1. Decarbonization of Off-Road, Rail, Marine, and Aviation Program

The Vehicle Technologies Office (VTO) supports research, development, deployment, and demonstration (RDD&D) of new, efficient, and clean mobility options that are affordable for all Americans. The office's investments leverage the unique capabilities and world-class expertise of the national laboratory system to develop new innovations in vehicle technologies, including: advanced battery technologies; advanced materials for lighter-weight vehicle structures and better powertrains; 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); combustion engines to reduce greenhouse gas (GHG) emissions; and technology deployment and integration at the local and state level. In coordination with the other offices across the Office of Energy Efficiency and Renewable Energy (EERE) and the U.S. Department of Energy (DOE), the Vehicle Technologies Office advances technologies that assure affordable, reliable mobility solutions for people and goods across all economic and social groups; enable and support competitiveness for industry and the economy/workforce; and address local air quality and use of water, land, and domestic resources.

The VTO Decarbonization of Off-Road, Rail, Marine, and Aviation (formerly Advanced Engine and Fuel Technologies) subprogram supports research and development (R&D) necessary for industry to develop efficient engines that can utilize renewable fuels, such as advanced biofuels, hydrogen, and e-fuels, to reduce GHG emissions and achieve a net-zero economy by 2050, all while creating good paying jobs with the free and fair chance to join a union and bargain collectively. Internal combustion engines will continue to be an important power source for off-road vehicles including construction, agriculture and forestry, and rail and marine, during the next several decades. Increasing their efficiency and reducing GHG and criteria emissions will ensure that the clean energy economy benefits all Americans. Optimization of high-efficiency engines and emission control systems, integration of hybrid and electrified powertrains, and utilization of renewable fuels has the potential to improve heavy-duty engine efficiency.

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.

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 1-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
ace023	Controlling NOx Reduction and Low Temperature Oxidation	Yong Wang (Pacific Northwest National Laboratory)	1-8	3.38	3.63	3.63	3.38	3.53
ace027	Fundamental Understanding of Copper-Zeolite Selective Catalytic Reduction (SCR) Catalyst Aging Mechanism (Cummins CRADA)	Feng Gao (Pacific Northwest National Laboratory)	1-12	3.50	3.63	3.75	3.00	3.53
ace100	Improving Transportation Efficiency through Integrated Vehicle, Engine, and Powertrain Research - SuperTruck 2	Darek Villeneuve (Daimler Trucks North America)	1-16	3.20	2.80	3.20	2.63	2.93
ace101	Volvo SuperTruck 2, Pathway to Cost-Effective Commercialized Freight Efficiency	Eric Bond (Volvo Trucks North America)	1-22	2.90	3.00	3.40	2.88	3.01
ace102	Cummins-Peterbilt SuperTruck 2	Jon Dickson (Cummins)	1-28	3.80	3.70	3.60	3.75	3.72
ace103	Development and Demonstration of a Fuel-Efficient Class 8 Tractor and Trailer SuperTruck	Russell Zukouski (Navistar)	1-33	3.80	3.50	3.30	3.50	3.55

ace124	SuperTruck 2 - PACCAR	Maarten Meijer (PACCAR)	1-38	3.67	3.42	3.25	3.08	3.42
ace150	Enabling Low-Temperature Plasma (LTP) Ignition Technologies for Multi-Mode Engines through the Development of a Validated High-Fidelity LTP Model for Predictive Simulation Tools	Nick Tsolas (Auburn University)	1-44	3.10	3.40	3.20	2.80	3.23
ace151	Hierarchically Informed Engineering Models for Predictive Modeling of Turbulent Premixed Flame Propagation in Pre-Chamber Turbulent Jet Ignition	Haifeng Wang (Purdue University)	1-49	3.20	3.20	3.10	3.00	3.16
ace152	Development of High-Fidelity and Efficient Modeling Capabilities for Enabling Co-Optimization of Fuels and Multi-Mode Engines	Matthias Ihme (Stanford University)	1-55	3.20	3.10	3.10	3.00	3.11
ace154	Heavy-Duty Hybrid Diesel Engine with Front-End Accessory Drive-Integrated Energy Storage	Chad Koci (Caterpillar)	1-60	3.00	3.00	2.80	3.38	3.02
ace155	Low-Mass and High-Efficiency Engine for Medium-Duty Truck Applications	Qigui Wang (General Motors Company)	1-64	3.50	3.25	3.38	3.38	3.34

ace156	Next-Generation, High-Efficiency Boosted Engine Development	Michael Shelby (Ford Motor Company)	1-68	3.50	3.17	3.17	3.17	3.25
ace158	Slashing Platinum Group Metal (PGM) in Catalytic Converters: An Atoms-to-Autos Approach	Wei Li (General Motors Company)	1-71	3.50	3.00	3.50	3.17	3.21
ace159	Reduced Cost and Complexity for Off Highway Aftertreatment	Ken Rappe (Pacific Northwest National Laboratory)	1-74	3.50	3.20	3.40	3.20	3.30
ace160	Optimization and Evaluation of Energy Savings for Connected and Autonomous Off-Road Vehicles	Zongxuan Sun (University of Minnesota)	1-79	3.07	3.00	3.29	2.79	3.03
ace161	New Approach for Increasing Efficiency of Agricultural Tractors and Implements	Andrea Vacca (Purdue University)	1-86	3.58	3.50	3.42	3.33	3.49
ace162	Improved Efficiency of Off-Road Material Handling Equipment through Electrification	Jeremy Worm (Michigan Technological University)	1-92	2.67	2.58	2.42	2.58	2.58
ace163	Ducted Fuel Injection and Cooled Spray Technologies for Particulate Control in Heavy-Duty Diesel Engines	Adam Klingbeil (Wabtec)	1-97	3.00	3.00	3.20	3.00	3.03
ace166	New Two-Cylinder Prototype Demonstration and Concept Design of a Next Generation Class 3-6 Opposed Piston Engine	Fabien Redon (Achates Power)	1-97	3.00	2.83	3.17	3.08	2.95

ace169	Greatly Reduced Vehicle Platinum Group Metal (PGM) Content Using Engineered, Highly Dispersed Precious Metal Catalysts	Yong Wang (Washington State University)	1-108	3.25	3.25	3.63	3.25	3.30
ace170	LLCF Effects on Emissions Control Catalyst Performance and Durability	Sreshtha Sinha Majumdar (Oak Ridge National Laboratory)	1-112	3.75	3.75	3.38	3.63	3.69
ace171	Simultaneous Greenhouse Gas and Criteria Pollutants Emissions Reduction for Off-Road Powertrains	James McCarthy (Eaton)	1-116	3.38	3.25	3.50	3.25	3.31
ace172	Fast Simulation of Real Driving Emissions from Heavy-duty Diesel Vehicle Integrated with Advanced Aftertreatment System	Hailin Li (West Virginia University)	1-120	2.50	2.38	2.88	2.38	2.47
ace173	Comprehensive Integrated Simulation Methodology for Enabling Near-Zero Emission Heavy-Duty Vehicles	Andrea Strzelec (University of Wisconsin-Madison)	1-124	3.13	3.13	3.25	3.25	3.16
ace175	Co-optimization of fuel physical/chemical properties and combustion system for mixing controlled compression ignition (MCCI) in a medium-duty engine	Flavio Chuahy (Oak Ridge National Laboratory)	1-128	3.50	3.40	3.60	3.70	3.49

ace177	Independent Fuel Property Effects of Fuel Volatility on Low Temperature Heat Release and Fuel Autoignition	Sibendu Som Jim Szybist (Argonne National Laboratory and Oak Ridge National Laboratory)	1-133	3.30	3.20	3.50	3.40	3.29
ace178	Development Of Advanced Combustion Strategies for Direct Injection Heavy Duty Liquefied Petroleum Gas (LPG) Engines	Dan Olsen (Colorado State University)	1-139	3.38	3.50	3.50	3.25	3.44
ace179	Propane longstroke engine R&D	Derek Splitter (Oak Ridge National Laboratory)	1-143	3.67	3.33	3.33	3.50	3.44
ace182	Fully Electric Powered, Hydraulic Assisted, Compact Track Loader	Perry Li (University of Minnesota)	1-146	3.21	2.71	2.86	3.14	2.91
ace183	Articulated Dump Truck (ADT) Electrification - Greenhouse Gas Reductions and Commercialization of New Technology	Brij Singh (John Deere)	1-152	3.00	2.75	2.50	2.75	2.78
ace184	Development of a Flex-Fuel Mixing Controlled Combustion System for Gasoline/Ethanol Blends Enabled by Prechamber Ignition	Adam Dempsey (Marquette)	1-157	3.63	3.38	3.50	3.25	3.44
ace186	Dynamic Skip Fire (DSF) on a Heavy-Duty Natural Gas Engine	Jay Shah (Cummins)	1-161	3.30	3.30	3.20	3.40	3.30

ace187	Opposed-Piston Two-Stroke Hybrid Commercial Vehicle System	Fabien Redon (Achates Power)	1-166	2.67	2.67	2.92	2.58	2.69
Overall Average				**3.27**	**3.15**	**3.24**	**3.12**	**3.19**

Presentation Number: ace023
Presentation Title: Controlling NOx Reduction and Low Temperature Oxidation
Principal Investigator: Yong Wang, Pacific Northwest National Laboratory

Presenter

Yong Wang, PNNL

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 50% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

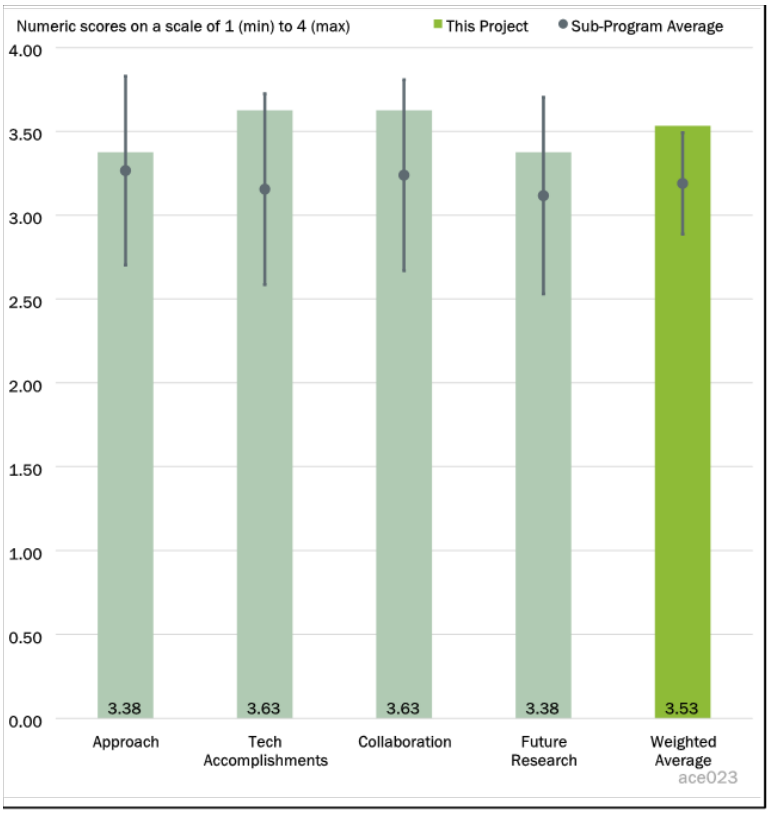

Figure 1-1 - Presentation Number: ace023 Presentation Title: Controlling NOx Reduction and Low Temperature Oxidation Principal Investigator: Yong Wang, Pacific Northwest National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the approach laid out by the team to address the critical barriers is impressive. The approach focused on applications and commercialization makes fundamental research such as this relate to better product development. The reviewer said the project approach bridges the gap between fundamental research and real-world applications and issues.

Reviewer 2

The reviewer remarked there are so many projects, at least five, covered by this review of a set of core issues that it is hard to evaluate them easily or well. But the sum of all the work is outstanding in advancing knowledge in important areas of catalysis. The approach to each topic is well matched to the information needed about that system.

Reviewer 3

The reviewer said the Pacific Northwest National Laboratory (PNNL) team is confronting several problems from fundamental approach; these include lab aging protocol development, low temperature selective catalytic reduction (SCR), nitrous oxide (N_2O) formation in SCR, single atom catalysts (SAC) for methane oxidation, and non-platinum group metal (PGM) oxidation catalyst. Each of these could be the single focus of a research team. To their credit, advances made are being published in top journals, indicating that the science meets high

standards. On the other hand, the findings have at this point limited application. The reviewer said that efforts should be made to focus on 1-2 problems with input from industry stakeholders.

Reviewer 4

The reviewer said this project, over the years, has delivered a significant amount of knowledge to the field. With changes in funding, however, the project needs to re-focus and prioritize. It can no longer continue to support the large variety of efforts it has in the past. Thus, the project should be re-designed. The reviewer said that with too many projects ongoing, focus is lost and timelines likely unrealistic. It is acknowledged that these comments are a direct consequence of funding changes.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said that significant progress has been made to understand the activity and aging of SCR, and interesting findings on N_2O formation.

Reviewer 2

Of the many projects studied the work on low-temperature carbon monoxide (CO)-oxidation on copper (Cu)-ceria (CeO_2) and the study of platinum on CeO_2 supporting palladium oxide rafts for water-tolerant methane oxidation are quite important for saving PGM and expanding the range of conditions where methane oxidation is possible. The reviewer said that much has been learned about inhibiting N_2O formation during SCR reactions and should be continued.

Reviewer 3

The reviewer remarked that considering the multiple sub-projects, the team did well in making progress towards better understanding the science and developing new catalyst technologies. A better definition of specific barriers (or even singular given the many projects) that each sub-project is directed towards will help.

Reviewer 4

The reviewer said the technical accomplishments at the fundamental level are strong based on the dissemination of findings in reputable journals. It is less clear that the findings are translating into commercial practice.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer remarked the number and quality of the collaborators for this project was excellent, even considering the number of topics it covers.

Reviewer 2

The reviewer said it is apparent that there is good collaboration amongst several of the partners. It is not as clear how strong the collaborations are with the industry partners, but it is for the academic and national lab partners.

Reviewer 3

The reviewer said the project has a large industry collaboration, which makes this work highly application-oriented and geared towards original equipment manufacturer (OEM) and Tier 1 suppliers to develop better emissions control system.

Reviewer 4

The reviewer remarked the PNNL team should strive to improve the input of practitioners. For example, comparisons should be made of findings to commercial catalysts and operating conditions. This would better frame the results and help practitioners implement upgrades.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said that continuing many of the same projects, especially those on greenhouse gas (GHG) (e.g., N_2O) from the SCR reaction in off-road engine vehicles, will lead to important further understanding. Emissions work on exhaust from engines with low carbon fuels is important, although we did not see much presented in the past year's summary.

Reviewer 2

The reviewer said the list included low load cycles, full useful life, fuels, GHG, and PGM use as remaining challenges and barriers—this is a massive list. The future research list is also long and unfortunately not focused. The reviewer noted that it contains ammonia (NH_3) SCR, and that seems to be a focus, but also contains PGM usage. A focused project seems more appropriate and would yield deeper knowledge.

Reviewer 3

The reviewer asked what is the limit of low-temperature SCR activity? Will urea hydrolysis be a bigger issue for lower temperature SCR activity? Should propane and dimethyl ether (DME) also be considered as possible fuels to assess low-temperature emissions control? Finally, the reviewer asked should the low-C fuel challenges include a potential of SCR for hydrogen (H_2) internal combustion engines (ICE)?

Reviewer 4

The reviewer said the research plan is more of the same with no plan to consolidate. This approach needs to be re-thought.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer commented the relevance of this group of projects is high, especially those on GHG studies and low temperature emissions from off-road vehicles.

Reviewer 2

The reviewer said this project addresses the VTO program objectives of developing cleaner and efficient diesel engines.

Reviewer 3

The reviewer said the project is focused on engine emissions.

Reviewer 4

The reviewer said the problems studies are relevant at fundamental level, though the translation to real world aspects were less clear.

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

Reviewer 1

The reviewer remarked the funds are certainly adequate to support the fundamental research of several problems, and the team should consider consolidating the focus to make a larger impact on 1-2 problems.

Reviewer 2

The reviewer said the project team is equipped with a lot of OEM expertise, state-of-the-art equipment, and fundamental knowledge of catalyst chemistry to address the critical barriers of this study.

Reviewer 3

The reviewer said resources for these studies exist at PNNL in abundance and at their collaborators' laboratories, if needed.

Reviewer 4

The reviewer said that given the significant drop in funding from fiscal year (FY) 2021 to FY 2022, the focus of the project needs to be re-evaluated. The list of future work surpasses the resources for FY 2022.

Presentation Number: ace027
Presentation Title: Fundamental Understanding of Copper-Zeolite Selective Catalytic Reduction (SCR) Catalyst Aging Mechanism (Cummins CRADA)
Principal Investigator: Feng Gao, Pacific Northwest National Laboratory

Presenter

Feng Gao, PNNL

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

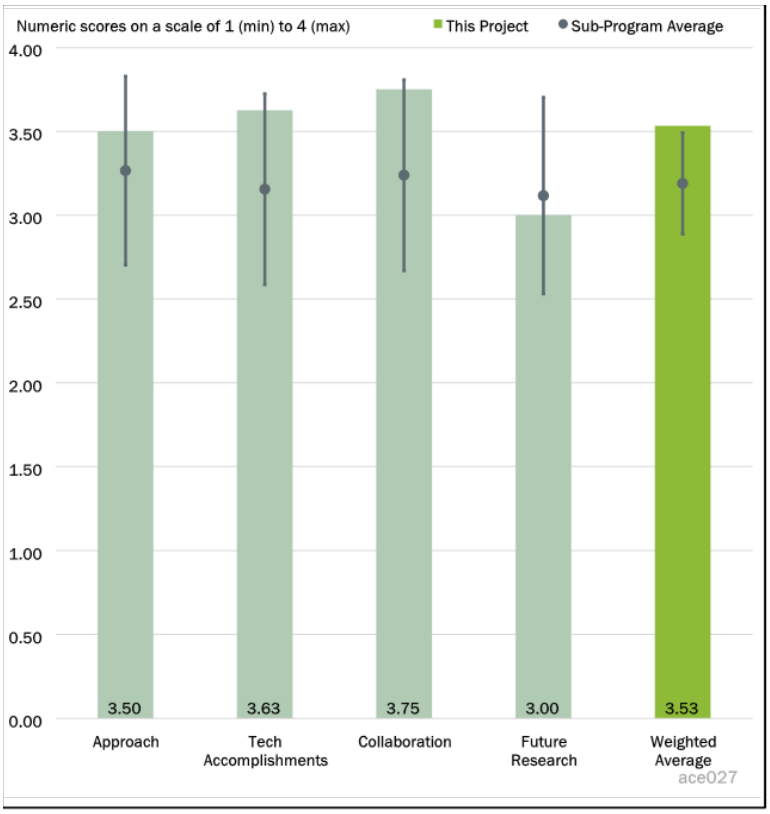

Figure 1-2 - Presentation Number: ace027 Presentation Title: Fundamental Understanding of Copper-Zeolite Selective Catalytic Reduction (SCR) Catalyst Aging Mechanism (Cummins CRADA) Principal Investigator: Feng Gao, Pacific Northwest National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the approach to studying aging of SCR catalysts in comparison with real world catalysts was excellent. Sulfur poisoning is also addressed, a well-known barrier in many studies.

Reviewer 2

The reviewer said the project approach is well designed to address the gaps in field-aging versus simulated again of catalyst. The approach clearly focuses on the studying the mechanism of sulfur poisoning and HTA on the catalyst aging. Will the study consider the effect of incomplete urea decomposition deposits on catalyst aging?

Reviewer 3

The reviewer said the PNNL team has made good progress in characterizing, via electron paramagnetic resonance spectroscopy (EPR) and kinetic studies, changes in SCR catalysts with exposure to real-world aging (RWA) and sulfur. Their strength is in catalyst characterization and the team has developed EPR to study SCR catalysts. The reviewer noted the team has also used TPR to identify catalyst traits. The EPR has proven a useful tool, and although there are some still ambiguous details regarding data obtained using it in combination with the kinetics, gains are being made. The reviewer noted there is a question regarding how this

characterization will ultimately be used to design a better system or slow degradation that would be meaningful in considering the impact.

Reviewer 4

The reviewer said catalyst characterization efforts have been comprehensive and milestones on that aspect have been fine. The collaboration between PNNL and Cummins is strong. The reviewer said what is less evident is how characterization will be translated to fundamental understanding of the mechanism and associated kinetics.

The two objectives—Characterize field-aged samples, identify and model the changes in active sites; and Develop accelerated procedures to simulate RWA of SCR catalysts—need to be emphasized to have a successful outcome to the project. The reviewer said it is unclear what "model" implies. Is this an empirical, statistical, or fundamental model?

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer commented that results showing the effect of HTA and HTA+sulfur oxide (SO_x) aging on the efficiency of the SCR is excellent. This is important to develop diagnostics of SCR catalysts. The project team has addressed previous reviewer comments effectively.

Reviewer 2

The reviewer said learning that lab aging tended to show more harsh hydrothermal aging than real world catalysts, while real world aging tended to have more impact from sulfur than seen from lab aging, is a very important finding for planning and modeling aging in these SCR catalysts.

Reviewer 3

The reviewer said the characterization and kinetics are solid contributions to the project. The decoupling of hydrothermal aging and sulfur, and the focus on the latter as the more important problem, helps the field. The reviewer remarked the inability to "see" particles although they are proposed to form is problematic. This should be a focus to confirm the assumptions behind the other techniques.

Reviewer 4

The reviewer remarked results on identifying the different contributions to the aging using TPR diagnostic is clever and translatable to other labs. However, the project has not yet demonstrated how this will be connected at the fundamental level in terms of mechanism and quantification.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said it is apparent that there are strong interactions with the industry partner.

Reviewer 2

The reviewer noted that Cummins is an excellent partner for this cooperative research & development agreement (CRADA) work with them, along with interactions with Jeff Miller at Purdue and the studies of operando measurements at Tsinghua University in Beijing.

Reviewer 3

The reviewer said testing of field-aged samples is vital to this study and collaboration with Cummins is the best approach to prepare these samples accurately. The collaboration between the Environmental Molecular Sciences Laboratory and Purdue also provides the requires instrumentation for this work.

Reviewer 4

The reviewer remarked collaboration so far has been excellent. Less clear is how data generated at PNNL will be translated to the "real world" with Cummins involvement.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said future model development incorporating sulfur poisoning, sulfur aging mechanism, and NH_3 storage is vital to understanding the effect of aging on the SCR functionality as a whole. These are excellent future research directions. The reviewer said N_2O formation needs more understanding and it is great to see it in the list of future research. The addition of urea deposit formation and its effect on SCR functionality would also be of interest.

Reviewer 2

The reviewer remarked it appears that the future work is primarily on the industry partner. There is a note that the team will shift to "off-road", but it is not clear what research will be performed.

Reviewer 3

The reviewer said future work described is very appropriate. More direct evidence of the interesting formation of oxidized Cu aggregates in the aged catalyst would very good to see as suggested in Slide 12 of the talk.

Reviewer 4

The reviewer commented future work needs to converge on how fundamentals will translate to an accelerated aging protocol.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said the project supports the VTO goal of developing cleaner and more efficient ICE for transportation and off-road applications.

Reviewer 2

The reviewer said nitrogen monoxide (NO) emissions control from diesel engines is important.

Reviewer 3

The reviewer remarked this work is very relevant to the increased off-road focus of the CRADA, because it relates to the same engines used in those systems.

Reviewer 4

The reviewer pointed out that the aging of SCR and resulting effect on catalyst performance is paramount. This project aims to connect fundamental measurements to understanding the underlying aging, and to translate that to devising accelerated aging that captures the real-world aging.

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

Reviewer 1

The reviewer remarked resources contributed 50:50 between federal and industrial partners are fine.

Reviewer 2

The reviewer noted the project's team members bring in an abundance of experience, stat-of-the-art equipment, and modeling capabilities.

Reviewer 3

The reviewer said this one is difficult to gauge—the future work is on the industry partner, so maybe funds are not required by PNNL. But the transition to off-road is mentioned although no details were provided.

Reviewer 4

The reviewer said both PNNL and Cummins have quite sufficient resources to devote to this project.

Presentation Number: ace100
Presentation Title: Improving Transportation Efficiency through Integrated Vehicle, Engine, and Powertrain Research - SuperTruck 2
Principal Investigator: Darek Villeneuve, Daimler Trucks North America

Presenter

Darek Villeneuve, Daimler Trucks North America

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 20% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

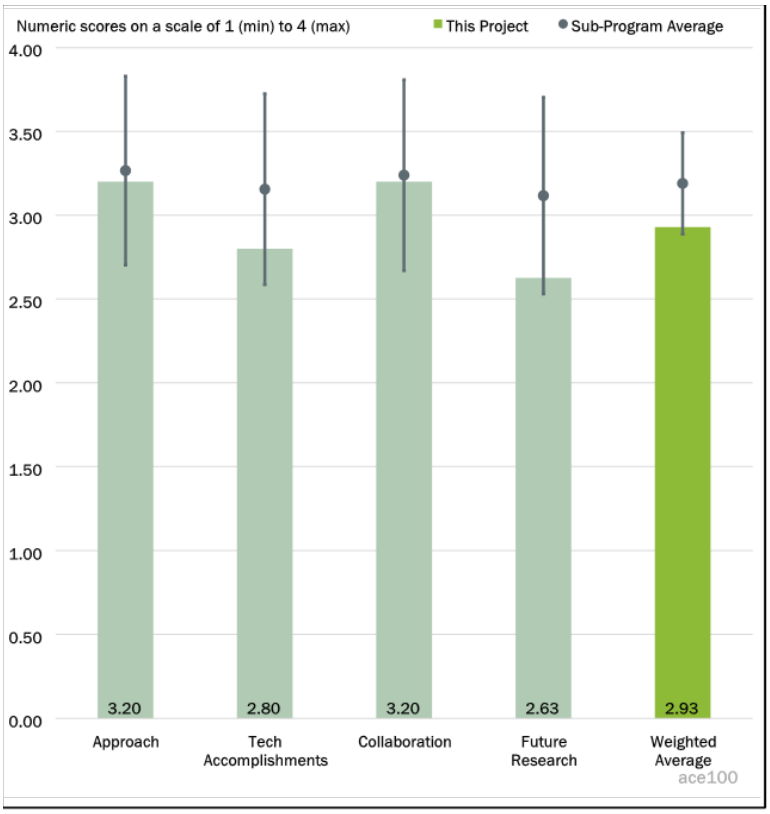

Figure 1-3 - Presentation Number: ace100 Presentation Title: Improving Transportation Efficiency through Integrated Vehicle, Engine, and Powertrain Research - SuperTruck 2 Principal Investigator: Darek Villeneuve, Daimler Trucks North America

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said overall, this team has taken a comprehensive approach to meeting the efficiency goals. In most cases, these have been successful.

Reviewer 2

The reviewer noted the project is in Phase 5, approaching final demonstration vehicle testing scheduled in third quarter with project completion expected by end of third quarter 2022. The project evaluated and effectively selected multiple technologies for the demonstration vehicle to achieve the goals of exceeding 115% freight efficiency, and the engine brake thermal efficiency of 55%. The reviewer said significant challenges identified by the project are optimizing hybrid operations, and software refinement. Predicted aerodynamic performance from analysis and test overestimated gains are seen on road, but the project had sufficient margin. The project, with extension due to COVID ramifications, is on track to complete and is successfully meeting or exceeding these two goals. The reviewer remarked in light of the challenges due to COVID and worldwide supply chain issues, the project has been executed well. Commercialization of the technologies with respect to a 3-year return on investment (ROI) were not discussed in any detail, although the project did have meetings with fleets to get early feedback on design choices.

Reviewer 3

The reviewer said the approaches taken on the vehicle side seems to be a little bit conservative because the stretching goal is only 125% better than the 2009 baseline, while SuperTruck I already showed 115% improvement. It seems that the program is more toward production-intent technologies rather than taking a more aggressive R&D approach, which is what DOE would like to see. The reviewer noted these observations may be partially due to the material and information presented, which contains fairly little detail on the technical approaches. For example, there is little or no information on weight reduction, and it is not clear how the advanced tires compare to baseline.

The reviewer remarked that on the engine side, it seems that the team has all they need to achieve the program, but due to the budget limitation as well as their early poor planning, one of the most advanced technologies, phase change cooling waste heat recovery (WHR), would not be able to be implemented into the dynamometer cell. Lack of this key technology makes this project unable to achieve the program's 55% brake thermal efficiency (BTE) goal.

Reviewer 4

The reviewer has been very impressed with the approach from this program team throughout SuperTruck II. But, this review was very unimpressive. Seemed to be many slides and details presented here from the last review. The reviewer said there was not much to be done in this last phase, but the reviewer would have liked to see more details on commercialization including the required efforts on total cost of ownership of concepts.

Reviewer 5

The reviewer remarked it seems like the timeline is going well, but the reviewer would have expected the 55% BTE engine to have already been demonstrated. It also would have been good to have more discussion on commercialization plans and costs for the technologies that are being developed under this program.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer thought the team has done a good job to meet the objectives of the project. Compared to some of the other teams, this reviewer did not see this team going above and beyond in as many areas and really pushing limits. The reviewer would have liked to see a bit more innovation—for example, the new tire design by Michelin and the ability to convert to 6x2 at highway speeds is extremely interesting. But on the other hand, the cab design was not a bottom-up design it was just a modification of the SuperTruck I design.

The reviewer understood that the 55% BTE engine would not be utilized on the demonstration vehicle as it was not a requirement of the SuperTruck 2 project, but this reviewer was disappointed that most of the SuperTruck teams would choose not to put the 55% BTE engines in their vehicle demonstration.

Reviewer 2

The reviewer said the project evaluated and effectively selected multiple technologies for the demonstration vehicle to achieve the goal of exceeding 115% freight efficiency, and the engine BTE of 55%. However, the two targets were not tied together, so the final demonstrator vehicle does not have the same technology as the 55% BTE engine because WHR is not on the demonstrator vehicle. The SuperTruck II teams interpreted the project expectations, and the DOE apparently did not specifically require the 55% BTE engine to be in the 115% freight-ton efficiency (FTE) vehicle. The 115% target and 125% stretch target are less aggressive than some of the other SuperTruck II teams' targets. The reviewer said the commercial viability return on investment of the technologies was not reported in this AMR review, however the team did report scaling back

on some aerodynamic choices based on fleet engagement due to concerns over commercial viability. The reviewer noted that analysis was reported as supporting exceeding the 115% FTE, so final physical testing is expected to be low risk in confirming this achievement with some margin of safety. The decision to have different tires on each of the tandem axles is technically sound, but introduces additional operational risks to fleets where these tires are moved to trailers or retreaded.

Reviewer 3

The reviewer said most of the technical accomplishments were very good. It is extremely unfortunate that the phase change cooling will not be demonstrated, and that only simulation from the supplier (who is not a collaborator) is being used to claim meeting the 55% BTE goal. As a reviewer, this person has to see this as a failure to meet the target.

The reviewer said the freight efficiency goal is still expected to be met with the final demonstration yet to occur, although underperforming the simulation predictions.

Reviewer 4

The reviewer was disappointed that some of the developed systems such as WHR did not make it into the final vehicle, and it seems like the final prototype could have been more aggressive.

Reviewer 5

The reviewer's biggest concerns on this program is the technical accomplishments on the engine side. The roadmap to 55% BTE seems to point to the disappointing direction that the program would not be able to achieve 55% BTE experimentally. The reviewer said it is even more disappointing that the phase change cooling WHR would not even be scheduled for the next tests (Slide 15). Also, it is not clear whether there is any WHR being used in the program, because the program has been dedicated too much on phase change cooling WHR and it would be hard to imagine that it would have resource for two WHR programs—one with a "conventional WHR" and other with phase change cooling WHR, even though the roadmap to 55% BTE on Slide 9 shows 2.3% benefits from WHR. The reviewer said if this came from the previous testing assuming an additive to the total BTE, this program would only achieve 50.6% BTE, which would be a total failure of the program. The reviewer asked the team to please clarify on this important matter.

The reviewer said technical accomplishments on the vehicle side seem to be fair, but the team only achieved no more than a 125% improvement compared to the 2009 baseline, and it is only 10% point better that SuperTruck I. The reviewer said there are very few details to demonstrate the progress on the vehicle side. It is not even convincing or even confusing how the progresses related to energy storage, low temperature cooling system, and stationary eAC testing mentioned on Slide 7 help to achieve 125% improvement goals, partially due to the way how the material is presented. The reviewer said that in addition, it is disappointing that no WHR technology is being installed in the vehicle, making this program much less competitive compared to its competitors in view of the progress on the engine side.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said the project effectively engaged with fleet, suppliers, and research groups to accomplish its objectives. Schneider National, Strick Trailers, Michelin, Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL), University of Michigan, Clemson University, and Solution Spray

Technologies were specifically called out in the review as participants, and others were also involved as suppliers.

Reviewer 2

The reviewer remarked it looks like a very good team has been assembled for this project. The reviewer thought it is great that Schneider was one of the partners. If there is an opportunity it would be great to hear directly from them on how they perceive the results of the in-use demo.

Reviewer 3

The reviewer said perhaps IAV should have been a partner so that they would have had more skin in the game, so to speak. The listed partners on Slide 17 all made significant contributions.

Reviewer 4

The reviewer remarked the team has all the partners needed, but it is clear that some of partners are unable to help the program to achieve the engine 55% BTE experimentally.

Reviewer 5

The reviewer said that coordination across suppliers and technology companies seems strong, but the reviewer again voiced concern about the lack of customer and voice of customer input and actions. The team claims this was done, but shared virtually no evidence. The reviewer said this was particularly alarming as this was a requirement, investigation of commercialization with total cost of ownership for this program. The reviewer was disappointed we did not see this across any of the programs.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer remarked the project is in its final Phase 5 due to complete in quarter three 2022, so it is essentially ended. Future work is not funded under SuperTruck II as SuperTruck 3 is an entirely new, non-diesel program. The reviewer remarked aerodynamic improvement through tractor ground aerodynamics and trailer aerodynamics, hybrid optimization, and routing strategy were proposed as future areas for vehicle research. The reviewer noted that future engine research proposed includes extending durability of cylinder coatings and new combustion approaches. This team specifically called out that final engine testing with phase change cooling WHR remains unfunded but planned to be completed.

Reviewer 2

The reviewer found it hard to judge this area—not a lot of details are given on the future research plan. That being said, the reviewer thought the overall targets are laid out clearly and the reviewer did not have any concerns about the trajectory of the future research.

Reviewer 3

The reviewer said we should see detailed test reporting and total cost of ownership analysis results as part of this program closeout, although no commitments were made in this review. A press release/ event should be completed after results and analyses are finalized.

Reviewer 4

The reviewer found it surprising that the phase change cooling WHR would not even be mentioned in the proposed future research. It seems that the program completely abandons this promising technology due to poor budgeting and planning in the early stage of the program.

Reviewer 5

The reviewer said the project is ending in 2022, so little DOE sponsored work is expected. Perhaps Daimler will have a chance in the future to wrap up a couple loose ends that seem to exist on this project.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said improved efficiency supports the objective of the Advanced Engine and Fuel Technologies program.

Reviewer 2

The reviewer said highly relevant given $6/gallon diesel fuel and the demands of GHGp2 and likely 3 requirements. This program is more relevant than even Daimler and the DOE are sharing. So much, maybe there is too much focus in communications on zero-emission vehicles. The reviewer said let's be proud of what has been accomplished and share it. More than just in the new program launches that the reviewer expects are coming soon.

Reviewer 3

The reviewer said this program does support the overall VTO objectives.

Reviewer 4

The reviewer noted that the SuperTruck II program in 2016 was very relevant to DOE goals, but diesel technology improvement seems to have been eclipsed in priority by zero and near-zero emission technology and market growth for commercial vehicles. However, diesels, from market demand and production rates, will still be coming out in significant numbers for the next decade and will be in use longer due to their long lives. The reviewer said the SuperTruck II program is however showing continued improvement for diesels and may see some of the technologies in production in parallel with new zero emission and near-zero emission vehicles.

The reviewer noted that DOE has now greater investment in a broader, multi-path approach to improving commercial vehicle efficiency beyond SuperTruck II diesel research. The SuperTruck II project timing is in parallel to industry development of battery electric vehicles, hydrogen fuel cell electric vehicles, autonomous vehicles, and a variety of hybrid technologies along with continued work on ICE engine refinement with multiple fuels such as renewable diesel, renewable natural gas (RNG), H_2, and other fuels to address both efficiency and reduce emissions. Infrastructure technology for these alternatives is also now a priority for DOE investment.

The reviewer noted that WHR is appearing to be not commercially viable based on conclusions from at least three of the five SuperTruck II teams. WHR may not be commercially viable in the remaining timeline of fossil fuel diesels versus zero emission and near-zero emission market adoption. The reviewer said aspects of the 55% BTE engine development with respect to friction reduction and coatings may be applicable to a range of engines in the near term. Aerodynamics, light weighting, and mild hybridization investigated in this project appear to be relevant to future commercial vehicles and DOE objectives. Development of new cabs and chassis have some potential to impact future designs, but they are still tied to diesel engine placement, so are less optimized to facilitate other powertrain choices.

The reviewer said the SuperTruck II project comparison to a 2009 baseline has some usefulness for continuity with prior SuperTruck I programs, but is less relevant to commercialization potential of the technologies in 2022 and beyond with respect to the 3-year ROI SuperTruck II goal, as the current truck buyers are not buying 2009 trucks, but much more capable 2022 trucks that have been through significant GHG 1, GHG 2, and commercial refinements in the period since 2009. These buyers also are now able to procure zero emission battery electric vehicles and other non-diesel alternatives.

Reviewer 5

The reviewer believed this project is very relevant, and thought it is important to especially focus on many technologies that will be important as the trucking sector transitions to zero-emission vehicles.

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

Reviewer 1

The reviewer said that from the information provided, the resources seem sufficient.

Reviewer 2

The reviewer said financial resources seemed to be sufficient, but perhaps there were some other resources that fell short (COVID related?) that prevented the 55% BTE demo from being completed.

Reviewer 3

The reviewer said the project, with a time extension due to COVID ramifications, is on track to complete and successfully meet or exceed the primary two goals while somewhat overrunning DDC and Daimler Truck North America budgets, but not exceeding DOE funding. The reviewer noted that in light of the challenges due to COVID and worldwide supply chain issues, and other unexpected issues outside of the project's control, the project has been executed well. DOE AMR reviews could benefit from standardizing AMR reporting requirements on budget, requiring spend to date, funds remaining, and additional detail to help reviewers determine resource adequacy. This could be done through a first page template.

Reviewer 4

The reviewer said resources are sufficient to complete, but expect to include a public sharing.

Reviewer 5

The reviewer said that if 55% BTE needs to be experimentally demonstrated, the program would not have enough funding to complete the program.

Presentation Number: ace101
Presentation Title: Volvo SuperTruck 2, Pathway to Cost-Effective Commercialized Freight Efficiency
Principal Investigator: Eric Bond, Volvo Trucks North America

Presenter

Eric Bond, Volvo Trucks North America

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 20% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

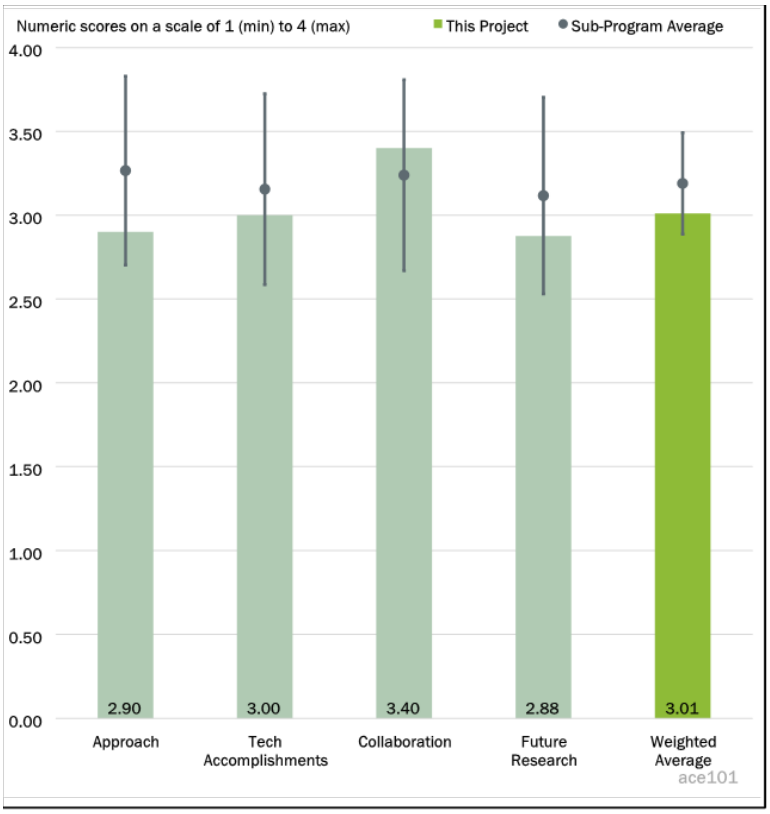

Figure 1-4 - Presentation Number: ace101 Presentation Title: Volvo SuperTruck 2, Pathway to Cost-Effective Commercialized Freight Efficiency Principal Investigator: Eric Bond, Volvo Trucks North America

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the team has good approaches to each specific goal for 55% BTE and 120% freight efficiency improvement. The concern here is that these seem to be two very separate pathways and not very integrated. The fuels work being done by University of Michigan also does not seem to be making a contribution towards either of the goals.

Reviewer 2

The reviewer said the team finished the project with gusto, and the reviewer is looking forward to seeing results presented after testing and total cost of ownership analysis is completed.

Reviewer 3

The reviewer really liked how the team did a lot of work to understand the most relevant duty cycle and combined vehicle weight and use that as the basis for their project plan. The reviewer would have thought the 55% BTE engine would have already been demonstrated at this stage, and would have appreciated more insights into commercialization plans and technology cost.

Reviewer 4

The reviewer noted the project is in its final phase expecting to be completed by December 2022. The team is on track to demonstrate greater than 100% FTE for the vehicle and 55% BTE for the engine. The team interpreted the DOE project goals in a way that the baseline 6x4 tractor capable of 80k lb. Gross vehicle weight was replaceable at 65k lb. as a 4x2. The reviewer remarked the engine used for 55% BTE testing is the larger 13L than the 11L engine installed in the vehicle demonstrator. The WHR system will not be part of the vehicle demonstrator. The reviewer said the 4x2 demonstrator vehicle is configured as a sleeper unit, which is somewhat contrary to the typical 4x2 market which are generally day cabs. The targeted demonstration vehicle improvements were less aggressive than some of the other SuperTruck II projects. The reviewer said overall, the project has accomplished or is on track to accomplish the individual project goals, but the path is somewhat disconnected.

Reviewer 5

The reviewer said there are a few fundamental flaws on the technical approaches taken in this program. First, different engine platforms are being used for the engine demonstration and vehicle demonstration. There are very little similarity or synergy between the 11L engine being used in the vehicle and the 13L engine being used in the engine demonstration, thus there is no integration between the engine and vehicle program, making these two programs separate, which provides little value to the overall program. The reviewer said many technologies being used in the engine dynamometer cell with 13 L engine has no opportunities to be applied to 11L engine used in the vehicle. The combustion system including different compression ratios is just one example, while the WHR developed from 13L engine would not be able to directly be applied to 11L engine.

