FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

NEXT-GENERATION ENERGY TECHNOLOGIES FOR CONNECTED AND AUTOMATED ON-ROAD VEHICLES (NEXTCAR)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001564
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	April 12, 2016
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, May 17, 2016
Submission Deadline for Concept Papers:	5 PM ET, May 24, 2016
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	5 PM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	TBD
Total Amount to Be Awarded	Approximately $30 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

- Applications found to be noncompliant or nonresponsive will not be merit reviewed or considered for award. For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 and III.C.2 of the FOA.

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REQUIRED DOCUMENTS CHECKLIST

For an overview of the application process, see Section IV.A of the FOA.

For guidance regarding requisite application forms, see Section IV.B of the FOA.

For guidance regarding the content and form of Concept Papers, Full Applications, and Replies to Reviewer Comments, see Sections IV.C, IV.D, and IV.E of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: o Concept Summary o Innovation o Proposed Work o Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, May 24, 2016
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
(i) reductions of imports of energy from foreign sources;
(ii) reductions of energy-related emissions, including greenhouse gases; and
(iii) improvement in the energy efficiency of all economic sectors; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E issues this Funding Opportunity Announcement (FOA) under the programmatic authorizing statute codified at 42 U.S.C. § 16538. The FOA and any awards made under this FOA are subject to 2 C.F.R. Part 200 as amended by 2 C.F.R. Part 910.

ARPA-E funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" and defines "development" as the "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."[1] Applicants interested in receiving financial assistance for basic research should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E Applicants and Awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on the improvement of existing technology platforms along defined roadmaps may be appropriate for support through the DOE offices such as: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy (http://fossil.energy.gov/), the Office of Nuclear Energy (http://nuclear.energy.gov/), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

1. SUMMARY

The ARPA-E NEXT-Generation Energy Technologies for Connected and Automated on-Road Vehicles (NEXTCAR) Program seeks to fund the development of new and emerging vehicle dynamic and powertrain (VD&PT) control technologies that can reduce the energy consumption of future vehicles through the use of connectivity and vehicle automation. Potential vehicle energy improvement technologies may include, but are not limited to, advanced technologies and concepts relating to full vehicle dynamic control, powertrain control, improved vehicle and powertrain operation through the automation of vehicle dynamics control functions, and improved control and optimization facilitated by connectivity. These improvements will include the reduction of the fuel and/or energy consumed by future individual vehicles undergoing either human operation or semi- or fully-automated operation, either in isolation or in

[1] OMB Circular A-11 (http://www.whitehouse.gov/sites/default/files/omb/assets/a11_current_year/a11_2014.pdf), Section 84, p. 8.

cooperation with other vehicles. Vehicle connectivity and automated operation hold significant promise to improve safety by reducing vehicle accidents and traffic fatalities in the US, but the full energy efficiency improvements enabled by the adoption of these technologies have not yet been tapped. Reducing the energy intensity of automotive transportation aligns directly with the ARPA-E mission areas of reducing energy imports, improving the efficiency of energy usage and reducing energy-related emissions, while promoting US innovation and competitiveness.

The NEXTCAR Program seeks to fund the development of new VD&PT control technologies for reducing the energy (or fuel) consumption of Light-Duty (LD), Medium-Duty (MD) and Heavy-Duty (HD) on-road vehicles. Future fuel and emissions standards such as Corporate Average Fuel Economy (CAFE) standards[2] for LD vehicles and NHTSA/EPA Phase 2 fuel efficiency and GHG emissions standards[2] for MD and HD vehicles will require substantial fuel efficiency improvements in the vehicle fleet. (*An explanation of a number of the terms, concepts and acronyms that will be used in this FOA is given in Appendix 1)*.

A large portion of future expected fuel efficiency improvements for all LD, MD and HD vehicles will be achieved through the commercialization and implementation of a mix of well-established fuel efficiency technologies, including engine downsizing and boosting, vehicle light-weighting, aerodynamic improvements, rolling resistance reduction, engine efficiency improvements, waste heat recovery, auxiliary and parasitic load reduction, electrification and hybridization. Vehicle fuel economy testing for regulatory purposes does not yet adequately take into account real-world (or "off-cycle") driving behavior or the potential efficiency advantages offered by vehicle connectivity or automation, or by cooperative vehicle operation. The energy efficiency improvements that the NEXTCAR Program seeks are in addition to, and beyond, any currently expected future vehicle fleet fuel efficiency improvements that will be required or driven by Federal or State regulations (CAFE and NHTSA/EPA Phase 2 fuel efficiency standards) [2].

