

Review of the 21st Century Truck Partnership Third Report

About a quarter of the petroleum used by on-road vehicles in the U.S. transportation sector every year is consumed by Medium and Heavy Duty Vehicles (MHDVs), with about 70 percent of that fuel powering Class 6 and Class 8 heavy duty freight trucks with diesel engines. While light-duty vehicles are expected to consume less fuel and produce fewer emissions in the coming decades as a result of technological advances and new regulations, fuel consumption by MHDVs is projected to increase substantially as demand for freight transportation and shipping rises to match the growing economy. As the government moves to issue fuel consumption and emissions regulations for MHDVs, federal agencies play an increasingly important role in the development of technologies to help the private sector achieve these policy goals while helping U.S. firms remain competitive in international markets. The 21st Century Truck Partnership (21CTP) brings together federal agencies and industry partners to coordinate research aimed at reducing fuel consumption and emissions in MHDVs while ensuring the next generation of these vehicles will be both safe and cost effective. *Review of the 21st Century Truck Partnership, Third Report* is the third independent review of the 21CTP conducted for the U.S. Department of Energy's Vehicle Technologies Office (DOE's VTO) by the National Academies of Sciences, Engineering, and Medicine, with two previous reports issued in 2008 and 2012.

Although the 21CTP is not a traditional centrally directed program with a single authority over budgets and priorities, the 21 CTP has made good headway in improving coordination and collaboration among the partners and documenting its associated projects and budgets. Since the second report in 2012, the Partnership has made impressive technical progress in some areas and has produced several noteworthy fuel-saving advancements through the process of fully integrating multiple technologies in SuperTruck demonstration vehicles. The engine systems goal of a 50 percent engine brake thermal efficiency (BTE) has been achieved. The SuperTruck projects have also demonstrated significant fuel consumption reductions through engine efficiency improvements and by reducing the overall power demands of the vehicle through advances in aerodynamics, rolling resistance, and weight reduction. The report recommends that the 21CTP continue to support vehicle integration projects like SuperTruck while making an effort to both standardize performance testing between prototypes and use currently existing trucks to research additional technologies.

MANAGEMENT STRATEGY AND PRIORITY SETTING

Formed in 2000, the 21CTP is a cooperative research and development (R&D) initiative between four federal agencies — DOE, DoT, DoD, and EPA — and 15 industrial partners with the



*500 kW Dynamometer with Diesel Engine-Under-Test in ORNL VSI Laboratory with Truck Outline Overlay.
Source: Smith et al. (2014)*

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goal of reducing the fuel consumption and emissions of MH-DVs. The 21CTP plays an important role by bringing together government agencies, national laboratories, and the private sector to exchange information and coordinate ongoing activities in a normally fragmented trucking industry. Through this government-industry collaboration, the 21CTP aims to avoid duplication of R&D efforts, identify industry needs, and help companies develop products that can be commercially deployed to meet future fuel consumption and emissions standards.

Unlike a traditional program with central control and responsibility for budgets and priorities, the 21CTP is a virtual organization coordinated by the DOE's VTO using a relatively flat and informal management structure, where the responsibility for each individual project rests with its funding institution. This structure is necessitated by the separate reporting and budgeting mechanisms for each agency. Under DOE leadership, the 21CTP has responded positively to prior Academies' recommendations to improve this virtual management structure by keeping a better inventory of current 21CTP projects and working to improve coordination between partner agencies. To make the 21CTP even more effective:

- The 21CTP should develop criteria for including projects under the 21CTP umbrella and work to tie those projects into specific 21CTP goals.
- In some areas, research funding has not been commensurate with well-defined goals. In some cases, e.g., efficient operations, funding is virtually non-existent.
- The EPA, DoT, and DoD should appoint a dedicated counterpart to the DOE's designated 21CTP leader.
- The DOE should publish a brief annual report on 21CTP accomplishments to help Congress and the public understand the work and scope of the Partnership.

ENGINE SYSTEMS

"Engine Systems" comprise the engine, the aftertreatment, and the fuel as an interlinked system. Research to improve engine systems is of central importance as the 21CTP seeks to improve thermal efficiency and safety while reducing petroleum dependency, emissions, and cost. Although diesel engines used in new trucks are among the most efficient and clean on-road transportation power plants available today, there are still opportunities for making them better. The 21CTP Engine Systems program is well managed and incorporates a closely coordinated set of research activities with the goal of better understanding the processes critical to efficient engine operation. The SuperTruck engine projects in particular were instrumental in achieving the 21CTP's first goal of a 50 percent BTE for an emissions compliant engine, and in carrying out the research to define a path to reaching its second

goal of a 55 percent BTE. Federal funding for the SuperTruck projects for diesel engine systems R&D to achieve 50 and 55 percent BTE amounts to about \$51.6 million.

RECOMMENDATION: The fundamental diesel engine research program pursuing advanced technologies and combustion processes and engine architectures to achieve 55 percent BTE should continue to be a focus of the 21CTP engine activities. However, the experiments and modeling should maintain a focus on dynamometer R&D, as opposed to attempting to build a demonstration vehicle. The achievement of this goal should be extended from 2015 to 2020 in order to have sufficient time to carry out R&D on this stretch goal.

