization" was or is constrained, not unconstrained. (Please note that this comment is not to say that this work is not being done, but rather to emphasize the importance of communicating it in the overall messaging.) The fourth suggestion from the reviewer was to consider, or at least acknowledge, other powertrain pathways. While the program is not trying to pick winners, it necessarily has to pick some areas in which to focus its efforts. With this in mind, the reviewer commented that there are a number of other technologies outside of the Co-Optima focus that are either in production or many would argue are production-viable and thus warrant research consideration. (Boosted spark-ignition [SI] and multi-mode advanced compression ignition [ACI]/SI are perhaps the powertrain pathways most pursued by specific U.S. light-duty (LD) OEMs, but there are other pathways.) Other pathways include the Mazda Skyactiv-G approach, Dedicated exhaust gas recirculation (EGR), high compression ratio naturally aspirated engines, turbulent jet ignition, variable compression ratio engines, mixed-mode with ACI at low load and mixing controlled compression ignition (MCCI) at high load, and more broadly engines designed for hybrid applications.

Reviewer 2:

According to the reviewer, the presenter highlighted that Co-Optima focuses on fundamental knowledge through pre-competitive research. However, the reviewer suggested that it would be good to communicate technical findings (if any) that can be leveraged by industry now given the constraints in the marketplace.

Reviewer 3:

Overall, the reviewer said that the approach is pretty good as there is reasonably good coordination among the different Laboratories and different projects. However, according to the reviewer, there is still room for improvement in getting the program to look less like several independent projects thrown together under one umbrella and more like an integrated, systemic approach to gaining the understanding of engine and fuel properties and technologies that build upon one another. There has been improvement in this area, but more improvement could be done. The reviewer stated that the program needs to better define the heavy-duty (HD) Co-Optima goals. Fuel economy is defined differently in HD than in LD—a percent fuel economy (FE) number does not have much meaning if it is not defined. This reviewer also asserted that the brake thermal efficiency (BTE) and emissions compliance goals for Co-Optima are excellent targets.

Reviewer 4:

The scope of Co-Optima is huge and, in the reviewer's opinion, the objective of pursuing the optimization of the engine and fuel is extremely important. As such, Co-Optima has a challenging task to bring together and coordinate the relevant expertise of the multiple U.S. Department of Energy (DOE) Laboratories. It appeared to the reviewer that they have done this very well, are pursuing relevant questions, and keeping the research focused at the appropriate fundamental level.

The Central Fuel Hypothesis seemed logical to the reviewer. If it were not true, then it will have large ramifications for the Co-Optima program. The reviewer asked if Co-Optima has plans to assess if the hypothesis holds.

The reviewer thought that stating that Co-Optima is working toward 60% shaft efficiency for medium-duty (MD) and HD engines (Slide 14) diminishes the credibility of the program. Many in the technical community view this as a pipe dream. The reviewer thought that it would be better, and more consistent with the objectives of the program, to state this in terms of a CO_2 reduction, a very important issue, which can also be achieved via reducing the carbon footprint of the fuel (Bioenergy Technologies Office [BETO]).

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

Overall, the reviewer indicated that the Co-Optima program has done an outstanding job in generating new and useful information and doing so on schedule. With regard to its overall goals of achieving specific improvement targets, as the presenter mentioned, it is challenging to tangibly demonstrate such improvements when performing precompetitive research. In the view of this reviewer, though, the overall program is on track for meeting its stated targets.

Reviewer 2:

The reviewer noted that progress in the LD space has been substantial, and the HD work is just ramping up. The work done to date has shown significant progress in understanding the fuel's influence on SI combustion and combustion anomalies. The collaboration among Laboratories in this space has been quite good, and this type of interaction will be even more important in the MCCI and ACI space going forward. According to the reviewer, the challenge will be integrating fuel efficiency, emissions compliance, and greenhouse gas (GHG) reduction (which was not mentioned, but is of substantial regulatory importance to HD companies) into the equation.

Reviewer 3:

The reviewer said that this is an overview presentation so minimal detail of accomplishments were given. However, a list of significant technical accomplishments was given.

Reviewer 4:

The reviewer would like to have seen see more supplementary material to highlight key technical findings. For example, more detail on Slide 19 would be appreciated. Additionally, the reviewer asked if any of the Co-Optima efforts address the cost and technical challenges of low-temperature gasoline combustion (LTGC) aftertreatment systems.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer remarked that inter-Laboratory collaboration has improved noticeably since the beginning of the work. The SI fuel and combustion work has cross-cut with several Laboratories and there truly appears to have been a concerted effort to do this. It will be even more important to ensure this level of coordination for the MCCI and ACI next phase of the work. The space is much bigger and less well defined from the start, which will make it even more difficult to ensure coordination. The success in the LD space provides confidence that this project team can manage future coordination as well.

The reviewer commented that it is critical for DOE to continue to keep this collaboration and team approach to solving technical problems going, even after the "Co-Optima" program has expired or has been completed. Significant effort was spent in assembling these project teams and encouraging them to collaborate. Effort will need to be spent in maintaining this high level of interaction and collaborations. The project team approach is much more powerful and focused than the previous way projects were funded and managed, according to the reviewer.

Reviewer 2:

According to the reviewer, the level of collaboration among the nine DOE laboratories and the multitude of stakeholders and professional working groups is outstanding. The reviewer said that it would have been nice to see a list of the university-funded projects and some indication of how they contribute to the Co-Optima objectives.

Reviewer 3:

The reviewer found this project to be a large endeavor engaging several National Laboratory researchers. Additionally, there is an external advisory board consisting of both academic and industrial representatives (Slide 7). There is no mention in the presentation material summarizing the recommendations of the external advisory board and its impact. The reviewer wanted to know how the advisory board's feedback has shaped the goals of the project.

Reviewer 4:

The reviewer noted that collaboration among the entire project team appears to be very good. There are extensive collaborations among the National Laboratories and, in many cases, third parties where appropriate. In the eyes of this reviewer, the most notable area in which to improve with regard to collaboration would be to expand OEM engagement in order to lay the groundwork for commercialization. This could be direct engagement with OEMs on specific projects, or it could simply be an increased effort to communicate results to the industry.

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 said that the future research addresses important fundamental questions.

Reviewer 2:

The future work in MCCI and ACI does not seem to be initially as well coordinated as the SI and the mixed mode work that ended. There is substantial work yet to do to define the targets for MCCI and ACI work and to select the pathway to achieving these targets.

Reviewer 3:

According to the reviewer, funding for Co-Optima 2.0 will overlap with the newly presented Light Duty Combustion Consortium. It seemed to the reviewer that both projects will involve several of the same Laboratory members moving forward. The reviewer asked what areas of Co-Optima can be synergistic without duplicating efforts.

Reviewer 4:

The proposed future work areas for the entire Co-Optima program are excellent. One area, as noted above in the Approach section, in which it could be worth considering additional future work is with regards to alternative engine and combustion approaches. Additionally, this reviewer had the following two suggestions: the first suggestion was to establish methodologies or criteria for assessing and comparing technologies. The presenter mentioned as a challenge the task of developing common engine conditions and metrics. Effort in this area would be well worth it because, in the opinion of this reviewer, this is the pathway to increasing the impact the Co-Optima program can have on industry. This can be achieved in a number of ways. For example, the reviewer stated that it could be the inclusion of key operating points in the speed-torque space (which industry can help define) when reporting results. It could also be a comparison to existing technologies based on fundamentals; as an example, to establish criteria for controllability and robustness, one could look at the change in the crank angle position at which 50% of the heat is released (CA50) for a given engine control parameter change, comparing advanced combustion modes to spark ignition and diesel combustion in terms of both the absolute size of the change and the rate at which the control parameter can be changed.

The second suggestion was to improve the communication of Co-Optima results. While not technically a research area for the overall Co-Optima program, the reviewer indicated that it would be valuable to improve the communication of the Co-Optima results. The presenter mentioned a website that would link to all of this content. This, along with the graphical depiction of Co-Optima efforts, would be effort well spent to ensure that others understand the Co-Optima progress and accomplishments.

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

Reviewer 1:
The reviewer commented that DOE's mission is to provide pre-competitive, advanced technical work that is in the best interest of the U.S. public. This program does that quite well. Co-Optima has been a departure from the business-as-usual way that DOE used to do things and the results are impressive thus far. Continuing to engage all the relevant partners will be very important to achieve the promise of this work.

Reviewer 2:
The reviewer indicated that yes, this project supports DOE's objectives and is developing fundamental understanding to support advanced engine and fuel concepts.

Reviewer 3:
The reviewer found the description of relevance in the presentation to be well stated.

Reviewer 4:
The reviewer remarked that this project aligns with DOE objectives but relevance to industry is not clear.

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 resources appear to be sufficient to continue this work at the needed level.

Reviewer 2:
The reviewer said that the resources provided are sufficient to support the proposed future research.

Reviewer 3:
While this is difficult to assess for the program as a whole, given that most or all of the projects appear to be on track, the resources appeared adequate to the reviewer. Two related areas, as noted above, in which additional resources and/or effort would be beneficial is in the communication of the overall program results and the increased engagement with OEMs.

Reviewer 4:
While the reviewer would like to have seen a larger budget for the Vehicle Technologies Office (VTO) activities on fundamental experimental and simulation efforts, it seems good progress is being made with the current level of resources.

Presentation Number: ft067
Presentation Title: Multi-Mode (MM)/Multi-Mode Compression Ignition (MMCI): Fuel Property Characterization and Prediction
Principal Investigator: Gina Fioroni (National Renewable Energy Laboratory)

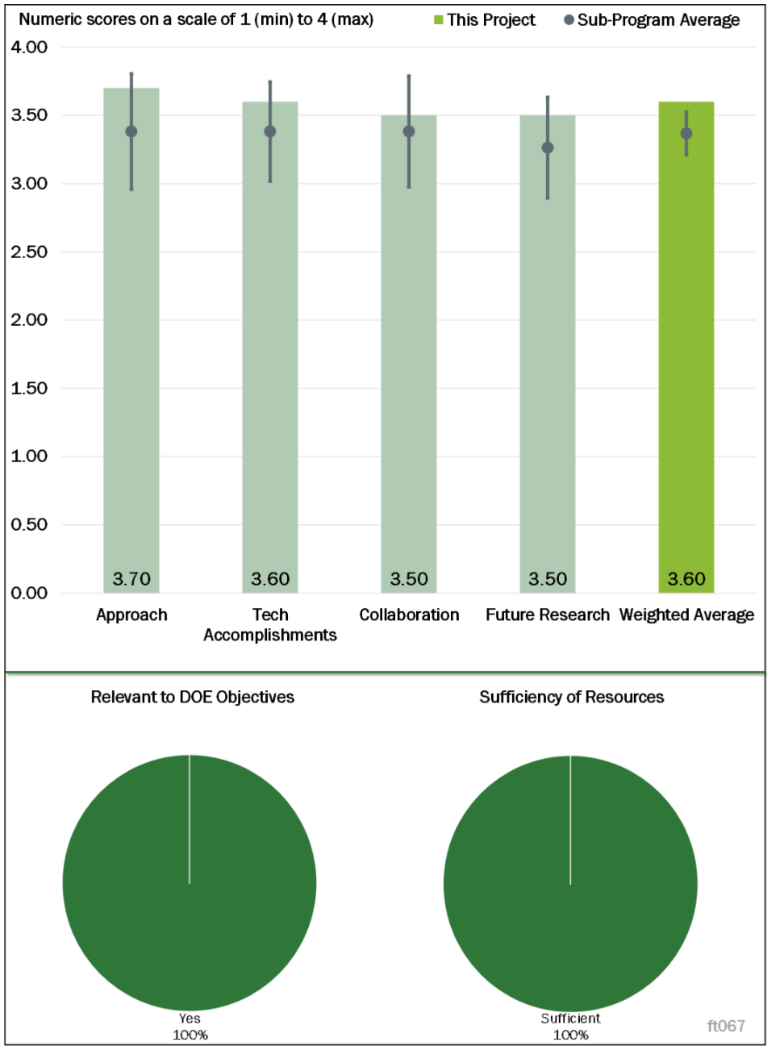

Figure 5-2 – Presentation Number: ft067 Presentation Title: Multi-Mode (MM)/Multi-Mode Compression Ignition (MMCI): Fuel Property Characterization and Prediction Principal Investigator: Gina Fioroni (National Renewable Energy Laboratory)

Presenter

Gina Fioroni, National Renewable Energy 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 and well-planned.

Reviewer 1:

The reviewer found this work to be a very comprehensive, multifaceted approach to discover key effects of heat of vaporization (HOV) and underlying principles for auto-ignition. The organization and coordination are very challenging and proving successful.

Reviewer 2:

According to the reviewer, this project seeks to expand understanding of fuel properties (auto-ignition, heat of vaporization, etc.) so that fuels can enable cleaner and more efficient combustion. The scope of the activities includes a variety of instrumentation for studying auto-ignition and anti-knock behavior, as well as other fuel properties. The reviewer stated that the scope and the tools available to this project team all are well suited to making significant progress on improving our understanding of fuel properties so as to enable the creation of better fuels. This “fuel science” activity ties well to the BETO fuel production activities and serves very well the advanced combustion activities within VTO under Co-Optima.

Reviewer 3:

The reviewer remarked that this project is aimed at measuring key fuel properties that underlie the entire Co-Optima project. This is a key and critical project for the entire effort. The Zigler work on small volume methods for auto-ignition under engine-relevant conditions is extremely interesting and of great value.

Reviewer 4:

The reviewer commented that the program addresses the lack of fundamental knowledge on critical fuel properties relevant to engine efficiency, including gasoline volatility and evaporation, auto-ignition behavior, and the mechanisms resulting in phi-sensitivity.

Reviewer 5:

The reviewer stated that development and improvement of new testing methods for characterization of fuels is central to developing increased understanding of fuels and fuel properties. It is very challenging to evaluate six different subtasks as part of one overall effort, but, in general, the focus and approach of each effort seem reasonable. The reviewer would like to have seen a more comprehensive discussion of why these specific fuel parameters were studied and what specific technical barrier is being addressed.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer found the array of instruments and studies ongoing under this activity to be impressive and quite appropriate. The outcomes from that work on understanding the volatility behavior of fuel mixtures, which influences mixture formation, are very good and have added to our understanding of how important fuel interactions are to the HOV behavior of a fuel mixture. In the kinetics studies, the simple flow reactor seems to be yielding valuable results, but there are much more sophisticated flow reactor systems (e.g., the Princeton variable pressure flow reactor used by Dryer, et al., for many years). The reviewer stated that the planned upgrades will be welcome to get closer to more engine relevant conditions. The Advanced Fuel Ignition Delay Analyzer (AFIDA) instrument appears to be quite useful for studying fuel impacts on ignition and, in combination with the flow reactor and thermogravimetric analysis (TGA) and differential scanning calorimeter (DSC) measurements, gives a good picture of some of the chemical and physical processes involved in internal combustion (IC) engine combustion. There did not appear to the reviewer to be a connection to spray phenomena directly, and the reviewer asked if these measurements were linked to the spray capabilities at Sandia Livermore. The AFIDA is showing good ability to explain gasoline sensitivity and octane numbers but it requires 40 milliliters (ml) of fuel to accomplish a sweep of test conditions. According to the reviewer, that is an enormous amount of fuel in relation to what bench-scale fuel production experiments typically achieve. The reviewer wanted to know how does the amount of fuel required for these bench-scale experiments connect with the BETO exploratory fuel production activities.

Reviewer 2:

The reviewer indicated that the heat of vaporization measurement methodology has been improved to reduce mass loss from 11% to 1.8% while maintaining (or even improving) the heat of vaporization accuracy. DSC, TGA, and mass spectroscopy (MS) experiments reveal that the evaporation of gasoline alcohol blends can depend on the exact alcohol blended with the gasoline (i.e., the azeotropic interactions impact the engine relevant behaviors, such as ignition, temperature stratification, and emissions). The reviewer noted that progress has been made on understanding the influence of oxygenate clusters on vapor pressure and asked whether work has begun to translate this fundamental behavior into evaporation modeling.

The reviewer stated that the latest results with the AFIDA system are encouraging for rapid assessment of research octane number (RON) for potential fuels using small sample sizes. It is mentioned that an AFIDA assessment at a second temperature will be utilized for motor octane number (MON). First, the reviewer was unfamiliar with the exact setup for the advanced fuel ignition delay analyzer, and there was not time within this summary presentation for a detailed overview. So, perhaps these questions are out of ignorance, but the reviewer wanted to know how the temperatures for the RON and MON AFIDA studies were being selected. The reviewer asked if they were based on the cooperative fuel research (CFR) engine test procedures, geared toward a modern multi-mode engine, or the temperatures were available with the AFIDA technique outside any relevance for the engine community.

The reviewer greatly appreciated efforts to increase the pressure of the reactor setup and suggested aiming for 50 bar. Most engines run well above the proposed pressure range during their compression events and the reviewer suggested aiming for a 50-bar pressure capability and testing at 10-, 20-, and 30 bar.

The reviewer observed that overall, these fundamental studies are absolutely necessary for the co-optimization of fuels and engines. Hopefully, the results will shed light on impacts seen in engine experiments over time and elucidate potential fuel for future utilization. However, the reviewer urged that distinct efforts must be made to bring these fundamental results (volatility, evaporation, etc.) into the combustion and engine community. The reviewer asked if there were a distinct plan and if the project team will provide guidance for inclusion of these metrics within engine models.

Reviewer 3:

The reviewer commented that discoveries in all parts of the effort are impressive and could even find value in current engine-fuel systems.

Reviewer 4:

The reviewer stated that all milestones are either complete or on target for completion.

Reviewer 5:

According to the reviewer, solid progress has been made across the board on all projects. However, for a grouped set of six different tasks across multiple Laboratories, having only four total milestones is rather disappointing and makes visualizing overall progress difficult. Small-volume AFIDA measurements seem to predict RON quite well. The reviewer pointed out that it would be useful to understand how close the predictions are in comparison to the repeatability and reproducibility of the American Society for Testing and Materials (ASTM) RON test. For the AFIDA tests in general, it was not clear to the reviewer to what extent these measurements go beyond the normal capabilities of instrument and, if so, what was done to enable these additional capabilities. With a mechanistic study of phi sensitivity, the reviewer indicated that results are limited to a written discussion, which suggests that tests were not successful.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer expressed that there was an extremely strong level of collaboration across multiple universities.

Reviewer 2:

The reviewer noted that the combined effort of the complementary expertise and research methods is leading to a range of scientific discoveries on key fuel property effects.

Reviewer 3:

The reviewer stated that the project team includes complementary capabilities across National Laboratories, industry, and university partners. A missing connection seems to be to real spray behavior. The combination of experiments and simulation across the partners involved seems very strong, with good agreement from the simulation activities and experiments. The reviewer said that the experiments are yielding good insights into elementary behavior, such as the interaction between ethanol and other components in a fuel during vaporization and ignition.

Reviewer 4:

The reviewer found good level of collaboration across a range of universities and industry groups. However, collaborations lacked a breakout by sub-project; so, it was not fully clear to the reviewer if each group has active collaborations beyond those innate to the Co-Optima structure. The reviewer would like to have seen more definition in collaborations to support each program.

Reviewer 5:

They are many moving parts to this project—the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), Argonne National Laboratory (ANL), and Oak Ridge National Laboratory (ORNL)—which appear to be working in concert for an effective collaboration. However, it remained unclear to the reviewer how to translate these fundamental results into tools and insights that the combustion, emissions, and engines community can use.

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 described the work as fantastic and indicated that the planned scope is just what the co-optimization community needs. The project team was emphatically urged by this reviewer to keep going.

Reviewer 2:
The reviewer noted that the gaps in knowledge and data are well-presented for future research. The future research is focused and specific.

Reviewer 3:
The reviewer stated that the proposed future work is directly aimed at the remaining barriers.

Reviewer 4:
According to the reviewer, the planned future work looks to be a good approach moving forward. It appears to have a strong focus on understanding phi sensitivity, as well as octane sensitivity, in connection with mixed-mode combustion. Providing foundational research on these topics is both relevant and novel. However, the reviewer encouraged the project team to consider that not all efforts should be exclusively focused on these specific parameters in relation to mixed-mode combustion. These may not be the only critical parameters for mixed-mode combustion, and there are other relevant properties that remain important and a worthy subject of this project team's work.

Reviewer 5:
The reviewer indicated that the proposed future work extends very well the ongoing activities. Expanding the capabilities of the flow reactor will be beneficial to relevance and outcomes from the fuel ignition studies. Connecting the phi-sensitivity studies to ACI engine behavior will secure a good link between the fuel science studies and combustion science studies. However, the reviewer noted that the approach to linking the fuel evaporation and fuel-air mixing (focusing on individual droplets via simulation) seems to be missing a link to spray behavior. Spray behavior influences how flames behave in engines, which for multi-mode ACI engines will remain important. Research by C. Hasse and co-workers has shown through detailed computational fluid dynamics (CFD) studies that not accounting for differential vaporization of gasoline fuel jets with ethanol will lead to incorrect estimation of anti-knock behavior and flame speeds. So, it seemed necessary to the reviewer to more thoroughly build the link between these complex fuel volatility behaviors to what will happen in evaporating sprays. Perhaps linking to standard fuel injectors used in the Engine Combustion Network (ECN) would establish this connection, and maybe this is already happening under Co-Optima, but not mentioned in this presentation.

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

Reviewer 1:
The reviewer found this body of work to be essential to understanding fuel behavior at a fundamental level so that, in concert with spray and combustion studies and in concert with fuel production and feedstock development, the overall improvement of fuel and engines is enabled. Better understanding of phi sensitivity and how fuel ignition is influenced by evaporation behavior of mixtures will help support fuel development for ACI and multi-mode engines. This is a key path of activity under Co-Optima. These efforts also clearly support the broader goals of the DOE for improving engines and fuels to enhance our national energy security.

Reviewer 2:
The reviewer indicated that this is foundational research supporting the understanding of fuel properties, which lies at the core of the Co-Optima program.

Reviewer 3:
The reviewer commented that the research supports longer range optimal use of biofuel streams, but also appears to be generating results that would be useful in near term engine and fuel modeling and technology.

Reviewer 4:
The reviewer stated that this type of project is exactly why Co-Optima was funded.

Reviewer 5:
The reviewer said that the projects are directly in support of the Co-Optima effort.

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 project seems to be appropriately funded and is making efficient use of the funding.

Reviewer 2:
The reviewer stated that resources appear sufficient.

Reviewer 3:
The reviewer commented that resources are sufficient, but recognizes that the sheer number of participants and required coordination are perhaps not the most efficient situation.

Reviewer 4:
The reviewer remarked that resources seem adequate to achieve the project objectives, although one would need to review the detailed budget plan for the NREL activities to adequately judge whether the resources have been acquired to expand the capabilities of the flow reactor experiment to higher pressure.

Reviewer 5:
The reviewer said to increase the reactor pressure.