Secondly, the reviewer remarked the 325 horsepower power rating for the 11L engine being used in the vehicle would be way too underpowered for the future Class 8 market.

Thirdly, the reviewer was not sure if there is any practical value to study the fuel property effect on the emissions, because there is no chance for the market to be able to accommodate the infrastructure of the new gas stations with the different fuel properties.

Fourthly, the reviewer said the 4x2 axle used in the program has very little chance that can be applied to market for Class 8 vehicles due to many practical reasons, such as lack of traction on slippery roads.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer remarked the projected has developed an advanced vehicle system including an all-new cab/sleeper with sleeper entry door and steps. The choice of 19.5-inch tires may impact operational tire life, while allowing a lower aerodynamic profile for improved fuel economy. The optimized powertrain with a 48V mild hybridization is a significant repackaging of the under-hood area. The reviewer noted that improvement from reducing friction and parasitic loads is a significant 1.9% on the 13L but it was not clear how much is achieved on the 11L demonstrator vehicle. The 55% BTE was accomplished for the 13L with WHR installed.

Reviewer 2

The reviewer remarked that team has shown excellent progress on individual pieces of the project, and demonstrations are in progress. I just wish there could be better connections between the two. I'm giving the benefit of the doubt in the rating, but am having a hard time seeing it, which may be getting lost in the 13L versus 11L engines and different CRs.

It would have been nice to see the freight efficiency improvement summarized in a stacked bar chart (like Slide 9 did for the engine efficiency demo).

Reviewer 3

The reviewer commented there were number of accomplishments that were very notable, innovative, and practical, including new, aerodynamic cab design with many nice interior features, all electric heating, ventilation, and air conditioning (HVAC), and more. My understanding was that the 55% BTE engine will not be utilized on the demonstration vehicle. I understand that this was not a requirement of the project, but it is disappointing that it seems like none of the SuperTruck II teams will be utilizing their 55% BTE engines in their vehicle demo.

Reviewer 4

The reviewer said that little evidence was presented to confirm total cost of ownership and the work done with customers. Presenters suggested that the work had been completed, but robustness and even results were not shared to the degree I expected to see. This program maintained and reported on the waterfall charts every year and were more open to share details.

Reviewer 5

The reviewer remarked there is little progress that has been made on the engine side in terms of hardware demonstration. As shown in Slide 9 - Progress - Validation of powertrain Technologies, the roadmap to 55% BTE still largely relies on simulations. It seems that at this time only less than 50% BTE has been demonstrated in an actual engine hardware.

The reviewer said there were not a lot of vehicle progress reported in this report, which only includes two slides (Slides 5 and 6). Similar to the engine programs, there are not a lot of tangible activities and progress that can be evaluated for the program progress.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer commented the project effectively engaged with fleets, suppliers, and research groups to accomplish its objectives. The partnership with Metalsa, Michelin, Wabash, Bergstrom, ORNL, University of Michigan, Motivo Engineering, Johnson Matthey, Mobil, Knight Transportation, and Wegmans has accomplished the primary project objectives.

Reviewer 2

The reviewer said good description of the team and areas of contribution on Slide 14. On Slide 7, ExxonMobil is mentioned (for some unknown reason), but they are not part of the team so their role is a bit undefined.

Reviewer 3

The reviewer found it hard to say too much about this question given that none of the partners are too involved in the presentation. It certainly seems as if a good, well-rounded team has been assembled. As mentioned above it does seem like there is close coordination with the partner fleets—the reviewer would be very interested to learn more about their perspective on the final demo vehicle.

Reviewer 4

The reviewer said good collaboration was evident across suppliers and technical organizations, but more customer focus group efforts would lead to better results and interesting commercialization input.

Reviewer 5

The reviewer remarked it seems that all partners play their role in assisting the program, but not sure if they are able to help Volvo to achieve the program goals.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Plans to finish the project with testing and total cost of ownership conclusions were shared and seemed robust. I would like to see a press release and or event for Volvo to share the results with the public. This will ensure the appropriate sharing as we meet commitments for diesel efficiency going forward

Reviewer 2

The reviewer said that the team is completing the demonstrations on both the engine efficiency and freight efficiency. Project will be over soon, with no indication of whether any aspects of the project will carry forward towards future production product.

Reviewer 3

The reviewer commented that the project is entering is final phase and is due to complete by end of fourth quarter 2022, so it essentially ended with respect to AMR. Future work is not funded under SuperTruck II as SuperTruck 3 is an entirely new, non-diesel program. The reviewer noted the team hinted at future work with blended fuels but was unable to discuss details due to non-disclosure rules. No other new work was suggested by the team.

Reviewer 4

The reviewer said the future research listed is fine, but very scant details were given so the reviewer was not quite sure how to comment on this with any detail.

Reviewer 5

The reviewer remarked it seems that there would be a lot of challenges facing in the program, particularly on the engine program, and therefore one page that should be specifically dedicated to this Future work with a lot of details should be included. Rather, it only contains a few sentences on the future research.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer remarked advanced Engines and Fuels Technologies goals for improved efficiency were relevant in this project.

Reviewer 2

I believe this project is very relevant. I think the Volvo team has been strategic to focus on many technologies that will be important as the trucking sector transitions to zero-emission vehicles (ZEVs) and to also focus on ways to make those technologies the most useful and appealing to fleets, which is extremely important for consumer uptake and commercialization.

Reviewer 3

The reviewer said the SuperTruck II program in 2016 was very relevant to DOE goals, but diesel technology improvement seems to have been eclipsed in priority by zero and near zero emission technology and market growth for commercial vehicles. However, diesels, from market demand and production rates will still be coming out in significant numbers for the next decade and will be in use longer due to their long lives. The

SuperTruck II program is however showing continued improvement for diesels and may see some of the technologies in production in parallel with new zero emission and near zero emission vehicles.

The DOE has now greater investment in a broader, multi-path approach to improving commercial vehicle efficiency beyond SuperTruck II diesel research. The SuperTruck II project timing is in parallel to industry development of battery electric vehicles, hydrogen fuel cell electric vehicles, autonomous vehicles, a variety of hybrid technologies along with continued work on ICE engine refinement with multiple fuels such as renewable diesel, RNG, H_2, and other fuels to address both efficiency and reduce emissions. Infrastructure technology for these alternatives is also now a priority for DOE investment.

WHR is appearing to be not commercially viable based on conclusions from at least three of the five SuperTruck II teams. WHR may not be commercially viable in the remaining timeline of fossil fuel diesels versus zero emission and near-zero emission market adoption. Aspects of the 55% BTE engine development with respect to friction reduction and coatings may be applicable to a range of engines in the near term. Aerodynamics, light weighting, and mild hybridization investigated in this project appear to be relevant to future commercial vehicles and DOE objectives. Development of new cabs and chassis have some potential to impact future designs, but they are still tied to diesel engine placement, so are less optimized to facilitate other powertrain choices.

The SuperTruck II project comparison to a 2009 Baseline has some usefulness for continuity with prior SuperTruck I programs, but is less relevant to commercialization potential of the technologies in 2022 and beyond with respect to the 3-year ROI SuperTruck II goal, as the current truck buyers are not buying 2009 trucks, but much more capable 2022 ones that have been through significant GHG 1, GHG 2 and commercial refinements in the period since 2009. These buyers also are now able to procure zero emission battery electric vehicles and other non-diesel alternatives.

Reviewer 4

The reviewer said the project is very relevant given high fuel prices and the requirements of GHGp2 and 3. Even more relevant than the companies and DOE seem to share. Much has been learned with this program and we should share its successes as we finish.

Reviewer 5

The reviewer said this program does support overall VTO objectives.

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

Reviewer 1

The reviewer said the project appears to be on budget. This is admirable to do in spite of the NCTE.

Reviewer 2

The reviewer said from the information provided the resources seem sufficient.

Reviewer 3

The reviewer said resources are sufficient

Reviewer 4

The reviewer remarked the project, with a time extension due to COVID ramifications, is on track to completion and successfully meeting or exceeding the primary two goals without requiring additional funding from DOE. The team did not report spend to date versus plan, but no issues were raised about funding by the

team. The reviewer noted that DOE AMR reviews could benefit from standardizing AMR reporting requirements on budget, requiring spend to date, funds remaining, and additional detail to help reviewers determine resource adequacy. This could be done through a first page template.

Reviewer 5

The reviewer said after reviewing the program with very little information on the progresses made, it is not sure if Volvo can complete the program goals with the current funding.

Presentation Number: ace102
Presentation Title: Cummins-Peterbilt SuperTruck 2
Principal Investigator: Jon Dickson, Cummins-Peterbilt

Presenter

Jon Dickson, Cummins-Peterbilt

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

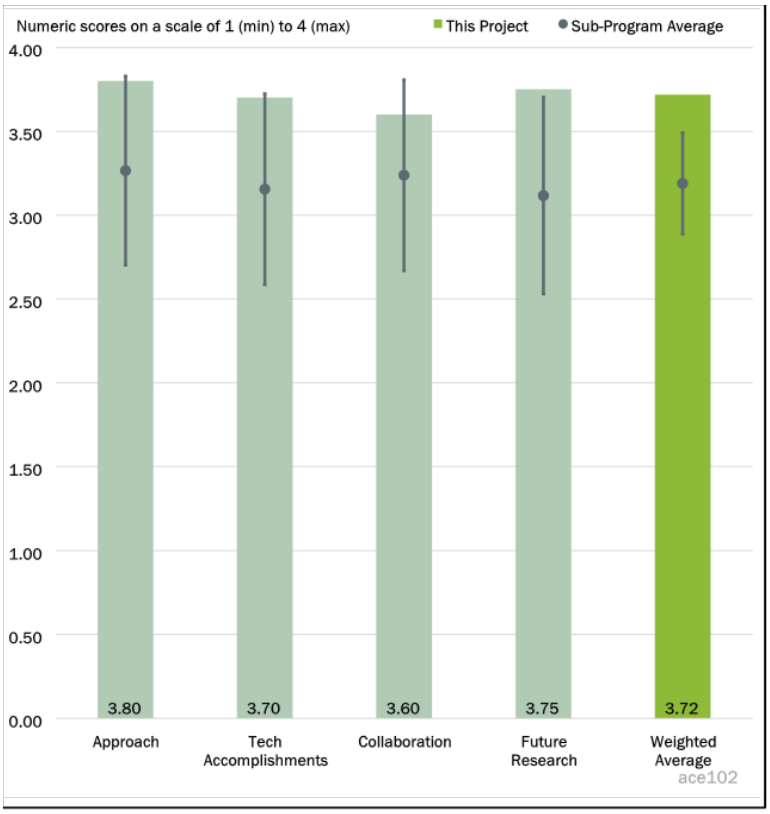

Figure 1-5 - Presentation Number: ace102 Presentation Title: Cummins-Peterbilt SuperTruck 2 Principal Investigator: Jon Dickson, Cummins-Peterbilt

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said this past year, the Cummins/Peterbilt team has focused on the vehicle/trailer because the engine efficiency demo was completed last year and the team will be using the same engine system in the demo vehicle. The team has done an outstanding job on this SuperTruck II project.

Reviewer 2

The reviewer remarked the ACE 102 project is entering its final phase with vehicle testing expected in third quarter 2022 and project end in third quarter 2022. The approach is well organized with a 55% BTE engine demonstration that is implemented in the greater than 125% FTE demonstrator vehicle. The reviewer his project team set aggressive targets for improvement and greatly exceeded the goals while delivering a 6x4 vehicle with 55% BTE engine. Technical barriers have been dealt with effectively while maintaining continuity to the capabilities of the original 2009 baseline vehicle. In light of the challenges due to COVID and worldwide supply chain issues, the project has been executed well.

Reviewer 3

The reviewer thought the timeline and overall project were well designed, and would very much appreciate more input on commercialization status of the technologies as well as cost analysis.

Reviewer 4

The reviewer said the program is nearly complete, so plan delivered to date and work going forward for final freight efficiency test is underway.

Reviewer 5

The reviewer remarked all approaches taken seem to be all in the right direction, and it is clear that all program goals will be achieved.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer remarked the system approach to accomplishing goals for both the engine and the engine in the vehicle while meeting 55% BTE engine targets and projected to greatly exceed 125% vehicle targets demonstrates a range of technologies can be adequately packaged and operated without compromising the comparison to the original baseline 2009 vehicle. The weight reduction of 4,700 lb, aerodynamic drag reduction of 63%, and tire rolling resistance improvement of 33% contributes to an estimated 170% improvement versus the 6x4 2009 baseline while incorporating WHR and mild hybridization. The development of active aerodynamics, particularly on-board yaw sensors and the adjusting rubber extenders, reflect a significant advancement from passive aerodynamic systems. The lightweight hybrid steel/aluminum chassis is similarly innovative.

Reviewer 2

It is clear that a lot of great technical progress has been made. I think there are some areas where the team could have been a bit more innovative—such as a bottom-up cab design rather than modifications to the SuperTruck I design (at least this is what I understood from the presentation). The team was able to demonstrate their 55% BTE engine ahead of many of the other SuperTruck teams, which is very exciting. Unfortunately, my understanding is that none of the teams will be using their 55% engine in the vehicle demo (I understand it is not a requirement, but somewhat disappointing nonetheless). The solar panels on the trailer were interesting and I believe Cummins/Peterbilt was the only team that is looking at that technology. Also, a significant weight reduction was achieved, which is a very relevant and important development especially if it can be done cost effectively.

Reviewer 3

The reviewer said it is amazing to see that the technical progresses that have been made. There is no question that this would be one of the best programs DOE has funded. It should be mentioned that this is the only SuperTruck II program that includes WHR in the final vehicle demonstration, making this program way ahead of its competitors.

Reviewer 4

The reviewer said the team is on the path to achieving all efficiency goals.

Reviewer 5

Progress has been made, but I again am underwhelmed by the amount of data and information presented here. There is good detail in the reviewer slides, but the greater industry players should benefit more from these programs. Maybe a press release/event, where the team details the accomplishments and the technologies moving forward. I understand the competitiveness of solutions, but this program should be sharing more.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer remarked nice identification of where the collaborators contributed to the project.

Reviewer 2

The reviewer remarked the project effectively engaged with fleet, suppliers, and research groups to accomplish its objectives. Duty cycle characterization with NREL and Walmart was a significant addition to the knowledge base on real world operations. Partnerships with Magna, Point Innovation, Valeo, RC, Pilkington, Bergstrom, Northwest Rubber, IMI Noorgren, Great Dane, Mahle, RMC, ZF, and other suppliers show significant involvement of a wide range of expertise.

Reviewer 3

Obviously good coordination between Cummins and Peterbilt. Regarding the rest of the team, that is hard to judge based solely on the presentation. My main comment/question is that I understand Walmart is part of the team, but would appreciate more information on how the team is collaborating with them and how the team is iterating your designs and work based on their feedback.

Reviewer 4

The reviewer would have liked to see more on the customer engagement. The team talks about getting customer buy-in on concepts, but little to no evidence has ever been showed during these annual reviews.

Reviewer 5

The reviewer said collaboration and coordination seem to be seamless with all partners.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said thank you for giving some specifics on future research. This is helpful to understand what remaining work the team has remaining.

Reviewer 2

The reviewer said the project is finishing in September 2022, so future work is not expected to go beyond the ending date.

Reviewer 3

The reviewer commented the project is entering its final phase with testing and completion by end of third quarter 2022, so essentially ended with respect to AMR. Future work is not funded under SuperTruck II as SuperTruck 3 is an entirely new, non-diesel program. The project proposed testing beyond the program needs using routes synthesized from the NREL/Walmart data and to test in comparison to current production models rather than just the baseline 2009 model to evaluate current market relevance of the technologies.

Reviewer 4

The reviewer said plans are in place to finish the testing, and the reviewer is looking forward to seeing the results.

Reviewer 5

The reviewer remarked proposed future research is more than adequate, ensuring that the program can achieve all goals.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said the Advanced Engine and Fuel Technologies efficiency improvement objectives are relevant to this project. The weight reduction aspects of the program are relevant to the materials subprogram objectives.

Reviewer 2

I believe this project is very relevant. I think there are a number of technologies being developed here that will be important as the trucking sector transitions to ZEVs.

Reviewer 3

The reviewer said very relevant, even more so than the program team, company, and DOE are showing. So much focus on ZEVs, but if we are to deliver on GHGp2 and 3 levels for diesel trucks, these programs are hugely helpful. We should be more vocal about them.

Reviewer 4

The reviewer said yes, this program completely supports the overall VTO objectives.

Reviewer 5

The SuperTruck II program in 2016 was very relevant to DOE goals, but diesel technology improvement seems to have been eclipsed in priority by zero and near zero emission technology and market growth for commercial vehicles. However, diesels, from market demand and production rates will still be coming out in significant numbers for the next decade and will be in use longer due to their long lives. The SuperTruck II program is however showing continued improvement for diesels and may see some of the technologies in production in parallel with new zero emission and near zero emission vehicles.

The DOE has now greater investment in a broader, multi-path approach to improving commercial vehicle efficiency beyond SuperTruck II diesel research. The SuperTruck II project timing is in parallel to industry development of battery electric vehicles, hydrogen fuel cell electric vehicles, autonomous vehicles, a variety of hybrid technologies along with continued work on ICE engine refinement with multiple fuels such as renewable diesel, RNG, H_2, and other fuels to address both efficiency and reduce emissions. Infrastructure technology for these alternatives is also now a priority for DOE investment.

WHR is appearing to be not commercially viable based on conclusions from at least three of the five SuperTruck II teams. WHR may not be commercially viable in the remaining timeline of fossil fuel diesels versus zero emission and near zero emission market adoption. Aspects of the 55% BTE engine development with respect to friction reduction and coatings may be applicable to a range of engines in the near term. Aerodynamics, light weighting, and mild hybridization investigated in this project appear to be relevant to future commercial vehicles and DOE objectives. Development of new cabs and chassis have some potential to impact future designs, but they are still tied to diesel engine placement, so are less optimized to facilitate other powertrain choices.

The SuperTruck II project comparison to a 2009 Baseline has some usefulness for continuity with prior SuperTruck I programs, but is less relevant to commercialization potential of the technologies in 2022 and beyond with respect to the 3-year ROI SuperTruck II goal, as the current truck buyers are not buying 2009 trucks, but much more capable 2022 ones that have been through significant GHG 1, GHG 2 and commercial

refinements in the period since 2009. These buyers also are now able to procure zero emission battery electric vehicles and other non-diesel alternatives.

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

Reviewer 1

The reviewer said the project appears it will reach completion on budget.

Reviewer 2

The reviewer said that from the information provided the resources seem sufficient.

Reviewer 3

The reviewer commented resources seem sufficient.

Reviewer 4

The reviewer remarked the project, with time extension due to COVID ramifications, is on track to completion and successfully meeting or exceeding the primary two goals without requiring additional funding from DOE. The project reported spend to date of $39 million with less than $1 million to be expended in the final period. DOE AMR reviews could benefit from standardizing AMR reporting requirements on budget, requiring spend to date, funds remaining, and additional detail to help reviewers determine resource adequacy. This could be done through a first page template.

Reviewer 5

The reviewer said it should have enough funding to complete the remaining program.

Presentation Number: ace103
Presentation Title: Development and Demonstration of a Fuel-Efficient Class 8 Tractor and Trailer SuperTruck
Principal Investigator: Russell Zukouski, Navistar

Presenter

Russell Zukouski, Navistar

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

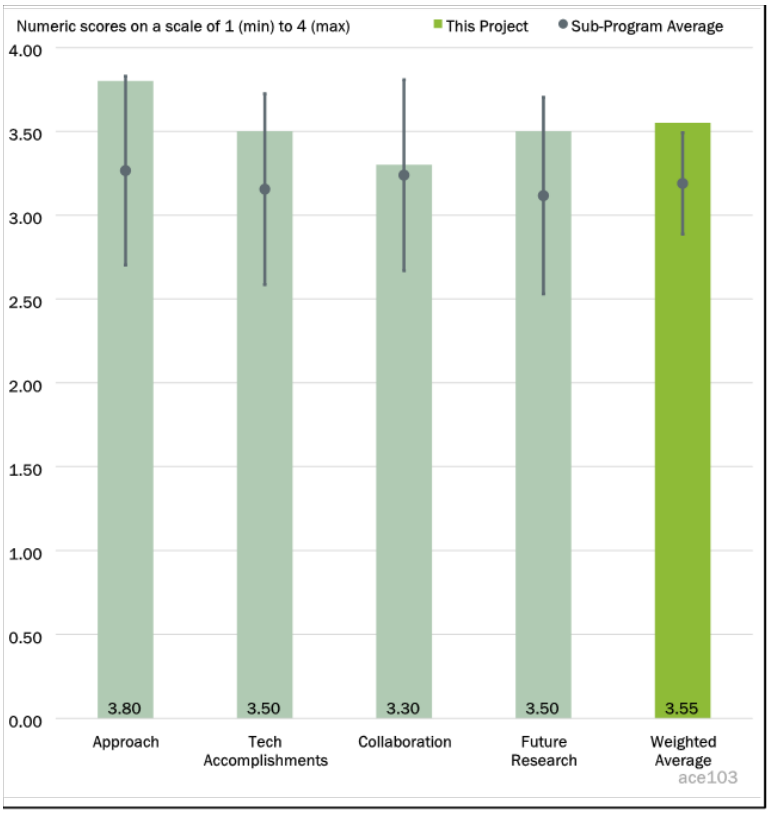

Figure 1-6 - Presentation Number: ace103 Presentation Title: Development and Demonstration of a Fuel-Efficient Class 8 Tractor and Trailer SuperTruck Principal Investigator: Russell Zukouski, Navistar

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the approach to achieving targets for engine efficiency and freight efficiency are very comprehensive with a number of innovations such as exploring a skip fire cylinder deactivation and incorporating a full high-voltage hybrid powertrain. Good exploration of the three-dimensional (3-D) printed cylinder head. The team is broad and capable.

Reviewer 2

The reviewer remarked the project is expected to be complete as of end of June 2022. Significant efforts to complete testing by that date seem unrealistic, but if testing and reporting continue into third quarter 2022, these would not be expected to impact DOE program budgets. The project is the only one that pursued full hybridization in combination with diesel engine developments. The new vehicle cab, and other technologies were done in a timely manner and consistent with comparison to the 2009 baseline vehicle. The project has demonstrated 55% BTE engine and on track to demonstrate a 140% FTE vehicle, exceeding goals with respect to the 2009 baseline.

Reviewer 3

My understanding is the Navistar program is essentially complete and all objectives were met or exceeded. Congratulations! I very much liked that the Navistar team took on some new and innovative ideas to integrate into this project. I would have appreciated more discussion on technology commercialization and cost.

Reviewer 4

The reviewer said the team aggressively pursued the big concepts to deliver performance. Of all the programs, evidence presented showed a good approach to total cost of ownership of selected technologies.

Reviewer 5

The reviewer remarked that both the engine and vehicle programs have a clear technology roadmap to achieve the program goals.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said congratulations are warranted on exceeding the 55% BTE target. The hybrid powertrain presents an opportunity for additional learning and data collection. Impressive integration of electric power into ICE-based powertrain. Completing a cost-benefit analysis of the hybrid system and the waste-heat recovery would be very valuable to DOE and the technical community. Ability to achieve ultralow nitrogen oxides (NO_x) would be good future target activity. The reviewer also noted great progress in weight reduction.

Reviewer 2

The project incorporates a full hybridization with 600 volt (V) systems, a significant accomplishment relevant to progress on zero and near-zero emission vehicles as well as diesels. The team produced a 61.3% aerodynamic drag improvement, 21.8% rolling resistance improvement, and weight reduction of 3,980 lb versus the 2009 baseline. The engine development demonstrated a 55% BTE engine with high flow cylinder head and other improvements.

Reviewer 3

Overall I was very impressed with Navistar team's technical accomplishments. First and foremost, this was the only team that developed a high voltage hybrid system. This is extremely relevant to future ZEV technology so in my view this showed good forethought. I would have liked to see a more bottom-up design to the truck cab instead of just modifications to the SuperTruck I design (this is how I understood what was done). My understanding was that the 55% BTE engine would not be utilized on the demonstration vehicle. I understand that this was not a requirement of the project, but it is disappointing that it seems like none of the SuperTruck teams will be utilizing their 55% BTE engines in their vehicle demo.

Reviewer 4

Team presented sufficient information for me to evaluate as a reviewer if the necessary progress was achieved. As with all programs, the reviewer expected a better final review of cost, commercialization, and performance. The reviewer knows we do not have testing complete yet, and the team did share that they will complete all the testing and then study all concepts for commercialization potential. The reviewer would like to see that published.

Reviewer 5

The reviewer noted that significant progress has been made on the engine side to achieve 55% BTE goal. The reviewer asked what kind of engine is finally installed into the vehicle? What are the key differences between

the engine dynamometer demonstrated engine and the engine that is installed in the vehicle? It seems that the WHR was not installed in the final vehicle for demonstration. Why not? Would that be because there is no space for that or just the team does not have the time and resources to make this happen? Any clarification would be helpful.

The reviewer is still curious, how would cylinder deactivation be attributed to any benefits to 55% BTE? It seems that a lot of funding or budget were relocated to something that has not been directly linked to the program goal. It is confusing if the program has really achieved 145% freight efficiency improvement shown in Slide 17 because Slide 16 still shows more vehicle testing is on the way. The reviewer requested that the team please clarify.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer remarked all partners played their role properly in this program.

Reviewer 2

The reviewer noted the project effectively engaged with fleet, suppliers and research groups to accomplish its objectives. Team partners with Navistar included Argonne National Laboratory (ANL), Lawrence Livermore National Laboratory, Bosch, TPI Composites, Dana, Borg Warner, Jacobs Vehicle Systems, Tula, and JB Hunt.

Reviewer 3

The reviewer said the team is comprehensive and made numerous contributions. The details of contributors could have been presented a little better in a tabulation because this is a specific scoring criterion.

Reviewer 4

The reviewer said it was difficult to gauge this question too well based on the presentation, and the reviewer would have appreciated more feedback from JB Hunt on the demo truck.

Reviewer 5

The reviewer noted that coordination seems strong, but more evidence of working with customers, or even industry groups, dealers, etc. who could have helped with voice of customer would have improved the project, both internally to the project and with the greater industry.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer noted the project is essentially complete as of June 2022. Future work is not funded under SuperTruck II as SuperTruck 3 is an entirely new, non-diesel program. No future work was specifically proposed, but the project alluded to future work with cylinder deactivation was on-going.

Reviewer 2

The reviewer said although the project is ended, the recommendation here is for a follow-on project conducting on-road studies of the hybrid electric vehicle (HEV) system and conducting a cost-benefit analysis of the HEV and WHR systems.

Reviewer 3

The reviewer commented it seems that the program is on the way to completion, and therefore, there is no need to have any future research proposal.

Reviewer 4

The reviewer said the plan is strong to finish the few deliverables yet to complete.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer commented yes, this program does support the overall VTO objectives.

Reviewer 2

The reviewer believed this project is very relevant, and thought the team has been very strategic to focus on the high voltage hybrid technology that will be important as the trucking sector transitions to ZEVs.

Reviewer 3

The reviewer remarked the features discovered and developed in this project will provide a significant opportunity for fuel savings and carbon dioxide (CO_2) reduction for many years while battery electric vehicle (BEV) and electric drive technology and infrastructure (including low-carbon electricity) are on a path to full readiness. Learning and manufacturing with HEV components will strengthen the supply chain base. Unfortunately, there was not yet a net-zero carbon fuel task in SuperTruck II.

Reviewer 4

The SuperTruck II program in 2016 was very relevant to DOE goals, but diesel technology improvement seems to have been eclipsed in priority by zero and near zero emission technology and market growth for commercial vehicles. However, diesels, from market demand and production rates will still be coming out in significant numbers for the next decade and will be in use longer due to their long lives. The SuperTruck II program is however showing continued improvement for diesels and may see some of the technologies in production in parallel with new zero emission and near zero emission vehicles.

The DOE has now greater investment in a broader, multi-path approach to improving commercial vehicle efficiency beyond SuperTruck II diesel research. The SuperTruck II project timing is in parallel to industry development of battery electric vehicles, hydrogen fuel cell electric vehicles, autonomous vehicles, a variety of hybrid technologies along with continued work on ICE engine refinement with multiple fuels such as renewable diesel, RNG, H_2, and other fuels to address both efficiency and reduce emissions. Infrastructure technology for these alternatives is also now a priority for DOE investment.

WHR is appearing to be not commercially viable based on conclusions from at least three of the five SuperTruck II teams. WHR may not be commercially viable in the remaining timeline of fossil fuel diesels versus zero emission and near zero emission market adoption. Aspects of the 55% BTE engine development with respect to friction reduction and coatings may be applicable to a range of engines in the near term. Aerodynamics, light weighting, and mild hybridization investigated in this project appear to be relevant to future commercial vehicles and DOE objectives. Development of new cabs and chassis have some potential to impact future designs, but they are still tied to diesel engine placement, so are less optimized to facilitate other powertrain choices.

The SuperTruck II project comparison to a 2009 Baseline has some usefulness for continuity with prior SuperTruck I programs,but is less relevant to commercialization potential of the technologies in 2022 and beyond with respect to the 3-year ROI SuperTruck II goal, as the current truck buyers are not buying 2009 trucks, but much more capable 2022 ones that have been through significant GHG 1, GHG 2 and commercial

refinements in the period since 2009. These buyers also are now able to procure zero emission battery electric vehicles and other non-diesel alternatives.

Reviewer 5

The reviewer remarked given fuel costs and abilities to meet GHGp2 and p3 regulations this program is more relevant than the awardees and even the DOE seem to state publicly. So much focus on ZEVs and this program has been critical for tech advancement on diesel powered long haul trucks.

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

Reviewer 1

The reviewer's understanding is the project is complete and the resources were sufficient.

Reviewer 2

The reviewer said resources seem sufficient.

Reviewer 3

The reviewer said the team should have enough funding the complete the program objectives.

Reviewer 4

The reviewer remarked the project is at conclusion, and had no comments on this question.

Reviewer 5

The reviewer remarked the project with a time extension due to COVID ramifications, is on track to complete and successfully meeting or exceeding the primary two goals without requiring additional funding from the DOE. The project expects to be complete by June 2022. DOE AMR reviews could benefit from standardizing AMR reporting requirements on budget, requiring spend to date, funds remaining, and additional detail to help reviewers determine resource adequacy. This could be done through a first page template.

Presentation Number: ace124
Presentation Title: SuperTruck 2 – PACCAR
Principal Investigator: Maarten Meijer, PACCAR

Presenter

Martin Meijer, PACCAR

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

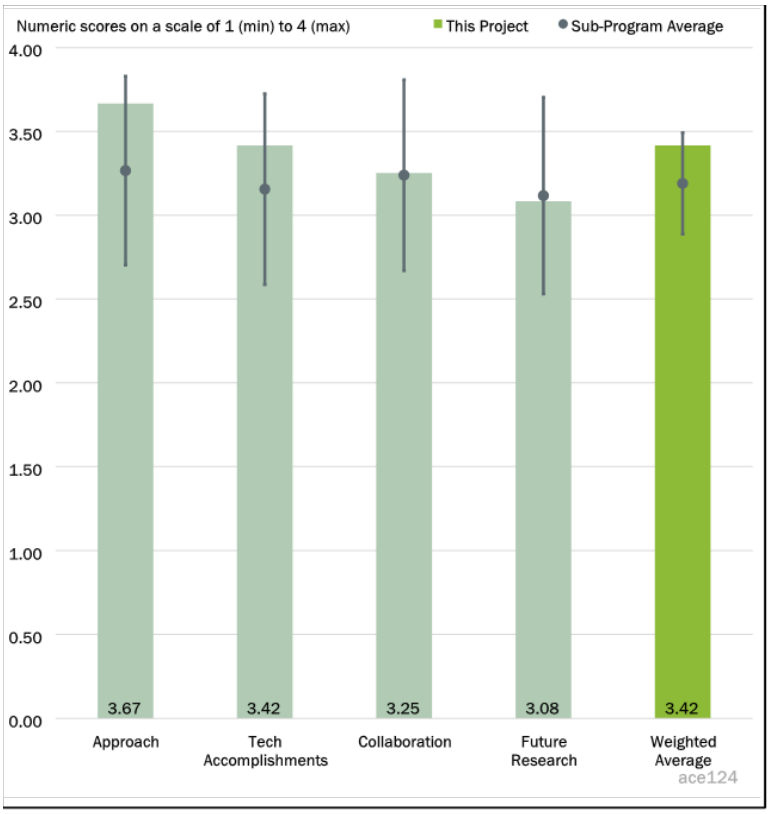

Figure 1-7 - Presentation Number: ace124 Presentation Title: SuperTruck 2 – PACCAR Principal Investigator: Maarten Meijer, PACCAR

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

In this reviewer's view the PACCAR presentation was the most impressive of the 5 SuperTruck presentations—even though PACCAR started one year later than the other teams. The approach seems to be both practical as well as innovative. The reviewer very much appreciated the wide range of technologies that the team appears will be ready to commercialize in 2024-2027 aided by this project.

Reviewer 2

The reviewer said the approach to technical barriers is thorough with little room for improvement within the Funding Opportunity Announcement (FOA) requirements. The reviewer appreciates the assessment of the gasoline compression ignition engine and thoughtful reasons for not continuing as a prime path. Perhaps it would be reconsidered in a program that included net zero carbon fuels. The team is very comprehensive.

Reviewer 3

The reviewer said improved efficiency engine, weight reduction, and aerodynamics improvements used in combination to achieve 170% freight efficiency improvement. These elements are nicely integrated into the project. The reviewer noted a well-designed approach.

Reviewer 4

The reviewer noted the project is expected to complete in December 2023, starting a year later than the other SuperTruck II teams. The project has made significant progress with developing an all-new vehicle capable of exceeding the goal of 120% FTE and towards an engine capable of 55% BTE. The project evaluated the potential for gasoline compression technology and determined NO_x emissions were unacceptable and chose not to pursue that technology. The reviewer said the project is working with Cummins on adapting a WHR system tailored to the PACCAR engine. This approach is low risk. The choice of a 4x2 configuration with sleeper for the demonstrator is somewhat contrary to typical 4x2 market which tends to be day cabs. In light of the challenges due to COVID and worldwide supply chain issues, the project has been executed well to date.

Reviewer 5

The reviewer said the team presented a solid plan to complete the build and testing of the frozen design. The slides and presentation were clear on the concepts selected and plans going forward.

Reviewer 6

The reviewer said the team has all pieces required to build the program, which could achieve the goals for both of engine and vehicle programs. However, the approaches seem to be too aggressive because of lacking prior experience, and putting all bets into one basket in the hope that one final engine demonstration can meet the program 55% BTE goal.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said progress is on a good path of designing and building components and prototypes. The project has another year to go so the team does not have engine efficiency demonstrated yet. The achievement of ultralow NO_x is commendable, because this was not a firm requirement in the FOA.

Reviewer 2

The reviewer said that for the engine efficiency demo, all components completed proof of concept and final demo build started. For the freight efficiency demo, a 48V hybrid battery system, e-HVAC, e-heater, dual loop cooling, and controls were completed and being built into the demo truck.

Reviewer 3

The reviewer said this is a complex all-new chassis and cab design with a center steer driver position. The vehicle is expected to be ultra-low NO_x 2027 compliant. The design incorporates mild hybridization with 48V systems replacing belt driven engine accessories. The aerodynamic refinement is significant for both the tractor and trailer as a system, including real world operational details such as accommodating for sliding trailer tandems and modeling aero loads from vehicles passing in opposite directions on two lane roads. The all-new chassis design is estimated to achieve a 28% weight reduction.

Reviewer 4

The reviewer said there were number of accomplishments that were very notable, including weight reduction on the tractor/trailer. New, bottoms-up aerodynamic cab design, and the team even demonstrated an ultra-low NO_x after treatment system. The reviewer's understanding was that the 55% BTE engine will not be utilized on the demonstration vehicle mainly due to WHR-related packaging constraints, and the reviewer understands that this was not a requirement of the project, but it is disappointing that it seems like none of the SuperTruck teams will be utilizing their 55% BTE engines in their vehicle demo.

Reviewer 5

The reviewer said good progress was made in this critical phase of the program, and the reviewer would like to see more data on cost relative to the requirement of commercialization of all selected systems. This seems to be missing from all SuperTruck II programs.

Reviewer 6

The reviewer said a lot of progress has been made on the vehicle side. Although it sounds to be ready to go for the engine, there are still many unknowns about whether the engine program can achieve the program goal. It seems that PACCAR has tremendous confidence that one set of engine hardware can achieve the program goal, but in reality, there could have been many more iterations to finalize the engine hardware and its key components. We will see.

The reviewer said it is confusing and not helpful at all when the improvements on many key components, such as powertrain efficiency (Slide 12) and freight efficiency (Slide 14), are shown as a percentage. At a minimum, in order to help the reader/reviewer understand the impacts of the improvements, some tangible values, such as weight reduction in absolute numbers, should be provided, just like the competitors.

The reviewer said it seems that the WHR was not installed in the final vehicle demonstration. Can the team clarify? The concern is that PACCAR jumped into the program late. It utilized a WHR from Cummins, which would certainly make a tremendous shortcut. Also, PACCAR has no experience on how the WHR can be installed into vehicle from SuperTruck I program, because they were not part of the program.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer remarked the project effectively engaged with fleet, suppliers and research groups to accomplish its objectives. Primary partners with Kenworth are Eaton, AVL, University of Washington, NREL, Ohio State University, DAF, Cummins, and the PACCAR Technical Center. Others, including fleets, were engaged in review of concepts. The reviewer noted the project tapped a wide range of expertise in developing the system

Reviewer 2

The reviewer said explanation of team members and roles in tabulation is instructive.

Reviewer 3

The reviewer noted that Slide 21 nicely lays out the collaborators and their areas of contribution. It would have been nice (maybe in backup slides) to identify some specifics of their contributions, as that is not detailed in the presentation.

Reviewer 4

The reviewer said all partners play their roles in the program.

Reviewer 5

The reviewer found this question a bit difficult to fully judge based on the materials that were presented. The discussions about the collaboration were limited. That being said, the slide that shows the different expertise that the partners are bringing to the project was very helpful. The reviewer acknowledged there was some mention about getting driver feedback on the cab design, but it also might be helpful to bring in a fleet into more of a partnership role.

Reviewer 6

Collaboration seems to be strong particularly with Cummins after two SuperTruck programs should be expected. The team discussed a Customer Council, but the reviewer continues to see a lack of sharing of information from voice of customer efforts. In all DOE AMRs on this program, it has been shared that we have that collaboration, just trust us, but the AMR is an excellent opportunity to share key customer demands and how the designs meet them. Even sharing areas of concern. The reviewer is disappointed to continue to not see this.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said plans are in place to finalize the program, and the reviewer is looking forward to another review next year.

Reviewer 2

The reviewer said it would be beneficial to produce vehicle CO_2 and fuel consumption numbers in simulation over the Federal Test cycles. Similarly, could engine bsCO_2 be shown over standard Supplemental Emissions Test (SET) procedure. It was not clear from the slides whether the WHR system was going to be used in the vehicle demo for freight efficiency. The cost-benefit impact of the 48V mild HEV will be interesting to see. Good luck on completing project.

Reviewer 3

The reviewer said everything looks on track to demonstrate the engine and freight efficiency goals within budget and the current timeline (the reviewer believed there was a COVID extension?)

Reviewer 4

The reviewer remarked the project is in budget period 4 of 5, due to complete at end of 2023. The project reported that completing the 55% BTE engine demo and completing build of the 175% FTE demonstrator vehicle remain to be done. These are the two core deliverables for the program. No additional research areas were identified.

Reviewer 5

The future research listed is fine, but very scant details were given so the reviewer is not quite sure how to judge this with any detail besides understanding that the next step is demoing the engine and the truck.

Reviewer 6

The reviewer said just a few words for the proposed future research of both engine and vehicle programs were way too simplified. Considering that no demonstration has been made in the middle of engine dynamometer tests, it would be too risky to believe that one shot with the final engine assembling and running can meet the program goal for 55% BTE.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said the technology discovered and developed here will have benefits toward reduction of CO2 and fuel consumption for many years in this difficult-to-decarbonize sector of freight movement. In follow-on efforts, if possible, the use and impact of low-carbon fuels could be evaluated.

Reviewer 2

The reviewer remarked Advanced Engine and Fuel Technologies subprogram goals of increased efficiency are relevant. The Materials sub program goal is addressed in the weight reduction aspects of this project.

Reviewer 3

The reviewer believed this project is very relevant, and thought the PACCAR team has been very strategic to focus on many technologies that will be important as the trucking sector transitions to ZEVs.

Reviewer 4

The SuperTruck II program in 2016 was very relevant to DOE goals, but diesel technology improvement seems to have been eclipsed in priority by zero and near zero emission technology and market growth for commercial vehicles. However, diesels, from market demand and production rates will still be coming out in significant numbers for the next decade and will be in use longer due to their long lives. The SuperTruck II program is however showing continued improvement for diesels and may see some of the technologies in production in parallel with new zero emission and near zero emission vehicles.

The DOE has now greater investment in a broader, multi-path approach to improving commercial vehicle efficiency beyond SuperTruck II diesel research. The SuperTruck II project timing is in parallel to industry development of battery electric vehicles, hydrogen fuel cell electric vehicles, autonomous vehicles, a variety of hybrid technologies along with continued work on ICE engine refinement with multiple fuels such as renewable diesel, RNG, H_2, and other fuels to address both efficiency and reduce emissions. Infrastructure technology for these alternatives is also now a priority for DOE investment.

WHR is appearing to be not commercially viable based on conclusions from at least three of the five SuperTruck II teams. WHR may not be commercially viable in the remaining timeline of fossil fuel diesels versus zero emission and near zero emission market adoption. Aspects of the 55% BTE engine development with respect to friction reduction and coatings may be applicable to a range of engines in the near term. Aerodynamics, light weighting, and mild hybridization investigated in this project appear to be relevant to future commercial vehicles and DOE objectives. Development of new cabs and chassis have some potential to impact future designs, but they are still tied to diesel engine placement, so are less optimized to facilitate other powertrain choices.

The SuperTruck II project comparison to a 2009 Baseline has some usefulness for continuity with prior SuperTruck I programs, but is less relevant to commercialization potential of the technologies in 2022 and beyond with respect to the 3-year ROI SuperTruck II goal, as the current truck buyers are not buying 2009 trucks, but much more capable 2022 ones that have been through significant GHG 1, GHG 2 and commercial refinements in the period since 2009. These buyers also are now able to procure zero emission battery electric vehicles and other non-diesel alternatives.

Reviewer 5

The reviewer said is more relevant than the presenters and the DOE seem to show. ZEVs are coming fast, but we need this research to be able to deliver on GHGp2 and then GHGp3 diesel trucks.

Reviewer 6

The reviewer said yes, this program does support the overall VTO objectives.

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

Reviewer 1

The reviewer said under the present scope, the resources appear to have been adequate. If the scope were expanded to net-zero carbon fuels, additional funds would be needed.