The ARPA-E NEXTCAR Program seeks transformative technological solutions that will enable at least an additional 20% reduction in the energy consumption of future connected and automated vehicles (CAVs), compared to vehicles without these VD&PT control technologies. For the purposes of this Program, the technologies to be developed will be required to demonstrate a 20% reduction in energy consumption when implemented on a 2016 baseline vehicle. In fact, a reduction of 20% in the fuel consumption of the LD vehicle fleet in 2016 alone would result in a reduction of US primary energy consumption by 3.0 quads and a reduction of 0.2 gigatons of CO_2 emissions per year. The technologies contemplated in this Program include solutions that consider powertrain optimization as a part of the vehicle fuel or energy efficiency improvements of future CAVs. Solutions that only take into account vehicle-level longitudinal (or vehicle dynamic) control or driver behavior optimization without regard for optimized powertrain operation are unlikely to achieve the energy efficiency goals sought by this

[2] http://www.nhtsa.gov/fuel-economy

Program. *In essence, the co-optimization of vehicle-level (vehicle dynamic) and powertrain-level operations is sought in order to minimize the energy consumption of future vehicles.* It is expected that Applicant teams may be composed of researchers and developers from a broad range of disciplines spanning automotive vehicle control, powertrain control and transportation analytics, to allow for the development of these advanced energy efficiency optimization technologies for future CAVs. ARPA-E is interested specifically in the ultimate commercialization of the technologies that it supports, because it is recognized that commercial implementation is essential to achieving the energy efficiency potential of these technologies.

2. BACKGROUND

Over the next few decades the automotive vehicle fleet (LD, MD and HD vehicles) will remain predominantly powered by internal combustion engines (ICVs), while the numbers of hybrid electric vehicles (HEVs), fuel cell electric vehicles (FCVs) and battery electric vehicles (BEVs)[3] will continue to increase. The fuels used will presumably continue to include gasoline, diesel fuel, electricity (for BEVs and plug-in HEVs, or PHEVs), hydrogen, natural gas and biofuels. For the purposes of the ARPA-E NEXTCAR Program, no preference is expressed for any particular fuel or energy source for propulsion. Well-established methods of reducing individual vehicle fuel or energy consumption, such as hybridization, electrification, fuel shifting or alternative fuel substitution, weight reduction, aerodynamic drag reduction, rolling resistance improvements, waste energy recovery and parasitic load and friction reduction, will certainly be widely used by the automotive industry to achieve future required LD, MD and HD vehicle fuel efficiency standards; however their further development or demonstration is specifically not of interest in this Program. Also, the emphasis of the NEXTCAR Program is on reducing the energy consumption of individual vehicles, and not that of the overall transportation system (through such means as transportation system network optimization) or transportation mode shifting.[4]

The focus of the NEXTCAR Program is on developing vehicle and powertrain controls that use increased information available via connectivity to reduce individual vehicle fuel or energy consumption, with or without the intervention of a human driver.

A range of improved powertrain control techniques will be made possible in the near future by the increase in useful information available on-board vehicles through connectivity such as V2V (e.g. look-ahead data), although it is clear that certain further improvements in powertrain controls will occur even without the use of this additional technology. It is envisioned that in the future, the total reduction in energy consumption of an individual vehicle will be due to some combination of

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[3] See, for example, The Outlook for Energy: A View to 2040, ExxonMobil, 2016. Available from: http://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2016/2016-outlook-for-energy.pdf

[4] ARPA-E has previously funded technology solutions to minimize energy consumption in America's surface transportation network without having to improve current infrastructure or vehicle efficiency via the *TRANSNET* Program. https://arpa-e-foa.energy.gov/Default.aspx?Archive=1#FoaIda65ecb06-eb2c-43e5-8b96-bd902efff4e8

- improved on-board powertrain controls (with improved real or virtual sensing and/or the use of V2V, V2I and V2X connectivity and real-time optimization),
- improved vehicle-level dynamic controls (using real or virtual sensing and/or the use of V2V, V2I and V2X connectivity),
- the utilization of new control system inputs from external sources, external optimization, or surrounding collaborating vehicles, and
- ultimately, the ability to operate in a fully automated mode, thereby removing the effect of the human driver from the vehicle and powertrain control systems.