Presentation Number: ft069
Presentation Title: MM: Fuel Property Impacts and Limitations on Combustion - Spark Ignition Focus
Principal Investigator: James Szybist (Oak Ridge National Laboratory)

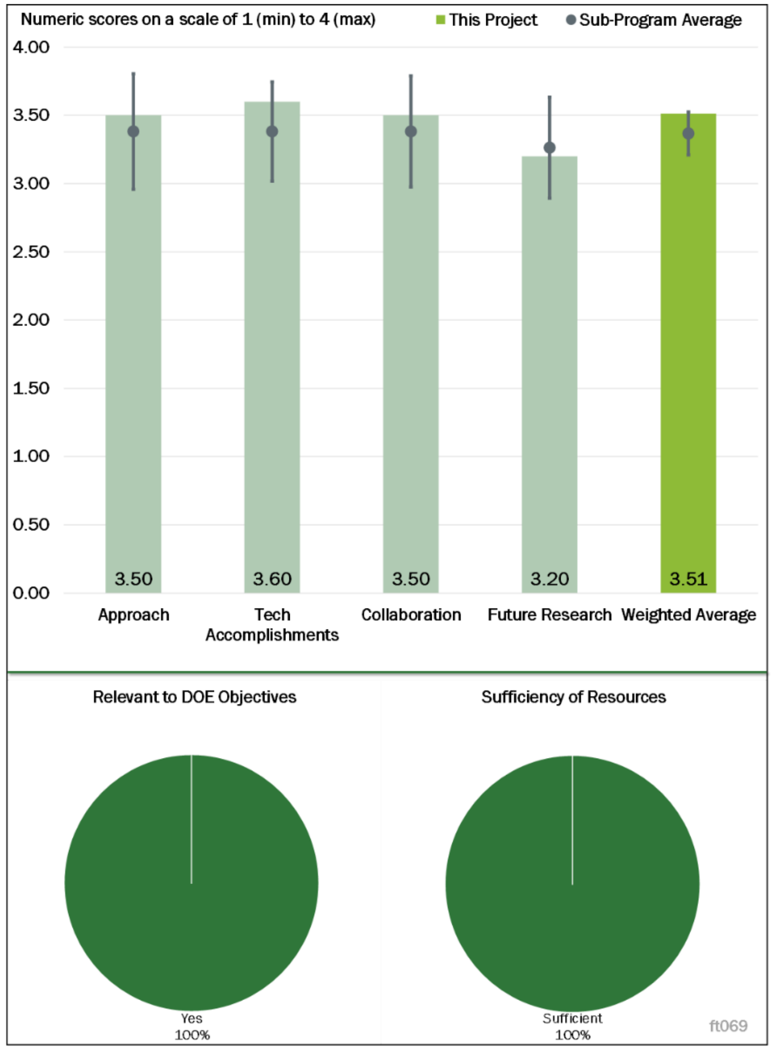

Figure 5-3 – Presentation Number: ft069 Presentation Title: MM: Fuel Property Impacts and Limitations on Combustion - Spark Ignition Focus Principal Investigator: James Szybist (Oak Ridge National Laboratory)

Presenter

James Szybist, 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 and well-planned.

Reviewer 1:

The reviewer noted that the work was well-done. The researchers demonstrated the ability to overcome technical barriers.

Reviewer 2:

Technically, the reviewer stated, these are very strong projects and sharply focused on important questions.

Reviewer 3:

The reviewer remarked that the project team seeks to leverage multi-cylinder engine (MCE) experiments, CFD modeling, and single-cylinder engine (SCE) work. The reviewer believed that this is a nice framework; however, from the presentation material, it was clear to the reviewer how the CFD leverages both the SCE and MCE work but not so much clear how the SCE work is feeding into the MCE work.

Reviewer 4:

The reviewer appreciated the continued effort toward stoichiometric SI combustion as well as ACI systems; the market barriers to ACI are still so large that it is critical to maintain the stoichiometric SI focus to enable a path to market impact. The reviewer largely appreciated the progress toward addressing the barriers and the project design. The reviewer thought that it is important to fully define the “impact” of the fuel changes, even if the different metrics are not used to choose a best solution. It seemed important to the reviewer to consider BTE as that is a fundamental metric of the engine, vehicle CO_2 emissions since they are regulated, and well-to-wheels (WTW) CO_2 since that is becoming increasingly an area of focus when comparing an internal combustion engine (ICE) against a battery electric vehicle (BEV) and a fuel cell electric vehicle (FCEV).

Reviewer 5:

Overall, the reviewer found that the approach to this set of projects is good. The Task F.1.8.1 work especially is excellent and world leading, although as noted below there is an opportunity to make this work more beneficial to the broader industry. The reviewer commented that the Task E.1.1.2 work, while well-intentioned, does seem somewhat oversimplified as recent work (e.g., https://doi.org/10.4271/04-11-03-0014 and several other SAE publications) has shown that RON and MON alone are insufficient to predict knock for SI engines (i.e., that K, from the octane index formula, depends not only on operating conditions, but also on fuel chemical composition). The approach to the Task G.1.10 work is good, according to the reviewer, whose suggested improvements are described in the Future Work section.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer had comments on the very nice progress: the combination of well-run experiments and accompanying CFD are providing important insight into challenging problems. The understanding of fuel characteristics, octane sensitivity, and engine operating conditions on knock is outstanding.

Reviewer 2:

Overall, the reviewer indicated that these projects are on schedule and achieving their stated goals.

Reviewer 3:

The reviewer found the progress to be excellent but would like to have seen a greater emphasis on translating the project outcomes to simpler relationships that could be used directly in engine calibration hardware and design.

Reviewer 4:

The reviewer said that the research team is using the transported Livengood-Wu integral to predict auto-ignition rather than advanced kinetics, presumably due to computational cost. The reviewer asked if the research team believes that this approach is satisfactory to simulate the octane index (OI) effect on knock limited CA50 that is shown in Slide 16.

Reviewer 5:

The reviewer pronounced the kinetic modeling and single-cylinder work to be outstanding and noted that the same analysis methods have been incorporated into other workplaces to help interpret results leading to higher engine efficiency. The reviewer was concerned that the multi-cylinder work is not quite as relevant for industry; steady-state testing to develop maps is a reasonable path given the limitations of the project budget and Laboratory capability. It was not clear to the reviewer that cold and hot operation is being considered, which may provide other insight into the value of the different fuels. Also, it is a minor thing, but when reporting the results, some care should be taken with significant figures and uncertainty analysis in results and computed data; the reported impact of increasing fuel HOV on vehicle fuel economy shows a difference between the base and modified cases, but at a level well below likely statistical significance.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer stated that the collaboration across the project teams appears to be excellent, particularly as related to the Task F and Task G work.

Reviewer 2:

The reviewer observed great cross-platform cooperation and encouraged the project team to please continue to develop the experimental aspects of this work to aid in the use of these ideas in on-road vehicles.

Reviewer 3:
The reviewer mentioned that the collaboration is one of the reasons their progress is so good.

Reviewer 4:
The reviewer stated that the project team involves collaboration between laboratories for modeling and experiments but also leverages hardware from OEMs.

Reviewer 5:
The reviewer remarked that both the intra-laboratory and extra-laboratory coordination appears to be quite good. The only area where the reviewer would like to have seen improvement is in more explicit efforts to build a path for technology transfer of the ACI findings to multi-cylinder technology development at the OEM's or other partners who could support that next level of development.

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 asked the research team to please try to continue to develop the experimental aspects of this work and develop simple algorithms that could be employed by engine designers and calibrators.

Reviewer 2:
The reviewer stated that the future work for CFD and ACI combustion looks quite good. The reviewer would like to have seen some consideration of cold and hot operation on the boosted SI task, as those will be important for real-world performance of the fuels, including cold starting (especially when considering the cold real-driving emissions [RDE] testing for global-focused products).

Reviewer 3:
It seemed to the reviewer that toluene, being an outlier, presents an opportunity. The reviewer wanted to know what is it about toluene that makes it an outlier. The reviewer would have expected to see this issue identified as an important question for further study.

Reviewer 4:
As part of the "Reviewer-Only Slides" section (Slide 33), the reviewer noted that the research team states in the second bullet that "barriers associated with bringing a new fuel into the market on a mass scale can be overcome if the benefits to society and industry are sufficiently high." The reviewer asked how future work addresses benefits to both society and industry.

Reviewer 5:
In the opinion of this reviewer, while much of the proposed work is interesting, more could be done to increase the value and applicability of the work. The presenter mentioned that a primary goal of this work is to improve the ability to predict auto-ignition in SI and ACI combustion modes. A valuable outcome of these efforts would be tools or correlations to predict auto-ignition in SI and ACI combustion modes in a simple way (emphasis on "simple"). To say this differently, the reviewer noted that the most value is not derived from the researchers whose work is funded being able to predict auto-ignition with their data, software tools, and models; the most value is derived from the researchers helping others predict auto-ignition based on the things learned and developed. On a related note, despite being shown in various studies to not be a particularly accurate technique, the so-called octane index and K value have gained so much traction because they are the best things the industry currently has to try to predict how different fuels will behave. Thus, the reviewer commented that a sensible goal of these efforts would be to develop something one step more complex than the octane index that is meaningful for both SI and ACI.

Specifically, with regards to the CFD efforts, the reviewer would suggest exploring “extreme” engine cycles as generally those are the ones that produce knock events. For example, some past work has observed that the slower burning cycles tend to be the ones that have end-gas auto-ignition because in them the end-gas has more time to react. For this reason, the reviewer stated that looking at average cycles is not as meaningful and suggested that it would be helpful to focus on different extremes of engine cycles contained in the experimental data.

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

Reviewer 1:
The reviewer stated yes, these projects are supporting DOE’s efforts. Broadly, the goal of these efforts is to improve the ability to predict auto-ignition for SI and ACI engines, which is highly relevant for both combustion modes. By improving the understanding of these combustion modes, DOE’s objectives are supported.

Reviewer 2:
According to the reviewer, understanding the interaction between fuel characteristics and engine performance is relevant.

Reviewer 3:
The reviewer commented that this project aligns with DOE objectives. The CFD modeling approach can be beneficial to industry in the near term.

Reviewer 4:
The reviewer responded yes and requested that this work be translated to a simpler level for use by engine designers and calibrators.

Reviewer 5:
The reviewer had no specific comments.

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

Reviewer 1:
The reviewer said that the resources for these efforts appeared to be adequate.

Reviewer 2:
The reviewer commented that resources seemed adequate.

Reviewer 3:
This reviewer assumed that the resources are adequate because the program is demonstrating good progress.

Reviewer 4:
The reviewer indicted that the resources provided are sufficient to support the proposed future research.

Reviewer 5:
No specific comments were offered by this reviewer.

Presentation Number: ft070
Presentation Title: MM: Auto-ignition in MM/Advanced Compression Ignition (ACI) Combustion, Part 1
Principal Investigator: Magnus Sjoberg (Sandia National Laboratories)

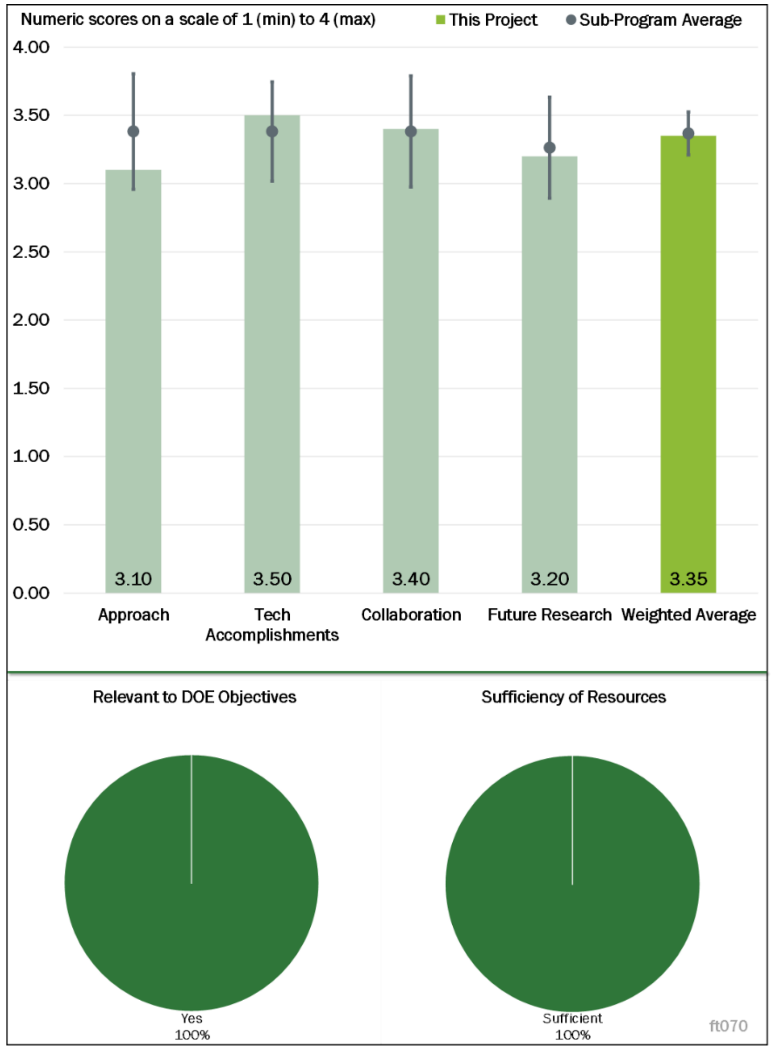

Figure 5-4 – Presentation Number: ft070 Presentation Title: MM: Auto-ignition in MM/Advanced Compression Ignition (ACI) Combustion, Part 1 Principal Investigator: Magnus Sjoberg (Sandia National Laboratories)

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 and well-planned.

Reviewer 1:

According to the reviewer, the approach is sound. There is a combination of optical and metal engines, high-fidelity CFD, and large data management to obtain the most relevant results. This work will be essential to enabling multi-mode, SI combustion.

Reviewer 2:

The reviewer observed that projects in the set are all carrying out useful studies and producing important findings about fuel property effects. Interdependence and synergies of the collection of projects toward a new integrated understanding of fuel effects on MM and ACI was also highlighted by this reviewer. Additionally, the reviewer commented that the overlap and interface between spark-assisted compression ignition (SACI), boosted SI, and ACI/LTC was fuzzy

Reviewer 3:

The reviewer remarked that these very high-quality engine studies and sophisticated CFD studies together can provide a good understanding of how to enable low-temperature combustion (LTC) and ACI combustion modes for a multi-mode (MM) engine. The reviewer found the experimental capabilities, which are linked to outstanding simulation capabilities, to be outstanding. The activities are very comprehensive, including linkage to basic fuel properties (e.g., heat of vaporization) to potentially support MM and ACI combustion. But in a mode-switching operation, the reviewer asked how the switching will be accomplished and managed. A missing element (which is perhaps at a higher technology readiness level (TRL) and is something that should be addressed by industry) to the reviewer was the role of a control strategy for mode switching, how smooth the spectrum of modes would be, and whether fuel can enable smooth transitions. It appeared to the reviewer that the current effort is focused on steady states. Much can be learned from steady-state studies; but to implement the outcomes from this work, the reviewer said that perhaps the approach can expand to include consideration of mode switching. Perhaps, the reviewer remarked, the data-mining task could include streamlined combustion simulation (e.g., a one-dimensional [1D] model) calibrated against detailed CFD and applied to simulation of mode switching across a driving cycle.

Reviewer 4:

The reviewer said that is a combined project of optical engine, metal engine, CFD, and data integration to address barriers pertaining to lean mixed-mode operation. The barrier does refer to controls, and there is not much activity on that end, according to the reviewer.

While piston-window imaging of the fuel spray is utilized for operating points of concern and occurs during skip-fired operation, the reviewer urged caution regarding interpretation of fuel film and spray-wall interaction results. The optical window has different surface properties (roughness being paramount) and thermal properties (conductivity, heat capacity, etc.), which will certainly influence the spray-wall interactions. While trend-wise agreement may exist between the metal and optical engines, the reviewer commented that the principal investigators do recognize inaccuracy of the absolute values.

According to the reviewer, results pertaining to desired fuel properties may be dependent on the exact combination of combustion modes chosen for mixed mode. This study utilizes a deflagration plus auto-ignition lean mode, which is much more heavily weighted toward deflagration than auto-ignition. The results elucidated here may not be relevant for studies that use a more kinetically driven lean mode, especially when it comes to desired fuel properties. The reviewer indicated that the participants may want to do the following: make these distinctions explicitly clear; collaborate with other groups whose lean mode combustion is more auto-ignition based to contrast and compare the desired fuel properties and performance; and determine crucial metrics of the fuel-dependent, lean mode combustion performance based on what type of lean mode combustion is implemented.

Reviewer 5:

Overall, it was not clear to the reviewer how, or if, the different tasks and approaches fit together within a cohesive effort, or how they are responsive to overcoming the technical barriers. For the optical engine work, the focus on the particulate matter index (PMI) and particulates does not seem well connected to the mixed-mode project focus. For the CFD simulations, it was not immediately clear to the reviewer what their contributions to the overall effort will be. For the overall focus on a given mixed-mode concept, it is important to categorize, from the start, not only the barriers to implementation, but also the opportunities for success with the particular concept. This includes how a final operating strategy might look, which operating regimes are possible, where an engine would operate in each mode, what limits operation in each mode, and rough projections of what overall efficiency improvements could be. The reviewer indicated that the Co-Optima program has an overall efficiency improvement target for mixed-mode combustion, and the tasks responsive to that area need to have a clear focus on how they will achieve that target, the barriers to reaching it, and what progress is required. Further, mixed-mode operation requires optimization of a fuel across two different combustion regimes so the extent to which fuel properties are pushed toward different values for each regime needs to be explored in detail. The reviewer said that emissions and any associated aftertreatment requirements must also factor into the analysis since this may change the overall optimal fuel properties.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer remarked that this was a tremendous amount of information to go over in 20-25 minutes (37 slides). Undoubtedly, information was completely missed just due to the time constraints of the short presentation window (and this was part one of three). If all portions are this dense, then five presentations may have been more adequate rather than three.

One accomplishment that stood out to the reviewer is the use of end-zone imaging to confirm the defiance of the PMI metric by several fuels. This is outstanding work—there could have been an entire presentation just on this result. Confirmation of the NO_x influence on auto-ignition while having a negligible influence on laminar flame speed is an archival result. The preliminary fuel search results that indicate that a four-component fuel may be enough for dual-mode operation are impressive.

Reviewer 2:
The reviewer said that significant progress has been made in exploring fuel impacts on PMI and weaknesses of those predictions, linking spray dynamics to piston wetting, and achieving good predictions of flame propagation and knock. Understanding fuel needs is very relevant to the overall Co-Optima progress toward enabling MM and ACI. The initial indications that fuel requirements are similar to those of conventional stoichiometric-boosted SI combustion is an important insight for fuel design. The reviewer stated that the milestones are on target, and this project continued to demonstrate very good progress.

Reviewer 3:
The reviewer found the technical progress on this project to be outstanding. The project is very coordinated and each aspect supports the others extremely well.

Reviewer 4:
The reviewer commented that the overall progress made over the previous year is substantial.

Reviewer 5:
The reviewer noted that accomplishments and discovery regarding PMI, measured particulate matter (PM), and fuel-engine characteristics are nice contributions, as is the octane requirement for SACI and ACI. The modeling work and data project outputs are a little vague on impact. The data analysis at LLNL to find fuels for MM is potentially impactful.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer remarked that coordination among the collaborators appears to be outstanding. There is considerable cross-sharing of results and the utilization of those results to guide future work.

Reviewer 2:
The project collaborators appeared to the reviewer to be working in concert.

Reviewer 3:
The reviewer noted that project collaborations cover a range of groups, including industry, universities, and National Laboratories.

Reviewer 4:
The coordination between the detailed experimental studies and simulation at ANL seems excellent. The collaboration between experiment and data mining yielded the SACI fuel requirement observation. Together the National Laboratory collaboration seems to be well coordinated and synergistic. The reviewer was unclear about the extent and depth of collaboration with other partners.

Reviewer 5:
The reviewer indicated that the project partners are all doing good research but the integration of tasks and sharing of data and findings in the influence of each partner activity is not very strong.

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 the effort to coordinate Laboratories and project for future research is very positive.

Reviewer 2:

The reviewer noted that this is a reasonable plan for future work. The reviewer would like to have seen a more detailed assessment of the mixed-mode concept to understand the overall opportunities available, and whether the efficiency benefits, operating range, and overall limitations make it a viable pathway moving forward, perhaps as a go/no-go decision point in the near future.

Reviewer 3:

The reviewer stated that the future proposed work in this project is very important. The only advice from the reviewer would be to take a bit more time to examine, not necessarily solve, but examine what technical barriers exist in moving this project from concept and low TRL toward a multi-cylinder engine. According to the reviewer, it is not necessary to resolve all of those issues but it would be very helpful to anticipate potential challenges and think about possible pathways toward resolution. This will be very important with moving to multi-cylinder engines and incorporating aftertreatment systems.

Reviewer 4:

According to the reviewer, the proposed future work should lead to additional important insights on fuel needs and benefits for MM and ACI. Fuel economy assessment from simulation of drive cycles will be valuable. However, the reviewer expressed interest in accounting for mode switching in real-time. The goal of fuel-property identification to support robust MM/ACI is quite limited if it only addresses steady-state operating points, due to the inherent transient nature of engine operation during a drive cycle. The reviewer indicated that the proposed work will be valuable and will provide additional new insights into in-cylinder conditions (thermal and fuel stratification) and knock and auto-ignition. The tools being employed will yield highly impactful outcome but there is a gap or missing link between these efforts and achieving the ultimate goal of fuel-engine improvements.

Reviewer 5:

The isolated comments regarding the Chemkin-GTPower model enhancement to account for thermal stratification were confusing to the reviewer. As this model was utilized for the MM preliminary fuel search, it is undoubtedly reduced order. Traditional Reynolds-averaged Navier-Stokes (RANS) models (whose thermal stratification would appear as squished concentric spheres at combustion-relevant times) will not display the proper combustion sensitivity to the imposed thermal stratification.

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

Reviewer 1:

The reviewer found this work to be highly relevant to developing the fuel science and combustion science to enable MM and ACI combustion processes. The depth of knowledge generation and the foundational science being explored will do much more than applied research could accomplish on its own.

Reviewer 2:

The reviewer remarked that this is exactly the type of project DOE needs to be doing.

Reviewer 3:
The reviewer indicated that finding the best roles for biofuels in future engines is an excellent path to reduced petrol dependence and overall lower GHG.

Reviewer 4:
The reviewer stated that enabling increased efficiency and the utilization of multiple combustion modes is in line with the DOE goals.

Reviewer 5:
According to the reviewer, the focus on understanding fuel effects for improved, clean, efficient transportation fits within overall 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 said that the funding seems adequate to achieve the project objectives.

Reviewer 2:
The reviewer found that the resources seem to be sufficient to continue progress.

Reviewer 3:
The reviewer said that all necessary resources are in place for this project's success.

Reviewer 4:
The reviewer remarked that overall resources are sufficient for the project scope.

Reviewer 5:
Although there are so many participants along with time-consuming coordination that one might look for economies and stretch funds for more impact and less churn, this reviewer described overall project team effort as impressive.

Presentation Number: ft071
Presentation Title: MM: Auto-ignition in MM/ACI Combustion, Part 2
Principal Investigator: Dean Edwards (Oak Ridge National Laboratory)

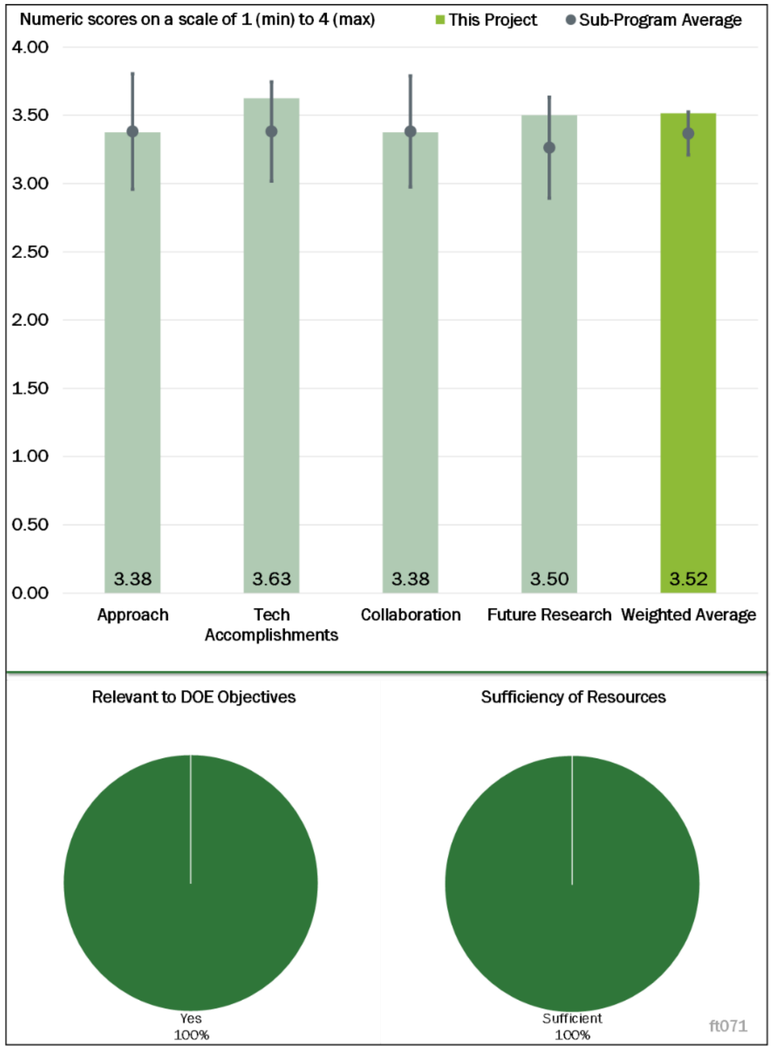

Figure 5-5 – Presentation Number: ft071 Presentation Title: MM: Auto-ignition in MM/ACI Combustion, Part 2 Principal Investigator: Dean Edwards (Oak Ridge National Laboratory)

Presenter

Dean Edwards, 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 and well-planned.