Reviewer 2

The reviewer said resources may be sufficient, but with the current progress without any prior experience, the project may not have enough funding the complete the program, specifically on the engine side, which may require a lot of tuning on the final hardware and calibration packages. We will see.

Reviewer 3

The reviewer said from the information provided the resources seem sufficient.

Reviewer 4

The reviewer said resources seem sufficient.

Reviewer 5

The budget shown on Slide 2 says FY 2022 Funding: $34.7 million, and the reviewer assumed this is the accumulative budget over the life of the project to date, as that would be an excessive one-year budget number!

Reviewer 6

The reviewer noted the project started later than the other SuperTruck II projects. Budget spent to date was not reported, however the project did not identify any risk with budgets in the review, and estimated FY 2022 funding was $34.7 million of the planned $40 million budget, so this year represent significant spending, and the project also reported they were 75% complete at the AMR. The reviewer said DOE AMR reviews could benefit from standardizing AMR reporting requirements on budget, requiring spend to date, funds remaining, and additional detail to help reviewers determine resource adequacy. This could be done through a first page template.

Presentation Number: ace150
Presentation Title: Enabling Low-Temperature Plasma (LTP) Ignition Technologies for Multi-Mode Engines through the Development of a Validated High-Fidelity LTP Model for Predictive Simulation Tools
Principal Investigator: Nick Tsolas, Auburn University

Presenter

Nick Tsolas, Auburn University

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

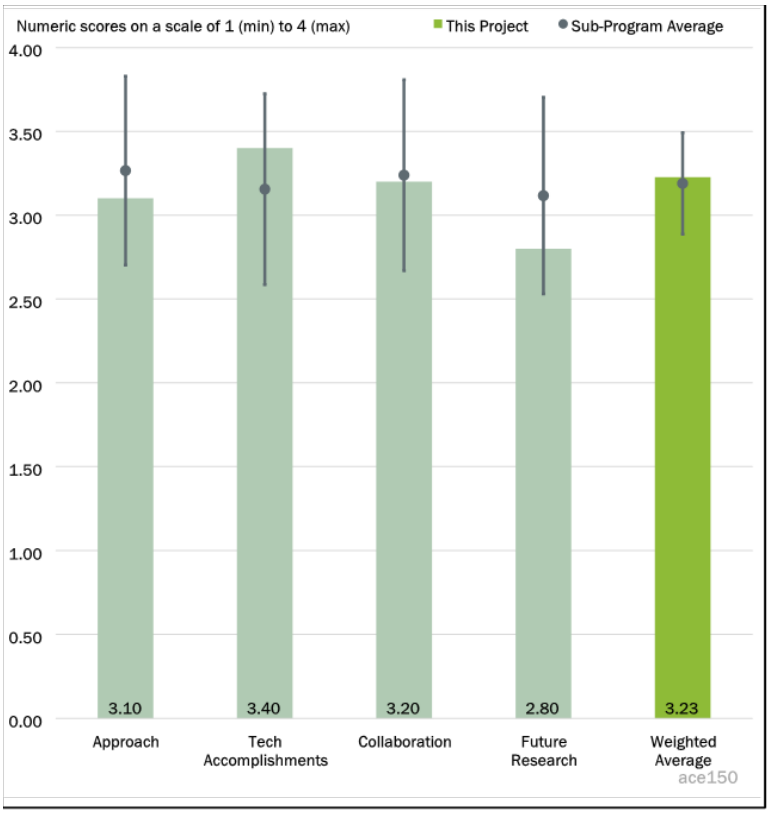

Figure 1-8 - Presentation Number: ace150 Presentation Title: Enabling Low-Temperature Plasma (LTP) Ignition Technologies for Multi-Mode Engines through the Development of a Validated High-Fidelity LTP Model for Predictive Simulation Tools Principal Investigator: Nick Tsolas, Auburn University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said good combination of simulation and experiment.

Reviewer 2

The reviewer remarked the approach was generally well designed. The reviewer tends to agree with one reviewer's comment that the temperature and pressure are not representative of engine-relevant conditions. It will hard to directly plug in the developed tools in engine applications.

Reviewer 3

The reviewer said the PIs adequately addressed technical barriers, and the timeline is reasonably planned. As will be discussed later though, one has to wonder if there is not a disconnect between the planned work and the needs of industry to actually apply actual engine development.

Reviewer 4

The reviewer said this project concerns developing low temperature plasma (LTP) ignitors to facilitate lean burn and exhaust gas recirculation (EGR) controls. It focuses on barriers the PIs believe must be overcome to enable plasma ignition to operate ICEs such as the connection between plasma-specific kinetics and the

combustion kinetics which sustain operation of the engine; and validation of the kinetics. The PIs intend that their results will provide higher fidelity modeling of performance using commercial codes such as from Convergent Science.

The reviewer said the approach is framed around fundamental studies on experimental designs that are principally the plasma flow reactor (PFR) and the ignition test vessel. In the PFR, species are detected at various times as the gases flow through the reactor and from this information an attempt is made to determine the reaction pathways, for iso-octane and ethanol as the two fuels of interest.

The reviewer posed several questions should be addressed.

- Iso-octane and ethanol are both liquid under standard conditions. Both are apparently pre-vaporized for the PFR and ignition tests. How does elimination of the liquid phase effect the results? Fuel is injected as a liquid into an ICE. Is there any coupling between droplets in spray injection and the chemistry of ignition (some literature suggests that there is a connection that should essentially be avoided by obtaining data under pre-vaporization (i.e., gas phase) conditions)?

- The engine environment is quite complex with turbulence, swirl, and gas phase unsteadiness. What assurances are there that the results of this study will be applicable to the more complex environment of an engine? Are the mechanisms broadly applicable? Mechanisms need to be validated, for example with Convergence simulations, and adjusted to improve the agreement with certain key metrics of the engine performance. The same holds true for any reduced mechanism developed. The result will likely be applicable to the specific engine being considered.

- How many reactions and species were there for the iso-octane and ethanol kinetic mechanisms. What guided the choice of the mechanism chosen?

Reviewer 5

The reviewer said the approach to develop a chemical kinetic mechanism for LTP kinetics is reasonable with Auburn focusing on developing the mechanism, Sandia National Laboratories (SNL) measuring the ignition characteristics and University of Texas/ANL supporting the integration into the exascale software. For teams such as this without any specific industry partners, the reviewer would recommend VTO to setup an industry advisory board that can provide periodic comments on the team's approach. The automotive industry is undergoing an inflection point right now and hence continuous input from industry stakeholders is necessary.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said good progress and results were shown.

Reviewer 2

The reviewer commented the technical progress looks good. Again, the pyrolysis modeling comparing to a detailed iso-octane mech is probably fine at 1 bar, and will become an issue at elevated engine conditions. It is a good effort to have the model available in a commercial code for engine combustion applications.

Reviewer 3

The reviewer remarked the PIs have done a very good job keeping the work on schedule as evidenced by the Milestone chart presented. The team presented many detailed results. Can the PIs please comment on the prospect that plasma igniters will actually be implemented in commercial vehicles. The concept has been known for some time now.

Reviewer 4

The reviewer said the team has completed 45% of the proposed work, which is only slightly behind the schedule.

Reviewer 5

The reviewer said technical accomplishments of the project are satisfactory. I understand that we have to walk before running but I believe multi-component fuels should also be investigated (at least primary reference fuels [PRF] and TRF fuels). Sensitivity and validation at engine relevant pressures should be conducted. Much of the work has been at 1-2 atm. The reviewer wonders if constant volume chamber experiments are necessary to be undertaken for mechanism validation under higher pressures.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said collaboration between the four PIs is quite good with good delineation between the different facilities.

Reviewer 2

It may be outside of the scope of the project, but the reviewer thinks there would be value in including an ICE OEM.

Reviewer 3

The reviewer noted that the project team consists of four groups, with Auburn in charge of the flow reactor and development of the kinetic mechanisms, SNL measuring fuel ignition characteristics, University of Texas performing ignition simulations, and ANL in charge of the Converge computational fluid dynamics (CFD) that uses the plasma kinetics to evaluate its performance. It could enhance the program to include an OEM on the team and show a stronger link with results of the present.

Reviewer 4

The reviewer said collaboration within the team is really good. The reviewer referenced prior comments about an industry advisory board for reviewing this project periodically will help.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The future work is noted for oxygenated and sustainable fuels and developing skeletal mechanisms for them. The principal investigator (PI) mentions methanol in this regard. It was not clear if the team envisions methanol by itself or as a blending agent to a petroleum fuel. If the latter, a surrogate-based approach would presumably be needed but was not noted in the future plans.

Reviewer 2

The reviewer said that in the future work, the PIs propose focusing mechanism development on EGR blends and oxygenates, inclusion of turbulence, turbulent mixing, etc. in numerical work, and considering lumping strategies in skeletal mechanism development, all of which will be very helpful for achieving the main targets. However, as in many DOE project, there is a significant disconnect between this research and the practical needs of engine developers—and the reviewer suggests some consideration of the following:

- The 3-D simulation in AMRex takes 3600 cores, 200 M cells and AMR resolution of O(1 mm), which is not feasible for industrial ICEs. Could the PIs provide a reasonable scheme or solution that is more practical in simulating LTP ignitors in real engines?
- The pressure range in SNL LTP ignition experiment is 1 - 4 bar, which is much lower than working pressure of OEM ICEs. It will be more useful if SNL can perform experiments at higher pressure with simulation work to validate the selected kinetic mechanism at these elevated pressure conditions.

Reviewer 3

The reviewer suggests considering semi-coupling method for the skeletal mechanism development in addition to the DRGEP approach.

Reviewer 4

The reviewer sees in the comments that contact has been made with Convergent Science, to incorporate the findings from this project. Hopefully those discussions are fruitful.

Reviewer 5

The reviewer said it was nnclear why methanol + EGR (understand it is the simplest oxygenate fuel) was chosen as its applications are limited. Also, ethanol+EGR should be validated. Plans could include methane air, propane air and PRF for future work.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said LTP is a useful enabler of efficiency and we currently do not have much understanding of the kinetics. This project is a step in the right direction for understanding the science.

Reviewer 2

The reviewer said yes, the project is relevant. If successful, this project will help to develop new LTP ignition technology useful for high-efficiency, next-generation ICEs.

Reviewer 3

The reviewer noted the outcome of this work is anticipated to improve the accuracy of commercial engine solvers such as from Convergence Science, Inc which the ANL partner is developing. The goal is to reduce emissions and improve engine efficiency. The PIs should discuss specific links of their work to their claim of lowering emissions and engine efficiency.

Reviewer 4

The reviewer remarked there is potential for LTP engine applications and it will be good to have a tool to facilitate exploration of the technology.

Reviewer 5

The reviewer said it is responsive to the overall VTO objectives, but questioned if the lack of accurate/predictive models is why LTP igniters have yet been adopted by industry.

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

Reviewer 1

The reviewer said resources are appropriate.

Reviewer 2

The reviewer said resources are deemed sufficient.

Reviewer 3

The reviewer said resources of the project appear sufficient to achieve stated goals.

Reviewer 4

The reviewer remarked the resources seem adequate, though without more details (e.g., overhead rate, scientist and technician salaries, equipment costs, etc.) beyond the bottom-line costs for the project provided in the presentation, it is not possible to adequately score this category. An ultimate judgement would have to come from a cost/benefit analysis based on DOE's investment relative to the commercialization potential of what the PIs are pursuing.

Presentation Number: ace151
Presentation Title: Hierarchically Informed Engineering Models for Predictive Modeling of Turbulent Premixed Flame Propagation in Pre-Chamber Turbulent Jet Ignition
Principal Investigator: Haifeng Wang, Purdue University

Presenter

Haifeng Wang, Purdue University

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

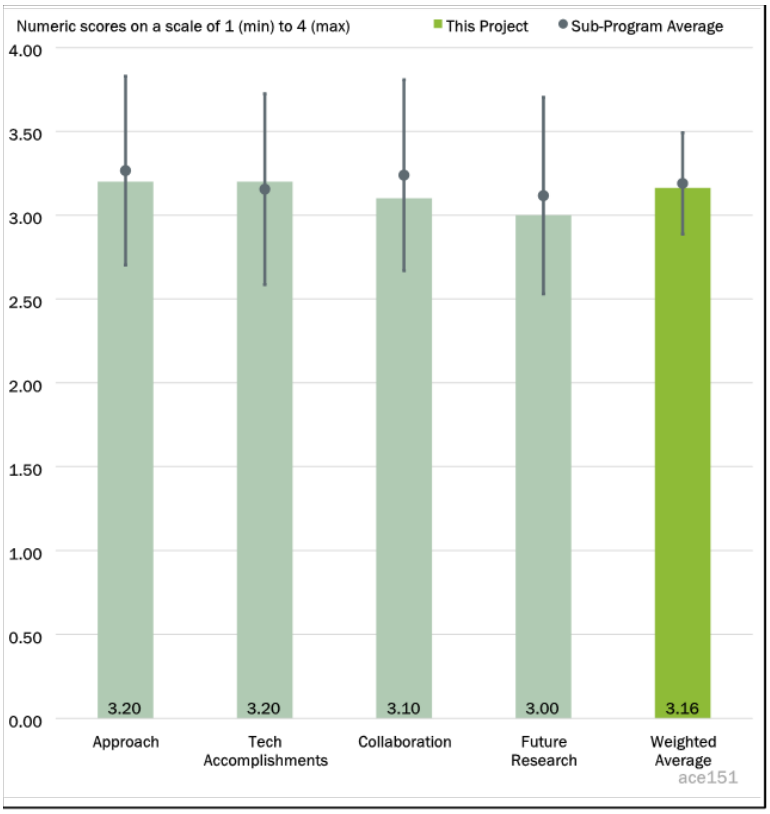

Figure 1-9 - Presentation Number: ace151 Presentation Title: Hierarchically Informed Engineering Models for Predictive Modeling of Turbulent Premixed Flame Propagation in Pre-Chamber Turbulent Jet Ignition Principal Investigator: Haifeng Wang, Purdue University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said prechamber technology is an enabling technology to achieve better engine performance. One of the challenges is to accurately predict the combustion jet from the prechamber to the main chamber. This certainly justified the project. The approach is sound by going from large-eddy simulation (LES) to Reynolds-averaged Navier-Stokes (RANS) to develop the methodology and evaluate the applicability of the model for engine applications.

Reviewer 2

The reviewer remarked pre-chamber ignition will play a substantial role in achieving the performance constraints, especially for high-horsepower engines that seek to explore the lean-burn benefits while employing low carbon fuels, H_2, or its blend with natural gas. Modeling the pre-chamber combustion is complicated because of the challenges posed by three parameters—flow field and the associated mixing, spark ignition, and the subsequent flame propagation. The current work has effectively addressed all these challenges except for the spark ignition—would be interested in seeing more work in this area or discussion of how challenge in this area will be resolved.

The reviewer noted that the report shows steady progress made over budget periods 1 and 2. The objectives planned for the budget period 3 look a tad overwhelming (also as stated in question 8) but they will offer a

good conclusion to this project. The project is well designed, and the timelines are reasonably planned. Concerns with the technical nature of the work are explained in the following comments.

Reviewer 3

The reviewer detailed that this project concerns improving the predictive accuracy and efficiency of turbulent combustion sub-models being used in simulating premixed flame propagation in various engine configurations for off-road, marine, and rail systems. More specifically it involves examining the potential of pre-chamber ignition engine fueled by H_2 off-road, rail engines and possibly marine and on-road engines. It appears that H_2 is the fuel of interest. The emphasis is on developing accurate and efficient models for turbulent flame propagation initiated by a pre-chamber turbulent jet ignition source. Turbulent submodels are being examined for simulating flame propagation initiated by turbulent jet ignition.

In the turbulent jet flame images shown are these for H_2?

The reviewer detailed three project objectives: examine properties of tubulent premixed flames using direct numerical simulations (DNS); develop a LES for turbulent jet ignition (TJI); and using machine learning (ML) to develop Reynolds averaged model based on LES. The DNS is considered to provide the bases for informing a reduced-order LES model for practical pre-chamber jet ignition. Engineering models for turbulent jet ignition are being examined and validated, then ultimately deployed.

The reviewer asked the team please provide some discussion of precisely what engine configurations are envisioned for applying results of the study.

The reviewer noted the approach is based on three levels of modeling, DNS, LES, and RANS. Is this necessary? Could just the DNS and, say, LES be examined without RANS? How is the computational time effected from the three approaches? Data are provided through SNL premixed jet flame studies along with the Purdue TIJ model and ANL's single cylinder engine data.

The reviewer was not clear how the engineering models for TJI are being validated. Is it a straight comparison between experiments and modeling? What is the strategy for addressing discrepancies between experiment and simulation in the validation process? How will the results and models be translated to the engine platforms envisioned (marine, rail, off-road)?

Reviewer 4

The reviewer noted that though TJI is being used at least in demonstrator engines, the science behind is not all clear. Hence, this work assists in understanding the science behind TJI and building robust models to mimic experimental results. The correlation between DNS and LES and a further development of RANS model for TJI will be a great contribution.

Reviewer 5

The reviewer said good approach. It would be better if more highly stressed conditions were included, such as operation at cold temperatures, light loads with high residuals, and lambda=1.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer commented the team has performed very well. The ML model predictions look promising. What is a bit disconcerting is the results from the unfueled prechamber. The same model is unable to do good predictions of unfueled pre-chamber spark ignition. The team needs to look into this issue and address the model deficiencies. In general, the reviewer feels that the model predictions of pressure and heat release are

sluggish compared to experiments and this most probably has to do with the turbulent chemistry interaction (eddy dissipation model?).

Reviewer 2

The reviewer said progress is good with demonstrated performance of the model at both laboratory and engine applications. The ML-assisted mixing model is interesting; however, it was more expensive computationally than the traditional mixing models, which is a bit unexpected. The reviewer remarked one would think the ML will significantly reduce the cost by pre-training datasets and ignoring physics.

Reviewer 3

The reviewer said accomplishments in the reporting period show that the project has hit the milestones, or on schedule to do so. The mixing model has been tested, ANL has carried out simulations to benchmark results from its single cylinder engine, and ML has assisted in the modeling of various targeted product species.

The experimental systems employed are far removed from the engine design; what assurances are there that the models and kinetics developed will be applicable to the various engine platforms that are envisioned?

The global chemistry for methane is noted. It appears to be single step, but it was not clear. If it is single step, is that realistic?

Reviewer 4

The reviewer asked what is the explanation (and solution) for the needed turbulence forcing? This needs to be predictive.

Reviewer 5

The reviewer remarked the current report has included promising validations for the two models developed—ML assisted mixing model, and ML assisted combustion model. However, the results shown are not compelling enough to address the project goal stated by the author in Slide 3—"Significantly improve the predictive accuracy and efficiency of turbulent combustion sub-models for the simulations of premixed flame propagation initiated by pre-chamber turbulent jet ignition." The report does not have statements/results that show a 'significant' improvement in the predictive accuracy leading to the following questions: Significant improvement in the predictive accuracy compared to what? Is the author referring to the RANS-based modeling framework that employs combustion models such as a detailed-chemistry-kinetics-model or a flamelet-based G-Equation model that needs improvement?

The reviewer noted it is difficult to rate the technical relevance and progress of the current work without the following information: What are the challenges of the existing (or as the author calls it—traditional) modeling strategies for capturing pre-chamber performance? Quantify the improvements offered by the new models. The author has shown a comparison of the traditional versus machine-learning models in Slide 9, which shows a reduction in the grid dependency. However, just one parameter does not explain if the new models offered a "significant improvement."

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer remarked good collaboration between team partners, and the team will benefit from an industry advisory committee for guidance and direction.

Reviewer 2

The report elucidates the collaboration between national labs (ANL and SNL), universities (Purdue), and industry (Convergent Science Inc.). The sub-models developed by Purdue are (or will be) validated against the experimental data from Argonne pre-chamber equipped single-cylinder engine, Purdue TJI rig, and the DNS data from SNL. The model successfully validated is being implemented to Converge via user defined functions. The current collaborative structure is more than enough for the successful completion of this project, meaning that additional collaborations may not be required.

Reviewer 3

The reviewer noted that the main partners are Purdue and ANL, and the SNL role is unclear. It is noted that regarding some testing and data collection are being pursued at SNL, whose role seems to involve '…premixed jet flame DNS case'. What is the 'testing' and 'data collection? A budget component for SNL does not seem to be included. NREL is also noted as a collaborator. What is their role?

Reviewer 4

The reviewer said it is good to see the collaboration with SNL/Zhejiang Uni/University of New South Wales. It will be good to briefly outline the collaboration. The reviewer noted that certainly, it is very helpful to have ANL validate the engine applications. However, it is missing a real industry input to get the feedback of the model performance in real industry usages.

Reviewer 5

The reviewer said it is unclear how the other two universities are contributing. The project would benefit from the involvement of an OEM. The reviewer would not wait until you are done to involve an OEM.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said proposed future work is satisfactory.

Reviewer 2

The reviewer said future work is to include the following: developing an LES model for the entire cycle of TJI combustion; validating the model using data from the Purdue TJI experimental rig; testing the RANS model for TJI; and incorporating the Purdue model into the Converge code. The reviewer said the above is reasonable. A natural gas engine is noted; some consideration of how results from the Purdue rig would be applicable to off-road natural gas engines would be appreciated.

Reviewer 3

The reviewer remarked the authors have clearly defined the future work for the budget period 3. The future work includes interesting topics such as development and validation of a high fidelity LES model for TJI combustion; development and validation of a data-driven RANS model for TJI combustion; implementing these models into the commercial tool Converge. The reviewer remarked the number of action items seems overwhelming to be completed in budget period 3. However, there is not enough information in the current report to check if the future work will achieve the proposed target, which the author states as "significant improvement from the existing modeling process." The reviewer referenced comments provided in Question 4.

Reviewer 4

For budget period 2, the reviewer encourages the PI to find another set of TJI case to validate in addition to the one at Purdue. The reason is that there are many uncertainties in the boundary conditions of the Purdue case. Not sure how much one would get to validate the model. A more recent and carefully tuned TJI case might be helpful to get the project team an conclusion.

For budget period 3, the reviewer suggests focusing on reducing computational cost of the RANS model and have the model evaluated in an industry setting.

Reviewer 5

The reviewer remarked the project would be more valuable if the resulting model/process was proven to be predictive under more operating conditions—especially where issues are likely to exist (e.g., cold, EGR-dilute).

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer commented yes, understanding the fundamentals of TJI is extremely critical and this project is attempting it. Very impressed with the work accomplished in this project.

Reviewer 2

The reviewer said yes, prechamber as an enabling technology is very relevant to the VTO platform, now and in the future off-road applications.

Reviewer 3

The reviewer said that TJI still has promise, and supporting tools are worthy of further development.

Reviewer 4

The reviewer said the project is relevant from a broad perspective, and that a closer link of the ANL engine test facility to the types of engines typical of off-road should be established.

Reviewer 5

The reviewer remarked the project is highly relevant. Pre-chambers will be an essential component for the spark-assisted low-carbon fuels or H_2 fuels and its blends, particularly for the high horsepower applications. Pre-chambers are already quite effectively used in natural gas high-horsepower engines. Hence, developing a sound understanding of its combustion characteristics is important to improving its design to overcome challenges such as pre-ignition, spark-plug life, etc. However, an important concern with the current work is the combustion modeling strategy. The reviewer said the ML-assisted combustion modeling developed by the author is based purely on flame propagation. There is no physics (or statistical component) in the model that accounts for auto-ignition. As a result, pre-ignition in the pre-chamber will not be captured. With the traditional modeling approach such as the SAGE detailed-chemistry-model in Converge, both the flame propagation and auto-ignition characteristics would be effectively captured. The reviewer noted that this observation again leads back to questioning the project goal stated by the author that says “Significantly improve the predictive accuracy and efficiency of turbulent combustion sub-models for the simulations of premixed flame propagation initiated by pre-chamber turbulent jet ignition”.

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

Reviewer 1

The reviewer commented spending is appropriate to the activities proposed, and that resources are deemed sufficient.

Reviewer 2

The reviewer said resources are sufficient for the proposed work.

Reviewer 3

The reviewer remarked the project has all the essential resources for its completion. Resources such as experimental facilities or computational clusters will not be the bottleneck for timely completion. The primary concern is if the author included too many action items in his future plans for the budget period 3, also as stated in question 8.

Reviewer 4

The reviewer said that resources seem adequate, though without more details (e.g., overhead rate, scientist and technician salaries, equipment costs, etc.) beyond the bottom-line costs for the project provided in the presentation, it is not possible to adequately score this category. An ultimate judgement of costs come from a cost/benefit analysis based on what the project is intended to accomplish. The SNL role was not clear in the budget.

Presentation Number: ace152
Presentation Title: Development of High-Fidelity and Efficient Modeling Capabilities for Enabling Co-Optimization of Fuels and Multi-Mode Engines
Principal Investigator: Matthias Ihme, Stanford University

Presenter

Matthias Ihme, Stanford University

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 60% of reviewers felt that the resources were sufficient, 40% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

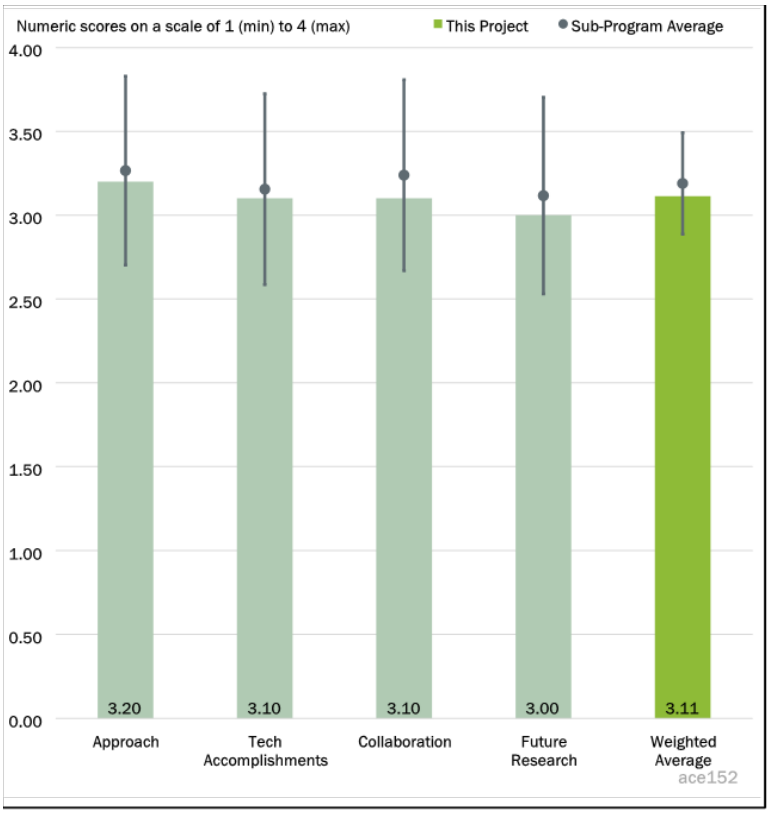

Figure 1-10 - Presentation Number: ace152 Presentation Title: Development of High-Fidelity and Efficient Modeling Capabilities for Enabling Co-Optimization of Fuels and Multi-Mode Engines Principal Investigator: Matthias Ihme, Stanford University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer noted that this project is conducted separately by three research groups:

- Stanford applied LES modeling to low-T chemistry's impact on rapid compression machine (RCM) ignition behavior and to spray combustion through duct fuel injection. The presentation did not explain how the study is relevant to the main goal of the project, i.e., developing high-fidelity and efficient models, and what fundamental improvement the work has been introduced.

- University of Connecticut (UCONN) addressed the fundamentally challenging issue during application of non-equilibrium high-energy plasma ignition chemistry in engine simulation. With the help of ML technique, the UCONN group proposed to train the Gaussian progress regression model under the ML framework, thus allowing the stiffness of non-equilibrium high-energy plasma ignition chemistry to be overcome during plasma-relevant engine combustion simulations.

- ANL implemented an effective Enrichment Wall model to treat the high-order near-wall flow simulation—an important step for improving wall heat transfer prediction in engine simulation. In parallel, the ANL group applied DNS to address triple flame formation in the initial flame kernel development in PFS-assisted SACI engine.

The reviewer noted the project started in 2019, so it is 75% complete in terms of project time. The three research groups have addressed most of the barriers listed but focused on different tasks separately. The project seems well balanced, and its execution is reasonably conducted.

Reviewer 2

The reviewer said the project was well designed to target the technical barriers in modeling engine combustions. These technical barriers are not just for multi-mode combustion, could also for gas engine applications.

Reviewer 3

The reviewer is looking forward to multi-mode simulation results to show exactly the level of improvement made in engine-relevant terms.

Reviewer 4

The reviewer said overall, the work product of this project is really good considering the dollars invested in this project by DOE. Improvement of physical submodels and numerical algorithms is necessary to enable co-optimization of fuels and engines.

Reviewer 5

The reviewer commented the project concerns extending lean combustion to intermediate conditions, investigating new ignition systems, and modeling multimode combustion and emissions including piston geometry effects. The approach is framed around four tasks that include models for combustion regimes, plasma ignition modeling, prediction of heat transfer within ICEs, and simulations on an exascale platform. Model validation is to come from DNS and experimental data. Submodels are indicated as being integrated into engine simulation codes.

The reviewer asked the team to please discuss where the PIs feel that RCM data will fit into the operation of an ICE. Do the PIs anticipate that ignition delay in an RCM will be the same as in an ICE? The reviewer noted there are many iso-octane mechanisms. Some elaboration of the need for the one used here would help. Are the RCM data used in any way to inform the combustion chemistry? The reviewer said the results presented showed how temperature is influenced by the number of pulses; please comment on the pulse duration and its relationship to peak power delivered compared to conventional spark ignition. If simulations have not been carried out on these aspects, the reviewer recommends that they be done. How do the results of Task 2 contribute to the potential for OEMs to adopt plasma ignition? Though plamsa ignition is an interesting and emerging concept the prospects for its incorporation into OEM manufacturer product lines is uncertain. The reviewer said this is one of the reasons that an OEM partner would help the project.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer noted that the team identified the huge uncertainty of low-temperature chemistries. This may suggest that a semi-coupling chemistry is the way to deal with chemistry-related concerns, i.e., proper tailoring or tuning. Very good progress was made at UCONN and ANL.

Reviewer 2

The reviewer said that in general, the project has progressed at a pace matching the original project plan. However, it is unclear what Stanford's Pareto-efficient combustion (PEC)-efficient combustion framework is and how much Stanford has followed its originally proposed plan.

Reviewer 3

The reviewer noted that a lot of progress has been made on the four tasks of the project. Impressive results for the MM engine simulations. The reviewer posed some comments to consider:

- There seem to be some differences between the LES and experimental data shown in the multimode combustion modeling. Is it due to the kinetic mechanism? It would be helpful to note the impact that thermal and transport properties have on the simulations.
- What is the configuration for fuel injection: a liquid jet, spray? For spray injection, is there consideration of the presence of droplets, and if not why not?
- Why is the fuel dodecane for the fuel injection studies while it was noted to be iso-octane for the RCM work?
- What was the computational time for the multimode combustion modeling effort under Task 1?
- The IDT data seemed scattered in the IDT versus temperature plot. Please comment.
- The effort on plasma chemistry is interesting. The assistance of an OEM here could help to facilitate potential transitioning of the computational modeling of high energy ignition to product design.
- For the ML framework, what is the relevance to considering a 0D (homogeneous) reaction configuration? Similarly for channel flow configuration for turbulent wall modeling.
- It would be helpful to show the big picture of how the wall modeling, plasma ignition, and multimode modeling work can all be incorporated into an engine solver, say Converge for example.
- Task 4 notes that an E30 surrogate was used. It was not clear what this consisted of, for example the components, fractional amounts and how they were determined. For the TPRF-E what were the fractional amounts of the constituents, and how was its kinetic mechanism developed?
- Provide more details of the wall heat transfer model.

Reviewer 4

The reviewer remarked accomplishments are satisfactory, and could be made stronger by clearly showing the change made, and the attendant quantitative benefit. Modeling of a ducted fuel injector is an accomplishment, but how does that move the state of the art forward?

Reviewer 5

The reviewer said it was a little disappointing to see that the LES predicted pressure trace is unable to replicate the RCM's pressure trace and is in line with the 0-D non-adiabatic simulation. This shows that the RCM has no turbulence (and hence no turbulence-chemistry interaction) and the inadequacies are in the chemistry. Before digging into the soot model issues, the reviewer would recommend getting some experimental data on equivalence ratios, polycyclic aromatic hydrocarbon (PAH) concentrations, acetylene concentrations and compare those with numerical simulations to understand whether the chemistry is being mimicked correctly by the model.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said very good coordination across the team with the limited budget in place.

Reviewer 2

The reviewer said great collaboration with partners.

Reviewer 3

Each of the three research groups seems to have a clear assignment on the tasks. While there is no overlap, there is also little significant collaboration among the three groups, except that UCONN worked on a reduced mechanism and ANL applied it in Task 4. There is no industry involvement observed or pathway provided to eventually transfer the capabilities being developed into the hands of industry. The reviewer said the tasks of each group seem to be well defined and distinctly different. The chance for the collaboration among the three groups seems low. The reviewer remarked that collaboration with industry needs to be encouraged, for example, non-equilibrium wall model could be used for industry to improve prediction of wall-heat transfer in engine simulations.

Reviewer 4

The reviewer said the project would benefit from having an OEM on the team. This could facilitate transfer of the results of the project to the prototype design space.

Reviewer 5

The reviewer remarked the project would benefit by having an industry partner.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer remarked proposed future research aligns with the objectives of the original project proposal. The project has a clear next-step plan for tasks.

Reviewer 2

The reviewer said proposed research is acceptable.

Reviewer 3

The reviewer commented proposed future work is satisfactory.

Reviewer 4

The reviewer said proposed future research looks good, no comments.

Reviewer 5

The reviewer said that future work will include validating PEC with RCM data, extending model reduction methods to plasma kinetics, analyzing ignition model against DNS, and data from a spark ignition calorimeter. Some discussion of the latter should be provided, specifically conditions of operation and relevance. The reviewer remarked please be more specific on what is meant by ‘algorithmic development’ for multimode engine simulations in the future work.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said certainly, these technical barriers will help the future off-road applications as well.

Reviewer 2

The reviewer remarked multi-mode combustion might have limited relevance going forward, but the fundamental learnings will still apply.

Reviewer 3

The reviewer said this project supports Co-Optima program and hence is a steward of DOE funds.

Reviewer 4

The reviewer remarked the PIs note the need for high accuracy modeling tools for implementing new strategies for control and optimizing multimode combustion. The submodels being developed are considered to improve simulations of various elements such as wall heat transfer, ignition, and combustion mode transition. Also, the numerical tools being developed have potential to lead to more efficient simulations.

Reviewer 5

The reviewer remarked fundamentally, the project supports the VTO subprogram objectives. However, industry involvement or a plan to transfer the technology being developed into industry hands would significantly enhance the project's ability to fully fulfill the VTO subprogram objectives.

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

Reviewer 1

The reviewer remarked the budget may seem a bit low to the reviewer. It will be hard to manage all these activities with the budget.

Reviewer 2

The reviewer thinks DOE can invest further in this project for additional experimental results for a thorough model validation. The reviewer feels the funding of $160,000 is definitely less for the value achieved considering it is nearly a 3.5 year project.

Reviewer 3

The reviewer said there is no indication that the research groups have encountered any issues on resources, etc., and the proposed future research seems manageable to the research groups.

Reviewer 4

The reviewer said resources are adequate, and should not be increased.

Reviewer 5

The resources seem adequate, though without more details (e.g., overhead rate, scientist and technician salaries, equipment costs, etc.) beyond the bottom-line costs for the project provided in the presentation, it is not possible to adequately score this category. An ultimate judgement of costs come from a cost/benefit analysis based on DOE's investment relative to the perceived value of what the PIs are pursuing.

Presentation Number: ace154
Presentation Title: Heavy-Duty Hybrid Diesel Engine with Front-End Accessory Drive-Integrated Energy Storage
Principal Investigator: Chad Koci, Caterpillar

Presenter

Chad Koci, Caterpillar

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

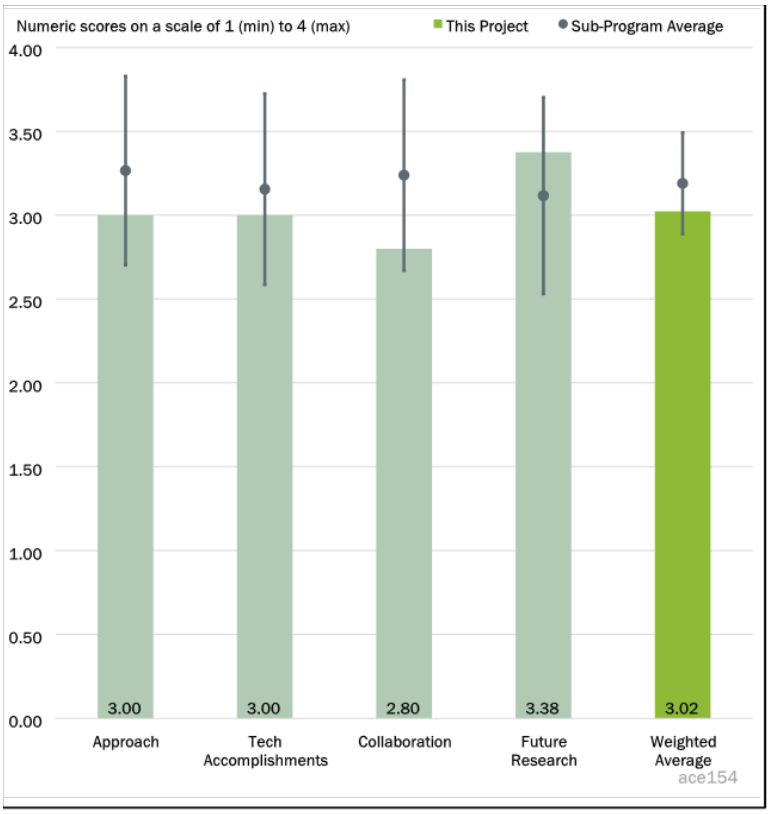

Figure 1-11 - Presentation Number: ace154 Presentation Title: Heavy-Duty Hybrid Diesel Engine with Front-End Accessory Drive-Integrated Energy Storage Principal Investigator: Chad Koci, Caterpillar

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer remarked the project is nearing completion, this project included sound approaches to increased efficiency in off-road duties. The adaptation of the engine to low-carbon fuels was probably not in scope. The technical approach has been carried out with considerable success.

Reviewer 2

The reviewer remarked the final hybrid system demonstration and characterization has yet to be done. The techno-economic analysis will be very useful also—hopefully this can be made public (or perhaps a public version can be made available) as the additional hybrid component additions will need to be offset with operational efficiency.

Reviewer 3

The reviewer remarked the project is almost complete. The industrial share was larger than DOE share and the reviewer thinks this is captured by the information presented at the review.

Reviewer 4

The reviewer said the work presented is excellent. A comprehensive analysis and assessment of an extremely complicated hybrid system—downsized concept engine with thermal barrier coatings, a Super Turbo with

Turbo-compounding, and high-speed flywheel—has been carried out. The researchers are in their final stages of equipment testing and it appears to be going well. We will find out at the end of the no cost extension. The reviewer said the work shows the level of complexity associated with applying hybrid concepts to unique off-road applications and gives a breakdown of the improvement potential of the different aspect of their approach. The techno-economic analysis will be interesting, and informative.

Reviewer 5

The reviewer said the project is well designed and the timeline is reasonably planned. However, the project was not completed on time (95% complete with 3-month no cost extension granted) and some of the architecture selection decisions could have been better. The architecture selected for this project seems to be an overkill and the system is unnecessarily complex with most of the efficiency improvement contributions coming from downsizing the baseline engine to the smaller concept engine.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said this project evaluated some very interesting hybrid configurations. While the final demonstration will be important, communicating these results to the broader engine community will also be very beneficial. Additional technical papers are encouraged that explain in detail the various approaches. It appears that a 'best' approach will be a strong function of the operating cycle—publishing these results is important.

Reviewer 2

The reviewer remarked the architecture selected for this project will make this a very costly product and most likely not to be commercially viable. The project team should evaluate whether some of the technologies investigated in this project such as the turbo-compounding, flywheel, thermal barrier coatings, and even the start/stop implementation should be replaced with more cost-effective alternatives. The reviewer remarked most of these have very little efficiency improvement contributions and may even have offsetting effects. The project team should also evaluate the control systems complexity.

Reviewer 3

The reviewer noted that it is an incredibly complicated system, and the research team has done a great job of overcoming the multitude of challenges in putting the system together.

Reviewer 4

The reviewer said progress has been systematic and the final configuration has been refined. Project targets appear to be achievable in the last months of the project. It would have been useful had the efficiency gains in the base downsized engine been reviewed in more detail. Perhaps the information is in the SAE paper cited.

Reviewer 5

The reviewer said it was difficult to extract the actual technical accomplishment when so much is linked to actual CAT products. The reviewer was not very clear what the work on other components than the engine downsize achieved for future research directions. The reviewer suggested that the final report should say more about the directions for flywheel and superturbo design, for various applications that may require individual optimization versus a "universal" approach.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said there was broad-based collaboration and coordination between an OEM, critical component suppliers, and a university within the project team.

Reviewer 2

The reviewer said the project is winding down. From the presentation it was not clear how the different groups created a synergy of effort.

Reviewer 3

The reviewer said the project appears to be largely an effort by Caterpillar, which is sensible for the work scope. Collaboration partnering not a strong part of the effort.

Reviewer 4

The reviewer remarked it seems like there is good collaboration between Caterpillar and the suppliers; however, it is not clear what University of Texas at Austin is contributing.

Reviewer 5

The reviewer was not very clear what the academic partner was doing in this project.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said the various hybrid approaches in this study are interesting and useful. Detailed sharing of the results will be an important conclusion to this work.

Reviewer 2

The reviewer noted the project ended in June 2022.

Reviewer 3

The reviewer remarked the work is proceeding well and with the no-cost extension it appears the final results will demonstrate the technical targets set out at the beginning of the program.

Reviewer 4

The reviewer said there is quite a bit of work to be completed and documented at this late stage of the project. The key deliverables are documented/recognized and will be valuable when achieved.

Reviewer 5

The reviewer said the future work listed are the remaining tasks required for project closure which is already at the last year and the project has been granted a 3-month no-cost extension. The reviewer said future work will most likely achieve its targets but the proposed solution will be cost prohibitive making this not likely to be commercially viable.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said the project is relevant and will support the overall VTO objectives if cost challenges with the proposed architecture solution can be addressed for commercialization. However, during the project review the OEM could not commit on any plans to commercialize this solution, which is to be expected.

Reviewer 2

As with many others, the reviewer believes the future in mobility will be more specialized technology for specific applications. The challenge will be additional cost, but there seems to be much opportunity to hybridize wisely for unique applications. Additional cost will be offset with the increased efficiency.

Reviewer 3

The reviewer remarked increasing engine efficiency for heavy-duty applications is an important part of VTO mission.

Reviewer 4

The reviewer said the program will show the complexity and potential benefit of hybridizing the unique duty cycles of off-road vehicles.

Reviewer 5

The reviewer commented emissions of GHG and other pollutants, and fuel consumption, is significant in the off-highway sector. Efficiency is a great lever to reduce CO_2 and requires no major changes in infrastructure. Unfortunately, low-carbon fuels were apparently not in the work scope.