Aftertreatment

The research agenda for 21CTP is focused on a wide diversity of heavy-duty emissions control work. There are impressive fundamental studies on selective catalytic reduction (SCR) catalysts, diesel particulate filter (DPF) fundamentals, low-temperature SCR and oxidation catalysts, passive NO_x adsorbents, multi-functional components, emissions measurement and modeling, system models, fuel effects, aging, and sensor development. These programs are delivering valuable results, but there are no program goals to guide future directions. The DOE should develop specific aftertreatment goals for the 21CTP. These goals will serve as a focal point for researchers to submit proposals and for the DOE to assess them.

RECOMMENDATION: The Partnership should continue to fund work on improved SCR NO_x efficiency (mainly low temperature without compromising high temperature efficiency) and aging and poisoning effects. California's and, potentially EPA's, move toward further heavy-duty NO_x reductions to meet National Ambient Air Quality Standards for ozone will be critical.

RECOMMENDATION: Technologies such as an SCR catalyst on a DPF or others that have the potential to reduce the volume, weight, and cost of the aftertreatment system should be a part of the program to develop a 55 percent BTE engine.

Fuels

The DOE should continue to explore how the United States might use its abundant petroleum, natural gas, and biofuel resources in the most efficient manner. The DOE has identified Fuels for Advanced Combustion Engines (FACE) that should be used to determine the fuel properties needed to improve efficiency and reduce greenhouse gas emissions for various advanced combustion engines. FACE and a common set of surrogate fuels should be utilized by all DOE facilities involved in combustion research programs in order to provide consistent fuel characteristics when evaluating laboratory experiments and engine test results.

HYBRID VEHICLES

Hybrid systems have demonstrated significant fuel consumption and emissions reductions in a number of MHDV applications, but cost effectiveness has been a barrier faced by many of today's hybrid drive manufacturers. As fuel consumption and emissions standards become more stringent, however, there is a need for 21CTP to support the development of advanced technologies such as battery-electric and hybrid drives that will help meet these goals.

Several manufacturers have commercialized medium-duty hybrid trucks and successfully demonstrated their ability to significantly reduce fuel consumption and emissions, particularly in vehicles with duty-cycles that include frequent stops and starts such as urban transit buses, refuse trucks, and city delivery trucks. However, while the demand for hybrid buses and trucks is growing in parts of China and Europe where concern about air pollution is high, the low cost of conventional fuels and the disappearance of federal financial incentives have made it more difficult for hybrid MHDVs to succeed in North America. The 21CTP has the opportunity to apply its resources to achieve long-term objectives that could significantly affect the prospects for U.S.-based manufacturers in future domestic and international markets for hybrid MHDVs.

Heavy-duty Class 8 long-haul trucks present a particularly challenging target for hybrid powertrain equipment. The large majority of Class 8 long-haul trucks travel long distances without stopping, preventing these vehicles from taking advantage of the hybrid drive's special ability to recover energy from frequent stops and starts. Nevertheless, the fact that the total fuel consumption of Class 8 long-haul trucks is higher than that of any other MHDV type means that even small percentage reductions in fuel consumption can yield impressively large total reductions in fuel use and emissions.

RECOMMENDATION: Recognizing the advantages that hybridization can offer in trucks, 21CTP should support the development of new technology that offers promise for significantly improving the performance and cost-effectiveness of hybrid truck technology in the longer term. This future work should take advantage of technology advances originally made and commercialized for light-duty vehicles, including new battery technologies as well as opportunities for integrated micro-electrification of truck functions such as start/stop operation, idle reduction, waste heat recovery, engine starting, and accessory electrification.

The SuperTruck project results show a limited potential benefit on long haul duty cycles for hybrid systems using currently available technology. Much of the benefit of a hybrid system can be captured with much less expensive and heavy alternatives, such as a GPS-based cruise control that uses the vehicle as

a kinetic energy storage device. Microhybrid systems enabling smart control of auxiliary power demand, possibly combined with limited energy storage to handle auxiliary or hotel loads, may prove to be a more promising hybrid approach for long haul trucks.

RECOMMENDATION: The 21CTP hybrid team is encouraged to use this opportunity to redefine its mission in a manner that will lead to vehicle efficiency and emissions reduction improvements via a range of technology options, including promising opportunities for electrification and other types of innovative drivetrain improvements.

The cost of hybrid drive equipment is not likely to fall sufficiently fast to meet commercially acceptable cost/benefit ratios in the near future. However, the demonstrated long-term benefits of hybridization for reducing fuel consumption and emissions in several types of MHDVs are too large to ignore despite the cost barriers. More stringent fuel consumption and emissions standards for MHDVs are now being developed by the federal government for the years beyond MY 2018, making it important for the 21CTP to develop technology that will help meet those goals and provide support to help develop standardized certification procedures for future hybrid vehicles.