Reviewer 1:

This reviewer remarked that the research identifies an important part of the Co-Optima program—improving operational efficiency by implementing multi-mode combustion operation. The project team is doing this with a well-coordinated program of four projects, of which two are computational and two are experimental. Additionally, the reviewer observed a comprehensive program scope.

Reviewer 2:

The reviewer noted an excellent approach to better understand the large parameter space in MM combustion. Working on two separate engines and two separate simulation efforts that all link to each other is an excellent way to cover this space. The reviewer noted that it is also critically important to cover the sensitivity of these parameters to the combustion system operation; this information is critically important for industry to focus attention upon the parameters that have significant influence (fuel stratification, thermal stratification, etc.) versus other aspects that might be less important. According to the reviewer, understanding these tradeoffs is extremely important.

Reviewer 3:

The reviewer found that the project seems to need constant adjustment based on new findings. This gave the reviewer the impression that the overall project is less organized and planned.

Reviewer 4:

Due to the condensed nature of the presentation (there is a lot of work in here), it was difficult for the reviewer to fully assess the work approach. That being said, the project aligns well with the barriers listed.

What was unclear to the reviewer is if the CFD approach to capture the global trends across the full ACI spectrum includes all of the appropriate parameters in the appropriate range. It was unclear how these parameters were selected. In addition, it was unclear to the reviewer how these results will be incorporated into experimental efforts and how the timeline of these and other CFD efforts interact with the experimental work. The reviewer asked how well global trends can actually reflect ACI operation and what kind of accuracy is required in the models.

The reviewer remarked that the fuel economy estimates of ACI in a limited range of the engine operating map are interesting; however, they are less relevant without considering the transition between ACI and SI. Transitions will be a critical part of utilizing ACI and the proposed work seeks to address that, but it should be stated that the conditions relevant to ACI and SI can be fairly different. The reviewer asked what the strategies are to enable mixed-mode operation, and added that this is part of the foundational science that needs to be developed in this program.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that progress has been quite good to this point and should be even better when the GM single-cylinder engine (SCE) comes fully online at ORNL. One suggestion for improvement is to better delineate precisely which aspects of the work are SI and ACI and which aspects are engine related, rapid compression machine (RCM) related, and mode line related. This reviewer commented that those delineations were a bit unclear in the presentation.

Reviewer 2:

The reviewer found this to be very nice work. The project team has demonstrated levels of improvement that might be achieved by implementing multi-mode operation; run a wide range of engine and operational parameters exploring multi-mode operation; evaluated the fidelity of the computational predictions, including the kinetic routines; and shown the importance of "practical" issues that must be addressed before such approaches can be implemented, such as in-cylinder heat transfer and thermal stratification.

Reviewer 3:

This reviewer indicated that each sub-project is making progress in computational methodology or experimental measurements and the project team is moving toward the stated goals.

Reviewer 4:

The reviewer explained that fully portraying the great work being accomplished in this project is difficult given the volume of work being captured in this presentation. The reviewer suggested to further breaking up the presentation, elongate the presentation time, or add more detail to each project in the reviewer-only slides. The reviewer anticipated difficulty with referencing this document in the future and taking much from it. The reviewer also noted that the ability to sample denser regions of interest for global trend evaluation in the ACI space is a good feature that will yield higher success rate in discovery.

This reviewer asked how the experiment parameters at ORNL are selected and inquired about the ranges. This information is not in the material, which prompted the reviewer to request clarity on whether these parameters are influenced by the CFD results and, if so, how timely the CFD and experiments are linked. Conversely, the reviewer asked whether the experiment carries on with its assumptions and the CFD model running in the background, with the results are compared and contrasted ex post facto.

The reviewer indicated that a good result of using the RCM instead of real engine conditions in order to determine boost requirements was achieved. This will accelerate data generation and understanding. The finding that RON and sensitivity do not fully capture fuel reactivity in ACI modes was certainly interesting to the reviewer and needs further work. As this result is aligned well with the Co-Optima goals, it is a good result. However, the reviewer expressed interest in knowing how significant the finding is and how representative it is when used in fuel blends. The reviewer asked if there are other competing effects that might wash out any difference in fuels, as is suggested in the analysis of alkylate and E-30 fuels.

The reviewer questioned how well the kinetic mechanisms are correlated to the RCM data shown in Slide 14. Specifically, this reviewer inquired about the tuning parameters and criteria for determining model validation, as well as how the researchers can be sure they are capturing all of the important reaction pathways when branching out to different fuels. Also, simply stating the chemical kinetics were updated does not address what the problem was the first time around; additional details on such comments might be helpful for other researchers. Furthermore, the reviewer commented that the plot axes on Slide 14 need more clarification and definition in case this document is referenced in the future.

The discovery of thermal stratification was very interesting to the reviewer, who suggested that the project team should be aware of work by Benjamin Lawler (a professor at Stony Brook University) on similar discoveries.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer stated that the collaborations are responsible for the excellent results.

Reviewer 2:
The reviewer found the coordination to be reasonable even though there are duplications in computational tasks.

Reviewer 3:
The reviewer remarked that this is a fairly comprehensive project team that leverages several key contributors and organizations. The reviewer noted that a bit more clarity in defining which work and organization are contributing which technical work would be helpful in future presentations, especially how the major take-away messages from each project link and support each other.

Reviewer 4:
It appeared to the reviewer that the partners are well-coordinated; however, the interaction and how timely the interactions take place were not well-addressed. The presentation comes off as “there are some experiments occurring over here, and there’s some simulation work over there.” The reviewer knew that the partners are working together, but it just was unclear in the presentation, particularly because the reviewer was interested in the interaction at ORNL.

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 said that future plans are a logical continuation of their current state.

Reviewer 2:
Future plans were described by this reviewer as reasonable and logical toward the goals.

Reviewer 3:
The future directions of this project looked to be well-developed and relevant to the reviewer. Better understanding the relative importance of the input parameter space is critically important to understanding the tradeoffs needed to make any of these ACI systems commercially viable. This reviewer remarked that some

types of problems are much easier or cheaper (or both) to solve and others are more difficult and/or more expensive. The opportunity to create a robust and effective combustion system depends upon proper understanding of these perturbations and tradeoffs.

Reviewer 4:
The reviewer indicated that proposed future work is logical based on the findings presented, and will help to address the barriers appropriate for this technology. It was the opinion of this reviewer that particular emphasis should be placed on transitions between ACI and SI, as well as the impact of thermal stratification. It was unclear where the focus on pre-chambers came from in future work. The reviewer asked if this work is meant to utilize ongoing work in other projects or whether it would be another request for funding, and suggested that it would be more cost effective and timely to investigate what other researchers have achieved in pre-chamber experiments.

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

Reviewer 1:
The reviewer commented that this project is very important to the potential development of a commercially viable MM or ACI combustion system.

Reviewer 2:
According to the reviewer, this work is important for understanding the challenges of achieving multi-mode combustion and what fuel properties will support or exploit its implementation.

Reviewer 3:
The reviewer stated yes, this work addresses DOE objectives by investigating the impacts of fuel properties and engine conditions on ACI in an effort to improve fuel consumption.

Reviewer 4:
The reviewer asserted that the project supports Co-Optima goals.

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

Reviewer 1:
Because the researchers are making good progress and meeting research objectives, it seemed to this reviewer that the project has sufficient resources.

Reviewer 2:
The reviewer remarked that the resource allocation seems to be sufficient to ensure future progress.

Reviewer 3:
The reviewer observed sufficient resources in each team member.

Reviewer 4:
Although perhaps a little low on the experimental side, overall funding seemed sufficient to this reviewer. It was unclear why or how the funding for experiments is equal to that for simulation work. The reviewer asked where the resources are going in simulation.

Presentation Number: ft072
Presentation Title: MM: Auto-ignition in MM/ACI Combustion, Part 3
Principal Investigator: Chris Kolodziej (Argonne National Laboratory)

Presenter

Chris Kolodziej, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

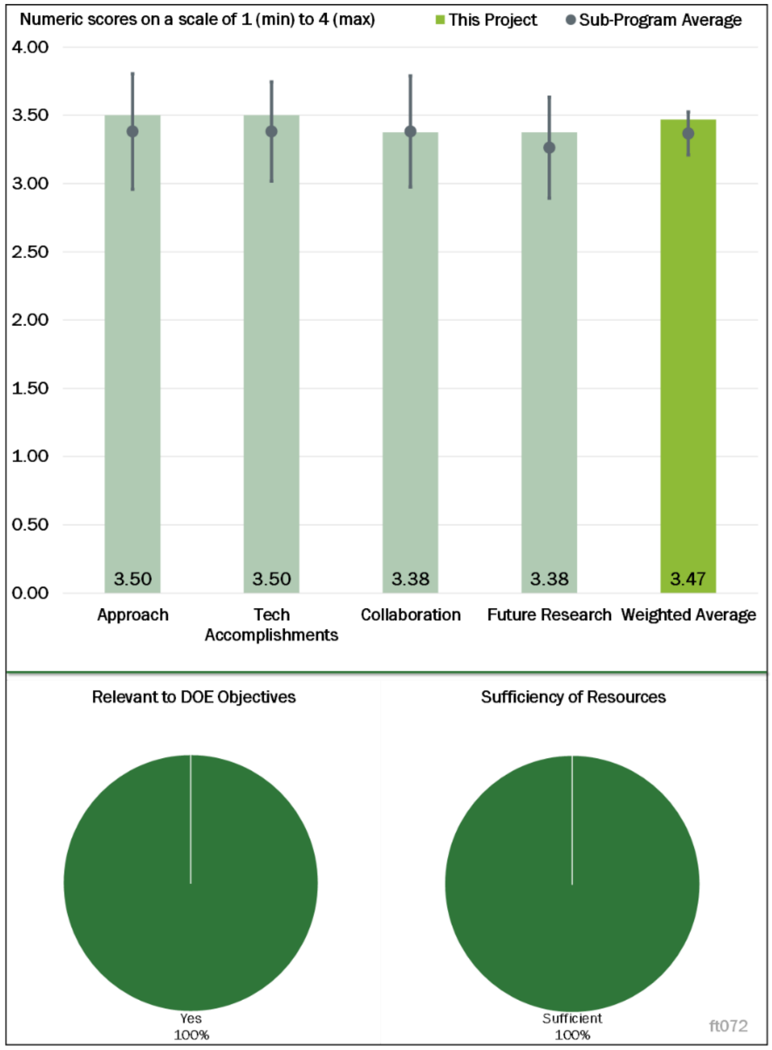

Figure 5-6 – Presentation Number: ft072 Presentation Title: MM: Auto-ignition in MM/ACI Combustion, Part 3 Principal Investigator: Chris Kolodziej (Argonne National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer commented that the approach to this work is extremely thorough and scientific. There is substantial technical detail in the work at SNL and ANL. Once NREL’s work fully comes onboard, this project should have a fantastic blend of the fundamental and more applied research. In addition, the reviewer indicated that this project has a basis in compression ignition engines, which should lead very well into the changing Co-Optima focus for larger engines in the HD space.

Reviewer 2:

The reviewer noted that the approach is well-focused on developing scientific understanding of fuel properties and characterization metrics, using complementary experimental and computational tools.

Reviewer 3:

Regarding SI and ACI multi-mode, this reviewer highlighted fuel properties on auto-ignition for SI knock mitigation and ACI phasing control, as well as a combination of engine experiments, fuel rating metrics, and CFD. These approaches seemed sound to the reviewer, who further commented that the value proposition of utilizing a modified CFR engine for HCCI-like fuel characterization is appealing.

Reviewer 4:

The reviewer noted that this group of project activities uses a range of engine experiments, homogeneous charge compression ignition (HCCI) engine (CFR engine-based) studies, numerical simulation, and kinetics optimization to develop the understanding of how fuel properties can be designed to enhance full-time ACI (and SI and ACI mixed mode to a lesser extent, it seemed). The base engine platform appears to be a compression ignition engine (diesel engine). According to the reviewer, the presentation could do more to explain how this builds on past DOE-supported work under the Advanced Combustion Engine activities (e.g., Ciatti and co-workers) and the base of understanding on which the current work is expanding.

During the presentation, it was unclear to the reviewer what was meant by LTGC and its relevance to the other modes on which DOE Co-Optima typically has focused. The reviewer wanted to know if this is gasoline compression ignition or HCCI-like operation and how LTGC is different from ACI or gasoline compression ignition (GCI). The reviewer asked why this acronym was added to the standard terminology, to which it was explained during the Q&A that LTGC is ACI with controlled levels of stratification. It did not seem justified to the reviewer to call this a distinct mode. Co-Optima has already introduced vague and overlapping combustion-mode definitions. This reviewer suggested consistency with the rest of Co-Optima for the future by calling it ACI, or MM and ACI.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer indicated that new experimental capabilities (a diesel single-cylinder engine) were added, extensive fuel characterization in a CFR engine (HCCI) led to correlation of CFR engine results and HCCI engine results, and good agreement is being demonstrated between a numerical simulation of the CFR engine and experiment. The simulations shed light on the inherent thermal stratification in the CFR engine, which can help with interpreting results from these engines. Using the CFR engine, detailed knock measurements with a piezoelectric cylinder pressure sensor were compared and correlated against the CFR knockmeter. The reviewer commented that these measurements also revealed fundamental differences in the behavior of primary reference fuels (PRFs) versus other fuels in knocking across a range of stoichiometry. The reviewer found this to be is a very enlightening result, which can assist with interpreting RON and MON as measured using traditional instrumentation, and it could help with understanding knock resistance and auto-ignition behavior under lean conditions relevant to ACI. Also, the reviewer stated that the team built an understanding of how the LTGC experiment conditions relate to the MON test to better interpret the impact of OI.

Reviewer 2:

The reviewer praised the technical progress at ANL and SNL as outstanding. The NREL work is ramping up and it should add significant value to the overall project. The technical detail that was presented is exactly the type of work this DOE program should be producing. The reviewer said that the very thorough, very extensive data and modeling correlation leads to much better understanding of how MM combustion systems link to one another and how fuel properties can enable this opportunity.

Reviewer 3:

The reviewer noted several important discoveries or findings related to fuel characteristics, such as the reason for difficulties with octane index and other impacts of phi and fuel chemistry. The publication output is impressive, which is important for low TRL work.

Reviewer 4:

This reviewer reported that a fuel blend was created (as a proof of concept) by blending selected high-performance fuels with 87 octane research gasoline (RD5-87) to enhance both the RON and phi sensitivity. While the enhancement of performance was slight, this is an encouraging result. The reviewer asked whether RD5-87 was the “right” starting point and whether there is an indication of how much phi sensitivity could be imposed on a current fuel.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

Once all members of this project team fully come online, the reviewer enthused that it will be outstanding, with the right team members performing the right tasks. This reviewer emphatically highlighted the excellent team on this project.

Reviewer 2:

The reviewer found that the NREL, ANL, and SNL collaborators are heavily integrated.

Reviewer 3:

The reviewer commented that it was good to see collaborations with private sector organizations outside the laboratory project team, which is indicative of some value to industry. The direct interdependence between laboratory activities is okay, but not strong. On the positive side, the laboratory efforts are synergistic and combine to create a body of knowledge relevant to the key barriers and questions.

Reviewer 4:

The reviewer stated that there seems to be limited interaction between the sub-groups that comprise this project team. There was some amount of integration between the sub-groups (shown in Slide 9) to compare the results from work at ORNL and SNL against the CFR engine. However, the reviewer commented that this presentation gave the overall impression of distinct projects that were only loosely connected through mutual interest in gasoline-like fuel ignition behavior.

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 indicated that this project may have the best future work opportunity because the project team members cover the entire space from the very fundamental to the applied, with simulation support. It is the only MM project that focuses on compression ignition without a spark plug in all regimes. The reviewer remarked that this is of primary importance to the non-automotive community.

Reviewer 2:

Expanding initial tests across a broader range of conditions (phi, boost, temperature) was reported by this reviewer.

Reviewer 3:

The relevance to biofuels seemed to have faded in this set of projects, according to the reviewer; perhaps that is okay in the overall Co-Optima plan. There is a general question about establishing the impact of the findings, to which the reviewer suggested assessing or tracking where the new data might have an impact, even in the nearer term.

Reviewer 4:

The reviewer described proposed future work as largely continuing the ongoing work, but also launching and beginning to utilize the single-cylinder diesel engine to explore gasoline property impacts on full-time ACI. Particularly, application of the CFR engine (through simulation) to test validity of the central fuel hypothesis is an exciting element of the future work plan. The reviewer commented that this hypothesis would seem to be very weak when contemplating the potential behaviors of many fuels considered under the Co-Optima program. The hypothesis breaks down for toluene and would be expected to break down for furanic species, which have highly non-linear blending octane numbers. The only concern expressed by the reviewer was whether the simulations have access to sufficiently robust kinetic mechanisms to capture the synergistic and antagonistic behaviors between fuels relevant to Co-Optima.

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

Reviewer 1:
The reviewer indicated that the project is very relevant to full-time ACI and MM and ACI fuel and engine development.

Reviewer 2:
The reviewer commented that this project very firmly supports DOE goals and objectives. The fundamental understanding and the potential to understand how that information can be applied (in the future NREL work) is very exciting. The reviewer asserted that this is the type of project DOE should be supporting.

Reviewer 3:
The reviewer remarked that the projects strive to determine optimal fuel properties for next generation of co-optimized engines.

Reviewer 4:
The reviewer noted that the project addresses overall DOE objectives for enhanced fuel efficiency.

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

Reviewer 1:
According to the reviewer, resources seem adequate to achieve the objectives of these projects.

Reviewer 2:
The resources for this project appeared to be sufficient for ensuring future progress from this reviewer’s perspective.

Reviewer 3:
The reviewer stated that the team appears to have all necessary resources for successful project completion.

Reviewer 4:
The reviewer indicated that a “sufficient” label is assigned, but suggested considering whether it is the best use of funds to set up additional SCE Laboratories where there are quite a number already across the laboratories and universities. Previously, concern has been expressed over redundant capabilities.

Presentation Number: ft073
Presentation Title: Co-Optima Emissions and Emissions Control for Spark Ignition /ACI Multi-Mode Combustion
Principal Investigator: Josh Pihl (Oak Ridge National Laboratory)

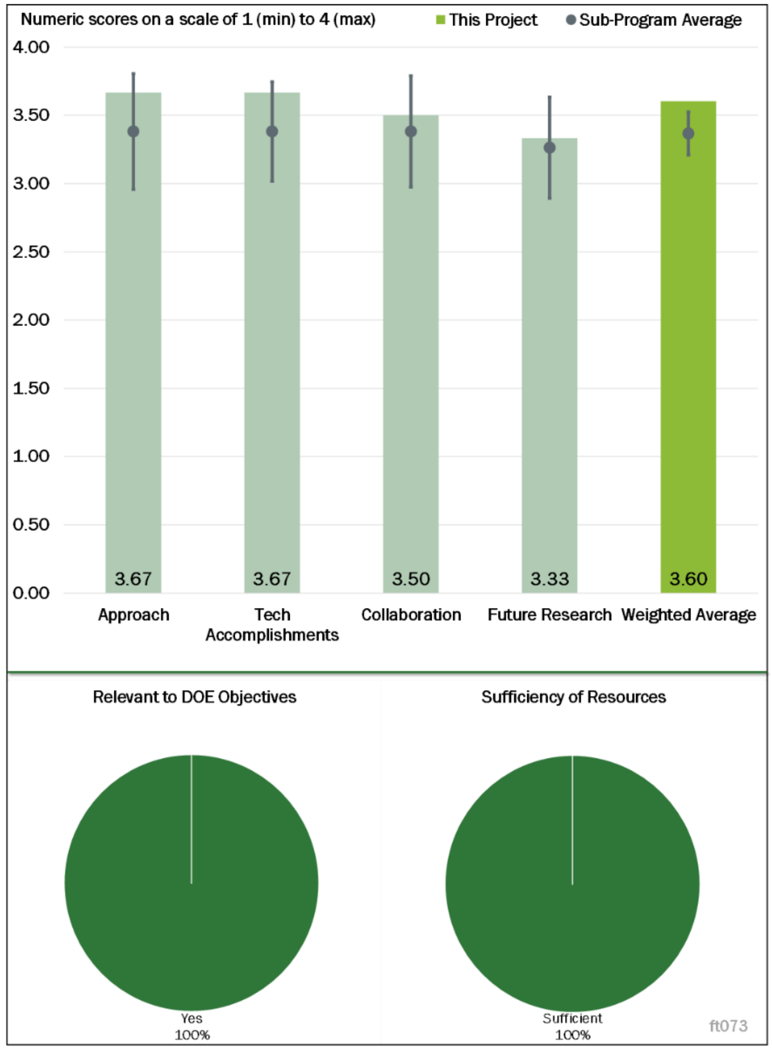

Figure 5-7 – Presentation Number: ft073 Presentation Title: Co-Optima Emissions and Emissions Control for Spark Ignition /ACI Multi-Mode Combustion Principal Investigator: Josh Pihl (Oak Ridge National Laboratory)

Presenter
Melanie Moses-Debusk, Oak Ridge National Laboratory

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 and well-planned.

Reviewer 1:
According to the reviewer, use of a wide range of laboratory tools at Oak Ridge to see how various fuels affect emissions and emission control devices is the approach needed and the one chosen.

Reviewer 2:
The reviewer remarked that finding how fuels couple with advanced combustion to impact emissions is a good and important approach. The work on finding fuel composition impacts on catalyst light-off is quite important, given the push for higher amounts of ethanol in gasoline. The reviewer suggested that it will be useful to add or somehow align with engine and vehicle testing.

Reviewer 3:
Overall, the reviewer stated that the approach is solid to address key technical barriers. Studying particulates (PM and particle number [PN]) is an important area for both ACI and SI engines when looking at future emissions regulations. The reviewer indicated that this needs to be reflected in the aftertreatment system (ATS) layouts (i.e., whether a gasoline particulate filter [GPF] or diesel particulate filter [DPF] is required to meet Euro7, RDE, and super ultra-low emission vehicle 30 [SULEV30]), and that it would be a key motivation factor.

The reviewer commented that it is good to study the stratification and fuel effects together. When doing so, the reviewer explained the importance of holding certain engine operating parameters constant (e.g., CA50, EGR rate) among different fuels. In addition to PM, it will also be interesting to look at PN. The reviewer commented that the investigation also needs to be expanded into a wider speed and load range. The impact of ethanol content on particulates and hydrocarbon (HC) emissions is also a good area to study. Additionally, this reviewer noted that the approach for catalyst light-off is excellent and described it as well-planned and having strong technical value.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer reported that emissions from a range of blendstocks have been quantified for their levels of stratification in ACI combustion modes. Using up to 30% Co-Optima blendstocks, it has been shown that the new fuel will neither deteriorate nor improve emissions in a very strong way in emissions testing. The reviewer further explained that this will occur because most of the emissions of concern are related to aromatic HC content, which does not change that much.

Reviewer 2:

The reviewer found that the project is identifying the impact of the combination of advanced combustion and fuel properties on emissions. Results generated so far are already valuable. From an aftertreatment perspective, it is an important finding that small perturbations (0%-30%) of fuel composition (ethanol, aromatics, etc.) do not affect the three-way catalyst (TWC) performance. The reviewer suggested that it will be good to add at least two more data points—such as at E50 and E85—to generate a curve of light-off temperature versus ethanol (and similarly, aromatics) content. Also, generating a clear list of speciation, especially under cold start, will be useful to guide HC trap development.

Reviewer 3:

The reviewer remarked that good progress has been made toward achieving the project objectives. The experimental data on the makeup of hydrocarbon and PM are important for developing proper oxidation catalyst, GPF units, and their operating strategy. It is a nice accomplishment to provide insight into the fuel constituent effects on TWC light-off.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer observed an excellent collaboration and indicated that the project has a rich collaborative environment because it is under Co-Optima. It will be very useful to tap into this for extending study results to engine transient levels.