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

Reviewer 1

The reviewer remarked it appears that the project will be successfully completed with the resources supplied.

Reviewer 2

The reviewer said resources appear to have been good.

Reviewer 3

The reviewer said resources for this project were sufficient to achieve the stated milestones in a timely fashion. Even though the project was not completed by the end date and an extension has been granted, the project will be completed within the allocated budget.

Reviewer 4

The reviewer said resources are at least adequate. The cost share by Caterpillar is pretty significant.

Reviewer 5

The reviewer noted that industrial partner funding share was more than 50%. It is difficult to comment on resources when it is so expensive to develop and test components such as those in this project.

Presentation Number: ace155
Presentation Title: Low-Mass and High-Efficiency Engine for Medium-Duty Truck Applications
Principal Investigator: Qigui Wang, General Motors

Presenter

Qigui Wang, General Motors

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

75% of reviewers felt that the project was relevant to current DOE objectives, 25% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

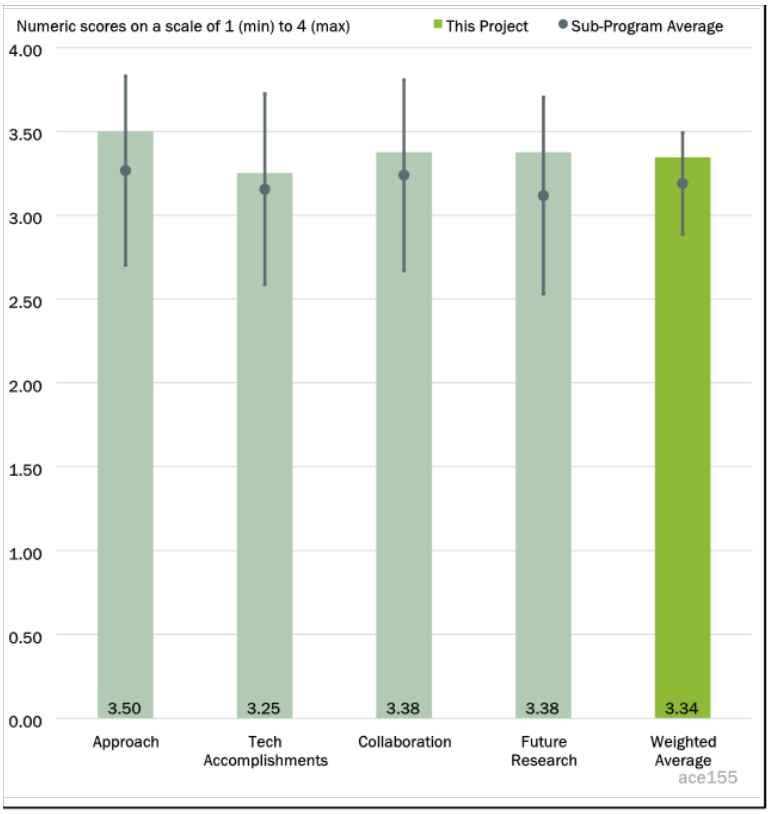

Figure 1-12 - Presentation Number: ace155 Presentation Title: Low-Mass and High-Efficiency Engine for Medium-Duty Truck Applications Principal Investigator: Qigui Wang, General Motors

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer noted the combined use of advanced materials, manufacturing, and combustion strategies expands engine efficiency, but also enables a lighter weight engine with increased performance and fuel economy. The project will help bridge the technology gap between light- and medium-duty engines. The approach implemented in this project could be applied to other engine systems to shorten development time and cost while reducing energy usage and CO_2 emissions.

Reviewer 2

The reviewer said the approach is solid. Largely relies on moderate-risk technologies that should be able to meet program targets with sufficient development. Some of the technologies such as additive manufactured pistons are quite interesting in a technical sense but do not hold much promise for near- or mid-term production introduction, so they are not as relevant to the technology transfer aspect of VTO goals as would be liked.

Reviewer 3

The reviewer said though not extensively covered in the presentation, the backup slide describing Phase II was very well laid out. Nice to see the connections identified to other VTO projects.

Reviewer 4

The reviewer said given the focus on fuel efficiency and weight, the team seems to have a good plan to deliver. Both metrics seem aggressive, but given the large funding, the reviewer expected more concepts to deliver to be investigated.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer is a little concerned about the actual demonstrated fuel economy gain relative to the predicted gain. The PI's organization has a very long history of successful combustion and engine system development and most of the improvements that were pursued were not exotic. The reviewer would have expected much better efficiency results by this point in the program and has some concerns about the pathway to a successful program completion.

Reviewer 2

The reviewer is not too critical of the delays caused by COVID and getting the steps out of sync. However, the measured fuel economy improvement compared to the model predictions were disappointing (Slide 8). The team does appear to be taking actions to rectify this performance shortfall and will still meet the project goals.

Reviewer 3

The reviewer remarked while the technical accomplishments of this project have not entirely met all of the goals, the team has a identified why and has a solid plan for meeting the goals.

Reviewer 4

The reviewer remarked given 55% of the project is complete, progress to deliver all of the goals seems somewhat at risk. Project leaders did not answer some of the reviewer questions around actions to deliver on the cost goals.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said the assembled team has a diverse set of backgrounds (academia, national labs and industry) that cover the needs of the project.

Reviewer 2

The reviewer remarked overall, this project has a good, collaborative team. Perhaps the disappointing combustion predictions could have been improved by leveraging some of the advanced, high fidelity modeling tools being developed by the National Labs. Collaboration on the materials aspects of this project look great.

Reviewer 3

The reviewer remarked there is clear activity at all of the team organizations, and that activity is culminating in hardware to work with at the prime organization. It is not clear if there is strong collaboration or if the activity is more supplier-purchaser activity.

Reviewer 4

The reviewer was surprised not to see more collaboration with customers, or even dealers or other forms of voice of the customer. Fuel efficiency, weight, and of course cost are three of the highest level demands by

customers and the lack of engagement by these parties is concerning. The reviewer is generally critical of most DOE VTO projects in this area, but it stood out here on this one.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said the team has identified appropriate corrective steps to get back on target for fuel economy improvement for the build in task 3 this year.

Reviewer 2

The reviewer remarked the project team understands the goals of their project and how to meet them.

Reviewer 3

The reviewer remarked the proposed work to build the engine and demonstrate the weight reduction seems well in hand and just requires time to execute. Not much information was provided to give any solid guidance on how the engine efficiency gain will be achieved. Some new combustion designs were discussed but predictions of their benefit relative to what was predicted for the first round of hardware was not given.

Reviewer 4

Again, concerned about meeting all goals including cost.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said yes, fuel efficiency improvement fulfills the objective of the Advanced Engine and Fuel Technologies subprogram, and the weight reduction is leveraging the materials subprogram.

Reviewer 2

The reviewer remarked the project supports high efficiency and lower emissions including CO_2.

Reviewer 3

The reviewer must say, spending this much money on a diesel engine program when battery electric powertrains are evolving to be a clear solution for much of this market seems misplaced. The reviewer realizes the award was years ago as BEVs have matured.

Reviewer 4

The reviewer said it is very unfortunate in these programs that VTO selects such outdated baselines for the participants to measure against. The engine that General Motors (GM) sold for this application in 2015 was a completely different engine than that which is offered today. The new engine was developed to satisfy U.S. Environmental Protection Agency (EPA) Phase 2 GHG rules and so already offers a significant improvement in efficiency relative to the baseline engine for the program. This then means that many of the technologies developed for this program are not as aggressive as they could be. If VTO funds are going to be used to support advanced development at OEM's, it seems that the goals should be much bigger or the baselines should be much more current.

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

Reviewer 1

The reviewer said the program budget seems fully adequate for the scope.

Reviewer 2

The reviewer remarked resources seem to be appropriate to meet the project goals.

Reviewer 3

The reviewer said the resources are sufficient.

Reviewer 4

The reviewer commented that resources seem sufficient.

Presentation Number: ace156
Presentation Title: Next-Generation, High-Efficiency Boosted Engine Development
Principal Investigator: Michael Shelby, Ford

Presenter

Michael Shelby, Ford

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers felt that the resources were sufficient, 33% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

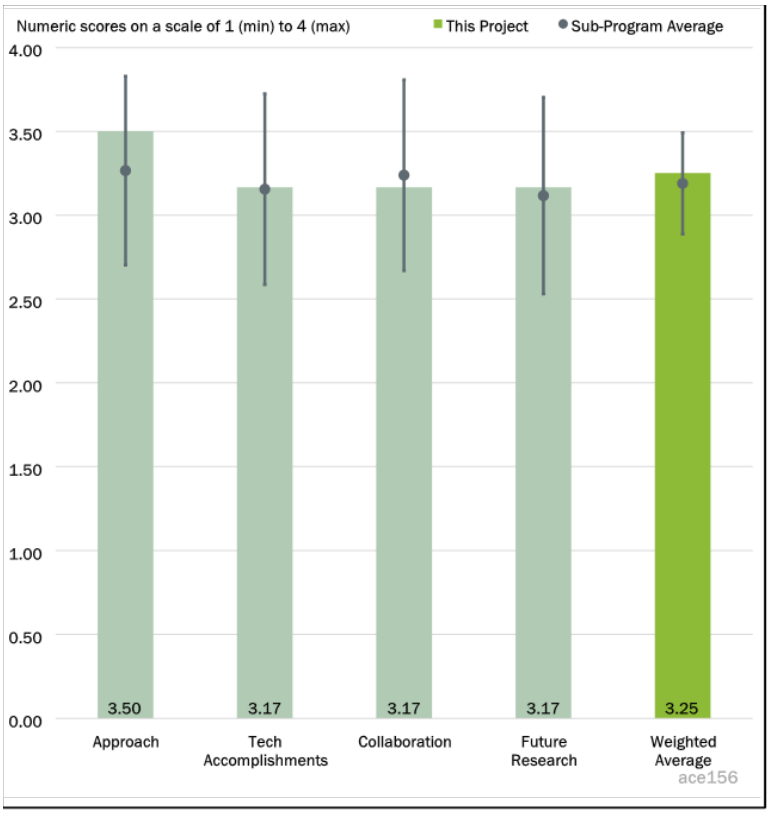

Figure 1-13 - Presentation Number: ace156 Presentation Title: Next-Generation, High-Efficiency Boosted Engine Development Principal Investigator: Michael Shelby, Ford

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the approach is largely based on a change in the engine configuration from V- to inline and adopting advanced but largely understood technologies. The probability of success for the project to meet the goals is high.

Reviewer 2

The reviewer commented that the approach extensively leverages analytical tools in the design and evaluation of concepts such as combustion system concepts for dilution tolerance, efficiency, and knock resistance. The use of simulation, single cylinder engines, and multi-cylinder engines to meet fuel consumption targets is solid.

Reviewer 3

The reviewer commented that approaches taken include all key elements to achieve the program goals. However, it seems to overestimate the impacts on the weight reduction due to the conflicting goal on the fuel consumption reduction in the early planning. Clearly, many technologies taken would increase the weight.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer remarked progress has been on track and generated promising results for both efficiency improvement and mass reduction. There is some delay in the project at present but the PI has a plan to hopefully get the project back on schedule during the current budget period. Current progress looks like it is on track to achieve the program goals.

Reviewer 2

The reviewer said that while there have been some delays, the accomplishments of the team have been outstanding.

Reviewer 3

The reviewer said the project looks good on the achievement of the fuel consumption reduction. However, it underestimates the technical challenging to reduce the weight at the same time.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer commented collaboration between the team members is outstanding and contributes to the success of the project.

Reviewer 2

The reviewer remarked the team members have task descriptions which appear to be progressing well. From the presentation it is unclear how much activity is coordinated between the members and how much is simply done independently and supplied to the PI as needed.

Reviewer 3

The reviewer said that while two key partners—FEV and ORNL—play a crucial role in helping to achieve the program goals, it is still not clear whether they are able to overcome the conflicting goals between fuel economy and weight reduction, thus helping the program to achieve the goals.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer stated the team understands the remaining challenges have added technologies to evaluate to meet the goals.

Reviewer 2

The reviewer said the efficiency improvement appears to be well in hand and to not require a massive ongoing effort. But the PI has identified a gap in the weight reduction that must be addressed. The proposed work to close that gap is very minimally described so it is difficult to evaluate if the plans are suitable or not.

Reviewer 3

The reviewer said the proposed future research provides the detailed steps on what they need to do next by identifying the main challenges. However, it is not clear how these steps can help the program to achieve the program goals on both fuel consumption reduction and weight reduction.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said the project is relevant to the goal of meeting higher fuel economy with lower emissions.

Reviewer 2

The reviewer affirmed it does support overall VTO objectives.

Reviewer 3

The reviewer's comments on this project are primarily directed at VTO and not the project team. They are the same as this reviewer had provided for the companion project awarded under the same FOA and topic area. The goals of the project as defined by VTO are not very aggressive and do not even push technology fast enough to satisfy EPA GHG and fuel economy targets, so the project is relevant to the published VTO goals but is not relevant to the actual needs of industry and consumers. This is not the fault of the project team as they are simply working to what VTO defined.

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

Reviewer 1

The reviewer said the budget seems good for achieving what is required.

Reviewer 2

The reviewer said resources are sufficient to meet the project goals.

Reviewer 3

The reviewer remarked it would be very challenging to meet the weight reduction goals under the current budget. Because of that, Ford may not have the enough funding to complete the program goals.

Presentation Number: ace158
Presentation Title: Slashing Platinum Group Metal (PGM) in Catalytic Converters: An Atoms-to-Autos Approach
Principal Investigator: Wei Li, General Motors

Presenter

Wei Li, General Motors

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

67% of reviewers felt that the project was relevant to current DOE objectives, 33% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

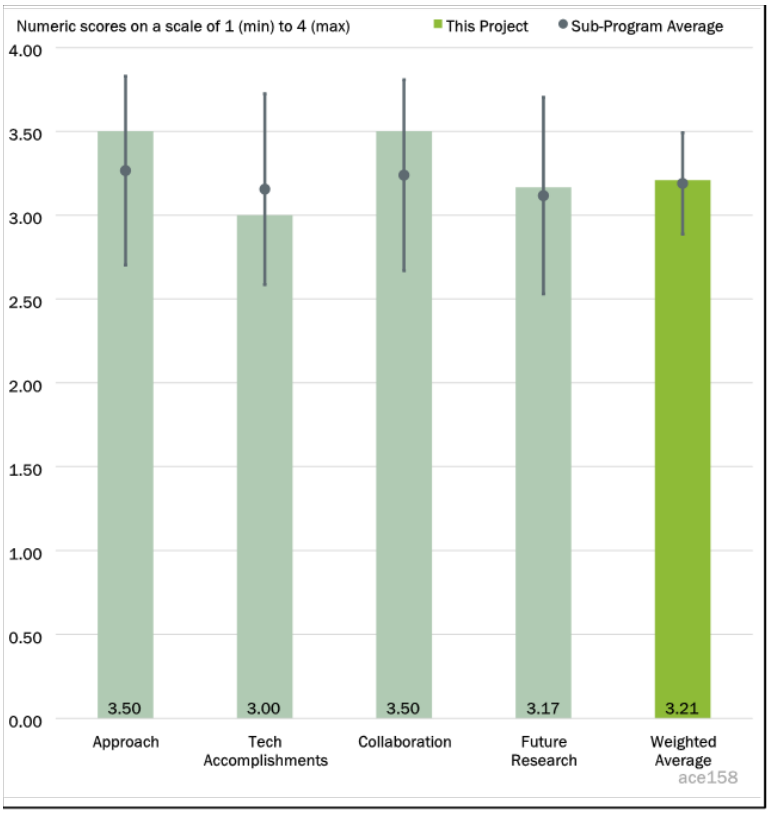

Figure 1-14 - Presentation Number: ace158 Presentation Title: Slashing Platinum Group Metal (PGM) in Catalytic Converters: An Atoms-to-Autos Approach Principal Investigator: Wei Li, General Motors

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the overall approach of using engineered supports, optimized deposition strategies and formulations, aggressive aging conditions, and scalable processes should identify promising pathways to three-way catalysts (TWCs) with lower PGM loadings. It would have been nice if the team could share a bit more about their fundamental understandings of what worked and what did not or to share a broader set of data that led to their current best formulations.

Reviewer 2

The reviewer said the approach to develop a new catalyst formulation method (Two Step IWI) for both palladium (Pd) and rhodium (Rh) is very appropriate to problem, if it works, as it appears to.

Reviewer 3

The reviewer remarked the project is well conceived with much potential for success. The project is well organized and looks to be on track although the actual "results" from the research are limited.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said the targets appear to have been achieved, but more data presentation of catalyst characterization (TEM, more reactor data) to support claims would have been appreciated. Seeing the kinetic data on the catalyst would provide understanding for the controls of the emission control software.

Reviewer 2

The reviewer remarked that the summarized results show impressive performance and excellent progress toward reduced PGM loadings, although the limited data and information shared in the presentation make it a bit difficult to fully evaluate the project progress.

Reviewer 3

The reviewer noted that while milestones for budget period 1 appear to have been met, the results provided in the presentation are not extensive. Most of the presentation describes the concept, which includes results from the existing literature.

The reviewer said the word "optimal" is used in one of the milestones. Optimal relative to what? Because this is a "completed" milestone, stronger evidence of why the catalysts prepared are optimal is needed.

The reviewer noted that the catalysts have been prepared with some characterization and testing, including diffuse reflectance infrared Fourier transform microscopy (DRIFTS) and light-off. The DRIFTS spectra shows a peak at 2080 1/cm that is purportedly CO bound to single Pd atom. It would be worthwhile to corroborate this assignment by providing the relevant literature, DFT calculations, etc.

The reviewer noted that the T50 plots provided do not show the actual temperatures. Why? Are the findings proprietary? The reviewer said no exposed metal area (dispersion) measurements or TEM images are provided, which would provide essential information about what the synthesis has produced. The research would benefit from kinetics measurements for simpler feeds, such as CO and propylene. This would enable the team to compare their catalysts to the extensive literature. Hopefully such missing elements are being investigated during budget period 2.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said a really excellent project team to fully explore, create, and characterize the new catalysts. Not too much seen from some of the groups.

Reviewer 2

The reviewer remarked the project team has a nice balance of roles and responsibilities. However, the project would benefit, as stated above, from kinetics and kinetic modeling and more extensive catalyst characterization including metal dispersion and electron microscopy.

Reviewer 3

The reviewer said the team covers all the basis, with an OEM leading the project and developing formulation strategies, a catalyst supplier to support baseline catalysts and scale-up, universities for novel catalyst development and fundamental investigations, and a national lab for detailed characterization. It would have been nice to see a few more details about which partner generated particular results or work components throughout the presentation.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said future work is a logical progression of the prior efforts and will eventually show whether the reduced PGM formulations can achieve desired performance under realistic operating conditions.

Reviewer 2

The reviewer said proposed future research goals are very appropriate. Full participation of the team will be needed with more supportive data.

Reviewer 3

The reviewer said that in light of earlier comments, the future work is vague, and the reviewer would have liked to have seen evidence of missing elements from budget period 1 at least queued up for budget period 2. The reviewer said the project needs some indication of plans to disseminate the results to the open literature.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer said certainly a relevant project for reducing the cost of aftertreatment catalysts.

Reviewer 2

The reviewer remarked achieving the goals of the project will lead to excellent energy efficiency of the ICE-aftertreatment system.

Reviewer 3

The reviewer was not clear how this project addresses the DOE VTO mission of decarbonizing the transportation sector.

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

Reviewer 1

The reviewer said the skills and resources held by the project team are excellent and, with focus, are well matched to the goals of the project.

Reviewer 2

The reviewer stated the project plan seems well designed to achieve the project goals within the available resources.

Reviewer 3

The reviewer commented the budget appears more than adequate to meet project objectives with nearly 50% cost share provided.

Presentation Number: ace159
Presentation Title: Reduced Cost and Complexity for Off Highway Aftertreatment
Principal Investigator: Ken Rappe, Pacific Northwest National Laboratory

Presenter

Ken Rappe, PNNL

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

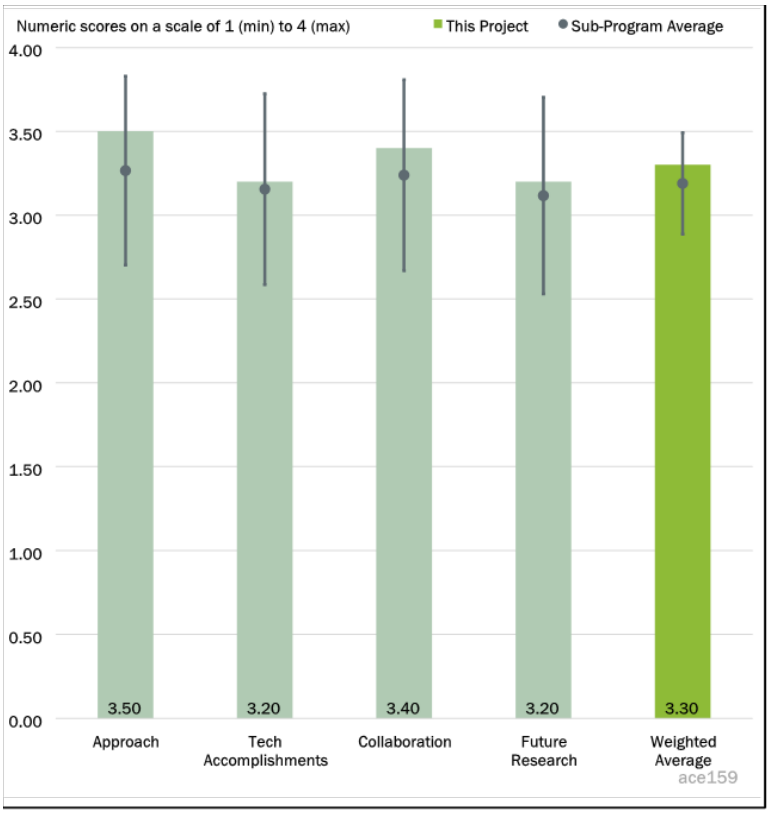

Figure 1-15 - Presentation Number: ace159 Presentation Title: Reduced Cost and Complexity for Off Highway Aftertreatment Principal Investigator: Ken Rappe, Pacific Northwest National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer commented the off-highway industry typically takes on-highway aftertreatment and applies it to off-highway. This project's goal is to optimize the system (reduce the size, improve the efficiency, and reduce the PGM). This will be accomplished by improving the Michigan Technological University (MTU) combined diesel oxidation catalyst and diesel particulate filter (DOCF) model by collecting in situ diesel oxidation catalyst (DOC) data with the Spaci-MS, determining the porosity and permeability using high resolution X-ray computerized tomography (CT) data, and verifying the model with laboratory engine results. The reviewer believed the project is well designed, is on schedule, and should be able to meet the stated goals.

Reviewer 2

The reviewer said using Spaci-MS to get detailed concentration and temperature profiles should provide unparalleled insight. The team is making reasonable progress in showing the capability of the SpaciMS method. In addition, modeling is applied to exploit the information provided by the data. The intent of the project is to advance the DOCF to simplify off-road DOC + diesel particulate filter (DPF) combination.

Reviewer 3

The reviewer said the approach to developing and modeling a DOCF device seems well conceived, especially with the inclusion of Spaci-MS information to test the model against as the gases flow down the device.

Reviewer 4

The reviewer stated this is a straightforward project in terms of the focus on a technology. It is of course not straightforward in terms of the development of said technology. The team has addressed the planned activities and barriers. It looks to be on path and target. The reviewer said the knowledge being gained is important to the field and appears that it will lead to a tangible solution.

Reviewer 5

The reviewer posted the following questions. In what way is the DOCF different from a continuously regenerating trap (CRT) system developed by Johnson Matthey, or even a simple catalyzed DPF that is commonly observed in all diesel engines? Is gravimetric weighing of the filter performed for soot loading tests on the engine? Why is there an increase in CO emissions along the axial direction? From the previous reviewer's comments, it appears that not enough testing was dedicated to understanding the soot management issue. The interaction of soot loading to nitrogen dioxide (NO_2) production is yet to be assessed.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said the MTU DOCF model has been updated to include 13 additional parameters from the initial 6 that were in the previous model. PNNL has developed the Spaci-MS and has collected data to verify the reaction kinetics. Finally, Kymanetics has performed the high-resolution X-ray CT scans to assist in determining the key parameter for the MTU model. The reviewer said it appears that everything is coming together. As stated earlier, the project is on schedule and the reviewer does not see any roadblocks that will slow down the team.

Reviewer 2

The reviewer said the team has made good progress in understanding their system and in designing a new system to integrate the devices and even improve performance versus baseline.

Reviewer 3

The reviewer said Spaci-MS appears to be working well in the data seen and will be very important in the model evaluation. The baseline model and characterization of the system have been completed. We await a more detailed comparison in the coming year.

Reviewer 4

The reviewer remarked while progress has been made with both experiments and modeling, what is not clear is how progress will be made towards advancing the DOCF. Critical to this reviewer is demonstrating the Spaci-MS method with the baseline conventional DOC+DPF so that meaningful conclusions can be drawn in the integrated DOCF. In other words, what testing shows that the integrated DOCF can treat the same gas as the sequential unit, and beyond that, how to show that the PGM loading can be decreased at the same time? Answers to these questions are not evident in the presentation. The reviewer remarked the team needs to clear think this through and provide a detailed plan.

Reviewer 5

The reviewer said technical accomplishments from the engine testing have not been clearly presented. Significant groundwork has been accomplished in model development. It is not clear why some parts of the selective catalytic reduction on filter (SCRF) model were reused, and the reviewer asked would not models of a catalyzed DPF be more suited than an SCRF? The reviewer said it would be interesting for the team to consider any CRT models if they are available for benchmarking purposes

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said there is clear collaboration across the team, in not just attending but actually participating and developing the technology.

Reviewer 2

The reviewer remarked collaborators are excellent for this project, especially for what the interaction between John Deere, PNNL, and MTU potentially offers.

Reviewer 3

The reviewer remarked the team of John Deere, PNNL, MTU, Kymanetics, and Carus is an outstanding collaboration that covers all aspects of the project. The project's current collaboration is sufficient.

Reviewer 4

The reviewer detailed the project team consists of PNNL, John Deere, MTU, Kymanetics, and Carus. PNNL, MTU, Kymanetics and John Deere have significantly contributed to the project and their contributions were pointed out in the presentation. Carus should become more involved in the future when they start to evaluate the mixed metal oxides in year 3. The reviewer said overall, good collaboration from all parties.

Reviewer 5

The reviewer said the project team has appropriate collaboration across the organizations involved.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said that as most projects, the first 2 years are kicking off the project and setting up for big advances in the later years. The DOCF model has been improved and needs to be verified with engine data. Once that is verified, the model will be able to assist in improving the catalyst and the intent is that the mixed medal oxide will allow thrifting of the PGM. The laid-out tasks are sound and should lead to a successful project.

Reviewer 2

The reviewer said the choice of Future Research goals is well designed and focuses on development of the model for temperature and emissions from the DOCF device.

Reviewer 3

The reviewer said the future plan appears quite reasonable and appropriate, and the reviewer is unsure what 3rd gen means (versus 2nd gen etc.), but this appears to be targeted at continuous improvement. It would be good to also figure out if the results from the one system are extrapolatable to enough to be generic.

Reviewer 4

The reviewer remarked the project is titled Reduced Cost and Complexity Aftertreatment system, however, the project fails to explain where the targeted cost reduction is likely to be observed. The merger of a DOC and DPF is a reduced complexity system, however, is the cost reduction only from a material aspect of the total operating cost of the system (DOCF and SCR)? If soot management is not addressed, then the cost associated

with the regeneration fuel penalty could be higher than a convention catalyzed DPF. The reviewer said future work is scheduled to address the testing of the validity of the model, soot management, and NO_2 production. This is a critical requirement that needs to be addressed.

Reviewer 5

The reviewer said that plans to close gaps, especially in demonstrating PGM and cost reduction versus incumbent technology, are needed.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer remarked clear support of VTO objectives.

Reviewer 2

The reviewer said VTO has been switching the research focus to off-road and to ensure off-road vehicles will meet future emission regulations at a reasonable cost. This project will accomplish that and the smaller aftertreatment size will have lower engine backpressure, which will lead to better fuel economy.

Reviewer 3

The reviewer remarked the project addresses emissions from engines and is integrating devices to achieve more cost-effective systems.

Reviewer 4

The reviewer commented the relevance of the project to its off-road focus is well covered with John Deere as a partner. The experience of many of the specific collaborators gives confidence that the design and carrying out of the project should be well handled.

Reviewer 5

The reviewer said the project is relevant in reducing the fuel use penalty associated with modern aftertreatment systems and reducing the use of PGM.

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

Reviewer 1

The reviewer said resources resident at PNNL, John Deere, and MTU are quite sufficient for their parts of the project.

Reviewer 2

The reviewer commented resources appear adequate.

Reviewer 3

The reviewer said resources appear to be sufficient. The largest effort will be the engine testing at MTU and with their ability to "cart" the engine they can save test cell time on installation costs. The modeling effort takes time, but that time is well budgeted.

Reviewer 4

The reviewer cannot tell in terms of resources moving forward, as they are not listed. The reviewer will note, however, that although not part of the project, there seems to be overlap in technologies being used between

NLs. Was a new SPACI necessary (and the funds for it and resources spent) versus one to use at a different NL?

Reviewer 5

The project has sufficient resources to achieve its goals of the project. The resources of the engine testing part from MTU are unclear. Does the project have resources such as Fourier-transform infrared (FTIR) spectroscopy for pre-and post- catalyst emissions measurement? Is the PM mass measurement (instantaneous soot measurement) pre- and post DOCF)

Presentation Number: ace160
Presentation Title: Optimization and Evaluation of Energy Savings for Connected and Autonomous Off-Road Vehicles
Principal Investigator: Zongxuan Sun, University of Minnesota

Presenter

Zongxuan Sun, University of Minnesota

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Project Relevance and Resources

86% of reviewers felt that the project was relevant to current DOE objectives, 14% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 86% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 14% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

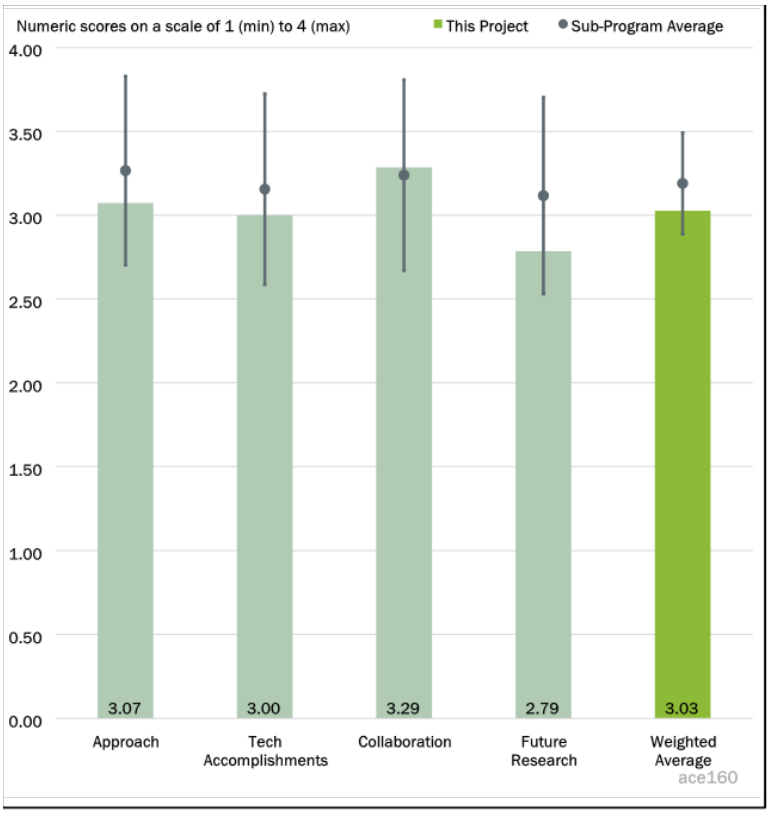

Figure 1-16 - Presentation Number: ace160 Presentation Title: Optimization and Evaluation of Energy Savings for Connected and Autonomous Off-Road Vehicles Principal Investigator: Zongxuan Sun, University of Minnesota

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer said the stated goal of this project is to use connectivity and automation to reduce energy consumption and increase productivity for off-road vehicles. The objective is to develop systematic optimization and control methods for connected and autonomous off-road vehicles. Successful implementation is expected to achieve 20%-40% energy savings and improve machine productivity. The reviewer said a hardware-in-the-loop (HIL) testbed will be constructed to evaluate energy savings potential of the control and optimization strategy. The intent is to use the HIL testbed to evaluate the energy benefits of different levels of automation. This is an excellent approach to improving efficiency of off-road vehicles through automation. Because the wheel loader is filling a truck, the use of automation necessitates inter-vehicle connectivity. This barrier is addressed by Worksite simulation and communication system.

Reviewer 2

The reviewer stated the project is well designed and the timeline is reasonably planned. The project team has done a fantastic job in defining the critical application functions that capture the architecture complexity for solving the system optimization problem.

Reviewer 3

The reviewer remarked the simulation and control optimization of the machine in this study is superficially explored and the conclusions are not break-through but rather expected and heavily focused on the very basic operation of a machine, which is very well known (at least by industry). Time-wise, it is challenging to give a positive comment based on how long it has taken (50% percent of the project time) to create such model and optimization. Additionally, the project title focuses on the connectivity of the machine and automation, but the presenter failed to comment or even demonstrate that any work at all has been done to tackle the real-life challenges of automating and communicating with the machine.

Reviewer 4

The reviewer commented the team is addressing the operator inefficiency barrier through developing an automated workgroup function during the dig cycle to optimize efficiency and bucket fill. The team is also addressing the operator inefficiency in the drive cycle through optimizing the drive path to maximize efficiency while maintaining operator cycle times at a minimum. The presenter indicated how the dynamic interactions between the workgroup and drive functions can lead to efficiency improvements. The reviewer said it would be beneficial to see how the team is optimizing dynamic interactions of the workgroup and drive and the efficiency gains achieved in doing so.

Reviewer 5

The reviewer agree with the technical barriers that the research team has presented. However, the challenges of the variations in the materials (soil and gravel) being acquired and transported (soil or gravel, etc.) and the expertise levels of the operator have not been addressed. It is important to establish robustness to these variations in any optimization scheme.

Reviewer 6

The reviewer questioned the approach. It is still not clear why the engine model is not used and why the project had to spend time and money developing HIL. The engine model could have been created like those of the propulsion and hydraulic circuit that were used in the project. Fuel consumption could be obtained from a good engine model and associated brake-specific fuel consumption (BSFC) maps.

Another question is related to the baseline wheel loader cycle: How is the machine baseline cycle determined. What is machine productivity in the baseline cycle? Is the productivity of the improved cycle verified and what are the values? The reviewer said fuel efficiency should be determined after productivity has been verified. It is also not clear what is the total opportunity for energy savings is (24.3% or...?) Is automation really needed for efficiency improvements; can the operator coaching be done?

Reviewer 7

This reviewer is a strong proponent of HIL systems and has extensive experience designing, building, and using HIL systems. That said, the reviewer questions if making a HIL system is the most efficient and cost-effective way to get to good test results in this situation. Powertrain and fluid power systems are well understood and modeled quite accurately. It would seem that a SIL/MIL setup would allow you to do the optimization more efficiently and those results should be good enough that you could go right to tests on actual hardware to confirm the modeling results. The reviewer can see the HIL system being very effective at testing the software but not sure it should be usedt for the majority of the system testing. At year 2 of 3 and it does not seem like much optimization has been done. That said, the team seems to be getting a lot of work done for the project cost.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer remarked the project team is reporting 50% completion, which is on track with the project plan. Good progress has been made with completed work in the areas of formulating the system optimization problem, developing and validating the vehicle model, and developing the communication system as well as demonstrating preliminary encouraging results on some of the solutions developed with plan on track fully integrated HIL testbed.

Reviewer 2

The reviewer remarked the team has achieved the milestones documented for the project per the timeline presented. The technical accomplishments documented align with the work plan and project objectives.

Reviewer 3

The reviewer said the reported model validation results are very good. It appears that the relevant machine dynamics have been captured. Optimization of the transport phase and digging phase are good first pass approach. The reviewer said that if the cost function is only fuel consumption, then there will be a low likelihood of acceptance in the marketplace, which seeks productivity maximization alongside or probably more than fuel efficiency. Both fuel consumption and productivity need to be in the cost function.

Reviewer 4

The reviewer remarked in this project, wheel loader propulsion and bucket motion have been optimized using model-based optimizations. The team estimated resistance using a model that incorporated fundamental earthmoving equations. The team accomplished model validation using flow, torque, and pressure data provided by the engine manufacturer. The modeling results indicated that automation could decrease fuel consumption by 16% relative to manual operation. 27.9% fuel benefit could be achieved with more aggressive steering. The technical progress is excellent. The reviewer said for the next quarter, the task is to integrate modelling, control, worksite simulation, and communication with the HIL testbed. While the engine and pump are in place, it is going to be a challenge to complete this phase in the allotted time.

Reviewer 5

The reviewer said honestly this was a bit hard to evaluate as the overall plan did not lay out accomplishments in detail in the presentation. A lot of time has been spent on the HIL system. We are close to being done with year 2 of 3 and still working on system models and the HIL system.

Reviewer 6

The reviewer said it is challenging to give a positive comment based on how long it has taken (50% percent of the project time) to just create a virtual model. Moreover, the model does not tackle the most significant challenges within the scope of the project, “Connected and Autonomous” machines.

Reviewer 7

The reviewer noted that good progress is made on the model development. After developing an optimal machine trajectory, the reviewer asked did you check for machine stability and operator comfort (the reviewer referenced a comment about more aggressive steering to gain 27.9% efficiency improvement)? The reviewer asked to please show the aggregate efficiency improvements, and does it exceed the 20% target? The reviewer noted the original project goals were to improve efficiency by using automation and connectivity, and it does not seem that the connectivity plays any role thus far.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

Appears that they have a strong team and are doing good work together.

Reviewer 2

The reviewer said fantastic collaboration and coordination with frequent touchpoints between the universities and OEM partners in the project team as well as well-defined contributions from each of the partners.

Reviewer 3

The reviewer commented the collaboration and coordination summary documented on Slide 17 demonstrate and appropriate level of communication and collaboration for the scope and activities within this project. Both universities and the industry partner are well engaged in the project and have demonstrated they are contributing their share of the work/content to support the success of the project.

Reviewer 4

The reviewer said there is a strong set of collaborators that is meeting in regular intervals, which seem appropriate for the project. The contribution of each collaborator was clearly described.

Reviewer 5

The reviewer said CNH has provided benchmark data from the 521 loader and an engine. The benchmark data great for validating models. The 521 engine is perfect for the HIL dynamometer. Texas A&M provided the FFE model for predicting the bucket forces. Based upon model the correlation between model and benchmark data, the FEE model was effective. If I recall correctly, Texas A&M is providing the worksite simulation. The worksite simulation task seems to be the least developed of all the project elements.

Reviewer 6

The reviewer said it looks like the collaboration between the lead PI and the rest of the team is acceptable, though it is hard to judge the contribution of each. It is great to have an OEM involved for guidance.

Reviewer 7

The reviewer noted that the presenter commented on the commitment of the partners through regular bi-weekly meetings; however, it was not properly explained what the tangible contributions are of the partners in the project.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer remarked the proposed future work consists of constructing the HIL testbed and using it to evaluate the energy benefits of different levels of automation. That is good.

Reviewer 2

The reviewer remarked good things are included in the test plan, though achieving all of that may be optimistic. The reviewer thinks more time will be spent on the testbed than the optimization.

Reviewer 3

The reviewer remarked the purpose of the proposed future research has been clearly defined and based on the preliminary results presented so far, there is a very high likelihood that its targets will be achieved. However, two things were not clear to this reviewer. First, the developed communication system developed has a latency of less than 100 milliseconds with no missing data. Is that the minimum requirement for the selected duty cycle and would the project team need a more capable communication system with even smaller latency, say less than 1000 milliseconds for a highly transient duty cycle. Secondly, how is the project team planning to incorporate or capture critical customer constraints such as least tire wear and ensuring the fullest loaded bucket.

Reviewer 4

The reviewer commented the proposed future research plan on Slide 19 is in line with the overall project plan and well documented. The timeline appears to be reasonable and achievable. I would like to see further clarity around the plan for optimizing the dynamic interaction of the workgroup and drive system. There was significant prior discussion and good work documented around the optimization of each of those functions individually in Slides 9-14, but little to no documentation of the optimization of the interaction of workgroup and drive functions.

Reviewer 5

The reviewer is still questioning the need for using HIL if the model has been validated. Is the approach general enough to transfer this methodology to other machine platforms? Another question is related to automation. How will the team decide what the operator will do versus what the machine automation controller will do (example: digging, driving, using implements etc..)? Is the operator going to interfere with the machine's trajectory and how is that going to impact efficiency, stability, productivity, etc.?

Reviewer 6

The reviewer said the proposed future research with timeline is reasonable and should be achievable. While the approach of separating the digging and transport phase into two separate optimization problems is reasonable, in reality, they are connected during the bucket filling phase of the work cycle. This overlap should be addressed. Similar, the dumping phase has been neglected from optimization and should be addressed. Perhaps is it outside the scope of this project, but field evaluation is important for establishing the performance of this automation and optimization scheme.

Reviewer 7

The reviewer said the proposed future work is to build a test stand to presumably validate some of the model results, which is disappointing as the main real-life challenges are completely disregarded.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer remarked the project is relevant and can lead to some low-hanging fruit for fuel consumption reductions in the near term.

Reviewer 2

The reviewer commented this project is very relevant and does support the overall VTO Advanced Engine and Fuel Technologies objectives because it focuses on optimizing highly connected and autonomous off-road vehicles for energy savings, which is well aligned with the agriculture and construction industry technology trends.

Reviewer 3

The reviewer said this project is focused on efficiency improvements, which aligns with the VTO objectives.

Reviewer 4

The reviewer remarked the project seeks to remove inefficiencies in the wheel loader duty cycle and would result in a direct improvement in productivity (material moved per fuel volume) and aligns very well with the sub-program objectives for system-level efficiency improvement.

Reviewer 5

The reviewer said this project aligns with VTO's goal of accelerating the development of clean, efficient transportation technologies that provide better and cleaner mobility options to lower GHG emissions and reduce petroleum fuel consumption.

Reviewer 6

The reviewer said yes, this project will demonstrate the potential in reducing energy and emissions using optimization and autonomous operation of a specific construction vehicle and operation cycle. The knowledge gained from this work will be extendable to other vehicles and operations.

Reviewer 7

The reviewer said the most relevant argument to run this project would be to explore the challenges for autonomous and connected machines and how to implement the optimization that has been created in the first 50% of the project life. These aspects have not been elaborated on, nor there has been mention that these have been or will be addressed.

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

Reviewer 1

The reviewer said resources are sufficient, but more resources could help ensure all the project goals are achieved.

Reviewer 2

The reviewer said it appears that more resources might be required to integrate the worksite simulation. Otherwise, resource allocation is sufficient.

Reviewer 3

The reviewer said the project is 50% complete at the mid-way point with allocated funding for budget periods to support the proposed future research for the project to achieve the stated milestones in a timely fashion.