RECOMMENDATION: 21CTP should make it a priority to encourage EPA and NHTSA to accelerate their efforts to strengthen and finalize procedures for certifying the fuel consumption and emissions of hybrid MHDVs, including procedures for chassis dynamometer testing of complete hybrid vehicles and dynamometer testing of hybrid propulsion drivetrains alone.

SAFETY

Although the 21CTP focuses on the development of technologies to reduce fuel consumption, an important consideration in the development of any vehicle technology is to maintain or improve safety for the driver and other motorists. The 21CTP identifies collision warning and avoidance systems as an area of research that has a potentially high-payback with regard to improving safety. Technology currently on the market could help reduce fatalities involving tractor-trailers by 24 percent, and data suggests that next generation versions of these systems will bring even greater benefits.

SUPERTRUCK PROGRAM

A major component of the 21CTP in recent years has been the SuperTruck initiative, which supports four teams that are separately developing prototype Class 8 tractor-trailer trucks that incorporate a suite of fuel-saving technologies including high efficiency engines, lightweight materials, aerodynamic improvements, and idle reduction. The four SuperTruck teams are Cummins-Peterbilt, Daimler Trucks North America, Navis-

tar, and Volvo Technology of North America. The SuperTruck projects are supported through government-industry cost-sharing contracts that each last about five years. The total budget for the four projects is about \$284 million. The American Recovery and Reinvestment Act of 2009 (the Stimulus) provided federal funding of about \$86 million to two of the teams.

The SuperTruck program uses a total systems approach to evaluating and demonstrating candidate technologies through stringent real-world vehicle tests. Funding for the SuperTruck program has proved fully justified, as the program is a great success and has driven technology development at a faster pace than industry would have achieved on its own. By combining technologies that had never been tested on a complete vehicle before, the SuperTruck teams were able to improve fuel efficiency while identifying the challenges that must be overcome to make new technologies cost effective.

The two teams that have finished their vehicle demonstrations have produced results substantially better than the targets called for in the SuperTruck contracts. Both teams reached the 50% engine brake thermal efficiency (BTE) target, but they went well beyond the goals for overall freight efficiency (freight ton-miles per gallon) improvement. Using the results to date, about 26 to 44 percent of the total vehicle savings are due to engine efficiency improvements, while about 56 to 74 percent are due to vehicle power demand reduction (i.e. aerodynamics, rolling resistance, friction, weight, transmissions). Competition among the teams has driven them to go well beyond the contract requirements, and the remaining two teams have plans to match or exceed their program goals by the time their projects conclude in 2015 and 2016.

RECOMMENDATION: The SuperTruck demonstration vehicles represent a huge investment. DOE should consider ways of

extracting additional research results from this investment by using the trucks that have been built to evaluate additional technologies.

As the four SuperTruck projects conclude, it is not too soon to develop proposals to build on their momentum and success, and prioritize the next set of objectives in a future resource-constrained environment.

RECOMMENDATION: Because of the great value demonstrated by the SuperTruck program, DOE should be working on at least one vehicle integration project at any given time. Owing to likely funding limitations, it will not be possible to have three or four similar projects running. A range of integration projects are possible, including these: (1) A regional haul SuperTruck, (2) A heavy-duty vocational SuperTruck (refuse, dump, etc.), (3) A SuperTrailer program to help trailer manufacturers build engineering capability, (4) A delivery truck of Class 3, 4, 5, or 6.

While the outstanding fuel savings achieved by the SuperTruck program are impressive, not all technologies incorporated into the prototypes would be cost effective in an actual production vehicle. The SuperTruck platforms include technologies with a wide range of production readiness, from some going into production soon, to some that may not be cost effective unless fuel prices increase substantially. Moreover, directly comparing the results between the four SuperTruck vehicles has proved difficult, because each SuperTruck project was allowed to select different baseline vehicles and test routes.

RECOMMENDATION: Any future system integration program with more than one team should entail performance testing on identical duty cycles, so that differences in the performance of specific technologies can be better understood.

COMMITTEE TO REVIEW THE 21ST CENTURY TRUCK PARTNERSHIP, PHASE 3: John H. Johnson, Michigan Technological University, *Chair*; Julie Chen, University of Massachusetts-Lowell; David Foster, University of Wisconsin Engine Research Center; Thomas M. Jahns, NAE, University of Wisconsin-Madison; Timothy V. Johnson, Corning Incorporated; Paul Menig, Tech-I.M.; James W. Morris, Volvo Powertrain NA (retired); Thomas Reinhart, Southwest Research Institute; Bernard Robertson, NAE, Chrysler Corporation (retired); Subhash C. Singhal, NAE, Pacific Northwest National Laboratory (retired); James A. Spearot, Mountain Ridgeline Consulting, LLC; Kathleen Taylor, NAE, General Motors Corporation (retired); John Woodrooffe, University of Michigan Transportation Institute

STAFF: James J. Zucchetto, Senior Program Officer/Director, Study Director; Dana Caines, Financial Manager; Linda Casola, Senior Program Assistant; Elizabeth Euller, Program Assistant; LaNita Jones, Administrative Coordinator; E. Jonathan Yanger, Research Associate

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