Reviewer 2:

The reviewer commented that an exceptionally large range of collaborators are connected and commenting on the goals and approach in this project, including 9 National Laboratories, more than 20 universities, and more than 80 companies with a stake in this research area.

Reviewer 3:

The reviewer said that it is good see the dissemination of the results through the Cross-cut Lean Exhaust Emissions Reduction Simulations (CLEERS) initiative and directly to OEMs and suppliers. It would be very encouraging if collaboration among the Co-Optima project teams can be demonstrated.

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 asserted the importance of seeing how new blendstocks will affect emissions in various combustion modes, and measuring how emissions from various blendstocks affect low-temperature light-off capabilities of several catalyst formulations under lean conditions. Stoichiometric conditions will need to be included as a reference.

Reviewer 2:
Overall, the reviewer described future work as well-planned. Referring to the ACI study, it would be nice to see it expand to a wider engine operating range (e.g., 1,300 revolutions per minute [rpm] at2 bar and 2,000 rpm at 10 bar). Also, the impact of ethanol content would be good to investigate.

The reviewer stated that catalyst light-off in the ACI mode is another key area that needs to be investigated. Perhaps the two project teams can work together to address both engine operating strategy for the light-off and feedstock impacts on the light-off behavior.

Reviewer 3:
The reviewer suggested that the project team consider adding a couple more data points to the TWC light-off versus ethanol and aromatics study and also extending this to engine and vehicle studies. Because future gasoline aftertreatment systems will include a GPF, it may be useful to analyze the impact of fuel properties on particulates (already underway), ash, and any impact of GPF filtration.

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

Reviewer 1:
According to the reviewer, this is a critical area that not only helps guide the catalyst development at OEMs and suppliers, but also provides insight and influences engine operating strategy. It supports the DOE objectives very well.

Reviewer 2:
The reviewer indicated that the key area this project covers that is very relevant to DOE goals is knowing how the chemical and physical properties of newly developed fuel blends impact emissions in various combustion modes and with various emission control systems.

Reviewer 3:
The reviewer pointed out that fuel properties are tightly linked to engine combustion and the resulting fuel economy and emissions. A coupled study of fuels and emissions is quite important to the overall DOE goal of improving fuel efficiency and meeting strict tailpipe criteria pollutant targets.

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 this project appears to have good access to many probes of fuel impact on emissions due to the skill set of the researchers on the project and the tools that are set up in the approach to the project.

Reviewer 2:
The reviewer found that there are adequate resources to achieve the project millstones.

Reviewer 3:

The reviewer remarked that the project seems to be well resourced. The project team may consider adding limited vehicle testing on transient test cycles to ensure there are no surprising results that were not obvious under laboratory conditions.

Presentation Number: ft074
Presentation Title: MM: GDI Sprays
Principal Investigator: Lyle Pickett (Sandia National Laboratories)

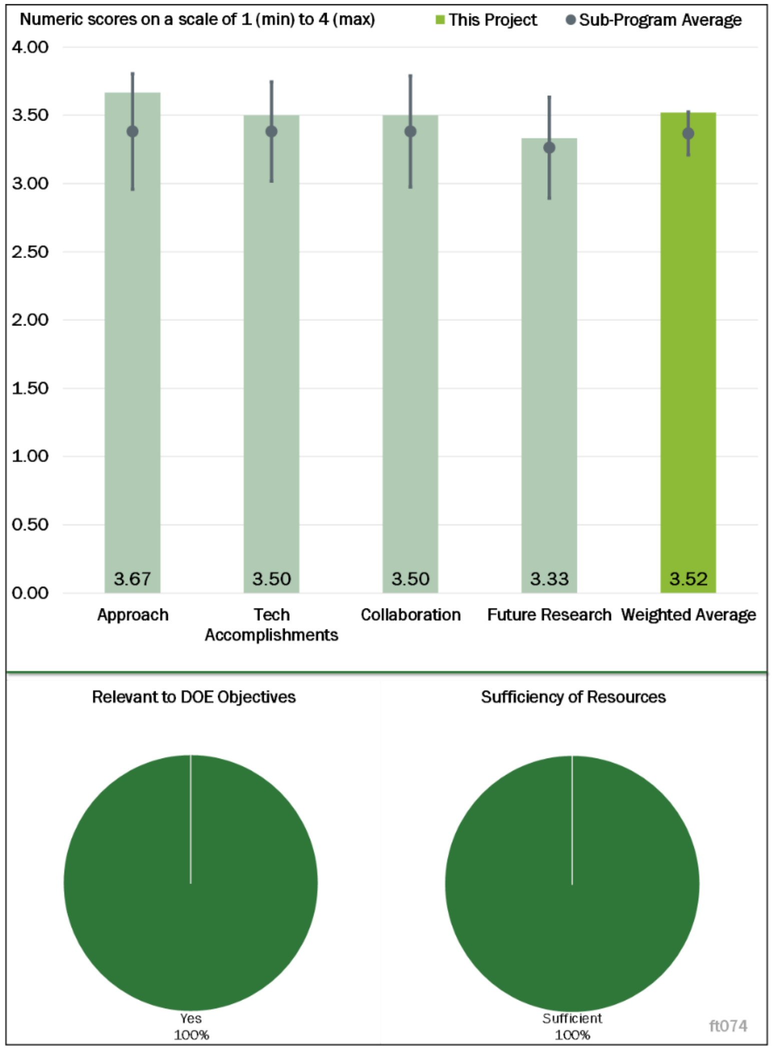

Figure 5-8 – Presentation Number: ft074 Presentation Title: MM: GDI Sprays Principal Investigator: Lyle Pickett (Sandia National Laboratories)

Presenter

Lyle Pickett, 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 and well-planned.

Reviewer 1:

The reviewer was impressed and could not suggest any improvements.

Reviewer 2:

The reviewer found the plan to be very logical and well planned. The three projects fit together very well to support each other.

Reviewer 3:

The reviewer commented that the approach of working with collaborators to understand fuel spray by evaluating the detailed studies of optical measurement of fuel effects and plume-to-plume interaction, X-ray measurement of quantitative in- and out-nozzle flows for CFD validation, and their volume of fluid (VOF) code development is good. However, the reviewer said that it would be nice to have had an open source CFD platform code to implement and test the improvements, which is very helpful for use in academia.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The technical accomplishments and progress are both outstanding. The reviewer could not think of any improvements that could be made.

Reviewer 2:

The reviewer noted that the project team has pursued and shown success in a broad range of sprays. The reviewer would like to have seen what can be done for transient sprays using the X-ray measurement. It seemed to the reviewer that the measurement of key elements in sprays is advanced while CFD of the model is not enough to support the physics found in the experiment.

Reviewer 3:

The reviewer commented that the new chamber is working and the new diagnostics show great promise of creating good data and good results. The X-ray is very helpful in looking at the near tip area fuel mass although the image intensity differences for the different fuels are a bit strange since the spatial distributions are similar and the fuel flow rates are the same. According to the reviewers, the results from coupled level set volume of fluid (CLSVOF) modeling of the atomization process show the promise of the method, but it might need improvements to reproduce the experimental results.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer found excellent coordination among the teams.

Reviewer 2:

The reviewer commented that the time available for the presentation was too short to allow the speaker to discuss collaboration and coordination in detail, but what the speaker did say in this regard certainly made it appear that collaboration and coordination are both commendable.

Reviewer 3:

The collaboration level seemed to be adequate to the reviewer but requires more data exchange and feedback between experiment and simulation.

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 said that future plans include the desirable improvements in each area.

Reviewer 2:

The reviewer found the work plan for the future to be good. The reviewer suggested continuing to work on CFD model improvement and seeing the 3-D liquid volume fraction for the asymmetric multi-hole spray injection.

Reviewer 3:

The time available for the speaker to address this point was very limited. Subsequently, the reviewer did not get much feel for this aspect.

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

Reviewer 1:

The project seemed to the reviewer to be well-aligned with DOE objectives, and their development will serve the community to better understand advanced spray systems, especially multi-hole spray injection.

Reviewer 2:

The reviewer mentioned that the research being conducted by the teams at the various National Laboratories is quite relevant to the overall DOE project objectives because they are investigating and assessing the effects of fuel formulation on the combustion process. Obviously, this links fuels and engines.

Reviewer 3:

The reviewer said that it supports the Co-Optima goals.

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

Reviewer 1:
It seemed to the reviewer that the resource appears to be adequate.

Reviewer 2:
According to the reviewer, there are sufficient resources in each team.

Reviewer 3:
The reviewer saw no areas for which the available resources are excessive.

Presentation Number: ft075
Presentation Title: MM: Fuel Kinetics
Principal Investigator: Scott Goldsborough (Argonne National Laboratory)

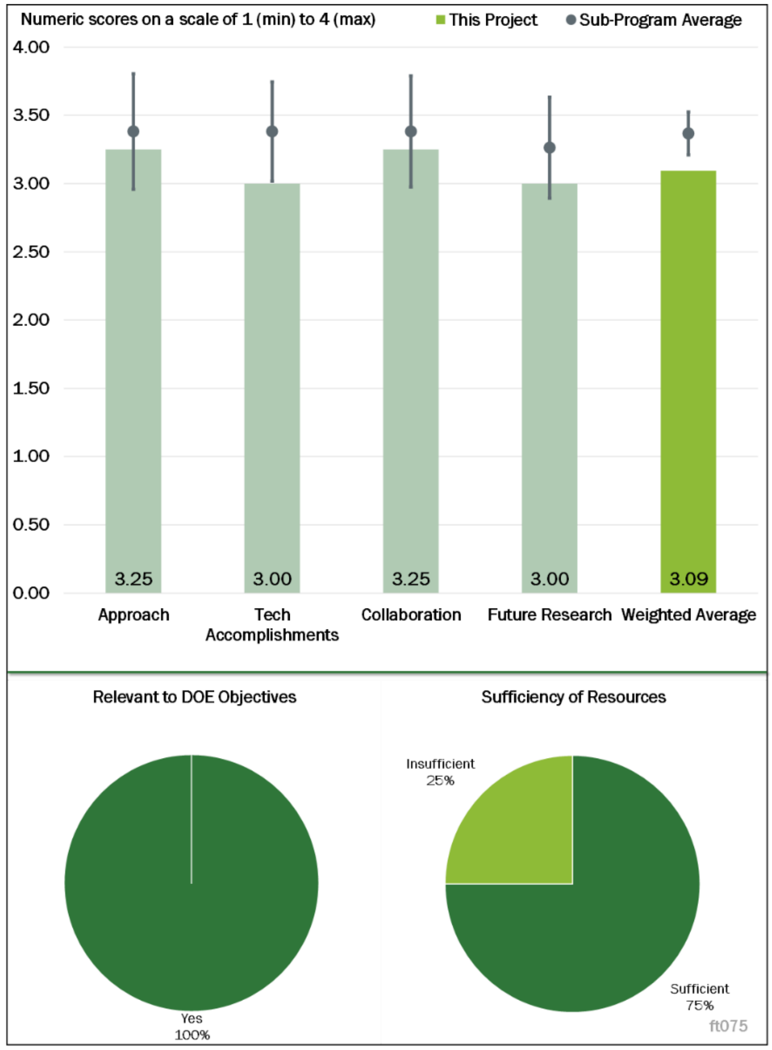

Figure 5-9 – Presentation Number: ft075 Presentation Title: MM: Fuel Kinetics Principal Investigator: Scott Goldsborough (Argonne National Laboratory)

Presenter

Scott Goldsborough, 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 and well-planned.

Reviewer 1:

This project uses a combination of kinetic studies of fuels of relevance to Co-Optima to develop relevant kinetic mechanisms, models for fuel property blending, ignition quality metrics, and fuel pyrolysis mechanisms. This is done by using datasets from fundamental auto-ignition experiments, prediction and validation of fuel properties, and quantification of fuel reactivity as a function of various parameters under relevant operating conditions. By closely coupling the kinetics studies to experimental and numerical studies for fuel structures and mixtures of relevance to the Co-Optima program, this set of projects will assist DOE in meeting its goals and develop robust and relevant outcomes.

Reviewer 2:

The reviewer noted this work systematically addresses advancing the development of chemical kinetic routines and blending models for candidate surrogates. These will be instrumental in developing metrics and merit functions for assessing the behavior of fuels in advanced combustion regimes.

Reviewer 3:

The reviewer reported that the project follows a reasonable approach. Development of kinetic mechanisms for new Co-Optima fuels, predicting and validating key properties and blending behavior, and quantifying reactivities at relevant timescales are all within scope and appropriate to support overall Co-Optima objectives.

Reviewer 4:

The reviewer asked for a definition of blendstocks and how these blends are being modified for better understanding of "controlled" chemical kinetics.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer found that the project team has made substantial progress during this year that has pushed understanding and kinetics available for understanding fuel impacts on mixed-mode and ACI combustion. RCM measurements and kinetic modeling studies captured the ignition impacts of iso-alcohols. According to the reviewer, good comparisons were generated for polycyclic aromatic hydrocarbon (PAH) formation during fuel pyrolysis, showing that blends of fuels lead to higher PAH than linear blending would predict. Modeling and experiments relevant to multi-mode combustion were completed to quantify phi sensitivity of relevant fuels.

Reviewer 2:

The reviewer noted that the project team has made good progress in achieving the objectives for the LD, multi-mode focus of the program. Progress on these objectives for the MD and HD sector is not as advanced. Looking at MD and HD issues associated with reducing emissions, particulate matter, and/or NO_x is a smart thing to do. The project team is still early in this part of the program, according to the reviewer.

Reviewer 3:

The reviewer commented that solid progress was made over the past year although several milestones in 2019 were delayed.

Reviewer 4:

The reviewer said that RCM databases will not provide the foundation to understand the chemical kinetics of the proposed "blendstocks."

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewed commented that this project includes extensive collaboration with researchers across the National Laboratories, with various universities, and internationally. These activities support many other activities under Co-Optima and thereby have a large and beneficial impact.

Reviewer 2:

The reviewer declared that Co-Optima seems to be setting the standard for collaboration.

Reviewer 3:

The reviewer said that there were good collaborations within the Co-Optima team, but the reviewer would like to have seen more collaborations outside of this space, along the lines of the collaborations listed as being outside VTO.

Reviewer 4:

This reviewer remarked that ANL should be a collaborator to provide fundamental chemistry involved in the "blend." A "blend" cannot be studied as if it were a single molecule "blend."

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 continuing work will explore broader ranges of conditions, including EGR dilution, and a range of phi and conditions. For the spectrum of combustion modes, the work will extend the ability to simulate combustion behavior as functions of dilution, phi, EGR, etc.; extend soot models to quantify formation and oxidation; and refine fuel metrics for specific combustion modes.

Reviewer 2:

The reviewer would like to have seen MD and HD issues listed in a more prominent position on the list of future research. The reviewer remarked that it is important for Co-Optima to make an assessment of whether fuel property manipulation can offer benefits for the MD and HD sector. If it cannot, that is a good thing to know, and the project team can put the issue to bed. If it can, there will most likely be a lot of work that will be to be done to understand the potential, and the project team will need to get busy.

Reviewer 3:

The reviewer said that proposed future research looks appropriate, but was concerned about the ability, or timeframe, to develop and refine a fuel metric for mixed-mode ACI given that experimental studies on mixed-mode ACI are only starting and are highly divergent in approaches.

Reviewer 4:

The reviewer referenced prior comments.

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

Reviewer 1:

The reviewer indicated that chemical kinetics underpin combustion, auto-ignition, and pollutant formation. Therefore, understanding reaction kinetics and having a robust means of describing and predicting them is fundamentally important to developing advanced fuels and advanced engines. The relevance of this activity is very high, and it is an essential, enabling component of the overall Co-Optima research effort.

Reviewer 2:

The reviewer commented that Co-Optima is relevant and these projects are a relevant part of Co-Optima.

Reviewer 3:

The reviewer remarked that foundational research on fuel properties supports Co-Optima mission and overall DOE objectives.

Reviewer 4:

If the collaboration is expanded, then the reviewer stated that the work can surely provide more insights into combustion efficiency.

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

Reviewer 1:

The resources seemed to be adequate to the reviewer to achieve the project objectives.

Reviewer 2:

This reviewer described overall resources as sufficient for deliverables.

Reviewer 3:

The reviewer said that the project team is doing good work. If more resources could help the team assess whether fuel property manipulation can benefit the MD and HD sector, then it could be money well-spent.

Reviewer 4:

The reviewer commented that enlarging and expanding chemical kinetics databases are necessary to reproduce experimental results.

Presentation Number: ft076
Presentation Title: Advanced Numerics and Modeling.
Principal Investigator: Matthew McNenly (Lawrence Livermore National Laboratory)

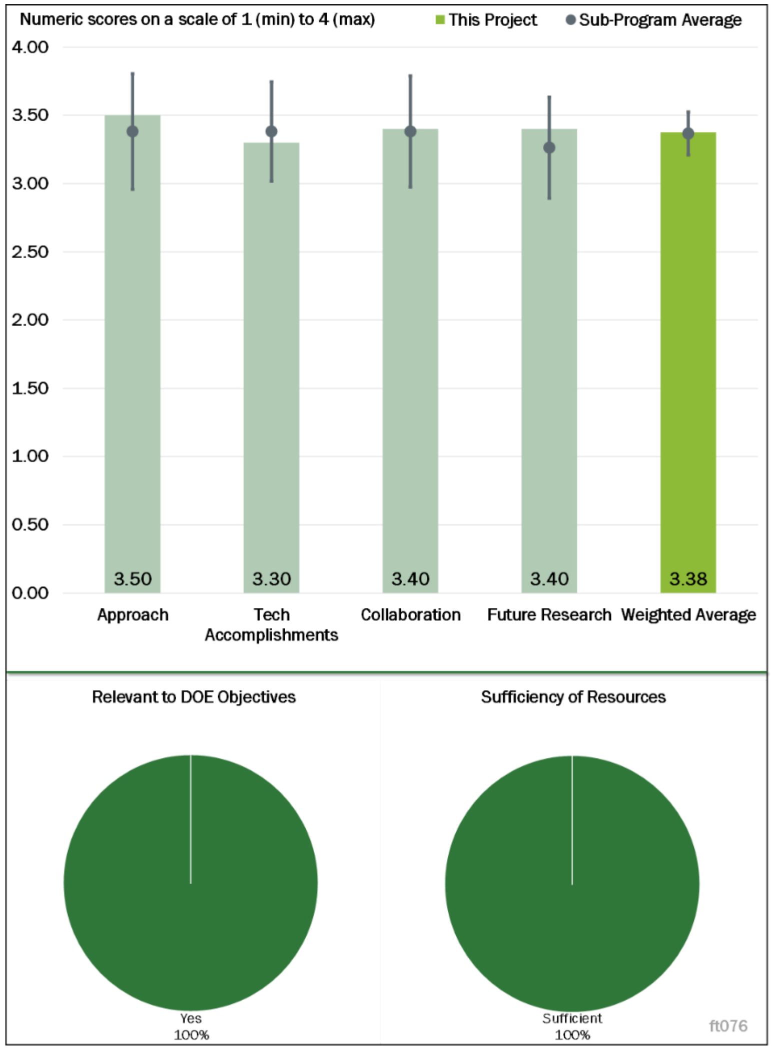

Figure 5-10 – Presentation Number: ft076 Presentation Title: Advanced Numerics and Modeling. Principal Investigator: Matthew McNenly (Lawrence Livermore National Laboratory)

Presenter
Matthew McNenly, Lawrence Livermore 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 and well-planned.

Reviewer 1:
According to the reviewer, the approach of this work is fantastic. It was nice seeing an effort to develop rapid screening tools for combustion properties of fuel blends that so nicely couples with the central fuel hypothesis. Because this work's foundation is solidly rooted in the two hypotheses outlined by the Co-Optima program, the directions taken by the program have significantly impacted the overall program. Additionally, the reviewer noted that the project team uses a number of different tools in order to achieve the project goals, allowing for optimization of the overall process and more likely success. The strong collaborations throughout the project ensure that the approach continues to have impact.

Reviewer 2:
The reviewer said that the approach is well designed and planned to enable fast testing to find optimal fuel combinations.

Reviewer 3:
The reviewer found the approach worthwhile to develop a "middle model" to explore several fuel compositions using detailed kinetics while managing computational cost. Similar to other LLNL tools, the reviewer asked whether these modeling tools will be available for download by the wider community similar to the announcement for Zero-order Reaction Kinetics (Zero-RK).

Reviewer 4:
The reviewer commented that it is the most appropriate approach to design the fuel screening tool, assuming the surrogate fuel models are accurate enough. The use of high performance computing (HPC) is a great idea

for this highly parallelable problem. The reviewer also suggested that one potential improvement is to utilize CFD simulation results to better interpolate what the project team has learned.

Reviewer 5:
The reviewer stated that the combination of kinetic modeling and engine pressure trajectory provides a feasible approach to evaluate fuel properties, such as RON and MON for different compositions. However, the results are limited by the large uncertainties associated with the kinetic mechanism, including uncertainty in the rate constant and activation energy, missing key pathways and physics, and incomplete kinetic interaction among different compounds. It was therefore not clear to the reviewer what the fidelity of the simulation is. The blending effect of, for example, ethanol on RON and MON is also largely dependent on the engine operating condition, which has to be further addressed. On the other hand, the reviewer said that for a mixed-mode direct injection spark ignition (DISI) engine, flame propagation subject to mixture stratification is essential, which unfortunately is insufficiently addressed.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:
The reviewer indicated that the results shown at this year's Annual Merit Review (AMR) indicate significant success in the project thus far. In particular, comparisons with both detailed kinetics and engine data show the progress of this method and its promise for a fuel screening tool. Further, the progress toward publication and open use of Zero-RK is fantastic and will have a significant impact on the industry. The reviewer encouraged the PIs to continue in this vein during the next year.

Reviewer 2:
The reviewer remarked that many advanced combustion processes employ the use of multiple fuel injection events to control heat release rates and asked if multiple injection can be accounted for in the current approach.

Reviewer 3:
Results of the improved Neutral Network Octane Model looked impressive to the reviewer. The GT-Power plus multi-zone, auto-ignition model approach enables fast turnaround time for testing a great amount of fuel mixtures. However, spray effects on the multi-mode combustion can be significant and may not be able to be overlooked.

Reviewer 4:
Although this reviewer indicated that the project seemed to be on track toward its overall goa, the reviewer expected to see results on uncertainty quantification of the simulation, suitable accommodation of mixing and flame propagation in the computationally efficient metric, as well as validation against DISI engine experiment in the future. Additionally, a more suitable performance metric has to be defined for other modes such as ACI and mixed-mode for fuel screening. The fact that fuels with the same RON and MON can perform differently does not necessarily invalidate the central fuel hypothesis because it is probable the key fuel property has yet to be correctly identified.

Reviewer 5:
According to the reviewer, solid progress has been made on improving RON and MON predictions. A comparison to the King Abdullah University of Science and Technology (KAUST) neural network (NN) model might not be a good example because it was designed for a different purpose.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer remarked that the level of collaboration is excellent among laboratories, stakeholders, and universities.

Reviewer 2:
According to the reviewer, there is significant collaboration on this project both in the National Laboratories and across the community. Collaborations with those doing more detailed kinetics helps strengthen the underpinnings of the method; collaborations with experiments ensure the success of the method. The reviewer commented that there is also nice collaboration with the university partners in Co-Optima, particularly Pennsylvania State University.

Reviewer 3:
The reviewer found that the project involves a coordinated effort between the modeling at LLNL and engine testing at SNL.

Reviewer 4:
The reviewer observed good collaboration within the team members.

Reviewer 5:
A wide range of collaboration and coordination has been conducted, which this reviewer emphatically described as a very good job. One area that has potential is to establish a streamlined process connecting to CFD. Once the fuel model recommends one or two fuels, the surrogate model can be quickly formulated and shared with CFD collaborators for initial evaluation. Of course, the reviewer stated, this has to rely on accuracy of the kinetic model.

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 the proposed future plans can move the projects closer toward the desired goals.

Reviewer 2:
The reviewer noted that the future research is clearly outlined and continues to put the program on a great path toward making future impacts relative to both the fuel and engine hypotheses. Particularly, the work with both more detailed chemical modeling and experiments will aid in ensuring program success.

Reviewer 3:
The reviewer said that the proposed research looks complete and had no further comment.