Reviewer 4

The reviewer remarked it seems that the project has enough resources to get things done.

Reviewer 5

The reviewer said the level of resource allocated to the project appear to be appropriate for the level of activity and project scope and objectives.

Reviewer 6

The reviewer said the project brings together an excellent team with great experience combined with good DOE and partner resources which should enable the achievement of the stated milestones in a timely fashion.

Reviewer 7

The reviewer said the amount of funding provided for this project relative to the outcome is excessive.

Presentation Number: ace161
Presentation Title: New Approach for Increasing Efficiency of Agricultural Tractors and Implements
Principal Investigator: Andrea Vacca, Purdue University

Presenter

Andrea Vacca, Purdue University

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

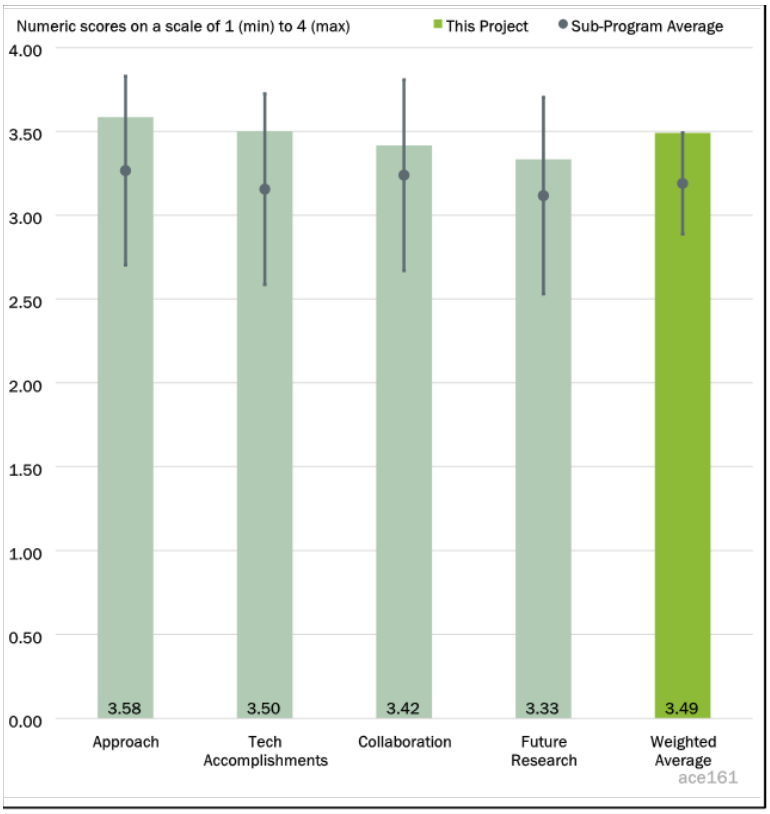

Figure 1-17 - Presentation Number: ace161 Presentation Title: New Approach for Increasing Efficiency of Agricultural Tractors and Implements Principal Investigator: Andrea Vacca, Purdue University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer remarked the objective of this project is to develop and demonstrate a multi pressure rail (MPR) hydraulic control system for a CNH tractor and planter. The goal is to double the energy efficiency of the hydraulic system, thus reducing engine fuel consumption by at least 15%. This is accomplished by benchmarking state-of-the-art planter performance in field tests, modeling and constructing a MPR standalone test rig, and modifying a tractor and planter to incorporate MPR technology. The impact on efficiency will be evaluated in field tests. The reviewer noted that naturally, a lot of modeling and simulation is required to optimize the MPR system. The standalone MPR system is useful for validating the simulations. The overall approach is outstanding. It includes all the requirements to overcome the technical barriers and culminates with a field demonstration of the MRP concept.

Reviewer 2

The reviewer said the proposed concept for meeting the project objectives is fundamentally sound and innovative with well-designed project activities. The results presented at the midway point demonstrate good progress by the project team with reasonable time allocated to the activities outlined in the future research to meet the remaining project milestones.

Reviewer 3

The reviewer said the scope of work to date has been focused on improving efficiency of the hydraulic system and eliminating throttling losses, which is directly in line with the technical barriers documented in the project. The project Is well designed and has a reasonable schedule with well documented milestones.

Reviewer 4

The reviewer noted that low efficiency of conventional load sensing systems like those used in tractors is well known, particularly in mixed load cases like a planter which have both high flow/low pressure loads and high pressure/low flow loads. The MPR system is a solid approach to this problem. Like other reviewers have pointed out in past reviews, the project would be more compelling if it were applied to a larger set of different implement loadings. However, the knowledge gained from the application to this specific tractor implement will have broad application to other use cases. Efficiency gains will need to be evaluated on a case-by-case basis.

Reviewer 5

The reviewer said the hydraulic architecture being proposed is well thought out as is the development plan. The largest concern this reviewer sees will be the increased cost of the system due to the increased complexity. It appears that the team is trying to address this. It is good that the team includes a major hydraulics supplier that is addressing the cost issue from the beginning.

Reviewer 6

The reviewer remarked this project is continuing to make good progress and addressing technical issues. The timeline looks reasonable. There are some technical questions about the approach: By observing Page 5 P-Q charts for the baseline system and improved system, the reviewer is curious if the % improvements are based on the worst-case scenario when the implements are active and consuming 100% flow? Is there a composite cycle that better represents actual machine usage and what would be the expected savings using one of the proposed MPR approaches?

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer remarked fantastic work with good progress being made against the project plan and encouraging results demonstrated so far. With the added complexity, it will be instructive for the project team to evaluate the system sensitivities and whether real-world conditions as well as application duty cycles will erode some of the efficiency increases that have been projected from simulation models and testing in controlled settings used for technology demonstration.

Reviewer 2

The reviewer said the team has made good progress against the proposed test plan.

Reviewer 3

The reviewer said that significant progress has been made on the project as documented on Slides 6-16 of the presentation. One challenge with the multi pressure rail system that can be seen in the graphs presented on Slides 14-15 is the transient actuator speed variation during rail switching. Is this behavior going to be a significant barrier to commercialization and is there a plan minimize the transient actuator speed variation in future work?

Reviewer 4

The reviewer noted that the team has completed baseline field tests on the fully instrumented tractor-planter, and measured the energy efficiency of the standard tractor-planter technology. The team constructed a standalone MPR test rig and collected data. The team validated the simulation model. Simulation of the MPR tractor-planter meet project go/no-go criteria. The reviewer noted that modification of the Tractor-Planter systems is underway. The technical progress is excellent. Can you please explain how efficiency improvement was calculated?

Reviewer 5

The reviewer said researchers have made progress and appear to be meeting the technical milestones listed in the project plan. The team measured baseline efficiency of the tractor and planter combination in field tests, and developed and validated with field test data a system model of the reference tractor and planter system. The MPR system has been modeled and simulated with drive cycles collected from the field experiments showing reduction in power consumption and increases in system efficiency to meet go/no-go 1. The team developed the MPR test rig and used it to determine the MPR architecture. It was not clear what the Gen. 1 and Gen. 2 MPR prototypes were. Expect these are in process and there will be more clearly described in the next AMR.

Reviewer 6

The reviewer said the project obtained good baseline data for the hydraulic system by running an actual machine, which helped with the model validation and identified power losses. Also, the team developed a two-layer controller, and designed and installed an MPR test rig. Controller tested and tuned for best behavior during switching between the rails.

The reviewer said it is not easy to follow all claims about efficiency improvements. Examples: Slide 3: objective to have 15% fluid power functions energy consumption reduction. Slide 4: Simulated MPR delivers over 60% higher efficiency (Is 60% coming from the fluid power functions?). Go/no-go 2 for the MPR delivers 40%. Of what? Slide 12: Increase in system efficiency from 89.95% to 119.32%. Slide 15: Average 45% efficiency gains (2 pump-system). Does this mean that the project will not be able to "double" the efficiency? The reviewer suggests making a table or some other way to summarize and clearly explain different gains. Is the pressure response a concern for the latest configuration and how is that going to affect the performance of the implements?

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer noted that university-owned farms serve as a site for field tests. CNH contributes to the project through personnel that provide expertise in hydraulic components, drives, simulation, and control. CNH also provided the reference vehicles for the technology demonstration and expert operators to assist on the field tests. Bosch Rexroth provides engineering support, and NREL provides analytical support from the Center for Integrated Mobility Sciences. Everything appears to be working together great!

Reviewer 2

The reviewer said this project has broad-based collaboration between university, national lab, OEM, and critical component suppliers with well-defined contributions from all the project partners.

Reviewer 3

The reviewer remarked there is a strong team, and they appear to have close collaboration.

Reviewer 4

The reviewer commented the project collaboration as documented on Slide 17 demonstrates each collaborator is fully participating in the project and achieving the deliverables for their responsibilities. University, industry partners, and a national laboratory are all actively engaged in the project.

Reviewer 5

The reviewer said the communication level is good among all the partners. It seems that the partners are sharing data well and having the machine available at the PI's location is also a big plus for this project. It is still not clear how Purdue and NREL share the responsibility for control strategies and how CNH performs simulation based on the devised and developed control strategies. Is this an efficient way of doing development?

Reviewer 6

The reviewer remarked there is a strong set of collaborators with an excellent set of resources that are available to the project. The contribution of each collaborator was clearly described; however, the frequency of collaborator meeting and interaction should be described and provided to the reviewers.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said defined future research work is aligned with demonstrating the technology and commercial viability of the proposed system, which is very likely to achieve the project energy efficiency improvement targets based on the encouraging results that have been demonstrated so far in the project.

Reviewer 2

The reviewer said future work documented on Slide 18 demonstrates the work content is focused on the remaining challenges with a clear purpose. The future work is likely to achieve the targets based on the information presented.

Reviewer 3

Upcoming work, which includes extending the system to include more functions, will be key from this reviewer's perspective. It is possible that having to satisfy a larger number of pressure and flow requirements will reduce the overall efficiency gains that can be achieved.

Reviewer 4

The reviewer liked the goal of exploring the opportunity to expand this MPR approach to other tractor functions, and is curious about how "generic" this technology is and how easily it can be replicated to other machine types. In addition, please try to better explain the cost analysis table. Is the second pump included in the cost analysis and the packaging on the machine?

Reviewer 5

The reviewer said proposed future research generally aligns with the timeline and milestones. However, there may be some creep on project scope, which should be managed well to make sure that the key milestones serving the project objectives receive the top priority.

Reviewer 6

The reviewer remarked proposed future work identifies challenges and associated tasks. The way the future work is described does not identify which tasks are sequential and which tasks are concurrent. In the future work table, can the team please explain what is meant by "Simulation of a MPR vehicle connected to a non-MPR one, evaluation of control aspects and energy efficiency?" Also, can the researchers please explain what is meant by "execute field tests according to test plan defined in budget period [BP] 1?" The reviewer thought this was done already. In the milestone chart market analysis is task N and comes in 2023 but it is listed as a 2022 task in future work. The reviewer said based upon previous performance, future research is rated as good, but the way it is reported is confusing.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer noted that this is a reasonably straightforward way to increase efficiency of agriculture equipment that can be extended to other industries

Reviewer 2

The reviewer said the project focus on increasing efficiency of agricultural tractors and implementing it will be beneficial to the off-road industry and supports the overall VTO objectives for the Advanced Engine and Fuel Technologies Program.

Reviewer 3

The reviewer said the project supports VTO's objectives to continue looking into technology development that will improve the efficiency of off-highway machinery.

Reviewer 4

The reviewer commented the project is focused on a system-level efficiency improvement and directly ties to subprogram objectives.

Reviewer 5

The reviewer stated this project aligns with VTO goals by improving the efficiency of commercial agricultural vehicles and reducing fuel consumption, thereby decreasing emissions and operating costs for farms.

Reviewer 6

The reviewer said yes, this project demonstrates the potential in reducing energy and emissions using new hydraulic system architecture that show good potential. The knowledge gained from this work will be extended to other tractors and implemented combinations as well as other off-road vehicles.

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

Reviewer 1

The reviewer said the resources defined on Slide 19 appear to be of an appropriate level and mix of contributors to achieve the remaining project objectives.

Reviewer 2

The reviewer remarked the project plan and budget appear appropriate for this scale of development project

Reviewer 3

The reviewer said the project is on track with a 50% completion rate at the midway point and is operating well within the allocated budget.

Reviewer 4

The reviewer commented it seems that all parties in this project have sufficient resources for the proposed future work. The team is very capable.

Reviewer 5

The reviewer noted that Purdue's Maha Fluid Power Research Center has ample resources. A strong team has been assembled. The budget is steep, but it is justified based upon the project scope, effort, and complexity. Every element of the project is progressing at a good pace. Resources are satisfactorily allocated.

Reviewer 6

The reviewer said the project brings together an excellent team with great experience combined with good DOE and partner resources that should enable achievement of the stated milestones in a timely fashion.

Presentation Number: ace162
Presentation Title: Improved Efficiency of Off-Road Material Handling Equipment through Electrification
Principal Investigator: Jeremy Worm, Michigan Technological University

Presenter

Jeremy Worm, Michigan Technological University

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

83% of reviewers felt that the project was relevant to current DOE objectives, 17% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 17% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

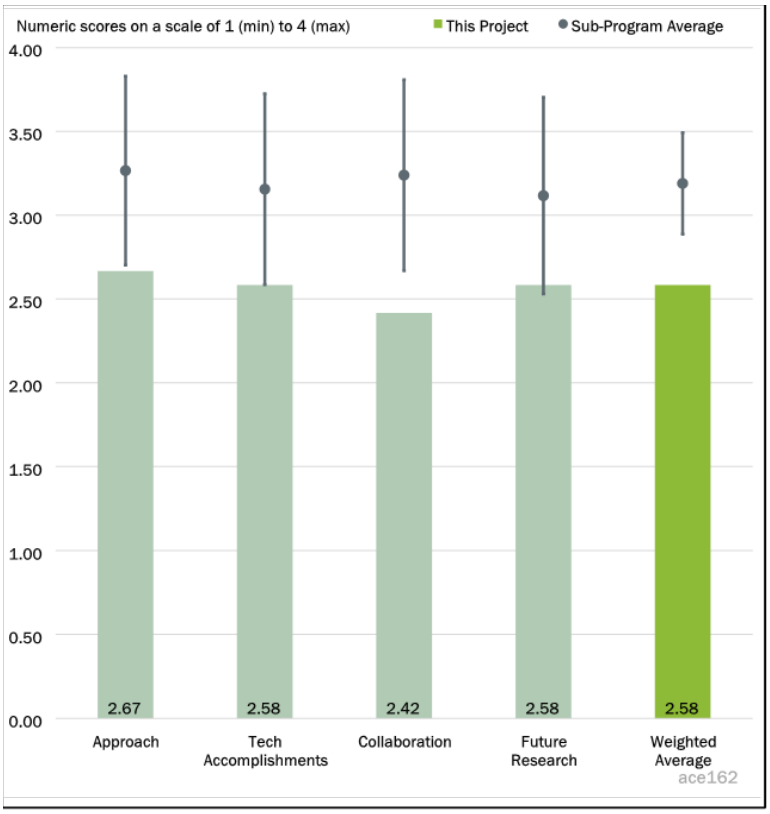

Figure 1-18 - Presentation Number: ace162 Presentation Title: Improved Efficiency of Off-Road Material Handling Equipment through Electrification Principal Investigator: Jeremy Worm, Michigan Technological University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer stated the approach is well thought out, leverages modeling, real-world drive cycles from an OEM, and appears to have a solid plan for culminating in a hardware demonstration.

Reviewer 2

The reviewer said the project team is taking a systematic approach in addressing the technical barriers that have been identified for this project. Good work is being done in leveraging proven methodologies to develop the standard operating cycles and industry best practices to determine the optimal electrification architecture. The proposed project activities are reasonable and well-designed but the project team might have to be creative in overcoming some of the logistics challenges or critical components procurement delays to keep the project on track.

Reviewer 3

This appears to be a decent workplan, but this reviewer was a little surprised at the clean sheet approach taken here when so much analytical modeling and previous work has been done in this area. It seems the project could have leveraged that more to spend less time on selecting architectures and more time on implementing

and optimizing the systems. The reviewer also would have liked to see a bit more discussion on cost. This is a relatively straightforward electrification project and cost is usually the main barrier to commercial acceptance.

Reviewer 4

The reviewer said the three barriers identified by the research are on target, and the researchers are taking a rational approach to address these barriers. The team specifically addressed the second barrier by developing a methodology for producing a standard operating cycle for the material handler and three operations that would be commonly done by the handler. The team only showed vehicle speed for a standard operating cycle, but in reality, regarding the speed of the other handler degrees of freedom must be part of the operating cycle, but those were not shown. The researchers should be more descriptive of what the operating cycle includes. To address the third barrier, many different vehicle architectures were considered relative to qualitative performance and design attributes. The reviewer said it was not clear what the different architectures were and how they were rated beyond engineering intuition and judgement. It would be helpful for this methodology to be described rather than presenting a decision matrix that has so many rows and columns that it cannot be read. The reviewer said the process of evaluating different electrical vehicle architectures is complex and so a well thought-out evaluation process could be a very useful outcome from this project.

Reviewer 5

The reviewer said the pie charts point out energy consumption by various subsystems. However, there is no estimation/analysis that shows the saving opportunity from each subsystem and the overall/aggregate energy-saving opportunity. Approach: Does the machine need to be electrified to produce energy savings? It would be good to understand how much savings can be done just by modifying the current machine architecture and how much extra (if any) is based on the electrification. The reviewer noted this project's objective is to demonstrate 20% savings. Is there a line of sight to achieve it and at what cost? The PI outlined a high risk of getting the components needed for electrification. This may hinder the project pace, based on the future architecture and needed components. Is there an alternative plan?

Reviewer 6

Utilizing an entire budget period to instrument a machine and characterizing standard drive cycles is something that could be replaced by standard drive cycles presumably known by the industry partners in the given application. The proposed timeline is not reasonable nor planned and executed properly.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said that progress appears to be good.

Reviewer 2

The reviewer commented that modeling work has been quite good, with development of a solid-looking modeling platform to guide the project into hardware selection and development. Unclear if the team has identified any specific hardware, or control approaches, etc. Seems like there is a great deal of work to do in less than 50% of the remaining project time.

Reviewer 3

The reviewer remarked it is good to see the progress that has been made so far on the development of representative operating cycles and modeling of the baseline as well as electrified architectures. However, the

lack of pre-existing information and field data may put the completion of some of the milestones at risk, but I trust the project team is exploring creative ways to keep the project on track.

Reviewer 4

The reviewer said that to date, the project achievements include drive cycle determination and a machine model. The details of the model, objectives, and its structure are unclear and results/conclusions are limited or of very basic nature.

Reviewer 5

The reviewer said this project made good progress in getting the machine cycle defined and the machine virtual model validated. The spreadsheet (Pugh matrix) is not readable and it is not easy to understand the decision-making process based on it. The reviewer noted the team seems to have ruled out a full BEV, but their selected architecture "schematic" does not make it clear where the engine power is used. Please elaborate on P0 and P3 architectures.

Reviewer 6

The reviewer noted that researchers have faced a number of obstacles to making progress on this project, and they again face the challenge of long lead time of electrification components. However, they have been persistent in moving the project along to achieve the project milestones. The lead time issue is concerning as all of us have been facing it. The reviewer said the team should plan multiple contingencies for this issue.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said the researchers appear to have a strong team that includes end user and component suppliers.

Reviewer 2

The reviewer said it looks like the OEM and other team members are starting to contribute to the project.

Reviewer 3

The reviewer remarked there is broad based collaboration between a university, OEM, and critical component suppliers with clearly defined contributions, but will require more co-ordination across the project partners to overcome some of the logistics as well as critical component procurement challenges.

Reviewer 4

The reviewer remarked from the presentation, it was clear that the partnership is little to non-existent. It is unclear what each of the partners tasks are.

Reviewer 5

The reviewer cannot really tell how much collaboration has happened to date.

Reviewer 6

The reviewer said there is a set of nine collaborators, which brings a good set of resources to the project. There were bullets outlining the contribution of each collaborator, but the description could have been clearer. The frequency of collaborator meeting and interaction should be described and provided to the reviewers. There was an issue with the baseline machine arriving at the wrong time, which delayed and affected the project. These types of issues should be addressed with better interactions between the collaborators.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said the remaining work plan is quite good and well-focused. It is moderately well defined but there are a great number of details which are not at all discussed. Integration, controls, etc. are massive challenges and they are not really discussed at all.

Reviewer 2

The reviewer said the design/build portion of the project appears long (FY 2023 and FY 2024) leaving less time for controls and calibration, which always takes longer. This reviewer encourages the team to accelerate that and leave more time for development and use of the hardware.

Reviewer 3

The reviewer remarked the plan is not tangible, nor did the presenter show any details on what the work scope is for the upcoming project budget periods.

Reviewer 4

The reviewer said the project milestones and approach are defined but the proposed future research activities do not have clearly defined timelines, and it is not clear to this reviewer whether the project team has a pathway for achieving the 20% fuel consumption reduction goal.

Reviewer 5

The reviewer said it looks like the team will demonstrate what they said they would demonstrate; what they demonstrate will be beneficial for the machine and the OEM of that machine, but the focus may be too narrow, and it is questionable how much it will be replicable to other machine types.

Reviewer 6

The reviewer remarked the proposed future research generally aligns with the timeline and milestones, but the task could have been more clearly stated as well as the purpose that the team seeks to achieve. Given the past challenges that the project faced, there are some concerns about retrofitting a vehicle and getting the testing done to achieve the milestones within the timeframe that was outlined.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer remarked the project focus on demonstrating 20% reduction in fuel consumption in off-road material handling equipment is critical for the industry and will support the overall VTO objectives for advanced engine and fuel technologies.

Reviewer 2

The reviewer said the project is relevant in that these applications have potential for large fuel savings and emissions reductions.

Reviewer 3

The reviewer said this project has good relevance to VTO objectives.

Reviewer 4

The reviewer remarked the project is targeting energy improvements and adding electrification as a means to achieve it. It is not easy to see how the project results and the techniques used will be useful to a broader spectrum of applications.

Reviewer 5

The reviewer said yes, this project demonstrates potential in reducing energy and emissions using electrification of a material handler. The knowledge gained from this work will be extendable to other off-road vehicles.

Reviewer 6

The reviewer remarked due to the basic nature of the project and the lack of progress overall, the project is not relevant.

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

Reviewer 1

The reviewer said resources seem adequate for the project.

Reviewer 2

The reviewer commented the budget appears to be good for the project scope and targets.

Reviewer 3

The reviewer said that based on the 30% completion rate reported with budget period 1 milestone activities completed, budget period 2 milestone activities on-track, and budget period 3 milestone activities not started, the resources should be sufficient for the project to achieve the stated milestones in a timely fashion based.

Reviewer 4

The reviewer noted the team has an OEM, many suppliers, as well as end-users for machine testing engaged (according to Slide 13). There is no easy way to judge their level of engagement, but the reviewer trusts that they will be providing substantial support for this project to move ahead.

Reviewer 5

The reviewer said the project brings together an excellent team combined with good DOE and partner resources that should enable the achievement of the stated milestones in a timely fashion.

Reviewer 6

The reviewer said the amount of resources provided relative to the amount of outcomes so far is absolutely excessive.

Presentation Number: ace163
Presentation Title: Ducted Fuel Injection and Cooled Spray Technologies for Particulate Control in Heavy-Duty Diesel Engines
Principal Investigator: Adam Klingbeil, Wabtec

Presenter

Adam Klingbeil, Wabtec

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

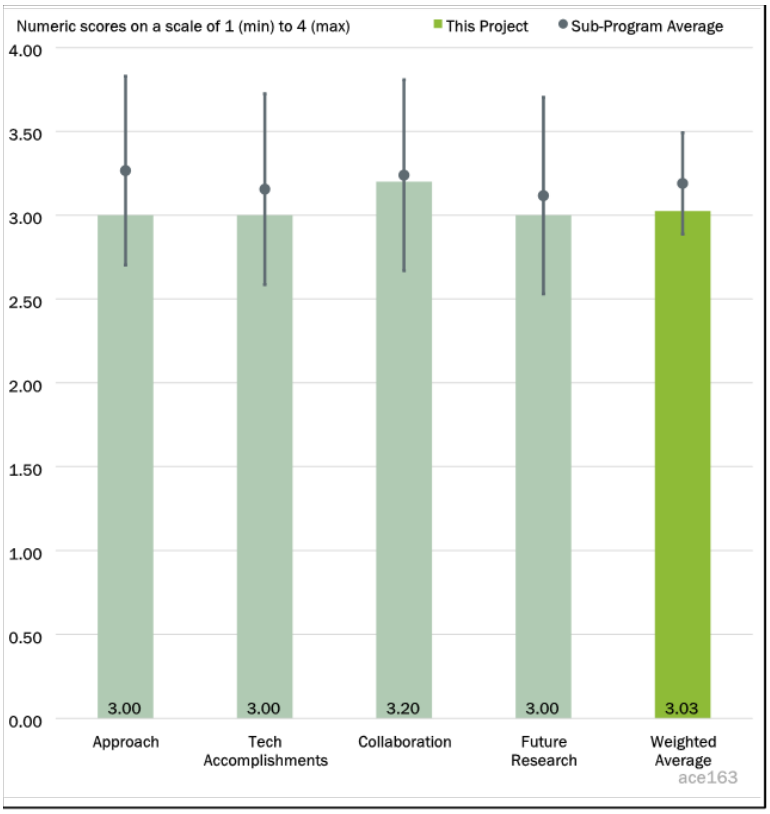

Figure 1-19 - Presentation Number: ace163 Presentation Title: Ducted Fuel Injection and Cooled Spray Technologies for Particulate Control in Heavy-Duty Diesel Engines Principal Investigator: Adam Klingbeil, Wabtec

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

It appears to this reviewer that the qualitative effects of ducts can be explained, but a detailed quantitative-fundamental explanation is missing. Additional efforts which include the fundamental aspects of this technology will be useful.

Reviewer 2

The reviewer said this is a nice collaboration between Wabtec, SNL, and Southwest Research Institute (SwRI) to develop a retrofittable ducted fuel injection (DFI) design—called Cooled Sprays—for heavy-duty diesel engines. In my opinion this is a high risk, high reward endeavor. DFI has been demonstrated to drastically reduce particulate emissions in a way that breaks the classic soot NO_x trade off. Doing so allows one to adjust the engine to more efficient injection timings, and furthermore it has been shown to show the same reduction potential when using oxygenated low net carbon fuels, yielding extremely low levels of criteria pollutants. The reviewer noted the objective of this work is to establish the understanding and propose a pathway for moving this concept from successful laboratory operation into real world application.

Reviewer 3

The reviewer said the project concept is novel and is presented as a potential reduction for soot emissions. Some of the barriers for the technology are brought up is alignment of the channel to the injector hole. There

would appear there are MANY more barriers: UHC owing to the close channel geometries, additional surface areas, and the interruption of the flow due to the added geometry. The reviewer cited that possible improvements on the project plan may be: Test fixtures could be re-thought to dramatically control the alignment issues noted; manage the alignment in multiple holes; improve or document the measurement scatter (NO_x and particulate matter (PM]); report on other emissions (UHC) and fuel economy for each test point; and align the metal and optical engine configurations as they are very dissimilar now.

Reviewer 4

The reviewer did not understand the lack of CFD work on this project. There are multiple questions that could be answered with simulation instead of extensive experimental work (e.g., what is the connection between the passage diameter and spray opening angle at various conditions).

Reviewer 5

The program proposes a development approach incorporating experimental evaluations of DFI on an optical engine, and of the cooled spray (CS) concept in a metal engine, then using that data to develop scaling relationships for the DFI/CS concept(s) to apply them more broadly across engine platforms. This is a reasonable approach to advancing understanding of DFI/CS. However, exclusively using an experimental approach to develop information for the scaling exercise seems like a very low efficiency approach, given the broad design space for injector, ducts, and combustion system. It would be helpful to understand the breadth of the design space being considered, and the approach to narrow it towards an optimum configuration. Using simulation would seem to significantly improve the process.

The reviewer said there is a mismatch between apparent scaling exercise work and the end-of-year milestone to collect performance results "in at least 2 updated CS designs" and program target indicating "3-5 more CS/nozzle concepts" in 2023. If the scaling laws are solely developed from experimental data, this seems like a low number of configurations given the degrees of freedom for the duct designs.

The reviewer noted that for a diesel engine, the efficacy of an injector design is coupled to the design of the piston bowl, and often the two are co-developed as a single combustion system. The program here does not appear to be considering design changes to the piston in conjunction with the new injector concept. This appears to be a gap, especially because the optical engine appears to have a different piston design altogether. It is challenging to see how either an optimal injector configuration, or strong scaling relationships, will result without optimizing piston and injector together, and between the optical and metal engines.

The reviewer was surprised to see a 1 mm diameter duct as one of two ducts being evaluated. This is smaller than the ducts the SNL has published on previously, even though the injector orifice diameter is quite a bit larger than what is used on the SNL engine. On the surface, this raises concern about the design selection process.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The reviewer said that accomplishments are excellent. A redesigned DFI concept has been developed and produced. It is being tested in both optical and metal engines. As expected in any such high risk, high reward endeavor, there have been some good as well as disappointing results. The researchers are learning from these results and are making progress consistent with their work plan.

Reviewer 2

The reviewer said excellent results (mostly experimental) have been obtained. The duct design and alignment work are very good, and the early experimental results are very interesting.

Reviewer 3

The reviewer said the presentation is unclear as to whether the experiments take place with DFI (ducted) or CS. A more detail explanation of the test geometries could be given with simple estimates of flow velocities, entrainment ratio, etc. It is also unclear whether the CS require fresh air injection into the cylinder, the schematic of Slide 4 shows what may a appear to be a re-entry point upward. How extensive has the present configuration been studied, what other arrangements are possible, what would be their pro-cons?

The reviewer said initial data shows promise, but it is limited to the lower rpm case. What is the benchmark the authors are looking to? How does this compare with competitive technologies in this same space of NO_x-soot tradeoff (examples may be effect of increased injection pressure, bowl-injector match optimization)?

Reviewer 4

The reviewer said the project is in initial phases, and this reviewer is afraid that expectations are too big for what the project will actually achieve.

Reviewer 5

Project has been making technical progress, and key milestones appear on track. It was not clear from the written or presented material how much design or development effort went into creating the prototype DFI/CS injector systems that were evaluated on the metal engine. Engine evaluation of two different configurations of nozzles across multiple operating points has been completed, along with a detailed effort to quantify and spray alignment with the prototype hardware.

Information from the metal engine experiments was incomplete, with results simply focused on soot emissions. NOx emissions were only reported at one condition, and hydrocarbon (HC) emissions and impact on efficiency impacts not covered, leaving a clear gap in understanding of the technical progress and performance demonstrated.

The importance of alignment between duct and injector orifice was explored, with substantive effort on developing techniques for quantifying the alignment. This has been identified as a key are for future work to establish better alignment on the ducts, especially challenging with a multi-hole injector.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said it appears to be a strong synergy of team members.

Reviewer 2

The reviewer remarked the team could have taken advantage of a CFD partner. It could have provided notable insight as to the fundamental dynamics taking place.

Reviewer 3

The reviewer commented good collaboration between the various parties involved in the project.

Reviewer 4

The reviewer said the combination of Wabtec, SNL, and SwRI is a strong and synergistic collaboration.

Reviewer 5

The reviewer noted that the presentation identified two partners for the program: SNL, who conducts DFI experiments in an optical engine platform, and SwRI for the metal engine testing. The role of SNL is quite clear, and is a key partner for any efforts in the ducted fuel injection space. The extent of SwRI's effort or project involvement beyond engine testing and data processing was unclear; are they only a test contractor, or are they adding additional value to the program?

The reviewer was surprised to see, given SNL as a partner, the appearance that not all learnings from the DFI studies at SNL were transferring to this program. Duct designs and geometries are inconsistent with the information SNL published previously. This raises questions on the effectiveness of this part of the partnership. The reviewer said key programmatic gaps in engine modeling and simulation could be addressed by the additional of project partners such as universities or national laboratories. Further, the challenges in manufacturing components with very specific alignment might be an opportunity to engage additional program partners to assist.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said future work is very clear and milestones clearly identified.

Reviewer 2

The reviewer said proposed future research is adequate.

Reviewer 3

The reviewer commented the proposed future work, at a high level, is in alignment with a path towards achieving the program goals and targets. However, achieving the goals stated with the limitations on the work being conducted—including lack of CFD/simulation effort, relatively small set of configurations being tested, only redesigning the injector and not the full combustion system—raise concern on whether the project will achieve its targets.

Reviewer 4

The reviewer said it appears that the future empirical work is based on educated insights. I feel the weakest part of this project is the lack of companion modeling. Why are the results so good at low speeds, but worse at high speeds? Modeling could likely help answer this question, and then guide the duct design directly. Please also include efficiency, emission and durability results in future experiments.

Reviewer 5

The reviewer remarked the researchers are learning from their results and making the appropriate adjustments to their work effort. It would be highly desirable to include a CFD effort to perhaps gain additional insights into the fundamentals governing their successes and their disappointments. The team currently does not have the resources for this, but in my opinion, it would increase the likelihood of success.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The reviewer commented the pursuit of lower soot in the CI context is excellent.

Reviewer 2

The reviewer said the novel concept would provide a means to improve the fuel air mixing in an engine with potential large reduction of soot formation, and therefore improve cost and durability of these platforms.

Reviewer 3

The reviewer said the project is supportive of the overall Advanced Engine and Fuel Technologies objectives to generate knowledge and insight necessary for industry to develop the next generation of engines. The project seeks to advance the state of technology and understanding of an advanced clean diesel concept that reduces engine-out criteria pollutants, in this case particulates. It is also well-focused on moving the DFI concept towards production viability in a market sector that is challenging to electrify, and constrained on solutions for emissions control.

Reviewer 4

The reviewer said decreasing diesel emissions is an important part of the VTO mission.

Reviewer 5

The reviewer referred to prior comments.

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

Reviewer 1

The reviewer said resources appear to be sufficient.

Reviewer 2

The reviewer said resources are adequate. The team employs good engine test facilities, though it could have utilized stronger input from modeling.

Reviewer 3

The reviewer said a funding level of $1 million year seems appropriate for the scope of work being executed.

Reviewer 4

The reviewer said it is difficult to comment on resources when the available funding is so small but experimental cost went through the roof in terms of expenditures.

Reviewer 5

The reviewer referred to prior comments.

Presentation Number: ace166
Presentation Title: New Two-Cylinder Prototype Demonstration and Concept Design of a Next Generation Class 3-6 Opposed Piston Engine
Principal Investigator: Fabien Redon, Achates Power

Presenter

Fabien Redon, Achates Power

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 17% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

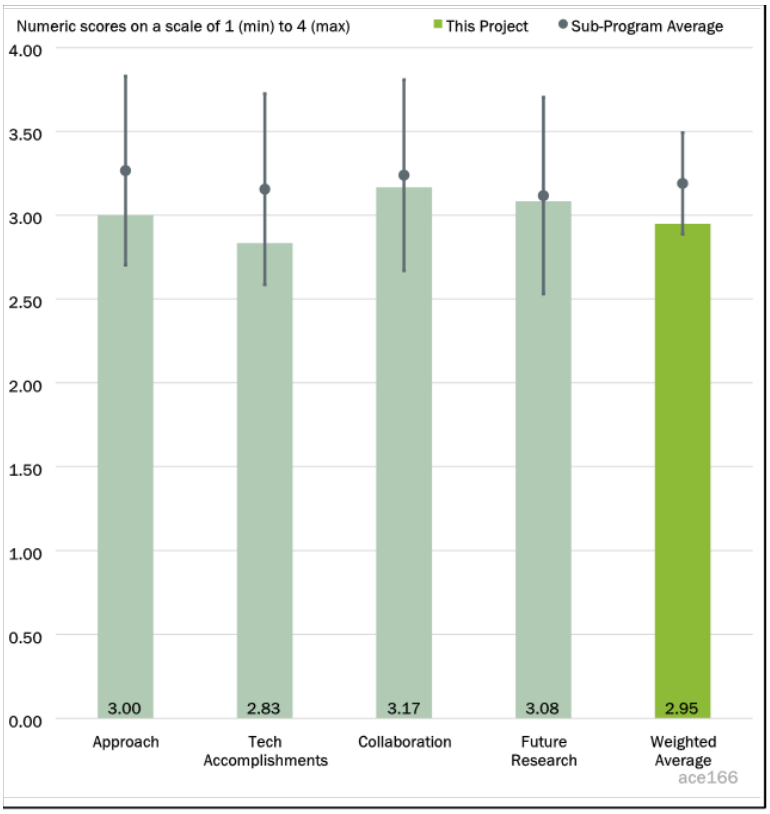

Figure 1-20 - Presentation Number: ace166 Presentation Title: New Two-Cylinder Prototype Demonstration and Concept Design of a Next Generation Class 3-6 Opposed Piston Engine Principal Investigator: Fabien Redon, Achates Power

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

Enhancing the cost-effectiveness of engines is a pretty big challenge. The opposed piston two-stroke (OP2S) architecture does not produce the cost-savings that are claimed by the authors. The cost savings only hold true if one starts a factory from scratch and uses that factory to only fabricate OP2S engines. The upfront cost of the brand-new factory will be substantial and will take time to amortize. If one needs to re-configure a current factory, there will be no cost-savings at all between re-tooling and scrapping cylinder head and valve assembly lines, recasting cylinder blocks and liners, and re-sourcing injectors and turbochargers/superchargers. A complete architecture change is a very unusual way to promote "cost-effectiveness", even if there is a slight reduction in aftertreatment cost.

Reviewer 2

The work addresses the noted barriers and those barriers are linked to the barriers of the VTO and 21st Century Truck Partnership (21CTP) Blueprint barriers. The presentation could more explicitly link to the 21CTP Blueprint which includes improving efficiency by identifying and addressing heat transfer losses.

Reviewer 3

The overall approach of simulation and prototype experiments is sensible for this particular engine architecture, for this specific project. An overall positive impact on the fuel efficiency and emissions compared to all combustion engines may not be evident from this work unless engine data are collected in standard test cycles and compared to the EPA database.

Reviewer 4

The project replaces typical diesel engines with opposed piston engines which, per the presentation, does not have the same barriers as the diesel engine.

The targets are specified and this is almost the end of the project but it is not clear if the targets are achieved or will be achieved by the end of the project.

Reviewer 5

The timeline is aggressive for this project given the 2 years to demonstrate superior efficiency and emissions from a two-cylinder OP2S in comparison to a benchmark OEM engine. To date the project is leaning heavily on simulations and the degree to which barriers will be addressed is better assessed after there is some experimental data. However, generally, this OP2S project does address barriers for today's four stroke engines relative to the OP2S.

Reviewer 6

The work approach is generally good at developing a workflow to optimize combustion, simulate combustion to optimize swirl and gas exchange, and to use Gamma Technologies - Power (GT-Power) models to simulate efficiency over a wide operating regime. This reviewer does not see a need to help simplify the open cycle simulations—the 16-day simulation is certainly impressive, but is unsustainable for iterative work. The team should be using these complex simulations to develop simplified models that can produce a substantial amount of the necessary information at a fraction of the computational cost. For engine development work, developing an approach to help with the open cycle simulations that is less computationally intensive is warranted.

It does not seem like the barriers that are being addressed in this project are really new barriers - these have all been addressed in previous versions of the OP2S engine, and are being scaled to a different cylinder count.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The simulation work done by both University of Wisconsin (UW) and Clemson University shows some promise in being able to meet ultra-low nitrogen oxides ($ULNO_x$) emissions through some combustion improvements and using conventional aftertreatment. However, the minimum BSFC shown on Slide 9 is very suspect, in the sense that a 6% improvement in BSFC is substantial and not many details were shown in the slide as to why that configuration was so much better on fuel efficiency than the baseline.

There does seem to be significant progress in the areas of two-cylinder design and procurement of hardware. It will be very interesting to track the progress of the two-cylinder work as it progresses.

Reviewer 2

The reviewer said CFD and GT-Power modeling for scaling the design to the target class have had good progress, and all parts for the new engine besides the electric turbocharger (e-turbo) have been received. Partner progress on vehicle level modeling is well underway.

The status of the model predictive control and what methods and validation are being used there were not clear in the presentation.

Reviewer 3

The progress in combustion simulation, GT-Power models, and fabrication of engine is commendable. COVID-19 impacts are acknowledged. There is a nice comparison of fuel efficiencies in vehicle simulations over known drive cycles.

Reviewer 4

Progress to date is leaning heavily on simulations that were calibrated with a different OP2S engine (three-cylinder) than the project's targeted two-cylinder OP2S. The project is executing well against the project plan as evidenced by significant modeling and simulation, and design work on the two-cylinder OP2S. The next four months of experimental work are arguably the most critical to the project.

Reviewer 5

There has been good progress made on optimization of the combustion chamber, open cycle simulations, and using GT-Power to predict the engine performance. It would have been nice to see an engine build, but COVID-19 and supply chain delays associated with the air handling equipment are reasonable and understandable.

Reviewer 6

It looks like the university partners are progressing really well but it is not clear what the industry partners are doing. Even though there seems to be a lot of progress at the universities, surprisingly there are not too many publications. Of course, some information is protected but the information on the slides could result in multiple papers.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

This team seems well-constructed to address the issues in this project. There is a good combination of industry and university partners.

Reviewer 2

This is a good collaborative team with partnership with industry and university. There are clear contributions from Clemson University, UW, and Isuzu Technical Center of America.

Reviewer 3

The involvement and contributions by the partners are adequately presented and explained. Partners appear as substantial contributors.

Reviewer 4

It is very apparent the project has strong collaborations across the two universities and the OEM. This is evident by the sharing of engine simulation results and the fuel economy analysis with OEM guidance.

Reviewer 5

There appears to be a good project team with delineated workflow and the correct expertise. The contributions from the university partners are clear, and all partners appear to be producing results as part of this project.

Reviewer 6

It looks like the universities are doing the bulk of the work and coordinating with each other. It is not clear what the industry partners have accomplished in the last 2 years.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Building and testing a two-cylinder engine is the only way to validate the proposed concepts of this project. The assumption is that a family of multi-cylinder engines (2, 3, or 4) of the same geometry would be cheaper to make than 3-cylinder versions of different displacement engines.

The target seems achievable. It would be good to understand how validation of the vehicle systems simulations and drive cycle estimates will be completed.

Reviewer 2

The reviewer recommends the project to consider adding engine data over Federal Test Procedure (FTP) and (SET cycles. Validating achievement of ULNO$_x$ will be important.

Reviewer 3

A lot of work is proposed for the last part of the project. The reviewer expresses uncertainty in whether all of the work can be done in the remaining time.

Reviewer 4

It is very clear the next phase of the project will yield the most useful results based on engine testing. One recommendation is to explore as many engine operating points as possible versus a couple or few selected points. This additional information could be very valuable to the project team and the industry in general.

Reviewer 5

The project is wrapping up at the end of 2022. The remainder of the project focuses on engine validation and vehicle simulations, which is appropriate for this stage of the project.

Reviewer 6

The pathway to complete the project was clear with noted collaboration with Clemson University after shakedown. It is not clear what role remains for UW.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

This project is relevant to advancing DOE goals in lowering $ULNO_x$ and reducing GHG by improving fuel efficiency.