Reviewer 4:
Future research appeared aligned with Co-Optima goals; however, the reviewer suggested that it may be good to include “stretch” goals of applying this tool to higher priority industry concerns. For example, given that the kinetics approach leverages the GT-Power framework, the reviewer asked whether there is any plan to extend the chemistry modeling farther downstream in the exhaust to simulate transient combustion products entering the aftertreatment system.

Reviewer 5:
The reviewer summarized the suggested future work: uncertainty quantification of the simulation; proper accommodation of flow, mixing, and flame propagation in the computationally efficient metric for multi-zone DISI; validation against the DISI engine experiment; and an improved performance metric, in addition to the conventional RON and MON.

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

Reviewer 1:
The reviewer indicated that the PI clearly linked this work back to both the central fuel and central engine hypotheses; these are clearly the guiding principles of the work. As such, this work's relevance is clearly linked back to the goal of the Co-Optima program. Further, this reviewer commented that making the Zero-RK tool publicly available is an important step toward knowledge dissemination.

Reviewer 2:
According to the reviewer, this project aligns with DOE objectives with particular emphasis on developing advanced modeling tools.

Reviewer 3:
The reviewer commented that this project supports the Co-Optima goals.

Reviewer 4:
An efficient fuel model is very necessary to quickly screen the fuel options for certain engine architecture, which supports overall DOE objectives from this reviewer's perspective.

Reviewer 5:
If successful, the reviewer noted that the proposed work helps to design and screen fuels through fast computations, which certainly supports the overall objectives of Co-Optima and the DOE.

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

Reviewer 1:
The reviewer observed sufficient resources provided to support the proposed future research.

Reviewer 2:
Sufficient resources in each team were noted by this reviewer.

Reviewer 3:
The reviewer stated that resources outlined are sufficient for continuing program success.

Reviewer 4:
Combining all the collaboration and coordination stated in the presentation, the reviewer found that the resources are sufficient for the project.

Reviewer 5:
Project resources seemed to be sufficient from this reviewer's perspective.

Presentation Number: ft077
Presentation Title: Heavy-Duty Mixed-Controlled Compression Ignition (MCCI): MCCI and Ducted Fuel Injection, Part 1
Principal Investigator: Charles Mueller (Sandia National Laboratories)

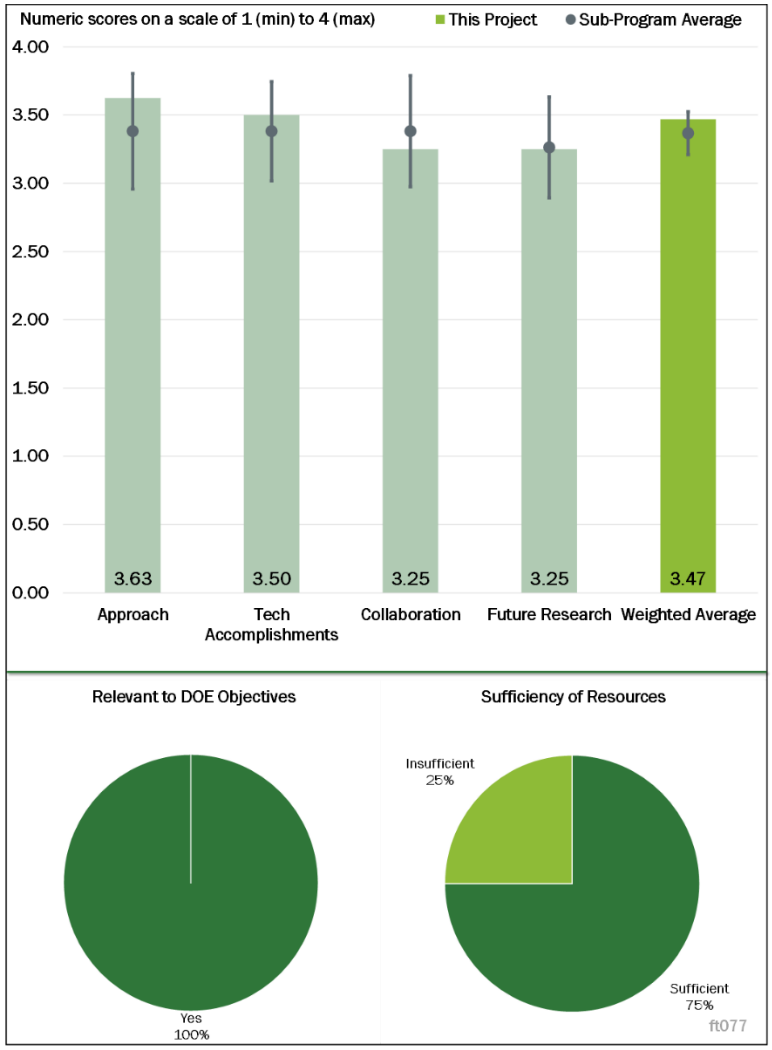

Figure 5-11 – Presentation Number: ft077 Presentation Title: Heavy-Duty Mixed-Controlled Compression Ignition (MCCI): MCCI and Ducted Fuel Injection, Part 1 Principal Investigator: Charles Mueller (Sandia National Laboratories)

Presenter

Charles Mueller, Sandia National Laboratories

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 and well-planned.

Reviewer 1:

Although this presentation covered a lot of work, the reviewer was most impressed by the Skeen soot work. The experimental approach undertaken to separate the effects of mixing was extremely clever.

Reviewer 2:

The reviewer remarked that the approach to this work is good, although some additional CFD support (if it were present, it was not shown) would be useful in understanding the fluid mechanics boundary conditions of ducted fuel injection (DFI). The reviewer praised the Scott Skeen collaboration as very valuable. This project has done a decent job of identifying the influence of biofuel blends upon DFI, but it may be fruitful to investigate some of the spray effects related to the different fuel properties and their combined influence on DFI combustion.

Reviewer 3:

Overall, the reviewer observed sound approaches for both tasks (ducted fuel injection and sprays) toward addressing the key technical barriers. The DFI approach is innovative and shows good potential on improving the NO_x-soot tradeoff. Because HD engines operate heavily at medium-to-high loads, a high-load demonstration will be critical. The reviewer suggested that it would be beneficial to provide sufficient clarification on the sector (on-highway or off-road) for which DFI is best suited because each sector has its own criteria pollutant standards that drive different engine-out emissions targets and aftertreatment layouts. Potentially, this may be a promising technology to address the proposed future California ultra-low NO_x standard.

The decoupling approach for sprays study is also well laid out and on track to achieve the technical goals. The reviewer commented that operating boundary conditions need to be clarified and representative of those in key HD engine operating points.

As part of Co-Optima, the reviewer remarked that in-depth analysis needs to be conducted on fuel effects. For DFI, optical diagnostics and CFD analysis should be considered to gain insight into the physical and chemical effects associated with fuel oxygenation. For the sprays study, fuel selection needs to be clearly defined.

Reviewer 4:

The reviewer described the approach as a very interesting physical method to achieve the long liftoff length combustion that Siebers and Pickett have shown in the past and was not realized through injector design alone. The work done in this past year has been really nicely focused on addressing the barrier in a way that is at least buildable and testable in the engine so as to evaluate the DFI concept more fully.

The reviewer thought that it is important, in a project like this, to spend some time to more fully define the barriers than what is written in the roadmap documents. The reviewer asked what should the engine-out NO_x and soot targets should be and explained that zero is the canonical answer, which is not really attainable. Philosophically, there does not seem to be any way to actually eliminate aftertreatment. Regulations tend to move in the direction of encouraging or forcing the use of all available technology, additively, to achieve the maximum reduction possible. Subsequently, the reviewer explained that the goal should be to build the science base that lets industry determine the optimum combination to achieve regulatory aims (so some in-cylinder emissions reduction to reduce the aftertreatment burden). That also leaves room for optimizing for other factors (efficiency, durability, drivability, and so on). Specifically, for this project, the reviewer was unsure that zero soot or zero NO_x is the real target. It is more to show some kind of “cost” to reduce each in terms of each other, brake-specific fuel consumption (BSFC), and so on.

The reviewer also noted that DFI does appear to be a really strong knob for soot, which is great. Now, the need is to identify jet-jet interaction and other factors as the system moves toward a full injection system that can achieve the required indicated engine mean effective pressure (IMEP).

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer observed outstanding accomplishments on both the DFI and soot work.

Reviewer 2:

The reviewer found good progress made on DFI to investigate the fuel oxygenation effects. This can be further extended to different engine speed, engine load, and EGR dilution conditions in the future to provide a more comprehensive picture. As a new start, the reviewer commented that the sprays study also shows good initial progress.

Reviewer 3:

The reviewer acknowledged substantial technical progress on this project. The ability to use dilution without a soot penalty is a valuable characteristic to this combustion system. The optical diagnostics have been utilized to better understand the combustion system and soot formation. The reviewer stated that more integrated CFD information and DFI spray information would have been good to see, however.

Reviewer 4:

The reviewer noted very promising results as well as the main areas needed to quickly close gaps: pushing toward a study of jet-jet interactions with DFI to more fully measure the PM and PN emissions and facilitate emissions accuracy with respect to regulatory requirements; and looking at jet-wall interactions under this new combustion regime.

Additionally, the reviewer would like to have seen a broader study of the effect of hydrogen (H_2) pilot on soot production. The free jet experiment is quite interesting, and there are methods for generating H_2 on board the vehicle. The reviewer asked whether the effect of H_2 spatial is what demands a specific injection location, or if there are ways to use this effect that are more compatible with typical engine geometric constraints.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer would like to have seen one of the modeling laboratories brought in to try and bring analytical tools to bear on the DFI system, and one of the laboratories with PM and PN expertise brought in to dig farther into the soot production aspects of DFI. Even with that said, the industry links are outstanding; the fastest way to vet this project's technologies are to subject them to OEM scrutiny and engineering to see how DFI fits into production constraints.

Reviewer 2:

The reviewer noted that the collaborators on this project are appropriate but this project would have benefitted from some additional support from CFD and spray work. The reviewer said that the coordination among current collaborators is quite good and the prospect of future collaborators in industry also appears strong.

Reviewer 3:

The reviewer commented that the project, overall, has good plans for collaborations with other National Laboratories, universities, and OEMs. For CFD analysis, a certain level of mechanism reduction is likely needed. This will need to be reflected in collaborations. For the sprays' study, the reviewer stated that the ECN would be a good platform to consider for information exchange and collaboration. As the project progresses, it would be nice to incorporate contributions from the different collaborating parties in the presentation.

Reviewer 4:

Although there is strong collaboration among the laboratories, this reviewer noted little university involvement.

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 proposed future research is well aligned with the remaining barriers.

Reviewer 2:

The reviewer liked all of the proposed tasks for the coming year and encouraged the quick addition of investigation of other DFI physical effects, particularly jet-jet interaction, but also the impact of injection strategies that reflect real engine operation (cold starting, transient, etc.). Those need to be understood early on to determine if the DFI concept is robust in all of the variable space the engine will cover.

Reviewer 3:

The future work plan looked reasonable and sound to the reviewer. There are plans for industrial collaborators and to include more support from other parts of the Co-Optima program. The reviewer said that it would be good to have seen a bit more investigation into recovering as much BTE as possible, however. Trading a potential emissions solution for a slight efficiency hit is a tough sell to industry. If there are geometry or fuel injector opportunities to allow ignition and combustion away from the walls and reduce the potential for heat transfer, the reviewer opined that this project will have substantial appeal to OEMs.

Reviewer 4:
The reviewer indicated that future work is planned reasonably well to address the remaining technical challenges and barriers. For DFI, higher load engine testing would be important. Proper diagnostics and CFD analysis would be beneficial to better understand the fuel effects. For the sprays' study, the reviewer stated that experiments need to be conducted at HD-relevant conditions as much as possible. Parallel CFD analysis and spray and soot model development will also be important.

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

Reviewer 1:
The reviewer commented that this project is quite relevant to DOE goals of improving engine use of biofuels and reducing emissions.

Reviewer 2:
The reviewer observed strong alignment with DOE objectives.

Reviewer 3:
The reviewer stated that this project addresses the key barriers in HD mixing-controlled combustion, thereby offering good support to the Co-Optima goals and overall DOE objectives.

Reviewer 4:
The reviewer indicated no specific response.

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

Reviewer 1:
The reviewer said that the resources are sufficient to achieve the project milestones and address the technical barriers.

Reviewer 2:
Resources seemed sufficient to this reviewer.

Reviewer 3:
It appeared to the reviewer that support work for this project in CFD and sprays may be resource limited. This project needs to have sufficient resources to explore the parameter space in DFI and fuels to ascertain whether DFI has a real opportunity to become commercialized.

Reviewer 4:
No specific response was indicated by this reviewer.

Presentation Number: ft078
Presentation Title: Heavy-Duty MCCI: MCCI and Ducted Fuel Injection Part 2
Principal Investigator: Christopher Powell (Argonne National Laboratory)

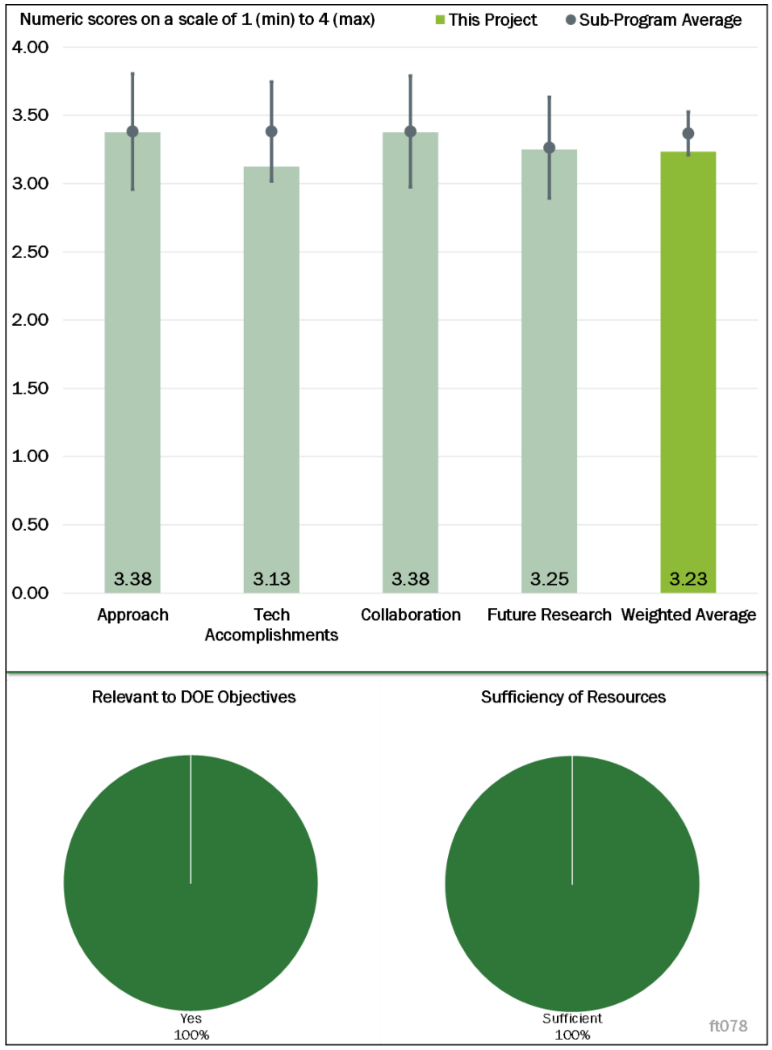

Figure 5-12 – Presentation Number: ft078 Presentation Title: Heavy-Duty MCCI: MCCI and Ducted Fuel Injection Part 2 Principal Investigator: Christopher Powell (Argonne National Laboratory)

Presenter

Christopher Powell, 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 and well-planned.

Reviewer 1:

The reviewer commented that the approaches are clearly articulated and focused on important issues that could impact a fuel's suitability to MD and HD applications and possible operational benefits that could be achieved with changes in fuel characteristics. The projects are just beginning; it is a good start.

Reviewer 2:

Although the reviewer understood the reason for the project title, something should be done, if possible, to make it more reflective of the project as it has now been reformulated. Frankly, the reviewer has a much higher regard for the proposed research than what the title would seem to indicate.

The reviewer stated that controlling cold start emissions is indeed a hot topic for diesel manufacturers. Some focused scientific research as proposed here could be very beneficial for providing alternative solutions to the standard approaches that have provided limited success to date. The approach here appeared sound, drawing upon various areas of expertise that the various DOE laboratories have to offer, although the reviewer hoped that multidimensional simulation will be used for more than just cavitation and erosion studies.

Reviewer 3:

The reviewer indicated that the in-cylinder approach for reducing emissions is relevant for catalyst light-off and catalyst heating. Mixing and cavitation studies are also undertaken to study fuel compliance. Although a single-hole study is a great starting place, the study should move to multi-hole, eventually. Overall, the reviewer commented that this was another 25-minute "fire hose" presentation outlining multiple projects. The reviewer noted that it may have worked in Year 1 of the project, but there will be too many results to make a single presentation feasible in Year 2.

Reviewer 4:

The overall approach seemed reasonable to the reviewer, although a number of the tasks do not seem well aligned with the overall Co-Optima mission. Cavitation work seems especially disconnected from key Co-Optima objectives. The focus of cetane number (CN) and cold-start experiments on very high cetane renewable diesel may not be a complete framework for identifying overall cetane impact on cold start given the vast differences in fuel properties beyond CN. The reviewer suggested including fuels with cetane levels covering a range closer to the baseline fuel level.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer pointed out that this is the first year for these projects and the early results are impressive.

Reviewer 2:

Considering that work has just begun on the revised project, the reviewer described progress to date to as acceptable.

Reviewer 3:

The reviewer remarked that projects are moving along nicely for the first year, and reported accomplishments to date: facilities upgrades completed to facilitate project task; oxygenated blends showed reduced total hydrocarbon emissions, although post-injection sooting impacts still need further investigation; erosion propensity has been predicted for several fuels; initial measurements detailing fuel effects on cavitation for a Spray C were successfully captured; and the model qualitatively agrees with the experimental findings.

Reviewer 4:

While recognizing this is a new effort, the reviewer commented that overall progress is limited. The March milestone is listed as 60% complete, which is an effort that is clearly behind.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said that the work is very well coordinated with the collaborators.

Reviewer 2:

Collaboration among Ford, SNL, ANL, NREL, and University of Central Florida (UCF) appeared to the reviewer to be effectively communicating.

Reviewer 3:

From the presentation, it appeared to the reviewer that excellent resources at ANL, ORNL, and SNL are all being brought to bear on the subject in a generally well-balanced effort. As previously noted, the reviewer thought that simulation could have a greater role beyond that stated to include looking at combustion, emissions, and perhaps even catalyst operation (light-off, etc.).

Reviewer 4:

The reviewer encouraged more extensive collaborations with outside partners, whether they be universities or industry.

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:

According to the reviewer, the project objectives appeared well aligned to shed insights on identified barriers.

Reviewer 2:

This reviewer commented that early results indicate there are impacts of changes in fuel properties for MD and HD applications. Future work appeared to be focused on appropriate questions that further assess the extent to which fuel properties can offer MD and HD sector benefits.

Reviewer 3:

The reviewer commented that it may be easier to see as work progresses, but the plan as stated is reasonably good. However, the reviewer was not sure that cavitation is necessarily a bad thing in the injection process although certainly erosion is a bad thing. The reviewer wondered if other approaches to solving the cold-start problem will be considered downstream.

Reviewer 4:

The reviewer found the proposed future approach to be a satisfactory extension of ongoing efforts. For the CN-focused effort, the reviewer would like to have seen conventional petro-diesel fuels in a more moderate range of cetane number tested, as opposed to blends of the two bookend fuels. For the cavitation measurements and simulation, the reviewer remarked that more extensive experimental measurements are required to validate the simulations. Recognizing the challenges of achieving longer tests for erosion, these appear crucial to overall program progress and success, and therefore, need to be prioritized.

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

Reviewer 1:

The reviewer stated that Co-Optima is relevant and this is a relevant part of Co-Optima. Understanding the potential of improved performance via fuel property changes in the MD and HD market is an important component of Co-Optima.

Reviewer 2:

The reviewer remarked that the project aims to develop a comprehensive understanding of fuel sprays, combustion, and emissions.

Reviewer 3:

The reviewer commented that the program is aligned in support of overall DOE objectives for clean and efficient transportation.

Reviewer 4:

The reviewer noted that controlling emissions certainly is part of overall DOE objectives as is promoting alternative fuel use. However, little was said in the presentation about considering the proposed solution's efficiency impact.

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 appear adequate for proposed research.

Reviewer 2:
The reviewer found that the project team has the necessary resources to address its objectives.

Reviewer 3:
Program resources for the project scope appeared sufficient to the reviewer.

Reviewer 4:
The reviewer commented that progress is good. It seemed that the researchers do not seem to be experiencing undue hardship because of a lack of resources.

Presentation Number: ft079
Presentation Title: Expanding the Knock/Emissions/Misfire Limits for the Realization of Ultra-Low Emissions, High-Efficiency, Heavy-Duty Natural Gas Engines
Principal Investigator: Dan Olsen (Colorado State University)

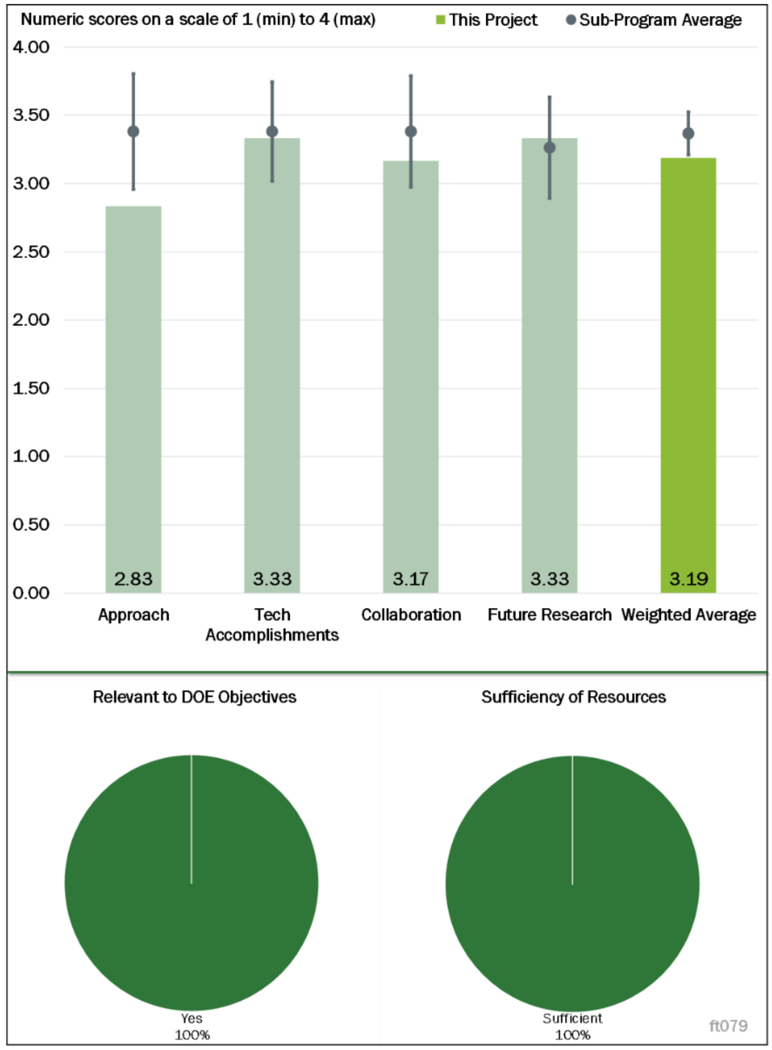

Figure 5-13 – Presentation Number: ft079 Presentation Title: Expanding the Knock/Emissions/Misfire Limits for the Realization of Ultra-Low Emissions, High-Efficiency, Heavy-Duty Natural Gas Engines Principal Investigator: Dan Olsen (Colorado State University)

Presenter

Dan Olsen, Colorado State 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 and well-planned.

Reviewer 1:

After years of experimentation, the reviewer asserted that the natural gas engine industry has converged on the optimal design with a compression ratio (CR) equal to12 and high dilution with optimal operational points close to the intersection of auto-ignition and forced ignition. This project aims to push on these boundaries by using a technology mix of higher CR, higher dilution by EGR, mixed-mode ignition, and higher turbulence. The reviewer described the projection of being able to achieve a 6% improvement in efficiency as rather optimistic, even a stretch. Also, the proposed end-gas auto-ignition (EGAI) along with large engine control module (LECM) require use of six-cylinder pressure transducers that can add an additional $12,000 to an engine that costs approximately $30,000.

Reviewer 2:

The research plan was logical to the reviewer and appeared to have steps that follow one another: RCM and kinetic model development; CFR and further model development; and 2.5 liter (L) SCE experiments. The reviewer's concern was that there was little attention given to the EGAI. This phenomenon appears to be a given that the project team can cause EGAI to occur and it can be controlled, although reviewer viewed it to be a fairly stochastic process. The reviewer encouraged the investigators to study the work in Co-Optima by Magnus to see if that research on end-gas ignition can be applicable to the project team's work.

Reviewer 3:

The approach has a lot of good elements, but it was unclear to the reviewer how they all fit together. There is a lot of effort being spent to get a reduced chemical kinetic mechanism working, including some fundamental rapid compression machine experiments. This was done in an effort to match the ignition delay kinetics. However, the reviewer said that the engine validation completed so far has been done at light engine loads that are not knock limited. It may sound simple to say that predictive knock modeling is the next step in the process, but the reviewer remarked that there is a big leap in going from the current status to predicting mild knock, knowing that knock-limited engine operating conditions have only about 10% of the cycles that knock. Thus, the reviewer did not think that there is a really strong pathway where an improved chemical kinetic mechanism will lead to higher efficiency in the engine.

On the other hand, the reviewer thought that there is a lot of opportunity to increase efficiency with improving this engine's fluid dynamics. A HD engine has a low charge motion combustion chamber, which leads to a slow flame kernel development process and ultimately, high cyclic variability. The reviewer believed that the path described in the presentation—investigating higher swirl configurations—will only have a limited impact. For spark-ignited engines, high tumble is more effective at increasing combustion rate and reducing cyclic variability, but that does not seem to be part of the work flow for this project. The reviewer thought that the higher tumble will be necessary to increasing the EGR rate for the engine, which is one of the major paths to increase efficiency. The passive pre-chamber spark plugs may help with this, but they will also likely have increased heat losses relative to a conventional spark plug.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer said that the project is still at an early stage, but early progress has included significant results with regards to the rapid compression machine, kinetic mechanism development, CFR engine, and modeling of the CFR engine. In terms of how impactful this early-stage progress is to meeting the efficiency goals, the reviewer noted that that will not be clear until the later stages in the project when these work flows are contributing toward improving the performance of the Cummins natural gas engine.

Reviewer 2:

In the first year, the reviewer noted that a smaller NG mechanism was developed, and it proved successful in validating measurements conducted in a RCM. This mechanism also proved successful in validating tests in a CFR engine via 3-D CFD modeling. According to the reviewer, this offers promise toward 3-D CFD modeling that will be used later in the project to optimize piston geometries for the single-cylinder engine.

However, the reviewer commented that the effort and presentation are very thin on details of the pre-chamber spark plug, technologies to be used for higher turbulence, ways to push the boundaries of knock, etc., that are the main focus of the proposed effort.

Reviewer 3:

The progress seemed very good to the reviewer for the first year of a complex, multi-party program. There was not much detail on how far Cummins had progressed in their construction of the SCE, which influenced this reviewer's score. The RCM work and the CFR work has made excellent progress in less than a year.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

In the first year, the reviewer commented that most of the work involved bench-scale testing and kinetic and CFD model development by Colorado State University (CSU). The deployment of LECM by Woodward, though important, is somewhat routine. However, the reviewer found the development of a single-cylinder engine by Cummins to be important as it paves the way for work to be conducted in the coming years.

Reviewer 2:

CSU appeared to the reviewer to have done most of the work to date. There was no clear evidence to the reviewer as to what Woodward or Cummins has contributed to date, although they have deliverables later in the project. The PI appears to be communicating well with the partners though.

Reviewer 3:

According to the reviewer, the collaboration team certainly has the right elements. Cummins and Woodward are the right partners to include in this team. The reviewer noted that it would be good to have seen enhanced interactions with Cummins on assisting with advanced combustion chamber design. Having a path toward a higher tumble combustion chamber would help the project. It would also be helpful to have more of a clean-sheet piston design. Based on the presentation, it looked to this reviewer that the project team is starting with the diesel piston with the re-entrant bowl and removing material from that. The reviewer explained that this will lead to high combustion chamber surface area, which can lead to high heat losses and low combustion efficiency. Leveraging the combustion chamber design expertise at Cummins could lead to a combustion chamber design with a higher efficiency ceiling.

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 outlined future work appeared very well thought out and logical to the reviewer. Success of this project lies in being able to evaluate the individual effects of high CR, high EGR, near knock operation, higher turbulence, and sharing relevant findings with others.

Reviewer 2:

The reviewer remarked that the project is following a logical path in moving from the CFR engine to the Cummins NG engine, both with CFD modeling and experiments.

Reviewer 3:

The reviewer reported the following from the Challenges (Slide 18): matching of CFR data with CFD, so CFD can be utilized for combustion chamber design for SCE; demonstration of controlled EGAI with high compression ratio and high EGR using the Woodward LECM; test cell setup for high EGR, advanced controls, and variable fuel composition; and final fabrication of SCE and commissioning in test cell. However, the reviewer noted that there were no barriers identified. The reviewer remarked that there would seem to be too many barriers to these points, not the least of which is the demonstration of EGAI; little information was presented on how the project team was going to achieve that. The steps are logical, though, and the future work follows a good plan.

According to the reviewer, the enhanced burn rate identified in Slide 4 is also a barrier. It seemed to the reviewer that Cummins-Westport has likely done an enormous amount of CFD work on improving the burn of its 12 L engine, so it was unclear what additional knobs the CSU team has to improve the burn rate. The CFD modeling should help the team explore many options, and the 2.5 L volume of the SCE provides more options

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

Reviewer 1:

The reviewer commented that this project aims to improve the efficiency of on-highway, heavy-duty natural gas engines, which conforms with the overall DOE objective of reducing our nation's petroleum consumption. With natural gas engines on a par with diesels on the efficiency front, their higher market penetration can be expected. This, in turn, will help reduce the environmental impact by reducing NO_x emissions.

Reviewer 2:

This reviewer indicated that the research is low TRL and appears to support DOE objectives in petroleum security and natural gas utilization in HD transportation. If the EGAI approach is successful and the project team improves the efficiency of an SI NG engine even a couple of percent, the reviewer said that would be a big deal.

Reviewer 3:

According to the reviewer, this project is definitely in alignment with DOE's goals of increasing natural gas consumption in the transportation sector and increasing the efficiency of natural gas engines.

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 funding allocated is sufficient with the proposed effort. CSU appeared to have the needed experimental facilities. The reviewer also noted that the LECM and single-cylinder engine provided by the industrial partners help achieve the intended goals.

Reviewer 2:

Resources appeared sufficient to this reviewer, although it is difficult to judge the resources of such a project.

Reviewer 3:

The reviewer commented that this question is a little difficult to judge because it was unclear how much help Cummins is going to give the project team with the CFD mesh of the ISX15 single-cylinder engine. If a model is provided, like ANL did for the CFR engine, then that will help a lot. Likewise, with Woodward, the reviewer explained that if a controller is thrown over the fence and there is not a lot of support, then the real-time control of EGAI will be very challenging.

Presentation Number: ft080
Presentation Title: Fundamental Advancements in Pre-Chamber Ignition and Emissions Control for Natural Gas Engines
Principal Investigator: Brad Zigler (National Renewable Energy Laboratory)

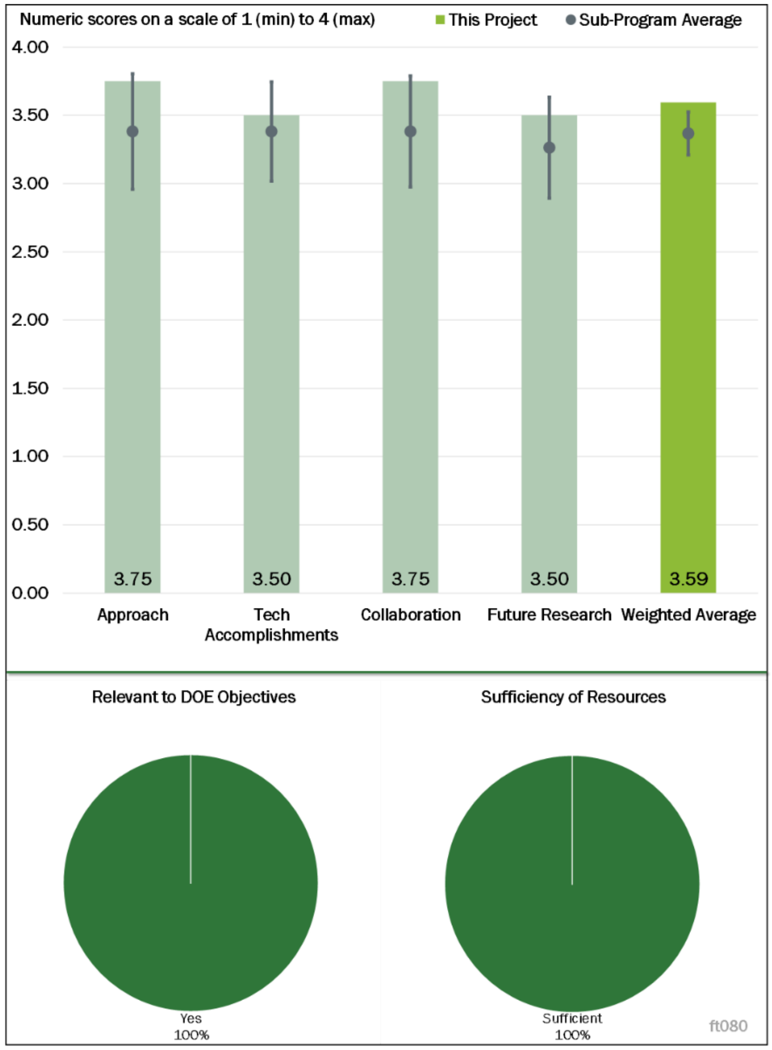

Figure 5-14 – Presentation Number: ft080 Presentation Title: Fundamental Advancements in Pre-Chamber Ignition and Emissions Control for Natural Gas Engines Principal Investigator: Brad Zigler (National Renewable Energy Laboratory)

Presenter

Brad Zigler, National Renewable Energy Laboratory

Reviewer Sample Size

A total of two reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer commented that evaluating pre-chamber ignition and combustion development across multiple experimental scales and in conjunction with modeling is a great approach. The fluid dynamics and chemistry problems are so closely linked and are in regimes where simulation is not validated; thus, the combination of approaches is well designed to address fundamental technology gaps and help guide development of practical and effective pre-chamber systems.

Reviewer 2:

The reviewer described the approach of addressing technical barriers as outstanding. The physics of pre-chamber ignition systems for lean NG are not thoroughly understood. Integration of a single-cylinder optical engine with CFD simulations will generate process insights that cannot be generated in other facilities. There is a unique opportunity to change fuel chemistry (add species, modify temperatures, etc.), measure the impact of those parameters on optical engine combustion, and feed that back to the CFD models for verifying that the models appropriately capture the system physics. The reviewer said that this will help ensure proper model validation.

It appeared to this reviewer that the model predictive control (MOC) is using methane (CH_4) as a fuel source for its development, although it was unclear from the presentation. While this is appropriate for an initial step, the reviewer mentioned that natural gas contains a number of other hydrocarbon species (as well as sulfur) that might interfere with catalyst activity. The impact of these species should be considered in designing a catalyst.

Additionally, estimating the potential MOC cost impact would be important in addressing the barrier for NG adoption.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:
The reviewer indicated that the project has made good progress on multiple fronts to generate data at the bench scale, optical engine scale, and modeling scale. The data sets appear to be rich enough to provide good guidance toward design space limits and offer a range of conditions over which models can be evaluated.

Reviewer 2:
The reviewer noted that fuel used should be more representative of what would be used in the field. Designing a catalyst for pure CH_4 might work in the laboratory, but may not exhibit the same properties in the field. According to the reviewer, the initial experimental work and correlation to simulation work are well done. It would be interesting to vary certain properties experimentally and verify if the CFD models capture the physics properly. It also appeared to the reviewer as though the pre-chambers in the multi-cylinder engine in ORNL are different from the ones run in the single cylinders. The reviewer asked how that might affect the results, whether one of the program goals is to come up with design parameters for the pre-chamber, and how the two injectors differ.

The reviewer would like to have seen more data and modeling inside the actual pre-chamber and questioned how scavenging in the pre-chamber works. The reviewer wanted to know whether the piston geometry would affect the main chamber charge and how that would then affect pre-chamber scavenging. The reviewer asked how this would change with speed and engine load, and whether there would be a problem at light or high loads with achieving appropriate conditions to create the required radicals for main chamber ignition.

The investigators have determined useful information already (e.g., strength of the rich mixture inside the pre-chamber does not impact flammability limits). Additionally, the investigators sufficiently justified using the G-equation to capture pre-chamber dynamics, to which the reviewer expressed curiosity in knowing what metrics were used to determine a validated model.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer observed outstanding project team collaboration. It was clear to the reviewer that each of the entities involved is using its strengths, talents, and available resources to address the research topic at hand.

Reviewer 2:
According to the reviewer, this project really does a good job of leveraging the strengths of the multiple laboratories involved, and the arrangement seems to be carefully considered to ensure that results translate well across the various experimental and modeling tasks. Description of the project team coordination arrangements was well thought out to ensure that the work remains synchronized and that the PIs can learn from each other as the tasks progress.

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 general future work plans are good; the key areas of need are to understand how the design features of pre-chamber systems impact the performance. The reviewer said that the work plan should

provide a significant industry boost in commercializing pre-chamber combustion systems if the bench-scale, optical, and modeling tasks can provide this information in a way that can inform design and then be demonstrated on the multi-cylinder task.

Reviewer 2:

The reviewer indicated that the proposed future work is adequate to address the science of pre-chamber ignition systems for lean NG operation, in addition to the MOC development. The reviewer proposed that additional consideration should be given to replicating real-world conditions (low load, high load, different fuel composition). This should be considered in the currently funded part of the program and would be applicable to any additional funding for a multi-cylinder demonstration engine. The reviewer also suggested that a cost-to-benefit study of the proposed NG ignition system and aftertreatment would be relevant when considering commercialization or relevance of such a concept.

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

Reviewer 1:

The reviewer indicated yes, NG fuel is a prevalent, low-cost fuel source. However, increased engine efficiency requires lean operation, which poses ignition challenges (which this program seeks to investigate). Additionally, catalysis of unburned CH_4 is notoriously difficult; being able to decrease light-off temperatures of catalysts will enable the use of NG fuel.

Reviewer 2:

No specific comment was stated by this reviewer.

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

Reviewer 1:

This reviewer observed a sufficient funding level for each task to achieve the stated goals and to address the scientific need in this area.

Reviewer 2:

The reviewer indicated that the project resources appeared to be sufficient considering the extent of experimental work. Additional information into the breakdown of where the funding goes would be helpful for the reviewer to address funding adequacy (ANL has both simulation work and experimental, but it is unclear how much funding each part receives).

Presentation Number: ft081
Presentation Title: Direct Injection 4.3 L Propane Engine Research, Development, and Testing
Principal Investigator: Brad Zigler (National Renewable Energy Laboratory)

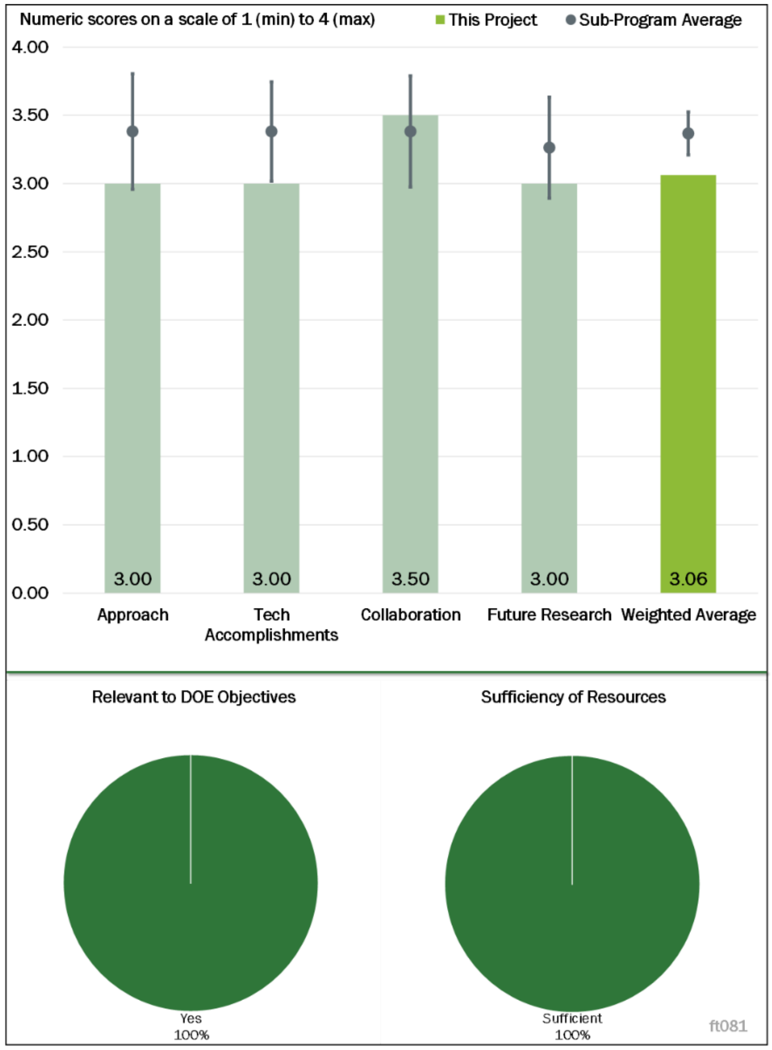

Figure 5-15 – Presentation Number: ft081 Presentation Title: Direct Injection 4.3 L Propane Engine Research, Development, and Testing Principal Investigator: Brad Zigler (National Renewable Energy Laboratory)

Presenter
Brad Zigler, National Renewable Energy Laboratory

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

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:
Given that the original project was an industry-led Funding Opportunity Announcement (FOA) and there is a direction change, the approach seemed appropriate to the reviewer. There seems to be a good understanding and plan of attack for the critical technical areas and problem areas. The reviewer commented that getting feedback from industry and the U.S. Environmental Protection Agency (EPA) shows a clear and methodical approach. Given the transitional nature of the project, the reviewer understood that there are some yet-to-be-refined approach aspects.

Reviewer 2:
The reviewer asked whether some of the shortcomings of using the 4.3 L engine could have been anticipated and potentially avoided with the selection of alternate engines.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:
The reviewer said that baseline comparisons to the existing 6 L port fuel injection (PFI) propane engine is very good. Development of the gasoline direct injection (GDI) propane fuel system seems to be the heart of the technology. Coordination with UPS for its package truck application drive cycle is excellent, and publication of this for others is also very useful.

The reviewer noted that simulation of the drive cycles between NREL and Freightliner resulted in slower vehicle performance, which the reviewer found to be understandable due to the lower engine displacement. The reviewer inquired whether the propane fuel system impacted the transient load response, or whether everything was here due to engine size. The reviewer also asked how the fuel system will work at Alabama to get correct boundary conditions to represent the real-world (restart, cold start, etc.) conditions. This seems to link to some of the durability concerns that generated the no-go decision.

The reviewer stated that understanding what the catalyst system needs to look like is very good and brings a complete package to the program. Additionally, the reviewer found a lot of powertrain work here among the engine propane conversion, transmission alignment, reverse calibration understanding, and aftertreatment. There are some good accomplishments here given the system integration level of difficulty.

Reviewer 2:
The reviewer indicated that engaging a fuel systems supplier could have accelerated progress. The reviewer asked if adequate focus was placed on the pump versus the other components.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
There looked to be really good collaboration across the multiple entities and participants in this transitional project from the reviewer's perspective. The project team is encouraged to please continue engaging and publishing what the project team has learned.

Reviewer 2:
The reviewer indicated that there was broad collaboration, including in the catalyst 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:
According to the reviewer, more detail on the dynamometer control research plans would have been helpful.

Reviewer 2:
The reviewer urged the project team to please continue focusing on fundamental knowledge surrounding the fuel system challenges with GDI.

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

Reviewer 1:
The reviewer commented that this project is extremely relevant to achieving DOE's objectives.

Reviewer 2:
GHG reduction was highlighted by this reviewer.

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 were sufficient given the reduced future scope.

Reviewer 2:
Resources for the given scope and tasks seemed fine to the reviewer.

Presentation Number: ft082
Presentation Title: High-Performance Fluids and Coatings for Off-Road Hydraulic Components
Principal Investigator: George Fenske (Argonne National Laboratory)

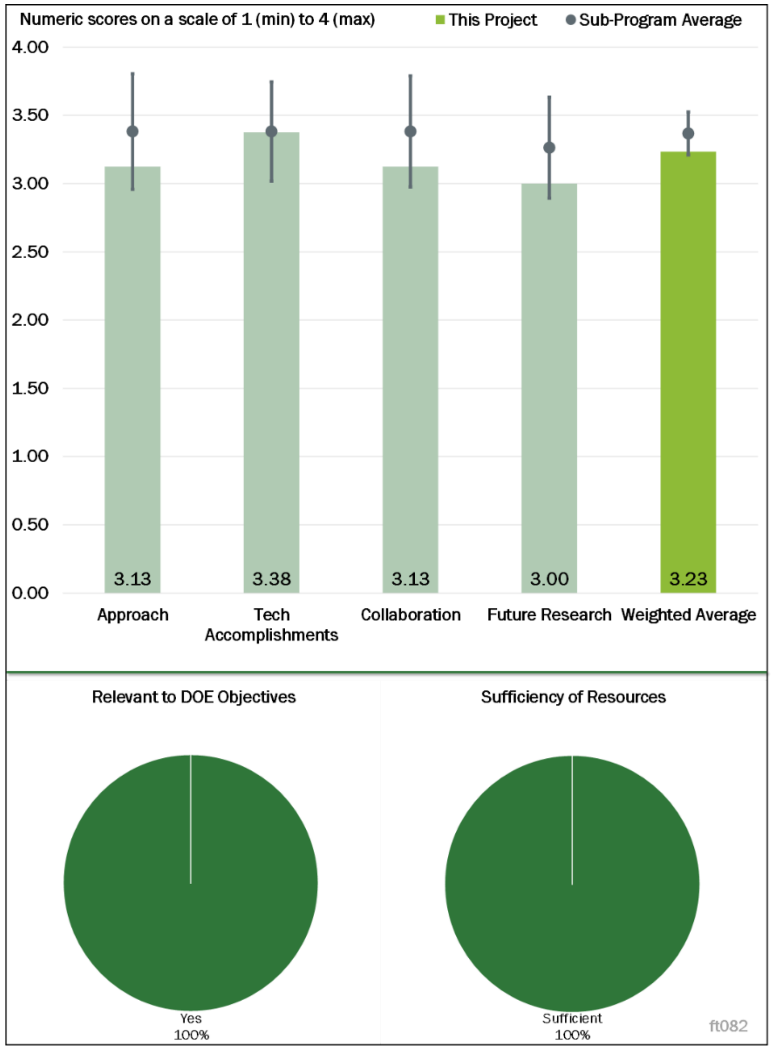

Figure 5-16 – Presentation Number: ft082 Presentation Title: High-Performance Fluids and Coatings for Off-Road Hydraulic Components Principal Investigator: George Fenske (Argonne National Laboratory)

Presenter

George Fenske, 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 and well-planned.

Reviewer 1:

The reviewer praised the approach as fantastic work. High-performance fluids and coatings are critical for mobile off-road vehicles. The reviewer commented that the project has been scoped to address mitigation of mechanical and volumetric losses while maintaining component reliability as well as stability of high-viscosity index fluids that maintain performance with age. However, the reviewer suggested that the scope should be modified to address technical barriers associated with cold weather operation for commercial feasibility because mobile off-road vehicles operate in cold weather.