Reviewer 2

The project directly supports VTO subprogram objectives around increasing efficiency for engine systems for medium- and heavy-duty vehicles.

Reviewer 3

In general, efforts to improve engine efficiency are always relevant for improved freight efficiency and reduced carbon dioxide (CO_2) emissions. The target of 10% fuel economy improvement over a Class 4 Isuzu vehicle over the customer derived real world drive cycles has an imprecise baseline and is not really adequate in the big picture.

Reviewer 4

This project is addressing barriers towards the development of ICE with low emissions, reasonable cost, and good fuel economy. It is focused on improving indicated thermal efficiency (ITE) while trying to maintain good emissions performance with an advanced two cylinder engine that is outside the norm compared to four stroke engines.

Reviewer 5

This project is focused on reduced fuel consumption, which is in line with DOE VTO goals.

Reviewer 6

This project was funded before the recent change of direction within the program.

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

Reviewer 1

The resources for this project appear to be sufficient to obtain a successful outcome.

Reviewer 2

Resources seem sufficient for achieving the stated milestones.

Reviewer 3

In view of past and ongoing government support to this engine's development, the cost share should be higher. The reviewer suggests comparing to cost share in SuperTruck projects.

Reviewer 4

The project seems properly resourced to hit project objectives. This reviewer's only suggestion is to perform as much engine map testing as possible within the budget.

Reviewer 5

Resources appear to be sufficient. All project partners are producing results, and project delays appear to be minor and unrelated to funding.

Reviewer 6

The role of the industry partners is not clear which makes it difficult to comment on the resources.

Presentation Number: ace169
Presentation Title: Greatly Reduced Vehicle Platinum Group Metal (PGM) Content Using Engineered, Highly Dispersed Precious Metal Catalysts
Principal Investigator: Yong Wang, Washington State University

Presenter

Yong Wang, Washington State University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

75% of reviewers felt that the project was relevant to current DOE objectives, 25% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

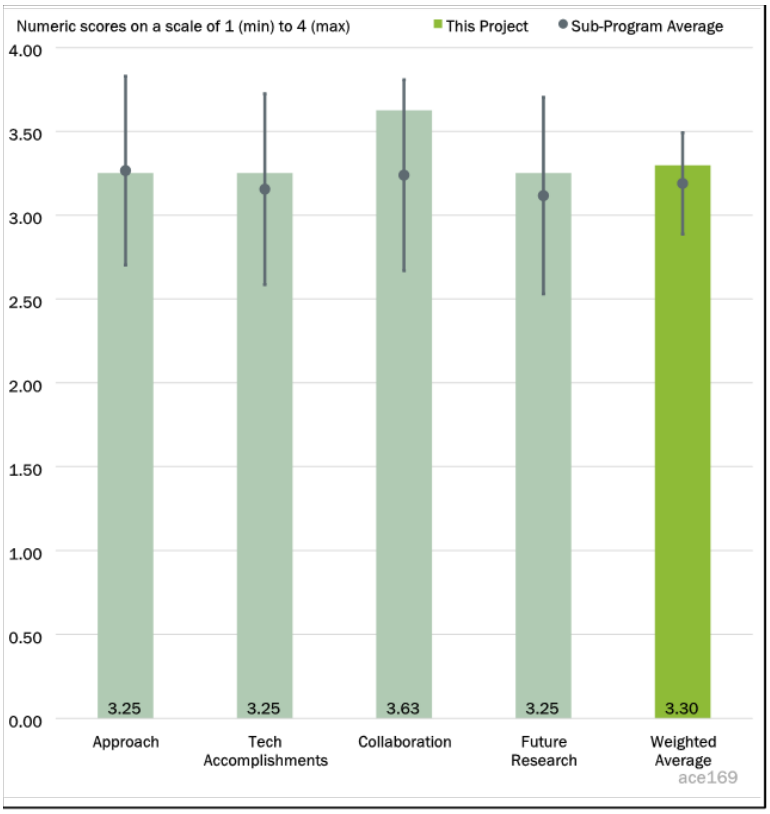

Figure 1-21 - Presentation Number: ace169 Presentation Title: Greatly Reduced Vehicle Platinum Group Metal (PGM) Content Using Engineered, Highly Dispersed Precious Metal Catalysts Principal Investigator: Yong Wang, Washington State University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The project appears well designed after 1.5 years of performance and has a good focus on appropriate technical barriers. Looking at Rh, as it is the most costly metal, is also appropriate. Even though there is likely less Rh in the overall catalyst system compared to other metals, the total cost of Rh is probably more than Pd, so the approach is reasonable.

Reviewer 2

This project is well-designed and well-planned to achieve enhanced TWC performance with single atom PGM/ CeO_2 catalysts in a real-world application.

Reviewer 3

The team has clearly tried multiple synthetic strategies to achieve sufficient performance with reduced PGM loadings, and made excellent use of their characterization tools to understand why some formulations look promising while others fall short. However, it is not clear if the synthetic strategies they are pursuing can be scaled up to industrially relevant processes; it would have been better to use scalability as a factor in

developing and down selecting synthetic pathways. Also, the baseline catalysts were not well-defined - it is not clear if they are production TWC materials or something else.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The team has made excellent progress in modifying their synthetic strategies with Rh-based catalysts, although they have not yet achieved performance parity with the baseline materials. Also, the progress on Pd was unclear from the presentation, as the only data set included in the presentation was a single light-off curve conducted in the absence of water in an undefined aged state (which probably means unaged). Pd must be addressed to significantly reduce PGM loading in TWCs.

Reviewer 2

Isolating deposition of Rh on only CeO_2 in the support is an excellent achievement. The observation that trapping sites are better in nanoparticles of ceria versus isolated cerium (Ce) is not surprising based on the literature. Looking at the effect of ceria particle size on successful and efficient trapping and maximal use of Rh (and Pd) would be useful to explore.

The production of 100g of catalyst with the new approach is also a significant accomplishment.

Reviewer 3

The project has shown good progress in developing a potentially scalable method for supporting SACs on ceria which are then supported on alumina.

The project would clearly benefit from kinetics and mechanistic analyses. While the oxidation of CO on SACs anchored by ceria is intuitive, the nitrogen monoxide (NO) reduction is not. Rate measurements and potentially exposed metal area measurements would help to elucidate the pathways for N_2O, NH_3, and molecular nitrogen (N_2) formation. Specifically, how does NO get activated on a single Rh atom? Does the NO dissociate on Rh atom with atomic oxygen (O) migrating to ceria? Or does the NO dissociate on the ceria? These questions are pertinent not only for advancing the science but also in assessing aging and scaling up the catalyst. The project would clearly benefit from kinetic and monolith reactor modeling components.

Reviewer 4

The response to the reviewer comments from last year regarding the performance were not adequately answered—either in words or in work.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The project team is excellent, and includes University of New Mexico (UNM), Washington State University (WSU), and PNNL. It shows in the results. Excellent collaboration for minimizing the use of PGM by making near-SAC catalysts that are reducing the metal content in the catalyst by a factor of at least five.

Reviewer 2

This is a really strong team with no gaps. The only area to work on is the aforementioned kinetics. There is a nice balance of academic, national laboratory, and industry partners.

Reviewer 3

The team has an excellent mix of universities, national laboratories, and industry partners including both an OEM and a catalyst supplier, and appears to have all the capabilities needed to succeed. The coordination across the team was documented and appears to be good, although it would have been interesting to hear a bit more about who was responsible for the work completed to date.

Reviewer 4

The team represents a good cross-section of the industry, suppliers, national laboratories, and universities.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The future research goals to be achieved will depend on a good interaction between PNNL, WSU, and UNM with BASF. The reviewer is curious to see how that works out.

Reviewer 2

The team has identified the right paths for next steps.

Reviewer 3

All the steps proposed in the future work are necessary to achieving success. However, it is not clear that the team has defined a pathway to scale up the SAC synthesis process to generate sufficient material for an engine/vehicle demonstration of the most promising formulation(s), or to define an industrially relevant pathway to catalyst production.

Reviewer 4

It is unclear how the future work plan will achieve the project goal. There is still a lot of focus on fundamental, bench-scale samples (powders, cores) and there is a large difference between that scale and demonstration.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The successful implementation of this proposed emission control system will lead to the most fuel-efficient pathway to meeting required emission control standards.

Reviewer 2

This project is a great fit with VTO.

Reviewer 3

The project is relevant to DOE goals for emissions reduction.

Reviewer 4

It is not clear how this project addresses the DOE VTO mission of decarbonizing the transportation sector.

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

Reviewer 1

The range of tools available to solve the issues in this project are quite sufficient in the laboratories at PNNL combined with UNM, WSU, and BASF.

Reviewer 2

There is a good balance of resources.

Reviewer 3

The project has a substantial budget, although the reviewer worries that the work plan and funding are front loaded toward the universities and national laboratory such that there will not be enough resources remaining at the end of the project for successful scale up and demonstration at the engine/vehicle level.

Reviewer 4

Resources seem sufficient for this project.

Presentation Number: ace170
Presentation Title: LLCF Effects on Emissions Control Catalyst Performance and Durability
Principal Investigator: Sreshtha Sinha Majumdarm, Oak Ridge National Laboratory

Presenter

Sreshtha Sinha Majumdarm, ORNL

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 50% of reviewers felt that the resources were sufficient, 50% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

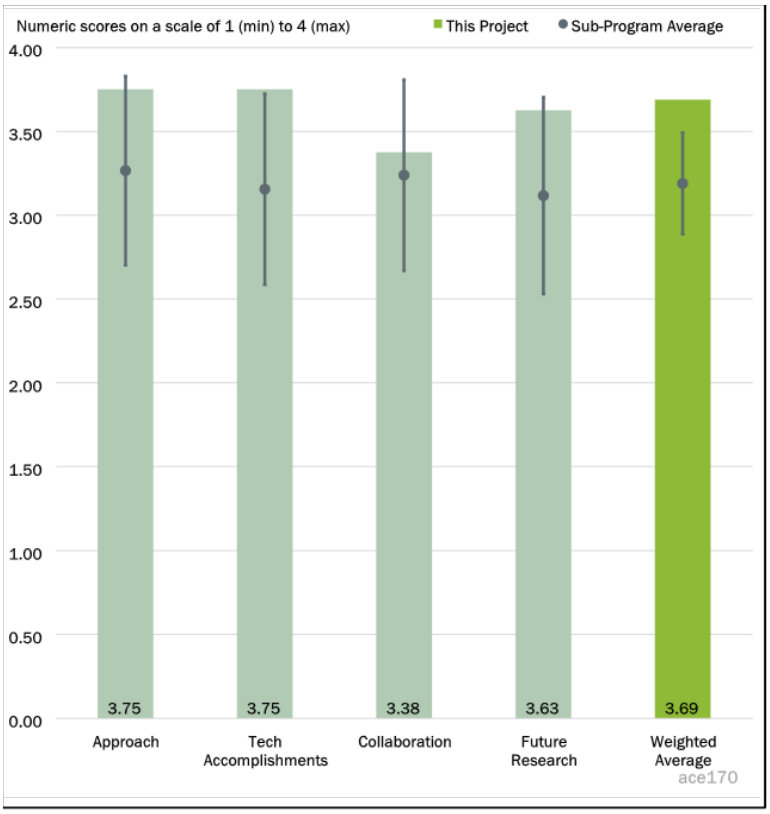

Figure 1-22 - Presentation Number: ace170 Presentation Title: LLCF Effects on Emissions Control Catalyst Performance and Durability Principal Investigator: Sreshtha Sinha Majumdarm, Oak Ridge National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The reviewer thinks this is a really excellent project. Low life-cycle carbon fuels (LLCFs) are a fast way to decarbonize the transportation industry. Fungible LLCFs could be deployed immediately through existing HC fuel infrastructure. With these fuels - there is no need for complete fleet turnover - and it would greatly reduce the pressures on the supply chain for a variety of materials. The key barrier to this deployment is understanding the combustion, emissions, and aftertreatment potentials of these fuels.

Starting with a questionnaire to stakeholders allows this project to start with an industry-relevant perspective. This reviewer admits surprise to see that ammonia scored as well as it did across the sectors—since there are significant safety issues related to it. There is a strong experimental plan, making good use of ORNL experimental facilities and experience. The timeline seems aggressive, but the project is on track. There is a good range of LLCFs in the study.

Reviewer 2

This is a rather straightforward project in terms of concept. The team is evaluating how well/poorly different primary pollutant components from different fuel sources are oxidized over a standard DOC. The fuel and emissions choices are based on previous Co-Optima findings. With common engine platforms for a variety of

fuels, knowing how a common emissions system might handle the emissions from those fuels is critical. This project begins to address that concern.

Reviewer 3

Using the methods and skills developed in this ORNL group to good advantage, this project is learning which LLCF would be good choices for decarbonization of engine applications that are difficult to electrify, and learning their emissions control issues. This approach is also wisely guided by a survey of companies that have indicated what they are most interested in learning about, and with the main catalyst of interest being a DOC.

Reviewer 4

The ORNL-led project focuses on low carbon fuels for difficult-to-electrify engines. This is an important scouting project, hopefully to define an expanded investment by DOE VTO.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The project has recently started and is making progress. The oxidation of a surprisingly large number of hydrocarbon types has already been evaluated. The rig being used has been used consistently in the past, and thus there is already confidence in the results.

Reviewer 2

The light off (LO) temperature for oxidizing LLCF fuels over a DOC has been analyzed and the temperature depends on the structure of the fuel. The alcohols are good choices, but they also partially oxidize to aldehydes at low temperatures at the same time that alcohols are being completely oxidized.

Reviewer 3

The project has made good progress in seeking input, defining the approach, and conducting initial experiments. The LO experiments would benefit from a more fundamental look at oxidation catalysis. There is a large literature on PGM-catalyzed oxidation of various hydrocarbons. It does not appear that the investigators have done a literature survey.

The first step in obtaining LO temperatures is fine. However, looking ahead, the issue of inhibition needs to be examined in terms of CO inhibition of HC, and potentially HC inhibition of CO. NO adds a further complication. In other words, the common exhaust constituents CO and NO can drastically impact the LO temperature. Such effects are known and reported in the literature.

Reviewer 4

It is not surprising that the DOC reactivity is dependent on the HC species—this is something the aftertreatment community has long known for petroleum HCs - however, identification of aldehyde intermediates from methanol, ethanol, and isobutanol with speciation is a key piece of information that will be important for understanding if the aftertreatment community will be able to meet emissions reduction goals.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

From the presented material, it is apparent that the industry partner is providing input. The role for PNNL or that PNNL is playing is unclear.

Reviewer 2

The partners for this project are excellent choices, since PNNL and ORNL have already worked on several projects together and Caterpillar would be a major user of LLCF fuels in their off-road products. Another off-road partner, such as John Deere, or a maritime partner, such as Maersk, would be other partners to consider, if they might be interested.

Reviewer 3

The project team has received excellent input to frame the problem with respect to LLCFs. The involvement of Caterpillar is a positive given its position as a leader in off-road. The project would benefit from a more fundamental perspective, potentially with an academic partner.

Reviewer 4

The reviewer would have liked to see university collaboration - though the timeline of this project makes that tough. The reviewer is not sure what PNNL brings to the project and suggests considering consolidating resources to just ORNL for this project.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The first proposed part of the plan, aldehydes and alternate oxidation catalyst materials, is solid. The other parts are too vague to evaluate. Also, how will cross-interferences between hydrocarbons be evaluated?

Reviewer 2

Excellent future research challenges are included, since they directly relate to known future needs, particularly for eliminating aldehyde emissions through system controls or an improved catalyst with, or as part of, the DOC.

Reviewer 3

This reviewer would have liked to see some of the issues around inhibition, kinetics, and modeling considered.

Reviewer 4

The reviewer thinks this is an interesting opportunity to consider catalyst formulations to deal with the aldehyde intermediates. Perhaps a partner like Umicore/BASF/Johnson Matthey would benefit to be part of this work?

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

This is a highly relevant study given the push towards decarbonization.

Reviewer 2

This program is relevant for emissions control from future engines, that will be running off a wide variety of fuel sources. It directly and nicely ties to the Co-Optima program.

Reviewer 3

This project has great relevance for the areas that it applies to. Assisting in the decarbonization of fuels is key in this area. In a more detailed sense, the details of how the real-world systems behave and guide research is very important as suggested. This reviewer would suggest renewing this project based on the important area it covers, which could end up expanding into other fuels, e.g., H_2 and NH_3, that could raise completely different challenges, but would be more clearly not adding any greenhouse gases to the environment.

Reviewer 4

Yes—this work supports the VTO goals of reducing CO_2 emissions. More work should focus on LLCFs/sustainable fuels, etc.

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

Reviewer 1

The funding does not appear to be sufficient to address issues not covered in the study.

Reviewer 2

Not enough money is being put into actualizable pathways for decarbonization. Sustainable fuels have a clear pathway to immediate adoption and could have significant impact on CO_2 emissions. Fungible fuels would not have any infrastructure delays. The reviewer thinks VTO should be investing more in this realistic area.

Reviewer 3

The resources appear appropriate. The reviewer would like to see more resources available, but in a manner to extend the project to include modeling, as that would ultimately be a great way for the results to converge—to be able to predict emissions as fuel blends change.

Reviewer 4

The resources at ORNL are especially relevant to this type of study, so for now the resources are very sufficient, unless other partners are added that may propose research in new areas requiring more staff.

Presentation Number: ace171
Presentation Title: Simultaneous Greenhouse Gas and Criteria Pollutants Emissions Reduction for Off-Road Powertrains
Principal Investigator: James McCarthy, Eaton

Presenter

James McCarthy, Eaton

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

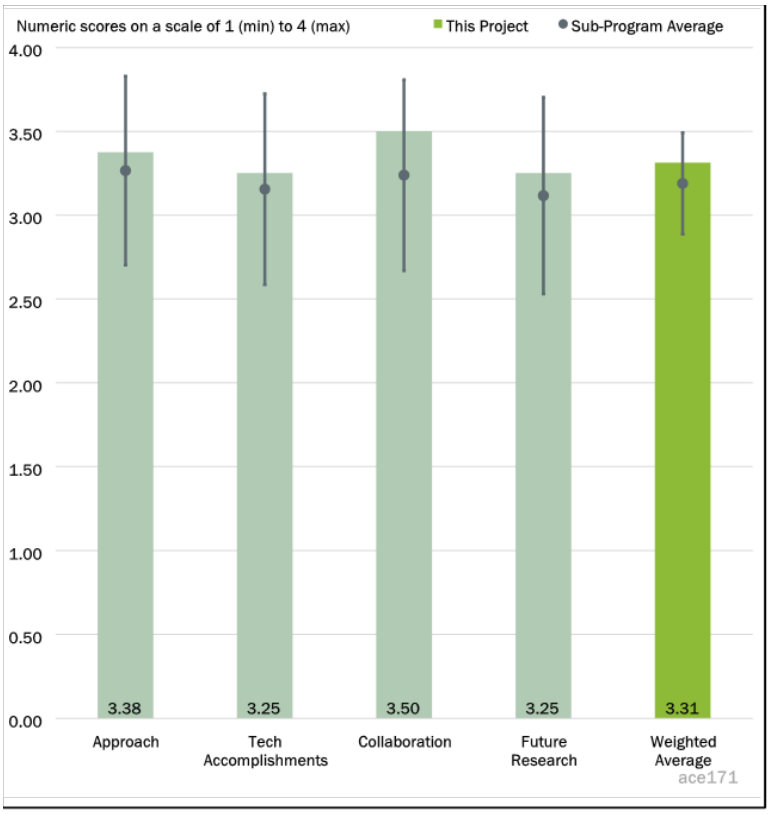

Figure 1-23 - Presentation Number: ace171 Presentation Title: Simultaneous Greenhouse Gas and Criteria Pollutants Emissions Reduction for Off-Road Powertrains Principal Investigator: James McCarthy, Eaton

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The barrier is to build a high-efficiency, off-road future engine. The project will add significant technology to an off-road engine to improve the engine efficiency. The technology includes: variable valve actuation, high-efficiency turbocharger, electric EGR pump and new controls. They will also look at other parameters to improve efficiency, that have been documented for on-highway engines. The new exhaust aftertreatment will be developed to meet the future off-road emission standards with the goal of also improving the fuel economy. The project is well thought-out.

Reviewer 2

The project is only beginning, but the approach is sound and appears well thought-out.

Reviewer 3

This project is just starting but the technical content is clearly stated, a capable cross-organization team is identified, and the timeline appears realistic.

Reviewer 4

The reviewer thinks overall the project can be improved. The timeline is reasonably planned. A lot has been done for on-road diesel engines to achieve ultralow emissions. So, compared to the on-road engine, what are the major differences and barriers for off-road?

It is not very clear how CFD will be used for optimization. Is it for engine and aftertreatment system simulation, or just for aftertreatment system? What is the baseline N_2O emission? It seems that the baseline engine has an extremely high N_2O emission, otherwise, it is not possible to achieve a 3.5% GHG reduction.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The project was initiated in February 2022 and the team has already made good progress moving the project forward. The team has the baseline configuration agreed upon and know how to correct for GHG, submitted their project management plan, and created a program schedule. This reviewer is not sure much else could have been accomplished.

Reviewer 2

The project started three months ago. Good progress has been made such as assembling the team, deciding a baseline configuration and GHG correction using measured data and CFD simulations for a single-pass aftertreatment system with a DPF, submitting the project management plan, etc.

Reviewer 3

Again, the project is just starting, so there has not been a lot of progress made. But the team has completed what is appropriate at this stage; they have assembled the team, have a plan, and identified a baseline.

Reviewer 4

This project is just starting so there would not be significant technical accomplishments expected at this point. However, the plan is well laid-out as the technical approach is founded in prior work but with a focus on off-road applications. This reviewer feels this project has a high probability of success.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

Eaton has taken the lead in the project and so far has been doing the majority of the work. However, it is evident that Fiat Powertrain has been contributing in terms of supplying engines, providing input on test plans, and determining the overall schedule. Tenneco will become more involved when aftertreatment selection is required.

Reviewer 2

The project team consists of two major suppliers, a national laboratory, and a research institute, which have extensive experience in engine and aftertreatment technology development.

Reviewer 3

They have assembled a strong team. It would be helpful to understand in a bit more detail the roles for the various partners. For example, who is doing the aftertreatment system simulation and who is doing the overall system analysis and integration?

Reviewer 4

The project is just starting but this appears to be a well-rounded team with extensive experience covering the breadth of the technical approach. The inclusion of Eaton with strong engine and subsystem background, Tenneco with a strong aftertreatment background, ORNL and Southwest Research Institute (SwRI) with extensive systems/testing background, and OEM manufacturer Fiat Powertrain is a well-rounded and capable team.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The project plan is well laid-out and has a step-by-step plan to move forward. The PI and his team have been doing this for years so they understand what needs to be accomplished.

Reviewer 2

The program schedule defines the time of the future work, which seems reasonable and likely to achieve the proposed targets.

Reviewer 3

The technology content chosen is sensible as are the proposed next steps.

Reviewer 4

This project has a well laid-out and logical plan starting with definition of requirements and moving into test bed development and system testing and optimization. This reviewer recommends to make sure sufficient analytical modelling is performed to focus testing and avoid less beneficial hardware and calibration approaches.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

VTO is switching their focus from on-highway to off-highway and this project expects to improve the fuel efficiency by 10% while meeting the future off-road emission requirements.

Reviewer 2

The objective of the project is to research, develop, and validate AT system-level strategies capable of greater than 10% GHG reduction and greater than 90% NO_x reduction for off-road powertrains over multiple duty cycles spanning the diverse applications in the segment, while maintaining affordability and robustness to ensure economic viability. It supports the overall VTO subprogram objectives.

Reviewer 3

Reducing CO_2 and NO_x emissions are both relevant, as are reducing system complexity and cost (for a given performance).

Reviewer 4

Applying a well-known technology bundle to off-highway applications is a good use of these resources. The off-highway duty cycles and use cases are unique and this work needs to be performed to ensure the right technology bundles are developed for off-highway.

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

Reviewer 1

The team has sufficient resources for this project. The program schedule shows that the stated milestones can be met in a timely fashion.

Reviewer 2

The project's scope and timeline are very aggressive and the budget does not support this. However, Eaton has volunteered to provide additional support beyond the original commitment and, with the additional commitment of a second engine and resources, the project should be completed on schedule.

Reviewer 3

Time and budget are reasonable for the proposed plan.

Reviewer 4

Resources are appropriate for a project of this size. The total budget may limit the number of hardware combinations that can be tested.

Presentation Number: ace172
Presentation Title: Fast Simulation of Real Driving Emissions from Heavy-duty Diesel Vehicle Integrated with Advanced Aftertreatment System
Principal Investigator: Hailin Li, West Virginia University

Presenter

Hailin Li, West Virginia University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

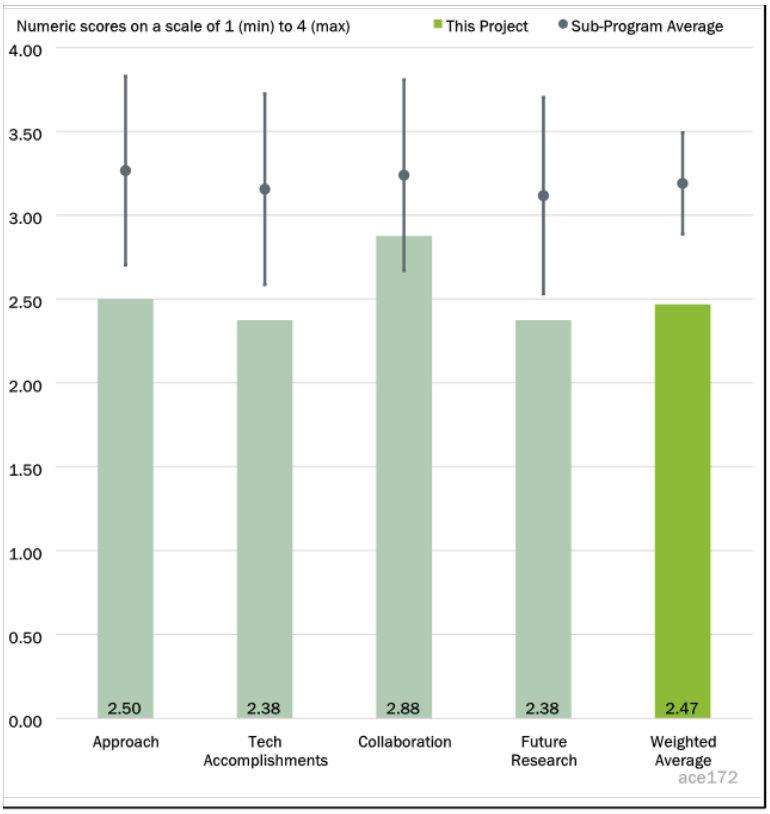

Figure 1-24 - Presentation Number: ace172 Presentation Title: Fast Simulation of Real Driving Emissions from Heavy-duty Diesel Vehicle Integrated with Advanced Aftertreatment System Principal Investigator: Hailin Li, West Virginia University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The technical barriers on modeling real world emissions are being addressed. The overall approach is well suited—however, the details on the work approach and how this effort improves the current state-of-the-art and how the current limitations with such models are being addressed were not clear.

Reviewer 2

The reviewer thinks it is disappointing that the project started in September 2021 and the team still does not have the final contracts signed at West Virginia University (WVU). This has definitely delayed the project. The overall project definition, as this reviewer sees it, is that the project will collect engine experimental data and then validate a CFD model for emissions and exhaust temperatures. This will then be ported into the GT-Power Model and aftertreatment model. The entire model will be validated and finally should have the capability of running a heavy-duty (HD) vehicle driving simulation. As far as this reviewer knows, OEMs are performing similar analysis today in different pieces. What this work does is pull everything together and should allow the overall model to be run in GT-Power. The GT-Power model would then assist OEMs in their models and help improve aftertreatment systems.

Reviewer 3

The reviewer would like to see more details on how the models will be developed/validated, and the expected level of accuracy/predictive-ness. Model robustness/predictive-ness should include a range of parameters, including hardware-based items (e.g., compression ratio, piston bowl shape, etc.) and/or controls-based items (e.g., injection timing/strategy, EGR rate, etc.). How (and when) the aftertreatment model switches between the simple and detailed approach would also be a good detail to share.

Reviewer 4

Bureaucracy and staff shortages at WVU are seemingly preventing this project from getting started. Some work has started.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

This project reviewed very early in the cycle. The full team meeting had not yet occurred at review time, but progress on models has already been made.

Reviewer 2

The contract is not officially signed, so not much progress has been made. The GT-Power models shown are pretty elementary and have not been exercised. In order to have a representative system, the project needs to identify every piece of the engine and this reviewer cannot tell if that has been done.

Reviewer 3

The project is only starting, so technical accomplishments are not really expected—yet. But this reviewer would have expected WVU to have processed the grant and all subs to be under contract. The fact this is not yet done is the reason for the "fair" score.

Reviewer 4

Some modelling work has started but the critical engine testing which will be used to correlate the models seems to be held up due to slow progress at WVU.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The participation of ORNL and ANL, along with Gamma, Converge and OEM Navistar and along with consulting supporting from Aramco and National Research Council-Canada (NRC-Canada), is a good project team with a breadth and depth of capabilities along with WVU to make this project happen. They need to cut through the red tape and get started.

Reviewer 2

The project has all the right partners to accomplish the project but not clear what each partner has contributed to date. Again, with the project not officially signed by WVU, it is hard to perform much work.

Reviewer 3

The reviewer thinks this is a strong team leveraging unique capabilities and expertise of the team members composed of industry (Gamma Technologies, Navistar who is providing the engine, and Aramco), a national laboratory (ORNL) and others—NRC-Canada. Specific contributions are noted.

It is very early in the project at this time for review, in terms of the reviewer being able to speak to the partner participation—the links between partners to note how collaborations will work was not clear.

Reviewer 4

Having the software providers and the national laboratories makes a strong team. The reviewer would like to understand better the OEM's role. The reviewer would like to see the OEM's comments/expectations on workflow (time and effort), and model predictive accuracy/run time. These will be key if this project is to have a real impact on the product/the market. What are the roles of Aramco and NRC-Canada?

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The project has a good end goal and the approach is straight forward. The reviewer would like to see more details on how to accomplish the goals.

Reviewer 2

The future work bullet points do represent the work required to complete the project to meet the defined goals. Details on the future work are lacking in the short presentation - model validation for low exhaust temperature and multi-injections were noted as the biggest challenges during the question and answer (Q&A) portion.

Reviewer 3

The basic plan elements are there, for development of a steady state model. It is unclear how / when vehicle level-transients will be handled - from both an experimental data gathering and a model calibration / verification perspective. On-road vehicle data will be great to have, but simple transients on engine dyno are likely very helpful as well - and not clearly shown. Also, what is meant by "Diesel engine optimization"? Is this hardware or calibration/controls?

Reviewer 4

A detailed workplan is needed. The overall scope is clear but a detailed step-by-step plan is needed, especially how the modelers will interface with testing.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

OEMs today are performing quite a bit of internal engine and aftertreatment models. Typically, they will run the CFD combustion model to obtain the emissions and exhaust temperatures and then use that as an input into the GT-Power aftertreatment model. This project would streamline the process and ideally allow the full simulation to be run in GT-Power. This would make it easier for the OEMs, but the reviewer is not sure it will

improve the current results. It would reduce the compilation time and overall lead to more efficient aftertreatment, which should lead to reduced fuel consumption.

Reviewer 2

The project supports the subprogram objectives of reducing NO_x emissions and aiming to optimize HD diesel engine and aftertreatment systems for overall reductions in CO_2 emissions.

Reviewer 3

The work is relevant. Having accurate tools for emissions performance and system optimization are needed.

Reviewer 4

This is a fundamentally valuable workstream. Correlated full system models are needed to shorten development times and optimize complex systems. The work steps are clear and well understood.

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

Reviewer 1

For what is proposed, the current resources should be sufficient to complete the project. There is some engine testing, which is expensive, but the rest is modeling and it appears there are sufficient funds to complete the modeling.

Reviewer 2

Resources seem sufficient for the project to achieve the stated milestones.

Reviewer 3

The reviewer would not increase the budget beyond what has already been allocated.

Reviewer 4

The reviewer thinks it is difficult to comment on if the resources are sufficient, because there were not many details given on the engine testing.

Presentation Number: ace173
Presentation Title: Comprehensive Integrated Simulation Methodology for Enabling Near-Zero Emission Heavy-Duty Vehicles
Principal Investigator: Andrea Strzelec, University of Wisconsin-Madison

Presenter

Andrea Strzelec, University of Wisconsin-Madison

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

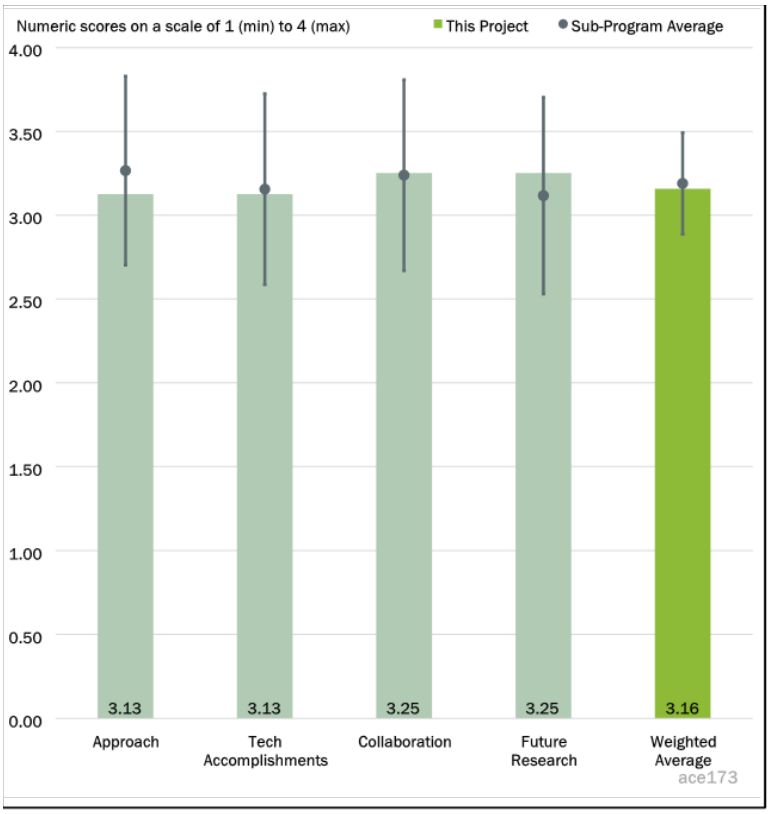

Figure 1-25 - Presentation Number: ace173 Presentation Title: Comprehensive Integrated Simulation Methodology for Enabling Near-Zero Emission Heavy-Duty Vehicles Principal Investigator: Andrea Strzelec, University of Wisconsin-Madison

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The barrier stated is that there is a lack of development models and simulation tools to predict engine and aftertreatment performance. There are some models in GT-Power but this research develops additional models for aftertreatment aging, advanced catalysts, and SCR spray breakup. Results will be used to improve the existing models and add the models that are currently not available.

Reviewer 2

It is a well-designed project to develop and validate an integrated reduced-dimensional engine, emissions, and aftertreatment system model capable of optimizing controls, thermal management, and insulation strategies while improving component conversion efficiencies to enable near-zero emissions and virtual real driving emissions. The timeline is reasonably planned.

Reviewer 3

This reviewer was pleased to see some description of the engine control variables to be explored (e.g., injection timing and EGR). The reviewer would like to see more description regarding what transient data are

being generated to support Milestone "Y1-2 -…and other transient variables in a compression ignition (CI) engine". Or will the model only be validated over steady state conditions? The reviewer hopes some level of transient operation is accounted for.

Reviewer 4

The project is reasonably planned and technical barriers are well addressed, especially in terms of the development of computational tools.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The project was initiated in fiscal year 2022 and the first two milestones have been completed. These include, first, the AT system model was calibrated under baseline data conditions. The second milestone improved the prediction emission quantities and other transient variables in the diesel engine. Progress seems satisfactory for the timeframe.

Reviewer 2

The project just started several months ago. The team calibrated the baseline AT system model and baseline combustion model. Other planned researches are on schedule.

Reviewer 3

Two baseline models were listed as complete, which is good. It would be even better to show some detailed proof about how well a given task was completed.

Reviewer 4

The project is on track based on the presented slides. It would have been useful to show some results from the Y1-2 milestone on Baseline Combustion model validation.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The project has the right partners for completing the project—Gamma Technologies for model assistance, ORNL for engine testing, FEV for engine testing and model development, Isuzu an OEM engine partner, Umicore for advanced aftertreatment, and Marathon for current and future fuel requirements. The project is in the early stages so it is not certain what each partner has contributed so far.

Reviewer 2

The project team includes a national laboratory, a university, an aftertreatment supplier, an energy company, an OEM, and a consulting company. Partners are full participants and well-coordinated.

Reviewer 3

There is a good list of capable partners, with a clear split of responsibilities.

Reviewer 4

The reviewer thinks this is a strong team of collaborators with clear roles and responsibilities defined. This is a good mix of university, national laboratory, and industry participation.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

This reviewer believes the project is very well laid out and has sufficient details to be carried out. The reviewer likes the fact that the plan includes revising the SCR aging model and integrating the SCR model into the GT-Suite. Another positive contribution is the prediction of the NH_3 and NO_x distribution maps at the catalyst inlet plane, and urea water spray mass histories. All the models (DOC, DPF, and SCR) will be integrated into GT-Suite. This would be beneficial to the engine OEMs and will lead to improved aftertreatment systems and improved fuel economy.

Reviewer 2

The proposed future researches are well planned and likely to achieve their targets.

Reviewer 3

The reviewer would like to see goals added to describe anticipated/expected model accuracy and run time. For model accuracy, the reviewer would like to see how it will be assessed—to be sure experimental data it is being compared to is different than that used to develop the model. Documentation of work flow, and effort, would be helpful as well.

Reviewer 4

Volume of fluid simulation outcomes may be heavily dependent on the internal of the injector flow. Developing ROM is a good idea, however, the team needs to ensure that the data used for developing such data driven models are reasonably validated and include enough upstream information.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The project targets reducing the time to develop an aftertreatment system, improving the aftertreatment system in terms of emissions and exhaust back pressure which will lead to lower overall fuel consumption, and addressing the VTO objectives.

Reviewer 2

The objective of the project is to develop an integrated simulation platform that can be used to design exhaust system architectures and control strategies that will meet future $ULNO_x$ emissions standards over the full useful life of an HD vehicle. It supports the overall VTO subprogram objectives.

Reviewer 3

Accurate models that operate on an engineering timescale are needed to meet future emissions regulations.

Reviewer 4

Yes, the project supports the overall VTO subprogram objectives.

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

Reviewer 1

Resources seem appropriate and they have the right partners to be successful.

Reviewer 2

The team has sufficient resources for this project and is likely to achieve the stated milestones in a timely fashion.

Reviewer 3

Resources are sufficient for the planned work.

Reviewer 4

The resources seem to be sufficient, although the budget table needs to be updated to correctly reflect the cost-share amounts.

Presentation Number: ace175
Presentation Title: Co-optimization of fuel physical/chemical properties and combustion system for mixing controlled compression ignition (MCCI) in a medium-duty engine
Principal Investigator: Flavio Chuahy, Oak Ridge National Laboratory

Presenter

Flavio Chuahy, ORNL

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 20% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

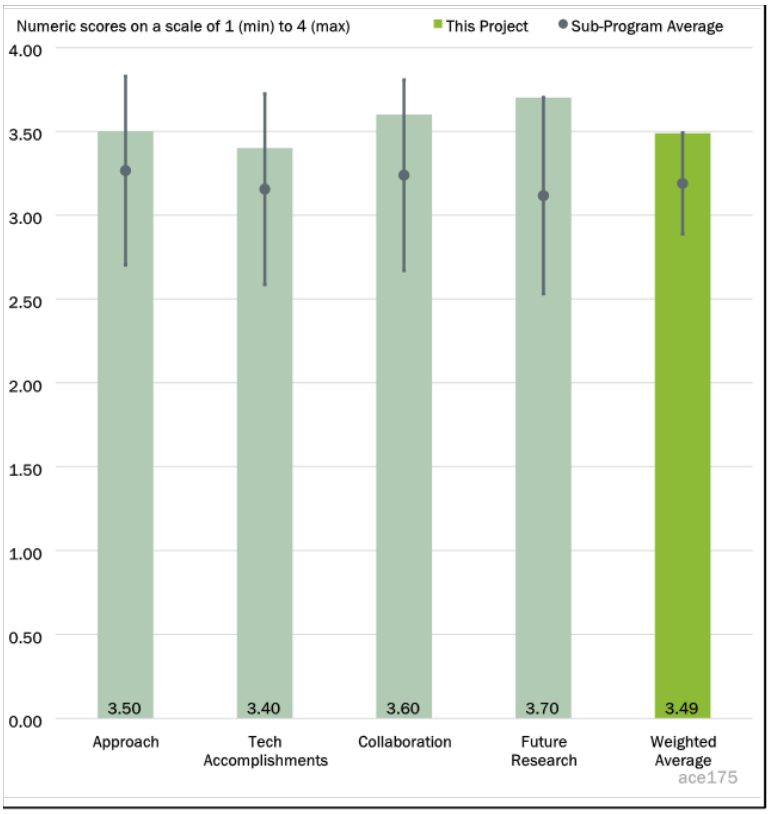

Figure 1-26 - Presentation Number: ace175 Presentation Title: Co-optimization of fuel physical/chemical properties and combustion system for mixing controlled compression ignition (MCCI) in a medium-duty engine Principal Investigator: Flavio Chuahy, Oak Ridge National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The work is the extension of the Co-Optima project and the SuperTruck II program. The idea is that better fuels will lead to better engines. A good portion of the background work has already been completed and the project will use extensive knowledge from Cummins engineers and their modeling expertise.

The program is only 5% complete but there is a good plan in place.

Reviewer 2

The project uses well-defined and validated simulation work to explore whether there may be opportunities to optimize a medium-duty (MD) diesel engine to operate on hydrotreated vegetable oil (HVO) fuel. HVO fuel will be a major portion of the MD decarbonization effort, so rational efforts to provide improvement to engine performance and emissions on this fuel will be most welcome.

However, the issue with HVO is generally not its suitability but its availability. It is not clear exactly what this project will uncover about HVO that will enhance its use in MD/HD engines. Were other fuel choices considered?

Reviewer 3

This project uses the combination of physical geometry adaptations in the piston bowl and injector along with injection strategy and fuel chemistry to improve engine efficiency and therefore reduce CO_2 emissions. The approach is well-designed to address the technical barriers using the fully coupled MD engine-fuel platform.

Reviewer 4

This being a simulation-only project and 18-month duration is very reasonably planned. The approach to setting up a CFD optimization process with geometric and operation condition variation is very good, and would allow for transfer to the partners for extended optimization at other conditions or use cases. Additionally, the use of past CFD model setups, expertise in the optimization and ML area from Lawrence Berkeley National Laboratory (LBNL), and OEM input from Cummins, is excellent. There was not enough time to go into the fuel property specification detail, but the reviewer does have a question as to how the HVO fuel properties will be constrained to what can actually be made or tailored within typical HVO production. Will you independently vary HVO physical and chemical properties to seek a unique optimum and then go back after and constrain, or will you constrain the properties initially in the upfront definition prior to CFD simulation?