Reviewer 2:

The reviewer said that the team has a solid technical approach. The project is well thought out with work distributed among National Laboratory team members. It was emphasized that this is an early TRL program. However, the reviewer suggested that the project team might want to more explicitly consider that the opportunity provided to conduct early TRL research also affords the freedom to be more forward looking and even more creative. According to the reviewer, a set of target metrics or goals is prominently missing. The project team may want to give this more consideration and more specifically define the highest value opportunities to significantly contribution to the field and focus future efforts accordingly.

Reviewer 3:

The reviewer described the approach to evaluate technical performance as well designed and well executed, although there was no indicator for commercialization. The reviewer inquired about the following: whether existing manufacturing processes can be used or new methods need to be developed; whether base elements are rare and expensive, or readily available and similar in cost to current; and whether there are known obstacles or challenges for commercialization.

Reviewer 4:

Generally, the plan looked good to the reviewer. Both coatings and oils contribute to components efficiency. It has been claimed that there are improvements in the viscosity index (VI) over current fluids, but most of the 100°Celsius (C) temperature viscosities reported are in the 6-7 centistokes (cSt) range. This, the reviewer noted, is not a big leap over the fluids that are currently being used; therefore, the reviewer indicated that most of the VI improvement impacts end up helping at really cold temperatures. Extreme cold temperature machine starts and conditions during hydraulic oil warm up are a consideration in hydraulic systems, but they represent about 1% of the machine duty cycle. The reviewer would have preferred to focus on VI improvements to get 100°C viscosities in the 10-12 cSt range and verify if the oil viscosity at really cold temperatures (-40°C to -30°C range) can be no worse than what current fluids already have today. Based on that, the machine warm up procedures and performance at cold temperatures will be no worse than now; at 90°C-100°C, performance will be improved and machines that allow oil to work in the high range for periods of time will be doing less damage to the hydraulic components. It seemed to this reviewer that a lot of independent work is happening in different areas, but stated that how it all comes together and gets tested together needs to be clearly depicted.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer emphatically stated well done, and observed good progress on the four tasks outlined in the project.

Reviewer 2:

The reviewer reported that the project team has contributed solid accomplishments across a broad range of technologies (hydraulic fluids, VI improvers, coatings, etc.). Several of these discoveries have the potential to make important contributions in the industry. As early TRL work, this reviewer described research to date as excellent. Looking forward, the reviewer remarked that expectations should be significantly higher for this team. The connections to industrial applications and knowledge of hydraulic systems should be much stronger so that there can be an increased focus. Some of the work appeared to be incremental and somewhat lacking in creativity (e.g., there were a number of claims about different improvements in physical properties that appeared to be a result of a simple Edisonian approach). The reviewer suggested that the team challenge itself to find opportunity for disruptive innovation and discoveries of the magnitude that National Laboratory researchers are expected to contribute.

Reviewer 3:

The reviewer found that the theological attributes of BioFluid 2 were attractive and have the potential to save fuel, especially in mobile applications that see large temperature swings. According to the reviewer, having a cost-effective alternative and environmentally safe alternative to zinc dialkyldithiophosphate (ZDDP) is needed in the industry (ionic liquid). The low friction and low wear properties of vanadium nitride doped with copper (VN-Cu) look good, but the reviewer did not know if it would be commercially viable for off-highway use.

Reviewer 4:

It appeared to this reviewer that the project team is achieving the goals set for this stage of the project and it has a solid plan for next steps. The reviewer recommended that the investigators more clearly explain the combination of oils, additives, and coatings have been tested and will be tested in the future and, based on that, clearly display associated results.

The reviewer inquired about the following: what the optimal VI index is that balances cost, shear stability, friction, oil durability and other relevant factors; what the estimated cost increases are for the 75% of the biofluids that were identified as "promising;" whether these high VI polymers (or additives) are mixed with the biofluid or with some other (base) fluids as that was unclear from the presentation; if the project team had already studied the impact of new formulations and, if not, whether there were plans for such studies; the estimated cost for the new fluids and new coatings and whether they are practical for production; and if there is any post-processing manufacturing process that needs to be applied after coating.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

According to the reviewer, the project team demonstrates excellent collaboration across a number of National Laboratories. This is a great example of using a Lab Call to focus efforts on industrial applications and leverage knowledge from outstanding researchers at three laboratories. The reviewer stated that there should be notably more significant collaboration opportunity in the next research phase as the team explicitly looks for synergies.

Reviewer 2:

The reviewer commented that there is fantastic collaboration and coordination across the project team through partnerships with fluid and additive OEMs. The reviewer suggested that the investigators should also collaborate and coordinate with off-road vehicle OEMs that can provide insights on application requirements as well as commercialization of the technology.

Reviewer 3:

It seemed to the reviewer that several project teams are working on their portion of the project and making good progress. The reviewer also would like to have seen this team referencing work that may have been done prior to this work; other oil manufacturers already studied different viscosity oils. Again, it is important to show a plan of how all the pieces come together and what an optimal solution for coatings, additives and oils is as a complete solution.

Reviewer 4:

The reviewer indicated that there was good representation from the fluid and additive industry (Evonik and Chevron). The reviewer said it would have been nice to have an industry partner for the coatings.

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 key project tasks are well defined and reported that the experimental test facility is currently set up to explore a temperature range from 20°-100°C. The reviewer suggested that the system capability should be extended to explore cold weather conditions as well as the effects on metals, seals, hoses, etc.

Reviewer 2:

Technical next steps looked good to this reviewer, who also recommended looking at commercial viability and cost.

Reviewer 3:

It seemed that reporting is still in the technical arena, which is okay per the plan to have a low TRL, but the reviewer recommended looking at the practical side of the solution—wear comparisons of a bearing, or mechanical efficiency comparisons of a pump or motor with and without a coating, etc. The reviewer questioned why the project team is only focusing on the bio oils. Bio oils are environmentally friendly, but also known to be significantly more expensive.

Reviewer 4:
This reviewer indicated that proposed future research focuses on identifying synergies between fluids and materials/coatings, and transitioning to higher TRL level. However, it was not clear to the reviewer why this is important and appropriate at this time. The reviewer stated that it would be helpful if there were a hypothesis presented about the potential synergies that might be expected along with metrics for success. Similarly, transitioning the fluids, etc., to higher TRL is potentially reasonable, but proposed without justification or target metrics. Subsequently, the ultimate goals of this future work were unclear to this reviewer. The project team might benefit from discussions with a range of industrial experts to understand better hydraulics challenges and to define goals and metrics before moving to future work.

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

Reviewer 1:
The reviewer noted that this project, which focuses on high-performance fluids and coatings, is a key enabler for fluid power systems used in mobile off-road vehicles.

Reviewer 2:
The reviewer remarked that fluids with flatter viscosity curves and materials with lower friction coatings have the potential to save energy in the off-highway market.

Reviewer 3:
According to the reviewer, the project does support overall DOE objectives as defined in the original FOA. However, the explicit connection to reducing energy consumption is not addressed. The reviewer recommended that the project team consider how to make this connection explicitly, and use this assessment to downselect and focus future work on only the most critical, promising technologies.

Reviewer 4:
The reviewer stated that oils and coatings do play a role in hydraulic component efficiency, but there is a limited contribution. Based on that, added cost to the fluids and coatings needs to be carefully monitored when a solution is proposed in order to be commercially viable and adopted.

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 good progress is being made at the current funding level.

Reviewer 2:
It seemed to this reviewer that the team is qualified and capable.

Reviewer 3:
The reviewer indicated that the project team appears to have all necessary resources from across the laboratories.

Reviewer 4:
According to this reviewer, accomplishments to date and budget remaining appear to be aligned for completing the project on time.

Presentation Number: ft083
Presentation Title: Efficient, Compact, and Smooth Variable Propulsion Motor
Principal Investigator: James Van de Ven (University of Minnesota)

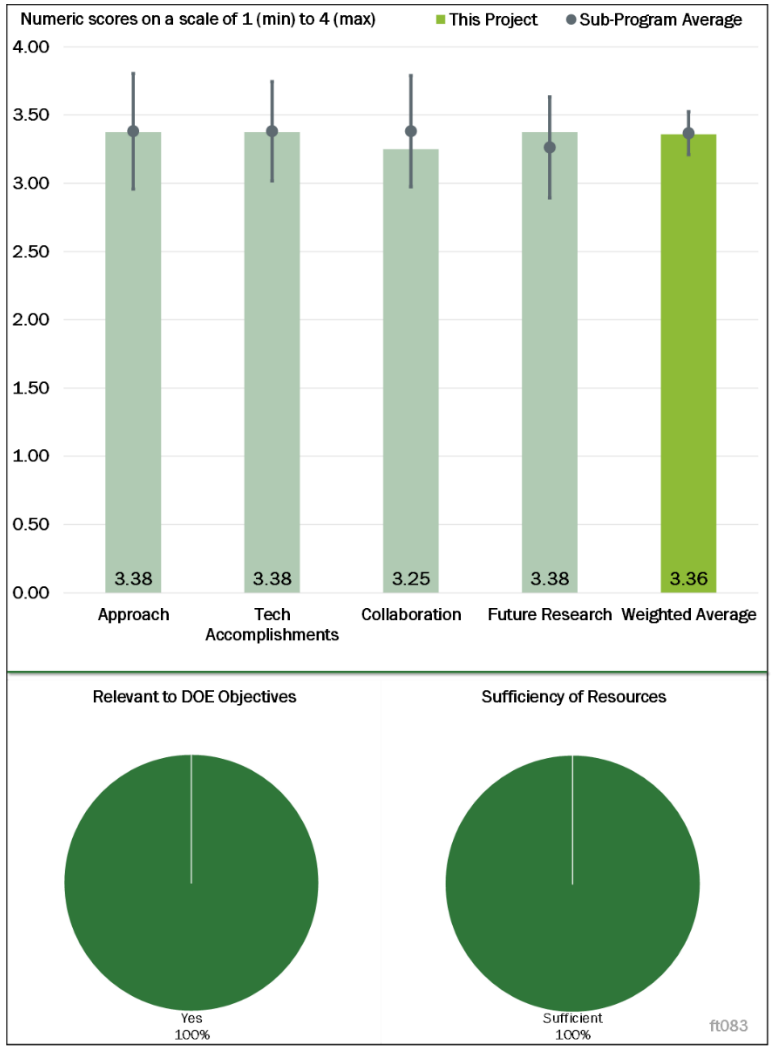

Figure 5-17 – Presentation Number: ft083 Presentation Title: Efficient, Compact, and Smooth Variable Propulsion Motor Principal Investigator: James Van de Ven (University of Minnesota)

Presenter

James Van de Ven, University of Minnesota

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 and well-planned.

Reviewer 1:

The reviewer stated that the modeling and prototype validation approach for this motor are appropriate.

Reviewer 2:

This reviewer observed good modeling and physics-based understanding. The approach to minimize controls effort (not having electrically operated valves, but rather using mechanical controls) was good, but there are issues with this approach related to tolerances, mechanism wear, and impact on the performance over time.

Reviewer 3:

The reviewer commented that the project team presents a creative approach to solving an important challenge for hydraulic systems. This is early TRL work with a program thoughtfully laid out based on appropriate levels of simulation. The university lead clearly has deep knowledge of hydraulics systems challenges and constraints. The reviewer noted that the project plan does indicate completion of a preliminary business case, but this was not apparent in the presentation, which focused on technical accomplishments. Even at such an early stage, the reviewer suggested it would have been informative to see a preliminary assessment of means to hit the proposed cost metrics and initial manufacturability comments.

Reviewer 4:

The reviewer found this to be an interesting and novel (and potentially complex) approach to improve hydraulic pump efficiency using a variable displacement linkage motor. Initially, and based on the VTO AMR slide deck, the concept was difficult for the reviewer to grasp, but with further digging into the author's prior work in this field, the concept became clear. The variable linkage and displacement concept enables motor operation at optimal speeds while varying displacement (via the variable linkage) to meet flow demands. The reviewer stated that the concept is novel and high risk; the variable linkage concept is a complex approach with potential issues related to reliability and durability of the linkage. Nevertheless, the PIs have identified the technical barriers and are making progress in the concept design and modeling. Further, the reviewer would have appreciated a discussion of variable linkage concept advantages versus other variable displacement concepts, such as those using swashplates.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer remarked that the project team has made excellent progress in budget period (BP)1. The team has done an outstanding job defining important metrics and appropriate go/no-go criteria. The research to date has established the technology's future potential, showing great promise. The opportunity defined for two times the pump downsizing could be quite significant. The reviewer suggested that it might be helpful if the team clarified targets around fuel consumption reduction and efficiency, and more clearly defined baseline technology comparisons. This would be especially useful to more broadly assess potential platforms and overall fuel reductions possible from this program.

Reviewer 2:

The reviewer indicated that design parameters have been optimized to exceed torque ripple and efficiency targets.

Reviewer 3:

The reviewer described the mechanical design as impressive. The reviewer expressed concern with the final product having many small moving parts and a lot of opportunity for failure, and suggested that a robust solution should be studied. This reviewer further asserted that precision manufacturing will be necessary and commercial viability needs to be studied.

Reviewer 4:

The reviewer reported this is the first year of a three-year project, during which the PIs have completed the initial design concept; modeled the kinetic and dynamic forces; developed a working model to predict parasitic friction losses in the bearings, followers, and cylinders; and met the preliminary go/no-go decision on efficiency and torque ripple. Although this is a three-year project, the reviewer commented that plans for year 3 were not presented and asked what the plans are beyond the fourth quarter of BP2.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer remarked that the excellent team includes a vehicle OEM, lubrication expertise, and a hydraulic OEM.

Reviewer 2:

The reviewer found good industry collaboration with representation from both an OEM and a Tier 1 motor manufacturer.

Reviewer 3:

This reviewer noted that collaboration seems to be working well, and further commented that component manufacturers need to be involved early in this design to provide feedback to the design team.

Reviewer 4:

The reviewer asserted that the definition of clear, important metrics demonstrates good collaboration with industrial partners. The work (appropriately) is being done by the university lead, but there is obvious collaboration on defining metrics. However, the reviewer indicated that an area for improvement would be asking the industry partners to provide the preliminary business case due as part of BP1. This was not shown in the review and may indicate a need for better partner support.

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 the project is very clearly defined in a logical manner. The project team has identified key challenges and barriers, and FY 2020 activities are well defined. The team has laid out an aggressive plan of research that will make an important contribution to the field.

Reviewer 2:
The reviewer stated that prototype construction and performance validation are the correct next steps.

Reviewer 3:
The reviewer commented that demonstration of the pump with all of its parts is definitely required to understand final performance, noise, etc.

Reviewer 4:
The reviewer said that BP2 will address design, fabrication, performance mapping, and model validation of a single-cylinder prototype. It was unclear to the reviewer if a multi-cylinder version is under consideration for BP3.

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

Reviewer 1:
The reviewer asserted that component efficiency is very important to overall hydraulic system efficiency improvements. High efficiency in all areas of pump displacement is what this project is focusing on; therefore, the relevance is excellent.

Reviewer 2:
The reviewer commented that performance under off-peak performance conditions is definitely of interest and relevant to the DOE mission on improving energy efficiency.

Reviewer 3:
The reviewer stated that DOE objectives are around fuel consumption reduction, and the program metrics address fuel consumption and cost. Further, the team understands the importance of cost and payback period for commercialization.

Reviewer 4:
According to this reviewer, improving hydraulic drive motor efficiency will directly save fuel and improving machine productivity will reduce total fuel needed for each job.

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 the Minnesota team to be very impressive in knowledge, achievements to date, and creating an aggressive (yet achievable) future work scope. There was no indication that there is a lack of resources to achieve the technical objectives.

Reviewer 2:
It seemed to this reviewer that the resources (former motor designer, component manufacturer, etc.) are sufficient to continue developing prototypes.

Reviewer 3:
The reviewer noted that the PIs have pulled together a team with relevant expertise to address major issues related to concept design, analysis, and materials selection.

Reviewer 4:
This reviewer remarked that accomplishments to date and budget remaining appeared to be aligned for completing the project on time.

Presentation Number: ft084
Presentation Title: Individual Electro-Hydraulic Drives for Off-Road Vehicles
Principal Investigator: Andrea Vacca (Purdue University)

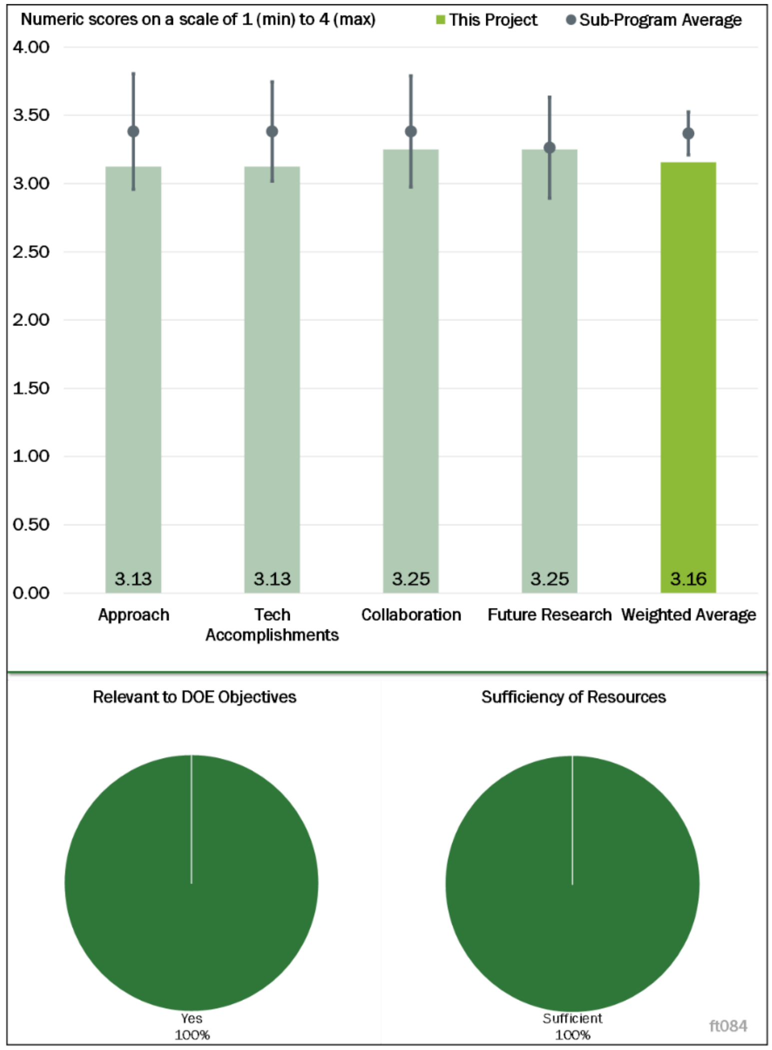

Figure 5-18 – Presentation Number: ft084 Presentation Title: Individual Electro-Hydraulic Drives for Off-Road Vehicles Principal Investigator: Andrea Vacca (Purdue University)

Presenter

Andrea Vacca, Purdue 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 and well-planned.

Reviewer 1:

The reviewer stated the project addresses improving the efficiency of off-road vehicles by using modular electric hydraulic units combined with an ICE and energy storage to reduce frictional parasitic losses. The project draws upon Purdue's capabilities and expertise in vehicle analysis, electric motor design, and hydraulic pump design. The approach is well thought out and has performance-based go/no-go decision points distributed through the project.

Reviewer 2:

The reviewer found the concept of retrofitting specific functions in off-road vehicles with individual electro-hydraulic drives to be a novel and fantastic concept that should be explored. However, the reviewer asserted that the project scope and vehicle integration strategy need to be better defined. The architecture defined is similar to existing hybrid electric vehicles that are currently in the market developed by off-highway manufacturers like Caterpillar, Komatsu, and John Deere on crawlers, excavators, and loaders, respectively. The reviewer commented that a skid-steer loader is a utility machine and may not be the best platform for electrification because the customers are very sensitive to the price point.

Reviewer 3:

This reviewer commented that the approach of first understanding the baseline performance and then looking for the opportunities to overcome efficiency barriers is very good. Additionally, the reviewer was very encouraged to see the use of modeling, simulations, and optimization before detail design is completed, and reported that two designs were displayed (both based on the gear pumps). The reviewer asked if one can predict whether the efficiency can be kept at the target level over time. The reviewer also wanted to know how much efficiency improvement the displacement control architecture (i.e., valve-less) would provide over the baseline machine versus applying the proposed electro-hydraulic actuator (EHA) components. It seemed to this reviewer that the generator design will allow higher displacements per overall package size than the traditional gear pump design, and asked if this is correct.

Reviewer 4:

The reviewer indicated that the project is well designed with a reasonable approach starting with vehicle analysis and moving through component, system, and prototype designs. The plan lays out efficiency targets at each stage. The research team has identified key challenges and created a plan that appears feasible. One caveat from the reviewer was that, when focused on the electro-hydraulic (EH) system, the research is well designed. However, there are some concepts presented around vehicle integration, including grid connectivity and use of storage, which appeared to be outliers presented with neither technical justification, nor inclusion in the proposed work. The reviewer stated that such concepts significantly stray from the fundamental proposal and distract from what is otherwise an excellent approach.

The reviewer suggested that the project team consider defining metrics for success more clearly. Efficiency metrics are presented, but the project team notes that the key metric for industry is a payback period of less than two years. If this is the singular metric for success, it was unclear to the reviewer that the team considered this metric in the program. There is no apparent mention of cost and translation of the efficiency improvement targets into fuel savings at the vehicle level. Further, this reviewer commented that the team should consider adding a task to the project plan for business case assessment.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that the project team has made excellent progress toward achieving project objectives. The technical accomplishments are significant and demonstrate great promise.

Reviewer 2:

The reviewer indicated that good progress had been made during the first (of three) budget periods. Initial power requirements for hydraulic units (boom and bucket) for the demonstration vehicle (skid-steer loader provided by industrial partner Case) were completed and used to design hydraulic pump (gear) and electric drive motors for the EH unit.

Reviewer 3:

The reviewer commented that preliminary performance results from simulation show promising energy savings on the order of 70%.

Reviewer 4:

Generally, the concept looked good to this reviewer, who also noted that there are added components because each circuit has an EHA. The reviewer expressed interest in what will be the pump speeds and component sizes (pump, load lock valves, etc.). Based on that, the reviewer inquired about the trade-off of the EH lock valve size and cost versus throttling loss through the valve. The reviewer stated that the project team may have to consider the effects of valves on response if they are opened and closed with each command, as well as the impact on controllability.

The reviewer also asked whether scalability of the EHA design has been studied and whether there are limits if this is to be scaled for the larger pump displacements. Perhaps it should be shown how pump/motor speeds and EHA dimensions are related. Additionally, this reviewer asked for further clarification on efficiency targets and improvements (from what point to what point). Based on that, the reviewer inquired whether the team could break down the total EHA target efficiency, and asked whether that is 70%.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The engaged team seemed very strong to this reviewer, who highlighted the Purdue team (software [SW] controls and modeling expertise), together with Bosch-Rexroth (design and component manufacturing experiences), and aided by the Case team (machine application).

Reviewer 2:

The Purdue team includes the Maha Fluid Power Research Center at Purdue (lead), Rexroth (world leader in design and fabrication of hydraulic components and pumps), and Case New Holland (a world leader in off-road vehicles). The only weakness seen by this reviewer is perhaps the lack of a hydraulic fluid supplier.

Reviewer 3:

The reviewer said that this project has a very strong team and noted that Rexroth provides design inputs while CNH provides the reference vehicle. Purdue is doing an excellent job in coordinating the program. The reviewer made a suggestion for the industrial partners to create a business case assessment and provide aggressive target metrics around cost, payback, etc. The metrics could be significantly expanded beyond efficiency and provide better insights to the university researchers on important commercialization aspects.

Reviewer 4:

The reviewer observed limited collaboration and coordination across the project team. The reviewer suggested more work should be done in expanding the number of industry partners that can provide guidance on commercialization of this technology.

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 said that the project milestones and decision points are well defined in the preliminary design phase, but very broad in the initial implementation and technology demonstration phases.

Reviewer 2:

The reviewer stated that the project has well-thought-out plans for the three-year project with the first period involving upfront vehicle analysis and design of pump and electric motor components. Period 2 and 3 activities are well conceived with period 2 addressing component selection and packaging, initial implementation and prototyping, and integration and testing on-board the vehicle. Period 3 involves technology demonstration to finalize the design and expert operator testing of energy consumption and cost analysis. It was unclear to the reviewer if long-term durability and reliability testing are planned.