Reviewer 5

HVO diesel is widely available in states like California. The use of HVO fuel does show lower NO_x and soot, and marginal reductions in CO_2 with no specific HVO calibrations. Fuel system optimization can definitely improve these benefits; however, the approach does not explain the interaction of other engine parameters such as EGR with the fuel system optimization. Does the ML-based optimization consider the influence of EGR?

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The project is 5% complete and the first milestone for defining the fuel properties, fuel system, and piston geometry ranges has been completed. It appears that Cummins will provide quite a bit of direction on the modeling which should enable sufficient progress on all the milestones.

Reviewer 2

This project is just getting started—5% completion for a less-than-three-month activity. Project progress is difficult to evaluate but the project plan and the partners involved have shown to be able to accomplish projects on-time in the past. At the moment, this is a difficult criterion to evaluate.

Reviewer 3

The project has just been approved on March 29th, 2022 so there has been very little time for technical progress. This being said, there are a clear approach and a clear objective laid out with reasonable deliverables and resources. It was a bit unclear as to what the soot modeling approach was going to be within the CFD simulations other than looking at PAH. The reviewer suggests to clearly define this soot work (reduced order, simple Hiroyasu-Nagle and Strickland-Constable), pre-tabulated, commercially available particulate mimic / particulate size mimic models in Converge, etc.). The soot prediction and optimization surrounding it should

be a very important aspect of the mixing controlled compression ignition (MCCI) optimization with a HVO that is more paraffinic and with less sooting tendency.

A final comment would be to include some thinking toward how the variation of the physical fuel properties may impact the internal flow of the fuel injection (cavitation potential increasing/decreasing), and therefore some potential changes in the injection rate shape.

Reviewer 4

Considering that the program was only approved at the end of March 2022, it is quite miraculous that the team has made any progress to date. This shows the benefit of the experienced team undertaking the work.

Reviewer 5

The project team is on schedule with their milestones, with completion of preliminary tasks associated with the definition of fuel property, fuel system, and piston geometry.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The collaboration between ORNL, Cummins, and LBNL is outstanding for a small project of this size and nature.

Reviewer 2

The collaborations in this project between an OEM and a national laboratory are outstanding. The addition of LBNL for the optimization algorithm is an excellent addition to the team. An addition of a HVO fuel supplier would be beneficial to the project.

Reviewer 3

Cummins appears to be providing significant input to the project and will help with the modeling optimization.

Reviewer 4

Because this is a CRADA, there are not many partners involved. Considering the modest budget, not many partners could be leveraged anyway. Cummins is certainly an excellent partner to have for work of this type. LBNL is also an excellent informal partner for the ML algorithm portion. However, there are no other participants or partners, whether university or otherwise. It would be helpful to have seen some university participation.

Reviewer 5

There is excellent coordination with the CRADA partner and good use of LBNL as an informal collaborator. The reviewer would have liked to see a university included to some extent.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Future milestones are well laid out and the schedule is quite aggressive but should be achievable.

Reviewer 2

The project has clearly defined goals and the strategy is very sound and appropriate. The simulations will explore the fuel physical and chemical property space, along with engine and injector geometry - to search for the optimization potential in a low carbon, commercially available fuel. The use of ML to speed up the algorithms and solution approaches, compared to genetic algorithm, is probably the most technically interesting portion of this project.

Reviewer 3

The project has just started and, since it was awarded, it was clearly deemed to be worthy of funding in a time where ICE R&D is pressured and lowered in priority.

Reviewer 4

Proposed future work is clearly defined for the remainder of the project—it looks like an aggressive timeline.

Reviewer 5

It is unclear about the future work-related optimization for conventional 45 cetane number diesel. Optimization and calibration of engine parameters for conventional diesel should be a task that has been widely performed by Cummins over the past decade to meet stringent NO_x and GHG regulations. How will this effort be different?

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The project is investigating improving combustion efficiency by identifying fuel properties to improve the combustion and increase engine efficiency. Another objective is to evaluate HVO which is a net low-carbon fuel. Both objectives are in line with VTO objectives.

Reviewer 2

This project is very relevant to help move the industry and ICE applications toward lower carbon sustainable fuels, such as HVO.

Reviewer 3

The reviewer said this project directly supports VTO objectives in reducing the carbon footprint for engines and potentially increasing efficiency. However, it would have been helpful to see more detail on how this project will enhance HVO use, when it is already well-known that HVO is an excellent drop-in fuel for diesel. It is unclear what additional fuel/combustion benefit will be gained in this project.

Reviewer 4

Optimization of engine fueling parameters for use of HVO diesel can help reduce the dependency on fossil fuel-based diesel.

Reviewer 5

Question 6:** This program supports the VTO subprogram objectives and keeps critical research on engines and fuels moving in a positive direction.* ***Resources: Are the resources sufficient for the project to achieve the stated milestones in a timely fashion?

Reviewer 1

They are insufficient—this critical research area is being woefully under-funded.

Reviewer 2

The resources seem sufficient for this simulation-only project and given ORNL's high-performance computing capability this reviewer had concerns on the ability to execute this project. The only lack of resources is one due to a lack of scope on the validation of the optimization. The reviewer encouraged additional funding and scope to test the produced MCCI combustion system and go back to validate the CFD predictions.

Reviewer 3

Resources are sufficient, based on the prior work that has already developed the baseline models and that are only being extended to the HVO fuel and extending the diesel fuel properties. Again, the support from Cummins will definitely improve the probable success of the project.

Reviewer 4

For a simulation project, the resources allocated should be sufficient to support progress toward the goals.

Reviewer 5

The resources provided by Cummins and LBNL are sufficient to complete the milestones of this project.

Presentation Number: ace177
Presentation Title: Independent Fuel Property Effects of Fuel Volatility on Low Temperature Heat Release and Fuel Autoignition
Principal Investigator: Sibendu Som, Argonne National Laboratory, and Jim Szybist, Oak Ridge National Laboratory

Presenter

Sibendu Som, ANL, and Jim Szybist, ORNL

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

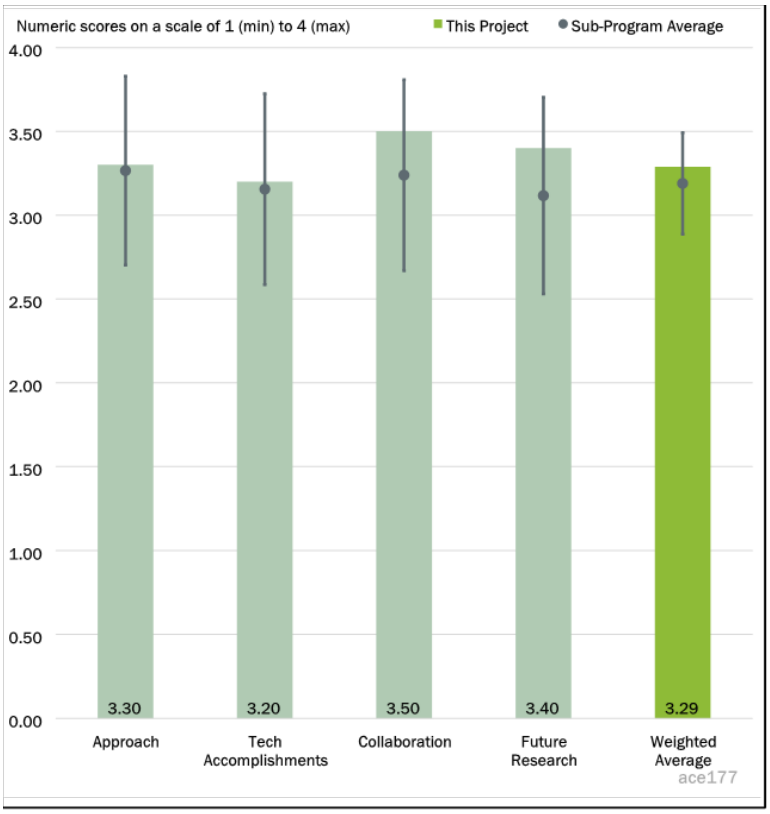

Figure 1-27 - Presentation Number: ace177 Presentation Title: Independent Fuel Property Effects of Fuel Volatility on Low Temperature Heat Release and Fuel Autoignition Principal Investigator: Sibendu Som, Argonne National Laboratory, and Jim Szybist, Oak Ridge National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

This is a new project and is just getting started. The approach follows on learnings from the Co-Optima program and seeks to explain an interesting subtlety of lower in-cylinder low temperature heat release (LTHR) behavior of fuels with the same research octane number (RON) and motor octane number (MON) but higher volatility. Using already established databases on the chemical composition differences during vaporization resulting from the azeotropic behavior of the higher volatility fuels, both experiments and simulations will be conducted for a matrix of fuels with known composition and volatility in an attempt to determine the reason of the observed differences in LTHR.

Reviewer 2

This work is well-designed to understand fuel effects on spark ignition (SI) combustion for boosted engines. A possible weakness, based upon the presentation material and questioning of the presenter, was that the work was claimed to be relevant to different combustion strategies / modes, but the presenter and the presentation material did not really expand well upon how exactly this would occur or be deduced. To say this differently,

to ensure that the work is relevant to a wide range of combustion strategies and modes, it is critical that the work span a range of pressure, temperature, and dilution conditions, with both fuel lean and residual gases used to achieve dilution -- and then the method for connecting the results to those combustion strategies and modes should be clearly explained. For example, how will the results be applicable to highly dilute SI engines, high expansion ratio SI engines, partially premixed compression ignition engines, etc.? Given previous work by the team members, there is little doubt that they can do this, but it just was not apparent from the material presented.

Additionally, while it clearly was well thought out, a bit more explanation behind the logic used for the fuel matrix would be helpful. (Why does it seem that the primary interaction that is being examined is aromatics with other compounds?)

Finally, a minor comment: while it is clear that the authors understand the phenomenon they are attempting to describe, this reviewer is not sure that the term azeotropic is being used correctly. (It has a very specific meaning which is not what the authors are intending to describe.)

Reviewer 3

The technical approach is well defined. It leverages the expertise of the project participants—Shell for fuel formulation, ORNL for combustion testing, and ANL for combustion simulations.

While the approach to investigate the impact of fuel volatility (vapor pressure) on LTHR and autoignition is well defined, it is not clear how the knowledge gained from this study will be applied. Perhaps the industry partner can help lay out the vision for utilizing the insights gained from this study to benefit boosted SI engines and/or HD advanced compression ignition (ACI) engines.

Reviewer 4

The project has a very specific goal and approach to achieve it. This is regarded as an effort for verification and validation of already developed capabilities and expertise for fuel modeling and in-cylinder combustion simulation with it. The reviewer wonders if any potential risk (e.g., model not reproducing the test results well) has been considered.

Reviewer 5

This study concerns developing an understanding of fuel property effects on engine performance. The project seeks to understand certain issues related to fuel volatility such as its effect on heat release rate and preferential vaporization associated with the highly multicomponent fuel systems. Here, the project incorporates several mixture blends (apparently surrogates) for 10% ethanol, 90% gasoline blend (E10).

The approach taken is to combine engine testing with detailed numerical modeling using fuels provided by Shell. This coordination is good. Somewhat lacking is a clear definition of ‘preferential vaporization’ (see below) that could guide the work to enable the PIs to work to monitoring and simulating.

It is unclear also if the engine tests are too system-level to resolve the influence of preferential vaporization (however the PIs define this term) on engine performance. It might be considered to include a more basic/simpler experimental configuration to first establish that preferential vaporization (according to the PIs’

definition) does occur for the fuel blends examined, and then to move to engine testing to determine if it is revealed in the data and its possible connection to LTHR.

The reviewer notes that in the ANL simulations please note the combustion kinetic mechanism being used and how it was validated. Also, since the Shell blends are comprised of several components, a discussion of the property database incorporated in the simulations would be appropriate.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

With the CRADA having been finalized in April 2022, the project is still in the initial stages. Consequently, the PIs have had a very limited opportunity to complete technical tasks thus far. As per the project timeline, the industry partner has completed designing the fuel matrix and fuel blending is in progress.

The project participants have an impressive track record of delivering high-quality data and analyses as evident from their prior contributions to the Co-Optima program. It is expected the PIs will leverage their expertise to further highlight the impact of fuel properties on enhancing combustion in modern engines. The results from this study and subsequent technical reviews are eagerly awaited.

Reviewer 2

This work is just starting, so this is difficult to evaluate.

Reviewer 3

The project is just starting so there are minimal technical accomplishments on which to comment. The program appears to be well thought out with cooperation between relevant stakeholders.

Reviewer 4

Because the project is fairly new, there is not too much of accomplishment to evaluate. The presenter mentioned that the number of fuels to be tested (and shown in the presentation) has been pushed back to Shell, due to too many variants. Is it because of the resource availability?

Reviewer 5

The outcome of this project is ostensibly to determine if preferential vaporization is responsible for suppression of LTHR in high volatility fuels. This is an important issue. However, from the information provided in the presentation, it was not clear precisely how the team defines this concept of ‘preferential vaporization’. What is the specific fuel property that would promote it? Is it fuel component boiling points? Heats of vaporization? And how is preferential vaporization revealed in the experimental results? That is, what specific metric in the engine test data would provide the evidence for its existence. It may be possible that the experimental output does not strongly suggest that one component dominates evaporation initially, then another and so forth. At the least, a clear definition of what is meant by ‘preferential vaporization’ should be offered and a discussion of how it is to be monitored provided.

The numerical modeling effort could provide insights into performance metrics that are inaccessible in the experiments. An example would be the internal distribution and evolution of mixture species in the liquid fuel as the components evaporate and ignite. Can the ANL modeling effort provide such a level of detail?

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

This is a good collaboration between two national laboratories and a fuels provider that leverages the expertise of each.

Reviewer 2

The reviewer noted well-aligned coordination.

Reviewer 3

Have the researchers considered interfacing with the United States Council for Automotive Research (USCAR) for comments on their approach? The program addresses fuels for spark ignition engines, so if successful these lower carbon fuels would be used mostly in the light duty legacy fleet. The auto industry might have good insight into whether technical challenges would be experienced in fueling legacy fleets with fuels of different volatility: once the reason for the sublet behavior is understood. Interaction with USCAR could inform the researchers if the changes in the fuels' volatility would be tolerable in the range of vehicles in the legacy fleet.

Reviewer 4

While the project is still in the early stages, in part due to the experience of the PIs and the industry partner having collaborated on studies in the past, the project appears to be off to a smooth start.

It is recognized that the objective of this project is to investigate the impact of vapor pressure on LTHR/autoignition and not to develop a production ready application/control strategy. However, the PIs and the industry partner are encouraged to discuss potential applications for implementing the insights gained from this study.

Reviewer 5

The work of the four groups appears to be well-coordinated as it combines numerical modeling (ANL) with engine testing (ORNL) and fuel blend preparation (Shell). The concern is, as noted previously, the extent to which the experiments can provide information to reveal preferential vaporization, or what one looks for in the simulation or experiments to evidence it.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The plan is good: some of the items mentioned above should be addressed in the plan, but overall the plan is good.

Reviewer 2

It is understood that as the project evolves, the future research needs may evolve as well. At present, the PIs have a well-defined plan for achieving the goals of the project with the roles and responsibilities of different teams clearly identified.

Reviewer 3

Again, there is a clear plan with milestones.

Reviewer 4

The planned activities seem to be more over-arching than detailed and specific, for example 'simulation of ORNL experimental measurements' (i.e., what specific variables will be simulated, what will be measured, what is the expected accuracy of the variables to be measured and under what operating conditions, and what is the strategy for closing the gap between simulation and engine testing if the agreement is not good?).

Reviewer 5

The experimental and computational program is well laid out. Do the researchers anticipate challenges in developing representative surrogate fuel compositions to accurately capture the volatility variations among the test fuels?

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

This project is aligned with DOE's goal of improving engine efficiency and identifying cost-effective high-performance fuels.

Reviewer 2

The project is aligned with the objectives to obtain better knowledge and to improve tools for higher efficiency engines to help decarbonization.

Reviewer 3

The project is relevant to DOE's interest from a broad perspective.

Reviewer 4

This program is very relevant to increasing efficiency, and so it supports the VTO objectives.

Reviewer 5

Because of the time required for the transition to an EV dominated mobility market, there will be combustion engines using liquid fuels for many decades to come. Reducing the GHG emissions of these vehicles via fuel modification will make a significant, integrated impact in GHG footprint reduction as we move toward the ultimate sustainable mobility system.

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

Reviewer 1

The team is highly capable and the resources are sufficient for project success.

Reviewer 2

The researchers made no comment about the adequacy of the resources. So, this reviewer assumes they are adequate.

Reviewer 3

The funding allocated for this project appears to be sufficient to complete the proposed work.

Reviewer 4

The reviewer thinks the project has sufficient resource allocation.

Reviewer 5

The resources seem adequate, though without more details of how the funds are spent it is not possible to adequately score this category. An ultimate judgement of costs comes from a cost/benefit analysis based on DOE's investment relative to the perceived value of what the PIs are pursuing.

Presentation Number: ace178
Presentation Title: Development Of Advanced Combustion Strategies for Direct Injection Heavy Duty Liquefied Petroleum Gas (LPG) Engines
Principal Investigator: Dan Olsen, Colorado State University

Presenter

Dan Olsen, Colorado State University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

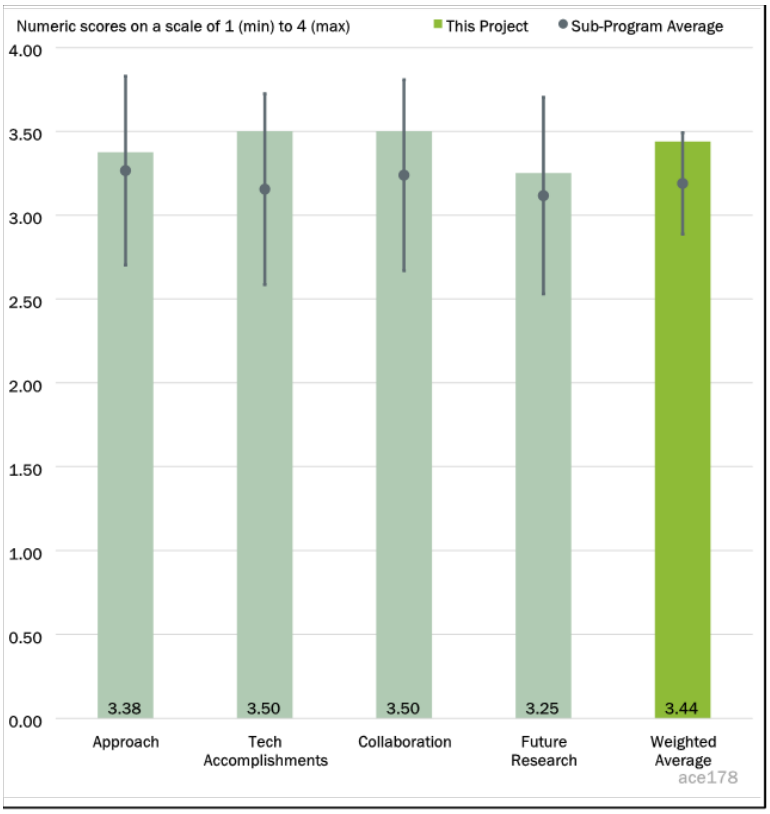

Figure 1-28 - Presentation Number: ace178 Presentation Title: Development Of Advanced Combustion Strategies for Direct Injection Heavy Duty Liquefied Petroleum Gas (LPG) Engines Principal Investigator: Dan Olsen, Colorado State University

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The objective of the project is to increase the peak efficiency of a 15-Liter liquified petroleum gas (LPG) engine to near-diesel efficiency. The project covers a fundamental LPG chemical kinetic study, spray research, and engine research. The timeline is reasonably planned.

Reviewer 2

The PIs understand the issues with operating a two-phase LPG engine and have tailored the objectives and plan to address them. The technical approach is impressive between the CFD modelling and the Schlieren imaging of the RCM combustion to determine the ignition effects of two-phase LPG sprays. Flame speed tracks extremely well between experiment and the model. The Schlieren images do show that the flame is not laminar. Modelling efforts to show fuel spray and knock are successful.

Did the PIs force the ignition with laser spark on the ignition delay timing plots? If so, does that explain some of the differences between the non-pure propane results?

Reviewer 3

This project has used chemical mechanism development, CFD model development, along with experimental studies (RCM, spray imaging, Cooperative Fuel Research (CFR) engine) to provide necessary fundamental understanding of LPG combustion and fuel spray for LPG engines to provide a pathway towards reaching 44% BTE. The timeline is properly planned.

Reviewer 4

The biggest technical barrier is the direct liquid injection and the team has been making efforts in achieving it. The issue is translating it into a system for a vehicle. In other words, for stationary engines or engines in test-cells, solutions with chillers will work. Translating this to real-world on-road applications will be a challenge. Nonetheless, a high flow injector, an electric lift pump, and a high-pressure pump are the way to go to enable direct injection (DI) liquid injection for propane.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The development of a high flow injection system for LPG is not an easy task. The researchers have done this without lubricity additives which is also impressive.

Reviewer 2

Overall, good progress has been made.

Some experimental investigations have been finished, including LPG ignition delay, flame propagation, spray visualization, and modeling. Good progress has been made on fuel injection visualization, development of the spray model with experimental validation, and CFR engine testing.

For the RCM ignition delay study, heat loss occurs for every experiment, and this needs to be corrected for in the model validation. The flame propagation in an RCM is not a laminar flame, thus the project needs to be careful when the data is used for flame speed validation.

Reviewer 3

The project enhanced the chemical kinetic mechanism for LPG combustion and the results for predicting ignition delay are experimentally validated against RCM ignition delay measurements. Another important accomplishment is the accurate modeling of two-phase LPG flow for high pressure direct injection, showing validations with varying reformed-exhaust gas recirculation % mass substitution conditions. A further important achievement is CFD model development and validation for combustion performance analysis and predicting heat release rate.

Reviewer 4

The team has performed very well and has accomplished the negotiated milestones so far. CFD analysis, chemistry mechanism development, and CFR engine testing have been completed. Port fuel injection testing is to commence and finally the DI testing will take place.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The collaboration between the industry partners, national laboratory, and Colorado State University is impressive. The quality of results from this project would not be as high if there was not such a high degree of collaboration.

Reviewer 2

Overall, the team did a good job in collaboration within the project team. For example, spray imaging was used to validate the spray model. Improvement can be made by better coordinating CFD and engine design. Also, it could be better to run the CFR engine at a compression ratio (CR) similar to the Cummins X15 single-cylinder engine (SCE).

Reviewer 3

The results presented show strong collaborative efforts among the industry partner (Cummins), the national laboratory (ANL), and academia (Colorado State University).

Reviewer 4

Excellent collaboration and this work is timely as Cummins is commercializing the propane B6.7 (6.7-Liter) engine.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Port injection and then DI is the way to go to reduce technical barriers. If success is found in port injection, this could also lead to a commercial solution.

Reviewer 2

Future research focuses on combustion strategy development, engine testing, and system optimization. What is the key contribution of the CFR engine experiments? Why not develop an advanced combustion engine using the X15 Cummins SCE directly? For Task 7 on System Optimization for Near-Diesel Efficiency on X15 SCE, it is not clear what will be optimized.

Reviewer 3

This project has a clear proposed pathway for future research to reach 44% BTE at peak torque.

Reviewer 4

A strong plan for injector modeling and hardware integration is considered. But the development of the combustion recipe to achieve near-diesel efficiency needs a more detailed plan.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

With the increased usage of HVO for renewable diesel and sustainable aviation fuel, there is an ever-increasing supply of renewable propane which is a byproduct of the process. This propane has a net zero carbon intensity (CI) score because the CI of the propane is applied to the renewable diesel. This allows for the usage of a net-zero carbon fuel in transportation. Once regulation catches up to the fuel and re-apportions the CI scores, it will still be a low-carbon low-emissions fuel. This is very relevant to current HD needs.

Reviewer 2

The objective of the project is to increase the peak efficiency of a 15-liter LPG engine to near-diesel efficiency. It supports the overall VTO subprogram objectives.

Reviewer 3

The project clearly supports VTO - Advanced Engine and Fuel Technologies objectives by increasing the peak torque efficiency to near-diesel brake thermal efficiency (44%); thus "generating the knowledge and insight necessary for industry to develop the next generation of engines for light-and heavy-duty vehicles."

Reviewer 4

Project is relevant to DOE goals for improving the technology and adoption of alternative fuel engines.

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

Reviewer 1

While there are sufficient funds at this time, the reviewer would recommend that the funding of the Decarbonization of Off-Road, Rail, Marine, and Aviation program (formerly Advanced Combustion Engines) be re-evaluated and possibly increased to 2022 levels. Research programs such as this are necessary for the transition to low carbon transportation.

Reviewer 2

The team has sufficient resources for this project. Key facilities, such as RCM, CFR, and high-speed Schlieren, were used for kinetic, spray visualization, and engine performance research. Cummins supports the design, fabrication, and delivery of the X15 SCE head, installation and commissioning. ANL supports the CFD modeling.

Reviewer 3

Adequate resources are available. Cummins' continuous involvement for different stages of the project for design, fabrication, and delivery of the X15 SCE LPG-DI head is very important.

Reviewer 4

Resources are sufficient to accomplish the remaining work elements.

Presentation Number: ace179
Presentation Title: Propane longstroke engine R&D
Principal Investigator: Derek Splitter, Oak Ridge National Laboratory

Presenter

Derek Splitter, ORNL

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers felt that the resources were sufficient, 33% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

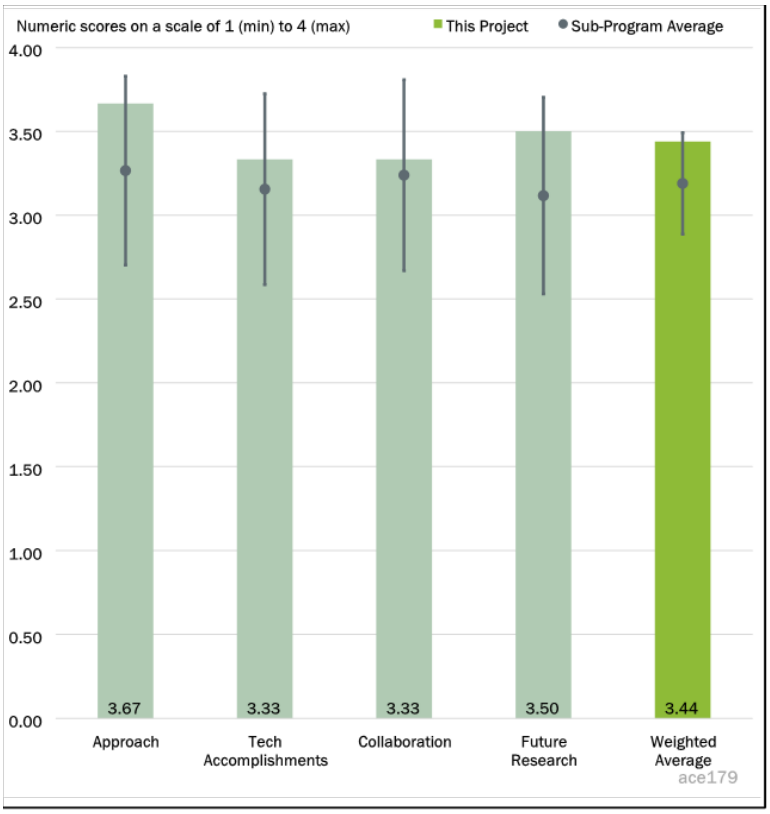

Figure 1-29 - Presentation Number: ace179 Presentation Title: Propane longstroke engine R&D Principal Investigator: Derek Splitter, Oak Ridge National Laboratory

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The project is very well designed and includes fundamental combustion kinetics, CFD analysis, SCE testing with the assistance of CFD-guided design, system-level simulation, and total cost of ownership/life cycle analysis (TCO/LCA). Overall, the timeline is reasonably planned.

Reviewer 2

The project provides a better understanding of the effectiveness of EGR to mitigate knock.

Reviewer 3

ORNL has performed a tremendous amount of work on the fundamental understanding of propane's robustness to EGR. In addition, the fundamental understanding of the ignition chemistry with the formation/dissociation of hydrogen peroxide is critical in understanding the behavior of these fuels with EGR. Currently, there are not many propane engines operating with EGR (the reviewer knows there are some from Zenith Power Products), but this project helps the propane industry in new product development. The reviewer would have liked to see the approach on direct liquid injection of propane, which was not shown at the AMR. This is one of the biggest barriers for commercialization.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The program is 30% complete to date. The delay is primarily due to the pandemic and supply chain delays, which is understandable.

The PIs did an excellent job in fundamental ignition simulation and conceptual understanding of dilution effects on flame and ignitions. Two-dimensional direct numerical simulation was used to understand the fundamentals of fuel properties enabling improved EGR tolerance. The team also made progress in developing the second-generation long-stroke engine.

Reviewer 2

The DNS results provide a fundamental understanding to explain why propane combustion is less affected with EGR changes. The Fast, Robust Engine Simulation Code (FRESCO) results provide experimentally validated CFD simulations for pressure traces.

Reviewer 3

The team was a bit behind on milestones but made up for it as acknowledged at the AMR. The project is proceeding as per plan.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The team is a good combination of a national laboratory, universities, and industry. So far, the team did a great job in coordinating tasks. For example, the chemical kinetics study supports the DNS and assists in developing sub-models for combustion system and engine design optimization.

Reviewer 2

The results presented show the collaborative efforts between team partners (e.g., Wisconsin Engine Research Consultants, Oakland University).

Reviewer 3

Katech should have a prominent role with the delivery of the DI system and this reviewer's concern is that no particular progress on Katech's development for the second-generation engine was presented at the AMR. As noted in Slide 16, "Katech–Sub recipient: Engine design integration for Gen 2 prototype" but this was not evident from the AMR presentation.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Future work includes a Gen 2 engine installation and experiments across a wide range of conditions demonstrating efficiency achievements; closing the loop on simulation results with Gen 2 engine validation, prediction, and optimization simulation; and life cycle and efficiency analysis against a diesel baseline engine. The team is likely to achieve the originally planned targets.

Reviewer 2

The reviewer said a clear path is presented for using the Gen 2 engine, and the design activities are planned.

Reviewer 3

The reviewer commented the proposed future work is in line with the objectives of the project. With diesel-like efficiencies with EGR, the TCO and LCA will clearly outline the value proposition of SI propane engines for the medium-duty market.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

This project will develop and demonstrate a propane-specific prototype single-cylinder advanced spark-ignition MD relevant engine that achieves diesel engine efficiency parity and shows pathways for dramatic engine efficiency increases. It supports the overall VTO subprogram objectives.

Reviewer 2

The project clearly supports VTO Advanced Engine and Fuel Technologies objectives.

Reviewer 3

This project advances the development and commercialization of alternatively fueled engines and is in line with DOE objectives.

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

Reviewer 1

ORNL could benefit with additional funds for a full experimental mapping of the long stroke engine. DOE should consider a total of $2 million federal investment for this project (i.e., an increase of $600,000 in funding for complete experimental evaluation).

Reviewer 2

The project was delayed by nine months due to the pandemic and supply chain issues. The reviewer is confident the team can catch up and achieve the target as planned.

Reviewer 3

Adequate resources are available and the collaboration with Stellantis would be helpful for the project support.

Presentation Number: ace182
Presentation Title: Fully Electric Powered, Hydraulic Assisted, Compact Track Loader
Principal Investigator: Perry Li, University of Minnesota

Presenter

Perry Li, University of Minnesota

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Project Relevance and Resources

86% of reviewers felt that the project was relevant to current DOE objectives, 14% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 86% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 14% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

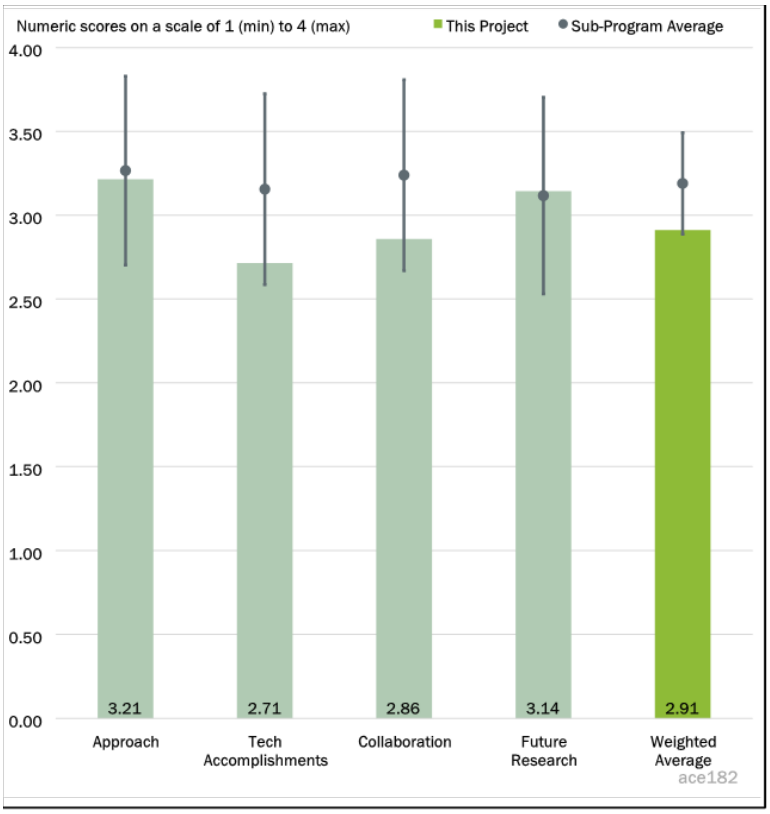

Figure 1-30 - Presentation Number: ace182 Presentation Title: Fully Electric Powered, Hydraulic Assisted, Compact Track Loader Principal Investigator: Perry Li, University of Minnesota

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The approach is very innovative and the timeline is reasonably planned. It leverages the advantages of both hydraulic (power dense) and electric (efficient) systems to design a highly efficient architecture with a battery size that is more pragmatic for off-road applications than traditional fully electric powered systems that will require high power electric machines. Well done!

Reviewer 2

The concept is unique and intriguing from the perspective of maximizing efficiency. This reviewer questions if the incremental gain achieved by adding the modulating motors/pumps will be worth the additional cost compared to just a multi-rail system without the additional pumps/motors. Hopefully the project will look at not only the efficiency gains, but will also look at the incremental cost and evaluate the ROI.

Reviewer 3

The project objective is to demonstrate a fully electric powered functional compact track loader using Hybrid Hydraulic-Electric Architecture. The goal is to decrease battery power requirements by 40%, thereby reducing the carbon footprint by 80% relative to a diesel-powered track loader. This is to be accomplished by using

small electric motors to drive individual pumps connected to a multi-rail system. This is a promising technology and the proposed technical approach is outstanding.

Reviewer 4

This project is brand new, but there are references to a previous project that the PI was conducting, which provides confidence in the approach and understanding. The concept is trying to utilize the "best of hydraulics and electrical components." The approach of getting the concept and simulation complete first and transitioning to an actual machine is very good. The timeline also seems reasonable.

The PI's statement that the project consumed ~$1,087,921 in fiscal year 2021 should be checked and corrected. The project did not start until February 2022.

Reviewer 5

The documented project scope and activities are well designed to target addressing the technical barriers identified. The timeline presented appears reasonable and the proposed progress of work and milestones demonstrates measured progress toward the overall project objectives.

Reviewer 6

This project does an excellent job of addressing the barriers of system efficiency, GHG emission, and the high cost of electrification by using a hybrid hydraulic-electric architecture that will maintain needed access to high power density actuation while reducing throttling losses. The project builds on results from a prior project. The project is well-designed and the timeline is well-planned.

Reviewer 7

The overall idea of using hydraulics on the propel for an electrified machine is not reasonable. The conclusion that a direct replacement of hydraulics on the rotary motion and its advantages in terms of efficiency has been well documented and researched. The timeline is very preliminary and very little details were shared; therefore, it is difficult to evaluate how reasonable it is.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The project has just recently started but appears to be off to a good start.

Reviewer 2

The project has been running since March and no progress was presented.

Reviewer 3

The project is at the initial phase but the proposed approach is fundamentally sound. The only suggestion for the project team to consider is that the proposed system architecture has three common pressure rails but they should also investigate how to optimize the number of common pressure rails since that will have significant implications on the system performance, cost and sound quality.

Reviewer 4

The progress on Slide 7 demonstrates a slow start to the project. Focus should be on team finalization and initiation of the activities identified for the current budget period as identified on Slide 7.

Reviewer 5

Not applicable as the project is at kickoff stage.

Reviewer 6

The project was just initiated so it is difficult to assess technical progress at this early stage. However, based on the results of the previous project, the team is well prepared to make progress toward the project goals.

Reviewer 7

Early to tell. Only 1% completed according to the PI. Previous work provides a good basis for this project.

Technical questions that the reviewer would like the PI to address: First, see how you are efficiently supplying multi-rails with one pump. It seems the key to the performance will be the "soft switching" valve. It will be interesting to understand the reasons for it and how to make this concept work smoothly. Was there a significant pressure ripple during the previous project study that led to a new concept? Second, define "input energy"—Is it the pump input energy of the baseline machine? Third, do you feel that the assumption that the machine spends an equal amount of energy on propulsion and the work circuit during operation is adequate? Perhaps the opportunity for efficiency improvements should be reconsidered. Recommendation: These machines perform many different tasks; the recommendation is to analyze a "composite work cycle" to understand overall energy savings. Fourth, is the engine efficiency only 25%?

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The reviewer said it appears to be a strong team with diverse backgrounds.

Reviewer 2

It was not explained how the partners collaborate and whether this is done on regular basis.

Reviewer 3

There is broad based collaboration across the project team between universities, OEM, and critical component suppliers. The roles and responsibilities as well as expected contributions of all the partners are well defined.

Reviewer 4

The identified partners/collaborators on Slide 8 are appropriate with defined roles and responsibilities. The slow start to the program may demonstrate that the collaborators are not well coordinated yet. Initial meeting cadence needs to be set and the collaborators need to be directed on initial activities to start executing the work plan.

Reviewer 5

The reviewer said not applicable as the project is at kickoff stage.

Reviewer 6

There is a set of five collaborators from a combination of university, OEM, and lead suppliers which brings a good set of resources to the project. Responsibilities of each party were outlined. The frequency of collaborator meetings and interactions should be described and provided to the reviewers.

Reviewer 7

There is no real understanding of collaboration by reading the presentation. The partners look very strong and in my opinion, they are capable to deliver on the assigned roles.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer suggests more emphasis on the cost and estimated ROI of additional hardware for the modulating pumps/motors.

Reviewer 2

The overall idea of using hydraulics on the propel for an electrified machine is not reasonable.

Reviewer 3

The project has clearly defined the relevance of the future work, which is likely to achieve its targets.

Reviewer 4

The proposed future research clearly outlines future steps (from modeling all the way to machine testing with the new concepts).

Reviewer 5

The future work defined on Slide 9 is well documented and has a clearly defined purpose. If executed, the future work defined should have a high likelihood of achieving the project objectives.

Reviewer 6

The plan to optimize the hydraulic system architecture for the demonstration rig, develop testbeds for control development, and select the soft switch valving concept for prototyping is logical and addresses the appropriate issues.

Reviewer 7

The project has just been initiated so most of the work is in the future. The purpose of the work has been defined. Based on the past history of the group, the project seems very likely to achieve its targets.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

This project is very relevant. The goals are consistent with DOE objectives and if successful could lead to significant fuel savings. This reviewer appreciates that this project is exploring new concepts/architectures as opposed to just an implementation project.

Reviewer 2

If the project team is successful in delivering the proposed energy savings, the solution will address a critical need in the off-road industry and support the overall VTO initiatives to decarbonize energy intensive industries as well as enable a net-zero agricultural sector.

Reviewer 3

The approach seems relevant for electrification and hydraulic system efficiency improvements. More detail would make it easier to assess, but a high-level statement of future work is relevant and aligned with OEM trends. The concept is trying to utilize "best of hydraulics and electrical components."

Reviewer 4

The project is directly working to improve the efficiency of the hydraulic-electric system on the machine and ties directly to system-level efficiency improvements.

Reviewer 5

A hybrid blend of hydraulic and electric architectures has the potential to improve hydraulic system efficiency and extend the range of battery powered off-highway vehicles, thereby supporting the VTO objective of decreasing GHG emissions.

Reviewer 6

Yes, this project investigates the potential Hybrid Hydraulic-Electric Architecture in reducing energy and emissions using electrification of a loader. The knowledge gained from this work will be extendable to other off-road vehicles.

Reviewer 7

The topic of electrified machines and their efficiency is very relevant; however, the technologies and approach presented on this project are not relevant.

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

Reviewer 1

The project brings together an excellent team combined with good DOE and partner resources that should enable the achievement of the stated milestones in a timely fashion.

Reviewer 2

The project appears to be well resourced.

Reviewer 3

The resources should be sufficient for the project team to achieve the stated milestones in a timely fashion.

Reviewer 4

It seems that the project has strong players and enough engagement from the team to get things done in a timely fashion (OEM, component suppliers, and two universities with the relevant experience in controls, hydraulics, and electric components).

Reviewer 5

The reviewer said the sufficient rating is an assumption that the project collaborators are assigning the proper resources to execute their responsibilities. The current state of the project and documentation included makes a data-based assessment of resources difficult.

Reviewer 6

The budget appears to be sufficient given the project scope, effort, and deliverables.

Reviewer 7

The amount of resources that have been provided to the previous project and the currently running project are excessive relative to the outcome and non-existent demonstration on a real machine.

Presentation Number: ace183
Presentation Title: Articulated Dump Truck (ADT) Electrification - Greenhouse Gas Reductions and Commercialization of New Technology
Principal Investigator: Brij Singh, John Deere

Presenter

Brij Singh, John Deere

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

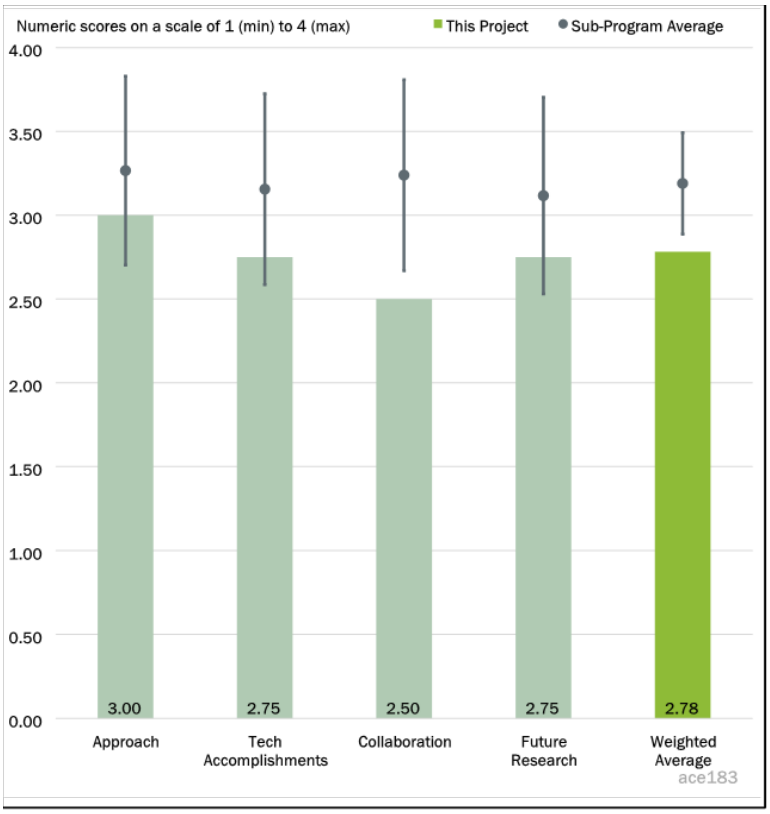

Figure 1-31 - Presentation Number: ace183 Presentation Title: Articulated Dump Truck (ADT) Electrification - Greenhouse Gas Reductions and Commercialization of New Technology Principal Investigator: Brij Singh, John Deere

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The project is fairly new but the approach presented is reasonable. The timeline is ambitious.

Reviewer 2

The approach is well balanced with its evaluation of technical and economic factors, and its comparison to an established production system.

Reviewer 3

The technical barriers are well addressed, and they are incorporated into the project goals/objectives. The principal investigator has a good grip on issues related to the dependency of the diesel-electric hybrid power train on the direct current/direct current (DC/DC) converter, soft-switch inverter and sizing of the lithium-ion (Li-ion) battery pack as well as on how the latest advances in materials science, such as silicon carbide (SiC), can improve converter and inverter components. The timeline seems reasonable but only the milestone schedule is given for year 1 of the three-year project. It would be better if the reviewer were able to see what accomplishments are planned for years 2 and 3 to gain confidence that the timeline is actually reasonable, exclusive of supply chain issues.

Diesel-electric hybrid powertrains already exist for railroad locomotives. The project should have been required to do an assessment of what technology can be transferred from existing diesel-electric hybrid powertrains and what cannot be transferred with reasons stating why in order to document lessons learned and to avoid the appearance of "re-inventing the wheel".

Reviewer 4

The reviewer identified as strengths the general approach appears sound including downsizing of the engine, adding an electric infinitely variable transmission and battery pack, and working to improve the technical performance of DC/DC converters and SiC inverter to meet project requirements. The project presents an approach to address the identified technical barriers of SiC inverters and SiC/Si DC/DC converters. Some details are provided on the technical specifics. The approach will leverage experiences from electrification of many vehicles in Deere.

The reviewer-only slides do discuss critical assumptions and issues and outline some alternatives with regards to soft-switched SiC inverters and SiC metal-oxide-semiconductor field-effect transistors (MOSFET)/Si MOSFET DC/DC converters. So, in a way, this is a targeted risk mitigation strategy. However, an overall project risk mitigation strategy has not been presented. If the identified requirements for the power electronics cannot be achieved, what is the fallback plan?

The reviewer identified as weakness as there is no mention of a preliminary cost analysis in Budget Period 1. A cost assessment appears to be put off until near the end of the project which is too late. No specific information is provided with regards to how cost reductions will be achieved to improve the odds the system will be commercially viable. For example, how can cost be captured / minimized upfront in the design process?

On the last slide for "Approach", no specific timeframes are provided for the "Fabrication, Testing, & Characterization of Components for the Diesel Electric Hybrid Powertrain" and "In-vehicle Integration of Diesel-Electric-Hybrid Powertrain and Technology Validation" tasks, including the Value Propositions. It can be surmised that these elements are proposed to be conducted late in Budget Period 2 or probably Budget Period 3. It would be beneficial if a preliminary analysis of these value propositions (i.e. fuel economy and system costs) could be conducted much earlier in the project (e.g., end of Budget Period 1). No specific milestones are provided past Budget Period 1.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

Difficult to evaluate due to the stage of the project.

Reviewer 2

The project was just initiated so there are no technical accomplishments to be manifested.

Reviewer 3

Given the project has not contractually started, technical progress should not be rated at this time. John Deere seems to have a clear understanding of their plan and ready to execute when the contract is signed.

Reviewer 4

This is a new project start and, as such, no specific technical accomplishments have been achieved. Some business-related activities such as brainstorming meetings and signings of confidentiality agreements have been conducted.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

Project roles and responsibilities appear to be well defined. This should result in excellent collaboration and coordination.

Reviewer 2

Difficult to evaluate due to the stage of the project. However, neither the presenter nor the presentation included any of the work breakdown and the responsibilities of each partner.

Reviewer 3

The partners include four internal divisions within John Deere and two academic institutions (i.e., North Carolina State University and University of Arkansas), so collaboration and coordination are extremely limited. It would be much better if a manufacturer or supplier of inverters and converters could be included on the project team so that the pragmatic expertise/experience of an important supplier could be taken into account.

Reviewer 4

As a new start, there is not much information to go on. However, the project appears to have initially established solid collaborations with two universities (North Carolina State University and University of Arkansas) for power electronics R&D. Given the criticality of power electronics advances to the success of the project, to mitigate risk it would be beneficial to explore further collaborations in this space including with other industrial firms.

It may also be beneficial to explore collaboration(s) with battery manufacturers, especially as the battery management system of the Li-ion battery pack has been identified as a critical issue.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Yes, the work has been clearly defined. Roles and responsibilities are clear and appropriate metrics are being used. Probability of project success is high.

Reviewer 2

All of the project is future work at this point.

Reviewer 3

This reviewer's evaluation of proposed future research is based on only the milestone schedule presented for year 1 of the project. As aforementioned, it would be better if the milestone schedules for years 2 and 3 were also available.

Reviewer 4

Not applicable as this is a new project. Discussion of upcoming work is discussed under Question 1 and 2 on "Approach to Performing the Work".

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

As stated, the proposed diesel-electric-hybrid powertrain will result in over 20% fuel savings in the pilot electric Articulated Dump Truck configuration. The technology is potentially modular and will have application in other vocational truck applications including many off-road vehicle platforms which will greatly enhance its potential energy and environmental benefits.

Reviewer 2

Electrification and architectures that are implementable and can be commercialized due to a reasonable TCO is key to the success of the VTO objectives.

Reviewer 3

It is hard to gauge the relevance of this project without some kind of independent, objective, background analysis to corroborate the alleged 20% fuel savings and reduction in 10,000 metric tons of greenhouse gases that will result from this project.

Otherwise, this particular project has relevancy to the categories of analysis, batteries, electrification, energy-efficient mobility systems and advances in materials.

Reviewer 4

This project addresses appropriate and pragmatic issues. Electrification will only be successful in fleet applications if it provides operators greater value than the vehicles they replace. This project is squarely focused on delivering fleet operators with greater value.

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

Reviewer 1

The outlined plan and resources seem reasonable.

Reviewer 2

The resources provided are reasonably sufficient for this project in light of the costs of SiC inverters, SiC converters and Li-ion battery packs as well as the dynamic modeling and re-design efforts.

Reviewer 3

There are appropriate resources based on the project plan.

Reviewer 4

The resources appear sufficient for the identified scope of the project. The project includes 25% contractor cost share.

Presentation Number: ace184
Presentation Title: Development of a Flex-Fuel Mixing Controlled Combustion System for Gasoline/Ethanol Blends Enabled by Prechamber Ignition
Principal Investigator: Adam Dempsey Marquette

Presenter

Adam Dempsey Marquette

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

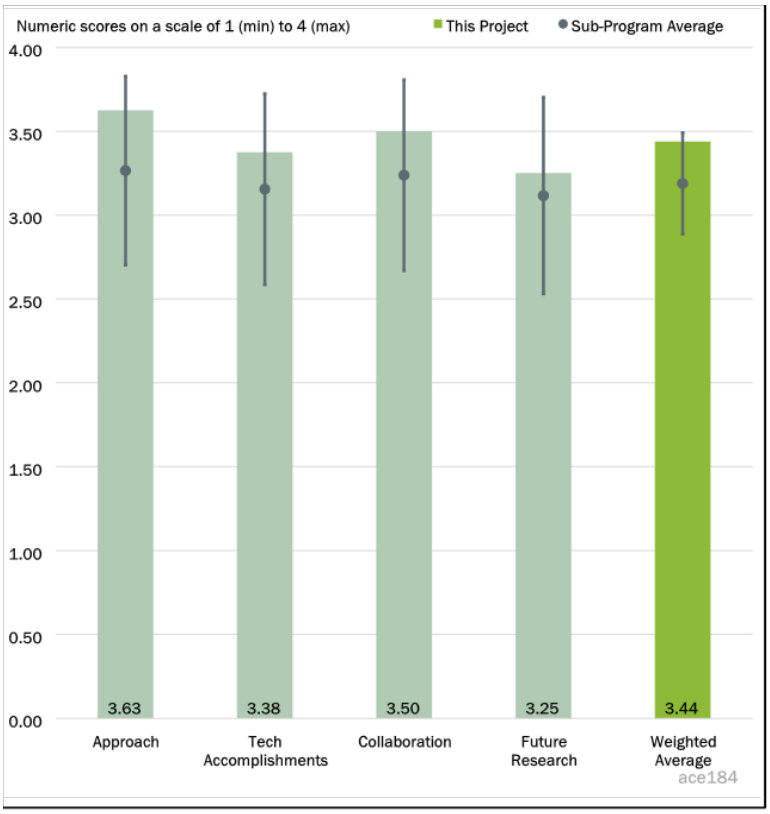

Figure 1-32 - Presentation Number: ace184 Presentation Title: Development of a Flex-Fuel Mixing Controlled Combustion System for Gasoline/Ethanol Blends Enabled by Prechamber Ignition Principal Investigator: Adam Dempsey Marquette

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

The approach should overcome most barriers. The proposed timeline appears reasonable.

Reviewer 2

The project is in initial phases and is on-track with respect to schedule.

Reviewer 3

This is a new project, so this reviewer's comments only encompass what has been planned and the organizational structure which has been set up which is just starting to operate. From that perspective it looks like it is off to a good start.

Reviewer 4

The overall approach is very sound with experiments and simulation. There is a good inclusion of fuel blendstocks for oxygenate blending (BOBs).

The reviewer suggests the project to consider showing the estimate of efficiency advantage of this system versus a traditional SI, high compression ratio engine. Also for maximum impact on CO_2 emissions reduction, the reviewer suggests to consider the use of a net-zero (renewable) gasoline or naphtha as the BOB, at least in a demo or conceptual activity.

Some mention of emission controls should be added, even if they are not needed. The reviewer suggests to consider a reference to prior work by Cummins on their 85% ethanol, 15% gasoline fuel blend (E85) engine of a few years ago, called "ETHOS".

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

The project is in early phases but is producing excellent technical progress in the RCM experiments and simulation. The reviewer appreciates the simplified CO_2 emissions analysis in the backup slides, Slide 17.

Reviewer 2

The results are very descriptive and the progress made since the project started is very good.

Reviewer 3

Since the project just began, only limited progress is expected at this point. The initial modeling looks good, and will be an important part of the project in establishing strong pre-chamber combustion.

Reviewer 4

The research group has established a good foundation by verifying the fundamental basis for the project. The team has done significant CFD analyses projecting the improvements in GHG reduction using the proposed Flex-Fuel Mixing Controlled Prechamber concept, have performed RCM experiments to assess the ignition delay and soot reduction potential of the concept, and have coordinated with their collaborators to establish proof of concept engine experiments and development of the multi-cylinder testing of the final configuration of the prechamber insert.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

The collaboration appears to be excellent, and referred to comments in Question 4.

Reviewer 2

The project looks to be well organized and has the potential to leverage the various strengths of its members.

Reviewer 3

The team is exceptional and has little room for improvement. Consider involving an organization engaged in "renewable gasoline" unless the project determines that 100% ethanol, 0% gasoline (E100) is the preferred path.

Reviewer 4

The reviewer thinks it is too early to assess collaboration and coordination across the project team.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The reviewer said future work has clear milestones.

Reviewer 2

There are a lot of design and control variables (in addition to various fuel mixtures) surrounding the pre-chamber—hopefully this can be managed. Perhaps some structured modeling (e.g., design of experiment) can help find 'best' approaches.

Full pre-chamber CI engines generally have lower efficiency due to increased heat losses. Please include efficiency measurements and comparisons as the work proceeds.

Reviewer 3

The project has a clearly defined sequence of tasks with go/no-go gates along the way. The reviewer would have liked to see more effort put on trying to make this approach retrofittable to existing engines. See Question 10.

Reviewer 4

Overall, the plan is well-formed. Including TCO analysis toward the end of project is highly valuable. The need or lack thereof for an aftertreatment study needs explanation.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

Use of low carbon fuels/biofuels is a strong near-, mid-term, and long-term contributor to CO_2 emissions reduction. Seeking high engine efficiency and low emissions is very important and relevant in this path.

Reviewer 2

This topic addresses an important challenge in the CI engine context—using low cetane fuels in diesel engines.

Reviewer 3

Increasing engine efficiency is a path towards decreasing emissions.

Reviewer 4

The work is relevant, but the reviewer has concern about its practical application. This is for off-road vehicles. If the project is successful and new engines are built, the vehicles in which they are installed will most likely be incorporated into legacy fleets, one piece of farming equipment among many other conventionally powered

pieces of equipment, for example. Would this cause logistic complications for the users? Now the user will have to have fueling infrastructure for legacy engines as well as for the new engines.

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

Reviewer 1

The resources appear to be good.

Reviewer 2

The presenter made no comment about being resource limited so the reviewer assumes the resources are sufficient.

Reviewer 3

Additional resources might be needed if a robust emission control system is needed.

Reviewer 4

It is difficult to discuss if resources are sufficient or not when the available funding across the DOE for the VTO ICE issues is so small.

Presentation Number: ace186
Presentation Title: Dynamic Skip Fire (DSF) on a Heavy-Duty Natural Gas Engine
Principal Investigator: Jay Shah, Cummins

Presenter

Jay Shah, Cummins

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 20% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

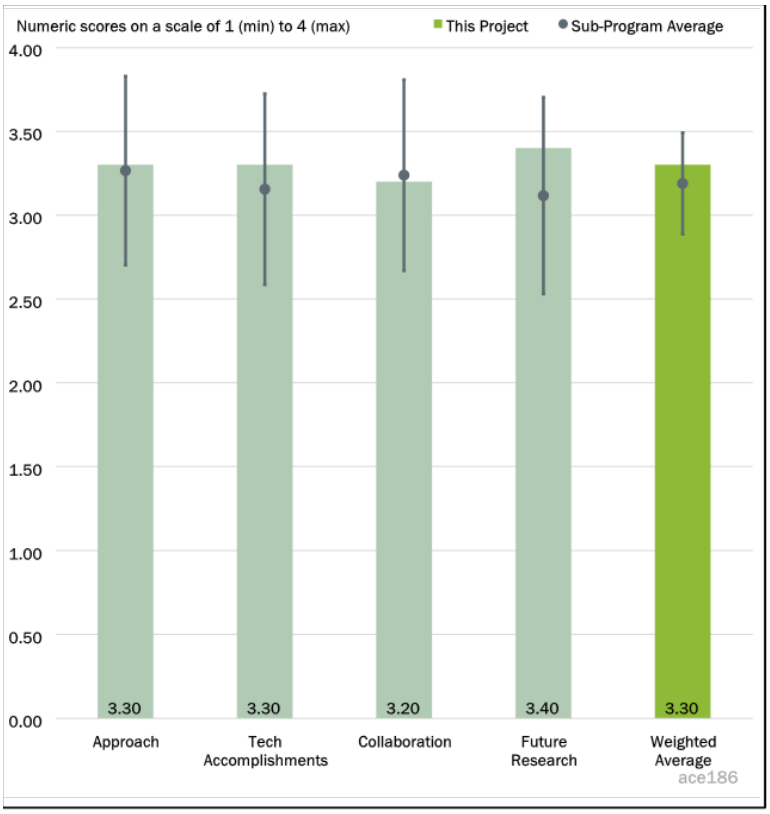

Figure 1-33 - Presentation Number: ace186 Presentation Title: Dynamic Skip Fire (DSF) on a Heavy-Duty Natural Gas Engine Principal Investigator: Jay Shah, Cummins

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

This is a well-designed project to apply dynamic skip fire (DSF) for a natural gas engine. The timeline is reasonably planned.

Reviewer 2

The DSF technology is a nice technology with proven, good results in SI engines and even some CI engines. Overall, the research is relevant to achieving efficiency with parity to diesel engines. However, the fuel efficiency benefits shown on Slide 2 are not huge, and may not be much if any greater than a "conventional" cylinder deactivation (CDA) approach, and the cost of the DSF system may not yield a favorable life-cycle cost. This needs a bit more investigation.

Reviewer 3

At a high level, the approach is appropriately defined.

Considering the vast scope of the project, the PI is encouraged to define the work plan in greater detail to ensure all milestones are achieved in a timely manner. For instance, a plan should be formulated for investigating some of the key technical challenges, including:

- Use of EGR: in view of the desire to operate at higher indicated mean effective pressure (IMEPs), EGR could be a key enabler for knock mitigation. Thus, it is important to ensure that appropriate levels of EGR are available at high IMEPs, especially when the DSF strategy is active. Based on the presentation it was not clear if EGR would be utilized when only one or two cylinders are firing.
- It is not clear if there is sufficient oil pressure to actuate the oil control valve at the lower engine speeds where this engine will often operate. If the oil pressure is insufficient, it may require the use of an auxiliary oil pump.
- Use of the two-stroke brake will cool down the TWC and potentially also make it oxygen rich. Based on the presentation it was not clear if this would adversely impact the ability of the TWC to meet the emissions targets.

Reviewer 4

This project is aligned with DOE's goal of reducing fuel consumption. In this case, the approach is to use natural gas engines that are able to meet future NO_x emission standards.

Overall, the technical barriers that are being overcome are relatively minor. There needed to be engineering work that integrated air brakes and DSF into the same engine, which had not been done before. However, DSF is, at this point, an established and proven technology that has been in production for several years with smaller engines. The biggest difference here seems to be that it is being applied to a larger engine.

Reviewer 5

The project currently focuses on the system integration of the CDA hardware to the engine. I believe the key technical barrier for a CDA system in a spark-ignition engine is going to be noise, vibration, and harshness (NVH) and oil consumption. The NVH evaluation seems to be only in the final phase with in-vehicle testing. The presentation does not mention if the NVH and oil consumption characteristics are going to be evaluated during the engine dyno phase where engine calibrations will be developed. The reviewer would encourage the addition of these factors into the engine dyno test phase if it is already not planned.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

Significant progress has been made with regards to designing the DSF valvetrain hardware into the engine, and combing that functionality with the engine braking technologies. Significant progress has also been made with the accompanying analysis on fuel savings with the technologies. There did not seem to be an extensive analysis of the emissions control catalyst, and the effect that the lean conditions and cooling would have on the catalyst performance. These conditions may not be part of some of the certification emissions cycles, but they will be part of the real-world emissions.

Reviewer 2

For a first-year project, the project's technical progress is excellent. The design of the overhead components is critical to this project and this important task has been completed. This reviewer would have expected some progress updates on the CDA hardware design. Is this task concurrently occurring with the overhead design or has this task not began yet?

Reviewer 3

The team has made excellent progress during the initial phases of the project. This has included simulation, hardware design, and controls development.

Reviewer 4

The project just kicked off a couple of months ago.

Reviewer 5

With the project having been kicked off a little over a month ago, the project team has not had sufficient time yet to make substantial progress yet.

In view of the short duration since project kick-off, completion of the valvetrain design indicated good progress and bodes well for the project.

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

Very good teaming with Tula who have pioneered DSF and applied it to several types of engines.

Reviewer 2

The project has only two team members (Cummins and Tula). Both companies have a long and extensive working relationship and they have continued their partnership in this project as well.

Reviewer 3

The team consists of Cummins, Tula, and NREL. Given the extensive experience of Tula in commercializing DSF and Cummins in natural gas engine development, the team has the capability to accomplish the proposed tasks.

Reviewer 4

While Tula is identified as the project partner responsible for DSF controls integration, key personnel from Tula or key tasks assigned to Tula are not clearly defined in the report. Consequently, Tula's role and responsibility is not clear. Similarly, the role of NREL personnel on the project team is not clear.

Considering the complexity of the project, successful execution will require extensive collaboration between all project partners. For future reviews, it may be helpful to define the roles and responsibilities of all project partners in greater detail.

Reviewer 5

The project is being led by Cummins, and Tula is a hardware and technology vendor partnering on the project. The fundamental technology that Tula is bringing to this engine project is well established and is in production

in smaller engines. The project team appears to be sufficient to perform the technical goals of the project, but there is no teaming with universities or diverse businesses or partners.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

Future work is well planned and likely to achieve its targets.

Reviewer 2

The remaining work for this engineering integration appears to be well planned and provides confidence that the result will be a fully functional prototype with integrated DSF technology.

Reviewer 3

The research plan is excellent and should result in improvements in fuel consumption in HD natural gas engines. Using RNG, these engines can contribute to the lowest CO_2 emissions of any HD freight propulsion system, along with their proven $ULNO_x$ ability. The reviewer suggests to check the cost effectiveness as work proceeds. The reviewer also suggests to check the emissions performance of the TWC with the skip fire impact on exhaust temperature.

Reviewer 4

The future research scope is well laid out. The project addresses all the important requirements such as hardware robustness demonstration and in-vehicle demo. It would help to identify some real-world challenges that may be observed with the CDA in natural gas engines.

Reviewer 5

The next steps, at least for the next one year, are clearly defined.

In view of the scale and complexity of this project, the project team is encouraged to develop a more detailed project plan to help ensure the various work streams are able to make progress in parallel. For instance, one of the deliverables for Budget Period 3 is a demo vehicle. This is a substantial undertaking and it may be beneficial to identify tasks in Budget Period 2, that may help with smooth execution of the vehicle build in the following budget period.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

Natural gas engines have been proven to achieve $ULNO_x$ and low PM and when using RNG can have zero or negative net carbon emissions. Hence the work here is highly relevant to extend RNG supplies by increasing ton-miles per diesel-gallon-equivalent (increased engine efficiency).

Reviewer 2

The objective is to design and develop DSF technology for HD natural gas engines to demonstrate a 6%-12% improvement in brake specific carbon dioxide emissions on low-loaded cycles while maintaining the capability to meet 0.02 g/hp-hr NO_x emissions. It supports the overall VTO subprogram objectives.

Reviewer 3

This project is aligned with DOE's goal of utilizing improvements in engine efficiency and utilization of alternative/low carbon fuels to improve vehicle efficiency and reduce greenhouse gas emissions.

Reviewer 4

This project supports the DOE mission to reduce fuel consumption, and does so in a direct way. The DSF is an established and proven technology to reduce fuel consumption at light loads, and does so within an acceptable NVH range.

Reviewer 5

The project is relevant in developing the next-generation high-efficiency, cleaner natural gas engines.

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

Reviewer 1

The funding for these projects should be reviewed and reassessed because of the general higher cost of everything in 2022. Funding may need increase to finish planned work.

Reviewer 2

Given the extensive experience of Tula in commercializing DSF and Cummins in natural gas engine development, the team has sufficient resources to achieve the stated milestones in a timely fashion.

Reviewer 3

Building prototype engines and demo vehicles is expensive. Thus, while the overall project budget appears to be significant, it is most likely reasonable.

Reviewer 4

Project resources appear to be sufficient.

Reviewer 5

An engine OEM and a Tier 1 controls development company are partners in this study. Both Cummins and Tula together have the technical expertise, manpower, and testing resources to complete this project successfully.

Presentation Number: ace187
Presentation Title: Opposed-Piston Two-Stroke Hybrid Commercial Vehicle System
Principal Investigator: Fabien Redon, Achates Power

Presenter

Fabien Redon, Achates Power

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 17% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

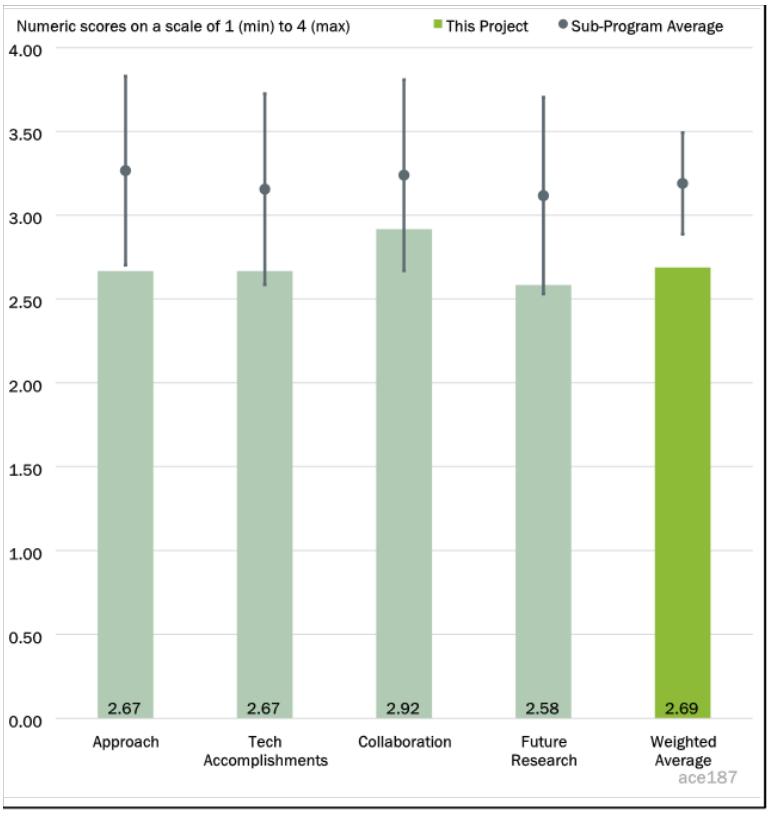

Figure 1-34 - Presentation Number: ace187 Presentation Title: Opposed-Piston Two-Stroke Hybrid Commercial Vehicle System Principal Investigator: Fabien Redon, Achates Power

Question 1: Approach to Performing the Work: Is the project well designed, and is the timeline reasonably planned?

Reviewer 1

An effective approach at addressing the barriers was presented that builds on improvements with hybridization with OP2S technology and the integration of H_2. The previous advancements that are being leveraged for this work as a starting point were well articulated. The objectives of the project are matched to the barriers and will have tangible outcomes.

Reviewer 2

The use of molecular H_2 has the potential to reduce GHG emissions (depending upon sourcing of the H_2). However, operating H_2 in compression ignition is a bit risky, in that there is not much work in the literature on this topic. Given the architecture of the OP2S engine, it is plausible to explore CI H_2.

However, hybridization of MD/HD trucks is fraught with challenge as well. If extensive emissions controls are needed - almost certainly with ULNO$_x$ - adding the NO$_x$ catalyst along with adding a complete high voltage electric system (600+V of direct current) will certainly add to the cost of the vehicle. The California Air Resources Board (CARB) and other regulatory agencies have stated that ICE solutions in vehicles will not count toward any ZEV requirement. The challenge in this project will be to balance performance and emissions with the cost of the vehicle. How much battery and electric drive are needed, how large is the

engine, and how much fuel will get consumed? The devil is truly in the details here, and not many details were presented in the slide deck or the Q&A session.

Reviewer 3

The timeline is reasonable based on recent past engine work on Achates Power's 10.6-liter two-stroke engine which sets the tone for this two-year project. This is a new start and not even the hybrid architecture has been chosen which will be one key component toward driving any fuel economy gains along with of course any engine system improvements. This project hopefully will demonstrate the possibility of an OP2S in a HEV powertrain to improve current state-of-the-art benchmarks by taking advantage of mid-load efficiency capability of OP2S engines in conjunction with strategic use of on-board energy storage. Further, exploring potential H_2 use will hopefully scratch the surface on alternative fuels use in OP2S engines.

Reviewer 4

There seem to be two sub-projects with two different sets of barriers included in this project.

The first sub-project is the commercial HEV. For this, the project seemed to focus on engine combustion improvements. There was not any information about the hybrid engine architecture. The reviewer assumes that this is a hybrid electric configuration, but there was not even that level of detail (for example, could it be hydraulic hybrid? Could it be pneumatic hybrid?). There was a stated goal of 13% fuel consumption reduction, but no indication of how. Hybrid integration work was a large part of the SuperTruck II programs, and that integration required a major effort. It would be helpful to understand what the targeted battery pack would be, targets from regenerative braking, etc. 13% is a very specific target, and while it is early in the project, there should be an initial plan in these regards to have given them the confidence that they could hit that target, even if the plan changes as the project progresses. So, the work and planning towards the hybrid architecture seems to be very thin at this point. Further, there seems to be a lot of effort centered around Achates collecting data from Achates' engine that was integrated into the Walmart truck. This reviewer understands a need to collect some additional/different data, but the reviewer asks if all of the steady state data should already be in-hand? Should they already have some/most of the transient data? Should they already have a powertrain and aftertreatment model since this has already been integrated in a prior project? This entire effort seems redundant to information they should already have.

The other sub-project that seems to be included here is the H_2 engine development project. There are no milestones that mention anything about a H_2 engine, nor is there any indication in the title of the project that this is related to a H_2 engine. That makes this reviewer wonder if the H_2 work was part of the initial scope of work, or if it was a part of the project that Achates added in later. There was no discussion in the presentation or in the slides about this, and whether this was a change in focus directed by DOE. There is no doubt that H_2 engines are of interest, especially in light of the DOE decarbonization focus. However, while all of the project milestones seem focused on the hybrid part of the project, a lot of resources appear to be focused on the H_2 part of the project. Completing just the hybridization effort in a thorough and rigorous manner that reflect real use cases will take a lot of effort, and that appears to be the original goal of this project based on the milestones.

Reviewer 5

This is a new project. The roles of the partners are not clear. The project is supposed be for hybrid commercial vehicles but there is not much discussion of the hybrid part of the work. The baseline vehicle is not a hybrid. It would have been great to have a hybrid vehicle to test as a baseline.

Reviewer 6

It is recognized that the project is just getting started, so plans may be in development. The vision and details of the hybrid powertrain are not adequate to fully assess the path. Overall, the approaches of hybrid power and low-carbon fuels are on the path to support VTO objectives.

Question 2: Technical Accomplishments and Progress: Comments on the technical progress that has been made compared to project plan.

Reviewer 1

This is a new start project which makes progress assessment difficult. But, the project is out of the gates fast based on past 10.6-Liter testing.

Reviewer 2

The project is only 10% complete, so it is difficult to evaluate progress. The plan and the partners appear to be sound, although some additional detail as to the level of hybridization that is planned to be explored would have been helpful.

Reviewer 3

This project is being reviewed early in the project cycle with a March 2022 start date. The H_2 CI approach selection and the collection of steady-state and transient data are underway.

Reviewer 4

This specific project is in a very early phase, although the technology in general has received support from DOE for many years. The improvement in efficiency noted over the previous, 10.6-liter opposed piston HD engine is good progress. However, the BSFC and CO_2 data should be compared to the state-of-the-art diesel engines, not just previous OP2S engines. The reviewer recommends showing fuel consumption and CO_2 data in comparison to EPA certification data for commercial engines of similar size. Most of the technical achievements are yet to come.

Reviewer 5

This is a new project.

Reviewer 6

In some regards, it is difficult to fully grasp the scope of the project plan because of the two different projects being merged into the single project, and this project is just getting started.

The technical accomplishments associated with the hybridization effort are minimal. This was limited to engine improvements (aftertreatment, air system, and friction). There was not any discussion of the hybridization approach, operating strategies, etc. There was no discussion of what the target battery size would

be, if it would enable downsizing, or how it would affect the engine operating duty cycle. This reviewer understands that Clemson University will be doing some of this work, but their approach was not covered. It seems that there should have been a lot of prior existing steady state and transient data for the project team to work with, considering that this is an Achates engine and they performed the vehicle integration, and that there should already be a powertrain and aftertreatment model as a starting point. There should be technical accomplishments that can be made immediately without having to spend resources reinventing these data and modeling tools.

In contrast, there were three accomplishment slides associated with H_2 engines. Again, there is nothing in the milestones about a H_2 engine and this reviewer is wondering if it was part of the original scope as it is not in the title or milestones. There seems to be a lot of effort, both ongoing and planned, focused on H_2. The future work indicated that two different versions of H_2 single cylinder engines will be built and there will be a lot of testing. What project resources will be left to address the main hybridization focus of the project?

Question 3: Collaboration and Coordination Across Project Team: Are there specific contributions made by industry, national laboratories, or other external entities? Are there areas where more collaboration is needed?

Reviewer 1

This team looks to be well-suited to perform the tasks to which each partner is assigned. There is a good combination of industry and university partners. Each partner has clearly defined roles and responsibilities.

Reviewer 2

This is a solid team assembled with clear indications of partner coordination and specific contributions with industry and universities leveraging signature strengths of each. It is not clear which partners will be responsible for the specific tasks in the proposed future research and how the collaboration will enhance that work. Specifically, it was not clear what exactly the Clemson University and Isuzu roles were. University of Wisconsin's roles were provided verbally.

Reviewer 3

The partners to Achates are highly capable and the roles are included in the presentation. Whether the partners contributed to the data in this presentation was not very clear. This can be easily improved. There is apparently a broad working group on opposed piston H_2 engines involving more partners. The reviewer may have missed that, if mentioned. It does not seem to be in the slides. The reviewer suggests to consider clarifying at a future opportunity.

Reviewer 4

It is not clear what each partner does. Slide 11 describes some of it but there needs to be more linkage to the previous slides when the approach is explained. Moreover, what University of Wisconsin is doing for this project seems to be exactly the same as they did with the same team on ACE166. How is their role different for this project?

Reviewer 5

Again, this is a new start, but the tasks of the university partners are very clear and it appears early on that activities have begun in H_2 combustion and vehicle system modeling and simulation.

Reviewer 6

There is a collaboration team consisting of Achates, Clemson University, University of Wisconsin, and Isuzu. The team appears to have a good working relationship and good delineation of responsibilities. This appears to be the same research team associated with the other DOE project being led by Achates, including the same PIs at each organization, so it is somewhat disappointing that the team was not altered to help separate responsibilities and to bring in different skill sets needed for hybridization. This team seems to be heavy on engine and vehicle systems expertise, and light on hybridization and electrification expertise. The reviewer would have preferred to see some additional expertise on batteries, power electronics, electric machines, and controls included. If those skill sets are represented by the teams, it did not come across during the presentation, and it does not appear to be a team with the deep expertise of electrification needed for a hybridization project.

Question 4: Proposed Future Research: Has the project clearly defined a purpose for future work? To what extent will future work likely achieve its targets?

Reviewer 1

The plan addresses most of the technical barriers and challenges. However, it would have been preferable to see Isuzu play a more active role in the hybridization portion of the project, since they actually make vehicles and would be in a position to evaluate the effectiveness of the hybrid system. The big challenge in this project is initiation and control of H_2 combustion in a CI system. There simply is not much work done here and the risk is fairly significant for such a system to not work as intended. A bit more detail on a mitigation strategy if H_2 CI fails would have been prudent.

Reviewer 2

It is not clear which partners will be responsible for the specific tasks in the proposed future research and how the collaboration will enhance that work.

Reviewer 3

The overall approach is okay, but is short on details. It appears that the hybrid system work is mostly simulation, which is a rather soft outcome. The H_2 combustion work will be interesting.

Reviewer 4

The future work feels like more of engine research rather than an engine for a HEV research. It would be good to have more emphasis on the hybrid portion of the drivetrain, too.

Reviewer 5

The proposed future research is focused on addressing project barriers and objectives. It includes a combination of simulation to develop a single cylinder engine H_2 combustion system, controls development for performing engine-in-the-loop HEV powertrain assessment, and eventual single cylinder engine testing for real world H_2 assessment. One key part of the project is the HEV powertrain assessment and thus it will be critical that the vehicle OEM ensures realistic assumptions are made during the vehicle model development portion of the project. Overall, based on funding level and timing this is an aggressive project that will give a decent initial OP2S-HEV powertrain assessment.

Reviewer 6

There is a lot of effort on areas where this reviewer does not think there should be effort, and too little effort on other areas.

Regarding the collection of engine and aftertreatment data, the team should have an extensive amount of data and baseline models that they could use as a starting point. The reviewer can certainly see the need for some additional data or model refinements, but there appears to be too much effort to collect data and build models that should already exist in some form.

Regarding the H_2 engine, there are no milestones about a H_2 engine, making this reviewer wonder if it was part of the original project. The future work includes designing and procuring a H_2 combustion system for a single cylinder engine in both Fiscal Year 2022 and Fiscal Year 2023, testing the H_2 engine to make H_2 combustion models, and using the H_2 engines to refine the combustion model. There are also major costs involved in installing a H_2 engine. Considering that this will take major resources and there are no milestones associated with it, this reviewer wonders if there will be sufficient resources left to do the hybridization work.

Finally, too few of the elements of the proposed work were focused on the hybridization effort and meeting the hybridization milestones.

Question 5: Relevance: Does the project support the overall VTO subprogram objectives?

Reviewer 1

The project is relevant because it addresses ULNO$_x$, GHG and vehicle efficiency improvement.

Reviewer 2

The project is well suited to decarbonization goals and freight efficiency goals.

Reviewer 3

The primary relevance is the assessment of whether a zero-carbon fuel is compatible with this engine configuration.

Reviewer 4

The project is relevant but needs to show more hybrid work.

Reviewer 5

Yes, it supports VTO objectives toward improving heavy vehicle fuel economy while meeting emission standards. Exploring the OP2S fuel consumption characteristics at medium load coupled with likely a mild parallel hybrid should directly address VTO objectives from an R&D perspective.

Reviewer 6

Yes, both hybridization and H_2 engines are relevant to the VTO subprogram objectives associated with reducing fuel consumption and decarbonization.

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

Reviewer 1

The resources appear to be sufficient to ensure the successful outcome of this project.

Reviewer 2

Total project funding seems sufficient to meet the goals considering previous advancements being leveraged as a starting point.

Reviewer 3

The project would benefit from clearly showing the annual accomplishments made with various annual resources.

Reviewer 4

This is a small project in reference to expectations. It appears there are sufficient resources to make an O2PS-HEV assessment though such an effort could realistically require further funding as experimental work gets underway.

Reviewer 5

It appears to this reviewer that there were enough resources allocated to this project to launch a H_2 engine development project inside of this project, even though the title and the milestones are not related to H_2. A H_2 engine development program takes a lot of resources, and if this was done with funds for this project, the funding was excessive.

Reviewer 6

University of Wisconsin seems to be doing the exact same thing they did for ACE166. The difference needs to be explained.

Acronyms and Abbreviations

21CTP	21st Century Truck Partnership
3-D	Three-dimensional
ACE	Advanced Combustion Engines
ACI	Advanced compression ignition
AMR	Annual Merit Review
ANL	Argonne National Laboratory
BEV	Battery-electric vehicle
BOB	Blendstocks for oxygenate blending
BP	Budget Period
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CARB	California Air Resources Board
CDA	Cylinder deactivation
Ce	Cerium
CeO_2	Ceria
CFD	Computational fluid dynamics
CFR	Cooperative Fuel Research
CI	Carbon intensity
CI	Compression-ignition
CO	Carbon monoxide
CO_2	Carbon dioxide
COVID-19	Coronavirus disease 2019
CRADA	Cooperative research and development agreement
CRT	Continuously regenerating trap
CS	Cooled spray
CT	Computerized tomography
Cu	Copper
DC/DC	Direct current/direct current
DFI	Ducted fuel injection
DI	Direct injection
DME	Dimethyl ether

DNS	Direct numerical simulation
DOC	Diesel oxidation catalyst
DOCF	Combined diesel oxidation catalyst and diesel particulate filter
DOE	U.S. Department of Energy
DPF	Diesel particulate filter
DPF	Diesel particulate filter
DRIFTS	Diffuse reflectance infrared Fourier transform microscopy
DSF	Dynamic skip-fire
E10	10% ethanol, 90% gasoline fuel blend
E100	100% ethanol, 0% gasoline fuel blend
E85	85% ethanol, 15% gasoline fuel blend
EERE	Office of Energy Efficiency and Renewable Energy
EGR	Exhaust gas recirculation
EPA	U.S. Environmental Protection Agency
EPR	Electron paramagnetic resonance spectroscopy
FOA	Funding opportunity announcement
FRESCO	Fast, Robust Engine Simulation Code
FTE	Freight-ton efficiency
FTIR	Fourier-transform infrared spectroscopy
FTP	Federal Test Procedure
FY	Fiscal Year
g	Grams
g/hp-hr	Gram per horsepower-hour
GHG	Greenhouse gas
GM	General Motors
GT-Power	Gamma Technologies - Power
H_2	Hydrogen
HC	Hydrocarbon
HD	Heavy-duty
HEV	Hybrid electric vehicle
HIL	Hardware-in-the-loop
HVAC	Heating, ventilation, and air conditioning

HVO	Hydrotreated vegetable oil
ICE	Internal combustion engine
IMEP	Indicated mean effective pressure
ITE	Indicated thermal efficiency
L	Liter
lb	Pound
LBNL	Lawrence Berkeley National Laboratory
LCA	Life-cycle analysis
LES	Large eddy simulation
Li-ion	Lithium-ion
LLCF	Low life-cycle carbon fuels
LO	Light-off
LPG	Liquified petroleum gas
LTHR	Low temperature heat release
LTP	Low-temperature plasma
MD	Medium-duty
ML	Machine learning
MON	Motor octane number
MTU	Michigan Technical University
N_2O	Nitrous oxide
NH_3	Ammonia
NO	Nitric oxide (nitrogen monoxide)
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NRC-Canada	National Research Council-Canada
NREL	National Renewable Energy Laboratory
NVH	Noise, vibration, and harshness
O	Atomic oxygen
OEM	Original equipment manufacturer
OP2S	Opposed piston two-stroke
ORNL	Oak Ridge National Laboratory
PAH	Polycyclic aromatic hydrocarbon

Pd	Palladium
PEC	Pareto-efficient combustion
PFR	Plasma flow reactor
PGM	Platinum group metals
PI	Principal investigator
PI	Principal Investigator
PM	Particulate matter
PNNL	Pacific Northwest National Laboratory
PRF	Primary reference fuels
Q&A	Question and answer
R&D	Research and development
RANS	Reynolds-averaged Navier-Stokes
RCM	Rapid compression machine
RDD&D	Research, development, deployment, and demonstration
Rh	Rhodium
RNG	Renewable natural gas
ROI	Return on investment
RON	Research octane number
rpm	Revolutions per minute
RWA	Real-world aging
SAC	Single-atom catalyst (catalysis)
SAE	Society of Automotive Engineers
SCE	Single-cylinder engine
SCR	Selective catalytic reduction
SCRF	Selective catalytic reduction on filter
SET	Supplemental Emissions Test
SI	Spark ignition
SiC	Silicon carbide
SNL	Sandia National Laboratories
SO_x	Sulfur oxides
SwRI	Southwest Research Institute
TCO	Total cost of ownership

TWC	Three-way catalyst
U.S. DRIVE	United States Driving Research and Innovation for Vehicle efficiency and Energy sustainability
UCONN	University of Connecticut
$ULNO_x$	Ultra-Low Nitrogen Oxides
UNM	University of New Mexico
USCAR	United States Council for Automotive Research
UW	University of Wisconsin
V	Volt
VTO	Vehicle Technologies Office
WHR	Waste heat recovery
WSU	Washington State University
WVU	West Virginia University
ZEV	Zero-emission vehicle

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