Reviewer 3:

The reviewer described the technical approach as excellent, but weakened due to a lack of key metrics. Although the project team has defined important focus areas for research and demonstration, this reviewer highly recommended that metrics around cost, payback, space, and power electronics requirements be defined before proceeding further to ensure focus only on the most critical issues. For example, the team proposes to address zero emission mode of operation. This will come at some cost for storage, power electronics, and space on the vehicle. It was not clear to the reviewer if this is critical to project success, or if this is a “nice to have” option. The reviewer further explained that this is an example of why more detailed metrics are needed.

Reviewer 4:

This reviewer suggested studying what the heat generation is with an intensive machine cycle and how the project team will manage heat dissipation from the EHA, therefore keeping the hydraulic loop cool. Seems like the concept needs to add some means for cooling and filtration of the closed loop EHA oil. The reviewer inquired as to whether there are cost targets for kW/kg or some other measure for an economical design, and further suggested measuring overall machine efficiency in a composite work cycle to understand overall impact on the customer (cost versus efficiency improvements). Future work needs to show a study that will link optimal voltage for component size, cost, packaging, etc. The reviewer remarked that it is very good to see that the machine demonstration is being planned as part of future work and that the expert operators will be able to evaluate the machine.

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

Reviewer 1:

The reviewer said that the project proposes novel concepts that will improve overall energy efficiency of off-road vehicles and encouraged the project team to keep up the good work.

Reviewer 2:

According to the reviewer, this project is targeting the right things that will contribute to overall machine efficiency improvements: more efficient components; improved circuit efficiency; and focused understanding of overall machine efficiency. It also adds the aspect of electrification.

Reviewer 3:

The reviewer said that the modular approach using electric-drive hydraulic units (e.g., those developed in the project) enables power-on-demand concepts. This mitigates use of common-rail hydraulic units that can often experience large idling losses and, thus, offers the potential for significant energy savings.

Reviewer 4:

The reviewer stated that DOE objectives are around fuel reduction. The team notes that hydraulic system efficiency can be quite low and there is significant opportunity for improvement. It was unclear to the reviewer how much fuel reduction is achievable in this program, and recommended an assessment to demonstrate the tie between EH efficiency and vehicle level fuel reduction potential.

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

Reviewer 1:

There appeared to be sufficient resources from this reviewer's perspective because the Purdue team is doing an outstanding job completing the research in a timely manner.

Reviewer 2:

According to this reviewer, resources available to the team through the Maha Fluid Power Research Center, CNH, and Rexroth are well suited to carry out the proposed research.

Reviewer 3:

The reviewer observed good progress being made at the current funding level with 30% of the project being completed in the first year.

Reviewer 4:

It seemed to this reviewer that the team has all necessary resources to execute this project.

Presentation Number: ft085
Presentation Title: Hybrid Hydraulic-Electric Architecture for Mobile Machines
Principal Investigator: Perry Li (University of Minnesota)

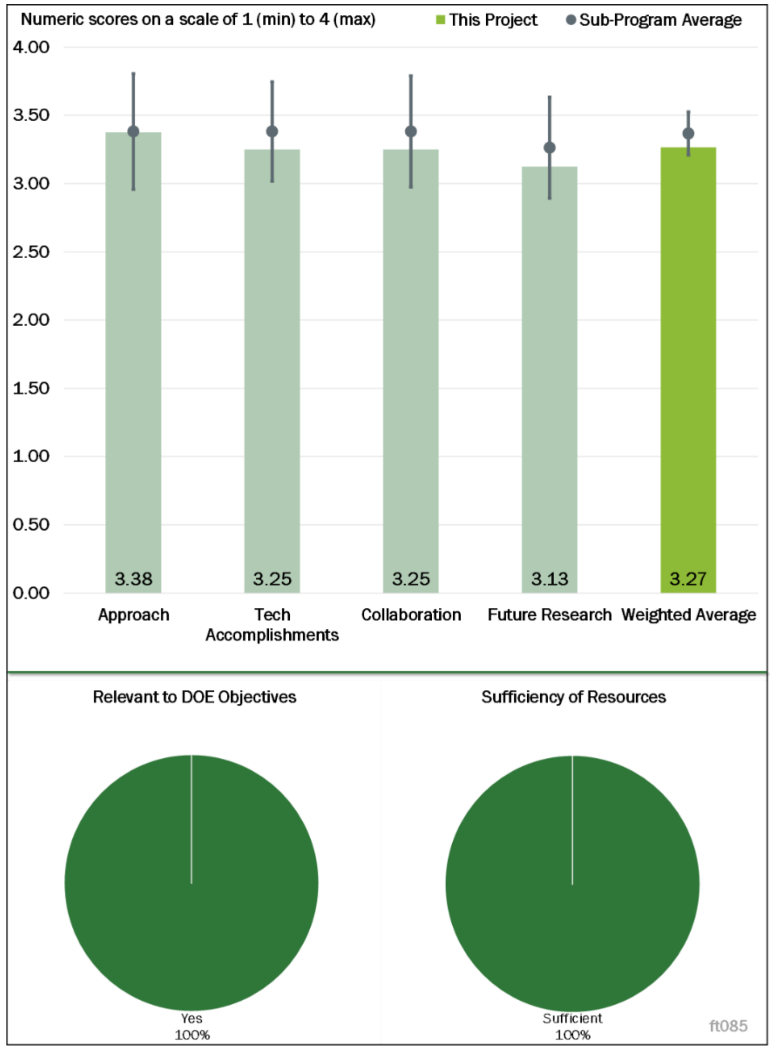

Figure 5-19 – Presentation Number: ft085 Presentation Title: Hybrid Hydraulic-Electric Architecture for Mobile Machines Principal Investigator: Perry Li (University of Minnesota)

Presenter
Perry Li, University of Minnesota

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 and well-planned.

Reviewer 1:
The reviewer noted fantastic work and indicated that the integrated hydraulic and electric system architecture is a novel approach that is conceptually well designed. The preliminary results from the energy-saving evaluation tool presented so far are encouraging in addressing the system-efficiency barrier. Off-highway customers have been more receptive to hydraulic-hybrid systems than electric-hybrid systems. The reviewer remarked that this hybrid-hydraulic electric architecture might just be the right compromise that will be readily accepted by off-highway customers and be able to address the barriers of control performance and electrification cost.

Reviewer 2:
The reviewer stated that the approach is logical for a new vehicle architecture.

Reviewer 3:
The reviewer remarked that the approach taken in this project utilizes a hybrid common-rail system consisting of a common-rail unit that provides constant hydraulic fluid at a given pressure that is assisted by modular electric-driven hydraulic units. The approach offers the potential to improve energy efficiency. The reviewer noted that the benefits and advantages of the hybrid-hydraulic electric approach were well discussed and provided a potential improvement of a target efficiency of over 65%. Three thrust areas were identified by this reviewer: analysis of potential energy savings in different sectors; development of control algorithms to achieve efficiency and fast and concise control; and development of a tightly integrated electric-hydraulic unit with demonstrated efficiency and power density.

Reviewer 4:

The reviewer commented that it is very good to see the use of modeling, simulations, and initial algorithm and controls development before the detailed design is completed. The project team is taking a systems approach when considering a solution with the intent of combining the advantages of hydraulics and electronics. This reviewer identified a concern related to the number of components (number of on/off valves and their size, pump motors, accumulators, etc.) used in this proposed circuit configuration from the installation, cost, and control complexity point of view. Further, the modeled pump efficiency looked pretty good to this reviewer.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer noted that modeling and estimating fuel savings of up to 70% on four different machines shows broad potential in the off-highway sector. The reviewer commented that this is a novel approach to combining the strengths of hydraulics and power electronics while minimizing the cost. The reviewer was very excited about the possibilities and looked forward to future updates.

Reviewer 2:

According to this reviewer, the degree to which progress has been made is reasonable with the 20% completion primarily from modeling, analysis, and topology selection work. The reviewer enthusiastically described the work as well done.

Reviewer 3:

This reviewer reported five different platforms for consideration during the first budget phase: two construction vehicles; two agricultural platforms; and one material handling platform. The team developed an energy-saving evaluation tool to model and predict energy potential; energy savings are based on specific force and duty-cycle requirements. Results were presented for two control architectures (load sensing and hydraulic-hybrid electric architectures). It was unclear to the reviewer if the analyses included power and energy requirements of the common-rail unit or just focused on the hydraulic-hybrid electric architecture (HHEA) and load-sensing assist modules.

Reviewer 4:

The reviewer suggested that the project team pick one of the applications and focus only on it in the future (e.g., an excavator). Based on that, the reviewer wanted to know how many pressure rails are sufficient for the wide variety of loads that are present in a common machine application. As an important part of the study, the project team needs to investigate machine controllability and verify how it will be impacted based on the algorithm for switching from one rail to another. Furthermore, the reviewer asserted that this needs to be studied on a simultaneous multi-circuit operation. This reviewer also suggested working with experienced component designers on the detailed component design related to optimizing pump design for both scenarios—when the pump needs to work below the rail pressure (pumping) as well as above the rail pressure (throttling). The reviewer indicated that if the duty cycle has a lot of low load cases, then the metering pump will have a lot of torque scenarios that the electric motor must control. Based on that, the time it would take before the electric motor overheats needs to be studied.

The reviewer further inquired about the following: what the tradeoffs would be for switching valves upstream of the pump causing throttling loss versus the amount of energy recovered; what the tradeoff would be of the directional valve size/cost versus the throttling loss; whether scalability of the pump design has been studied; and whether there are limits if pump design is to be scaled for the larger pump displacements. The reviewer enthusiastically commented that it will be interesting to understand what the practical size and operating speed capability will be as it becomes hard to fill the pumping chamber in really short periods of time.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer enthusiastically praised having participation from four OEMs and one Tier 1 supplier.

Reviewer 2:
The reviewer remarked that there is a reasonable amount of collaboration and coordination across project teams with a healthy list of industry partners. There is an opportunity to broaden the number of industry partners that can help with product technology commercialization.

Reviewer 3:
The team partnering on this project seemed to be very adequate to the reviewer (i.e., OEMs that are involved, University of Minnesota, Eaton, etc., all can contribute well to this project). According to this reviewer, the PI will need help in optimizing component sizes and performance, which ultimately need to be cost effective and fit on the machine.

Reviewer 4:
The reviewer remarked that the assembled team has the necessary partners to address early-stage design and modeling as well as later-stage demonstration activities. The role(s) of the multiple vehicle OEMS was unclear to this reviewer, who asked whether the project team will design and develop units for each of the four OEMs If so, this might present a significant challenge to address all four.

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 the future milestone targets and decision points to be fairly well defined.

Reviewer 2:
The next steps were logical to this reviewer.

Reviewer 3:
The reviewer remarked that there were good discussions of remaining activities for BP1 and proposed activities in BP2 (FY 2019-FY 2020). It was unclear to the reviewer if the plan includes a detailed demonstration of the HHEA concept that would include performance and durability/reliability studies onboard a vehicle platform.

Reviewer 4:
The reviewer noted that it is good to see plans for component testing on the bench. It would be good to see a clear proposal for algorithm and components and system simulations (all in one package) to prove the overall efficiency gains in a typical machine cycle.

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

Reviewer 1:
The reviewer remarked that there are very few ideas that can reduce fuel consumption by more than 65%, and stressed that the potential is huge.

Reviewer 2:
The reviewer stated that the proposed system efficiency improvement from 20% to 65%, if achieved, will support DOE objectives.

Reviewer 3:
If successful, the reviewer said that a projected or potential savings of 65% would definitely be relevant to DOE's goals on energy efficiency.

Reviewer 4:
According to the reviewer, this project is targeting the systems and controls architecture and design that will contribute to overall machine efficiency improvements: more efficient components; improvement of the circuit efficiency; and focus on overall machine efficiency understanding. It also adds the electrification aspect.

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 good progress being made at the current funding level.

Reviewer 2:
There was no indication to this reviewer that resources will be an issue to accomplish the milestones outlined in the review.

Reviewer 3:
Resources at University of Minnesota and University of Wisconsin at Madison are sufficient to meet goals from this reviewer's perspective. The level of Eaton and vehicle OEM involvement is unclear to this reviewer, who asked if they are providing hardware or performance testing.

Reviewer 4:
Resources spent to reach 20% completion was unclear to this reviewer, who also pointed out that planned spending for FY 2019 and FY 2020 was not listed.

Presentation Number: ft086
Presentation Title: On-Demand Reactivity Enhancement to Enable Low-Temperature Combustion of Natural Gas
Principal Investigator: Will Northrop (University of Minnesota)

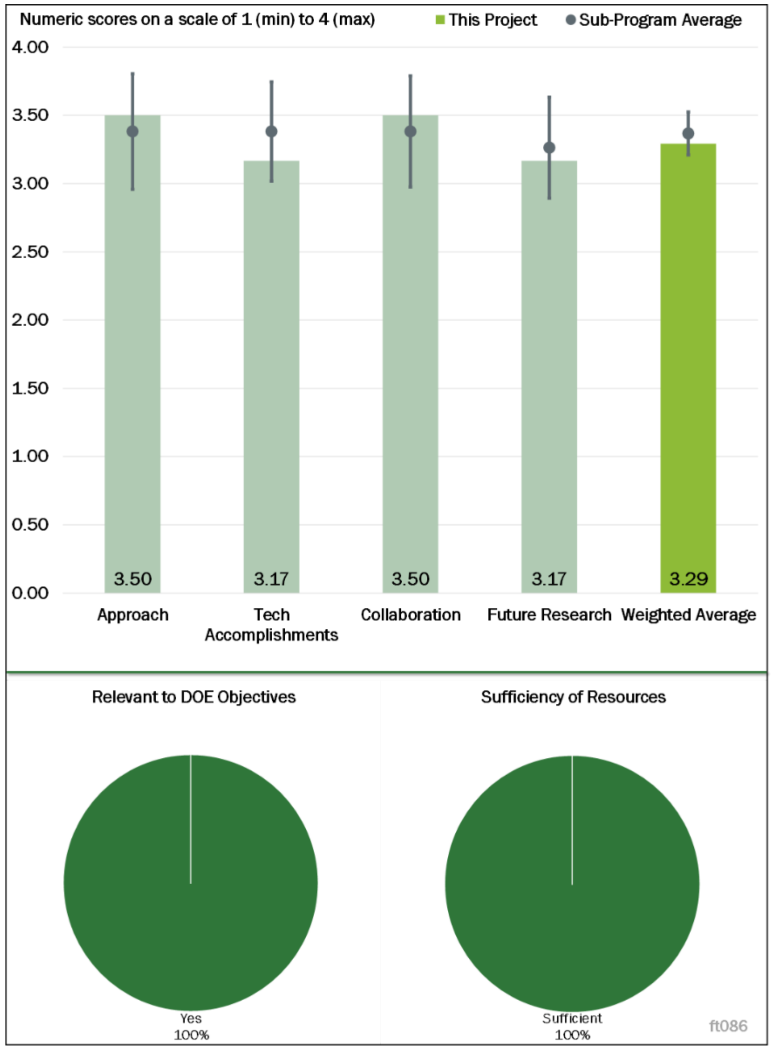

Figure 5-20 – Presentation Number: ft086 Presentation Title: On-Demand Reactivity Enhancement to Enable Low-Temperature Combustion of Natural Gas Principal Investigator: Will Northrop (University of Minnesota)

Presenter

Will Northrop, University of Minnesota

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 and well-planned.

Reviewer 1:

According to the reviewer, the project is focused on enabling ACI approaches with methane fuels. This is tremendously difficult; methane is a difficult fuel even for more conventional SI engines. The reviewer explained that the approach of developing catalysis systems that can “upgrade” the methane to generate a more flexible fuel is novel and, if successful, offers some significant potential improvement paths for future, high-efficiency natural gas engines.

Reviewer 2:

The reviewer observed a good approach by combining bench-scale reactor experiments, micro-reactor experiments, and CFD modeling to address technical barriers for reaching the overall objective of achieving conversion and selectivity goals. There is a good understanding of fundamentals to inform the approach, good validation while waiting for the catalyst to come in, and good direction in moving toward higher residence times with new annulus design, according to this reviewer.

Reviewer 3:

The oxidative coupling of methane (OCM) approach seemed to be similar in intent to methane reforming, but with some advantages, according to the reviewer. However, the explanation of how OCM products can be controlled or combined with reforming was unclear to the reviewer. Because this is first time this project has been presented, the reviewer said that a little more background is needed. The reviewer wanted to know if hydrogen is a co-product of OCM or if it is introduced from a reformer. It also seemed likely to the reviewer that seeding NG fuel with OCM products has been studied, and some results from literature would be useful. Furthermore, this reviewer asked how much OCM product is needed to sustain compression ignition.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that there has been a lot of good progress since the project start, especially because the presented material represents less than a full year of work. The early catalyst work is already showing promise and the engineering on an engine-feasible catalyst system is well underway. There are a lot of tasks remaining, but at the current progress rate, the reviewer had no concerns about a successful, whole project completion.

Reviewer 2:

The reviewer observed solid progress made toward the objectives in the period presented. The remainder of the FY will characterize the OCM in a bench-scale reactor. The project focus is to look at the catalyst itself, including residence time.

Reviewer 3:

The reviewer said that the effort with Johnson Matthey on catalyst discovery is showing good progress as well as modeling of the reactor with input from Carnegie Mellon.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The results presented looked to have very balanced progress across the whole team from this reviewer's perspective. It also appeared that the findings in one task are rapidly impacting technical work in the other tasks.

Reviewer 2:

The reviewer noted that the project team is divided to focus on project partner strengths, which expands the team's ability to overcome technical barriers of the advanced approach.

Reviewer 3:

The reviewer remarked that contributions from Johnson Matthey, Carnegie Mellon, and Ghent University are evident and a key to progress. It would appear advantageous to partner with an organization with suitable natural gas SCE already in place instead of setting up a new lab cell.

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 indicated that remaining planned efforts this FY move the project toward engine-scale evaluations, including moving to single-cylinder engine experiments. The focus on redesign and understanding the impact on residence time will be extremely valuable for moving into the future work.

Reviewer 2:

This reviewer remarked that future research on catalysts for OCM and associated tasks are well focused on the barriers. Referencing prior comments, the reviewer asked whether the project team has considered initial experiments with a NG single-cylinder engine already in operation at a suitable organization. Some additional literature on the impacts of ethane and ethylene on NG engines would be a good addition, and indicated that the information may have been included in the original project proposal.

Reviewer 3:

Having no real problem with the tasks as outlined by the PIs and, given the entities involved, the reviewer thought that this is the right list of tasks. However, the reviewer really would have liked to see this project push to partner with someone outside the team that can enable some kind of full-scale engine evaluation of the concept once BP3 is reached. The reviewer realized that this would probably require additional funding to permit, but showing this system in operation would really highlight the impact it could have. As it would be another large project to demonstrate a true ACI implementation, the reviewer suggested putting this on a conventional SI engine with high levels of EGR. This is already a challenging combustion system due to the slow flame speed of high methane number NG. This catalyst system could enable higher dilution levels, which should offer significant engine-efficiency gains with relatively little hardware modification; in turn, that could offer a fast path to commercialization.

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

Reviewer 1:

The reviewer stated that the project has an overall objective to increase engine efficiency, and also addresses known technical barriers for improving NG engine efficiency. However, the tie to Advanced Combustion & Emissions Control (ACEC) Tech Team goals (or similar goals) was unclear to this reviewer.

Reviewer 2:

The reviewer remarked that measures to extend the combustion of NG to higher dilution levels will help increase engine efficiency, which is necessary for NG engines to have competitive overall cost of ownership.

Reviewer 3:

The reviewer had no specific comments, but indicated that the project is highly relevant in enabling more efficient use of an abundant U.S. energy resource that offers significant CO_2 benefits.

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

Reviewer 1:

The reviewer observed well-provided resources for the tasks as currently outlined. If additional funding could be made available to extend demonstration of the catalyst to a full-scale engine demonstration, that that would be an excellent addition to the project scope.

Reviewer 2:

The reviewer noted significant technical project challenges, but the project team split is well organized to achieve significant results. The resources seemed to be well aligned with the effort and proposed future work.

Reviewer 3:

Resources appeared adequate to cover bench research and development (R&D), modeling, and exploratory engine experiments from this reviewer's perspective. Resources could be extended by using an engine already in place at a partner site, according to the reviewer.

Acronyms and Abbreviations

°C	Degrees Celsius
1-D	One-dimensional
ACEC	Advanced Combustion & Emissions Control
ACI	Advanced compression ignition
AFIDA	Advanced fuel ignition delay analyzer
AMR	Annual Merit Review
ANL	Argonne National Laboratory
ASTM	American Society for Testing and Materials
ATS	Aftertreatment system
BETO	Bioenergy Technologies Office
BEV	Battery electric vehicle
BP	Budget period
BSFC	Brake-specific fuel consumption
BTE	Brake thermal efficiency
CA50	Crank angle position in which 50% of heat is released
CFD	Computational fluid dynamics
CFR	Cooperative fuel research
CH_4	Methane
CLEERS	Cross-cut Lean Exhaust Emissions Reduction Simulations
CLSVOF	Coupled level set volume of fluid
CN	Cetane number
CR	Compression ratio
cSt	Centistokes
CSU	Colorado State University
Cu	Copper
DAS	Deputy Assistant Secretary
DFI	Ducted fuel injection

DISI	Direct injection spark ignition
DOE	U.S. Department of Energy
DPF	Diesel particulate filter
DSC	Differential scanning calorimeter
ECN	Engine Combustion Network
EGAI	End-gas auto-ignition
EGR	Exhaust gas recirculation
EH	Electro-hydraulic
EHA	Electro-hydraulic actuator
EPA	U.S. Environmental Protection Agency
FCEV	Fuel cell electric vehicle
FE	Fuel economy
FOA	Funding Opportunity Announcement
GCI	Gasoline compression ignition
GDI	Gasoline direct injection
GHG	Greenhouse gas
GPF	Gasoline particulate filter
H_2	Hydrogen
HC	Hydrocarbon
HCCI	Homogeneous charge compression ignition
HD	Heavy-duty
HHEA	Hydraulic-hybrid electric architecture
HOV	Heat of vaporization
HPC	High performance computing
IC	Internal combustion
ICE	Internal combustion engine
IMEP	Indicated mean effective pressure
K	Thermal conductivity

KAUST	King Abdullah University of Science and Technology
KDAS	Deputy Assistant Secretary for Transportation
kg	Kilogram
kW	Kilowatt
L	Liter
LD	Light-duty
LECM	Large engine control module
LLNL	Lawrence Livermore National Laboratory
LTC	Low-temperature combustion
LTGC	Low-temperature gasoline combustion
MCCI	Mixing controlled compression ignition
MCE	Multi-cylinder engine
MD	Medium-duty
ml	Milliliter
MM	Multi-mode
MOC	Model predictive control
MON	Motor octane number
MS	Mass spectroscopy
NG	Natural gas
NN	Neural network
NREL	National Renewable Energy Laboratory
OCM	Oxidative coupling of methane
OEM	Original equipment manufacturer
OI	Octane index
ORNL	Oak Ridge National Laboratory
PAH	Polycyclic aromatic hydrocarbon
PFI	Port fuel injection
PM	Particulate matter

PN	Particle number
PMI	Particulate matter index
PNNL	Pacific Northwest National Laboratory
PRF	Primary reference fuel
Q	Quarter
R&D	Research and development
RANS	Reynolds-averaged Navier-Stokes
RCM	Rapid compression machine
RD5-87	87 octane research gasoline
RDE	Real-driving emissions
RON	Research octane number
rpm	Revolutions per minute
SACI	Spark-assisted compression ignition
SCE	Single-cylinder engine
SI	Spark ignition
SNL	Sandia National Laboratories
SULEV30	Super ultra-low emissions vehicle 30
SW	Software
TGA	Thermogravimetric analyzer
TRL	Technology readiness level
TWC	Three-way catalyst
U.S.	United States
UCF	University of Central Florida
VI	Viscosity index
VN-Cu	Vanadium nitride doped with copper
VOF	Volume of fluid
VTO	Vehicle Technologies Office
WTW	Well to wheels

X	Times
ZDDP	Zinc dialkyldithiophosphate
Zero-RK	Zero-order Reaction Kinetics