From a control point of view, vehicles currently operate in isolation as a collection of single 'selfish' entities, even in dense traffic. Developments in connectivity and automation will allow vehicles in the future to operate in a range of cooperative modes with other surrounding vehicles. While such cooperative behavior has been the subject of much recent research, the full potential of improved powertrain control (as opposed to improved vehicle longitudinal or dynamic control) on the resultant composite energy efficiency of a cohort of vehicles undertaking cooperative vehicle behavior[5] has not yet been fully explored. *The focus of the ARPA-E NEXTCAR Program is on increasing the energy efficiency of each individual vehicle in the automotive fleet, through the improvement of vehicle dynamic and powertrain (VD&PT) control, by utilizing emerging technologies and strategies in sensing, communications, information, decision-making, control and automation.*

As noted above, future vehicle fuel economy standards already promulgated will by necessity result in the reduction of energy consumption by individual vehicles in the vehicle fleet. Noting that transportation currently accounts for 28% of the US primary energy usage, the ARPA-E NEXTCAR Program is aimed at investigating technologies that may provide *additional* opportunities for vehicle energy efficiency improvements beyond the base case expected across the next two or three decades. The technologies proposed in the NEXTCAR Program are required to be capable of meeting the prevailing regulated vehicle emissions levels at the expected time of their commercial deployment, and must ultimately result in equivalent (or at least acceptable) vehicle performance, utility, total cost of ownership and operation, functionality, drivability, power and energy storage density, reliability and maintainability.

2.1 The Current State of the Art of Automotive Vehicle Operation and Control

The most common LD, MD and HD vehicles today (at vehicle automation Level 0 – with no automated vehicle control features) are mostly either ICVs, or are HEVs, PHEVs or BEVs. These vehicles rely on a human driver to provide active high-level dynamic control of the vehicle through the actuation of accelerator pedal, brake pedal, and steering input (and sometimes gear selection). In turn the actual instantaneous powertrain operation is thereafter controlled by an electronic engine or powertrain controller that ultimately dictates the real-time powertrain power output, powertrain output speed, and by default, the vehicle fuel or energy

[5] Cooperative vehicle behavior requires connectivity and at least partial automation capability.

efficiency and regulated gaseous exhaust emissions (if any). In L0 vehicles, the human driver relies on visual inputs of road and traffic conditions (and traffic signage and signals) and an innate requirement for instantaneous vehicle speed and power, to govern the most immediate selection of the vehicle dynamic commands (accelerator, brake and steering). Concurrently the driver utilizes visual input and sensations of displacement in 6 degrees of freedom (3 axes of displacement, yaw, pitch and roll, along with their resultant accelerations and rates of change of acceleration, or 'jerk') in an almost entirely reactive fashion to dictate any required modifications to the vehicle control inputs. External informational inputs, such as those derived from navigation systems, are normally used by the driver in an ad-hoc and advisory fashion. Automated vehicle operation is viewed today predominantly as the ultimate vehicle safety enhancement, although the utility of automation in enhancing mobility and reducing environmental impacts has also been acknowledged. Fully automated vehicle operation will in the future allow for higher individual and collective vehicle driving speeds (and hence greater traffic throughput on existing roads) with vastly reduced collision and crash rates, and thereby free up the drivers' or occupants' time for other pursuits. Today, L1 vehicles (employing the automation of a single control actuator such as the accelerator in the case of adaptive cruise control, or ACC), L2 vehicles (two controls automated – ACC and steering for lane keeping, for example) and L3 vehicles (capable of automated operation but still requiring a human driver to take over full control if required) currently exist, and are anticipated to become the norm in the future. It is important to note the distinction between advanced driver assistance systems (ADAS) as implemented in L1, L2 and L3 vehicles, and fully automated operation (L4 vehicles) – the latter will require significantly higher levels of fidelity and bandwidth in sensor inputs, machine vision, connectivity, data fusion and higher levels of computation and real-time decision-making for the safe control of longitudinal and lateral vehicle dynamics alone. See Figures 1 and 2 for logic flow diagrams for L0 and L3-L4 vehicles, respectively.

L4 vehicles (fully automated and driverless) have the potential to lead to a significant reduction in individual vehicle energy usage as safety enhancements will ultimately allow for significant decreases in vehicle weight for the same vehicle functional utility. Conversely, as fully automated vehicle operation becomes the norm, total Vehicle Miles Traveled (VMT) by the automotive fleet has the potential to increase dramatically (the energy rebound effect), thereby offsetting much of the energy efficiency gain due to weight de-compounding on an individual vehicle basis[6]. For example, the reduction in energy intensity (classified as a positive energy outcome) by light-weighting and powertrain/vehicle size optimization is approximately equal to the increase in use intensity (classified as a negative energy outcome) caused by more travel[6]. *The optimization of the operation or energy efficiency of L4 vehicles is beyond the desired scope of the NEXTCAR Program, which emphasizes applications from L0 to L3 levels of automation.*

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[6] Gonder et al. NREL Research and Thoughts on Connected and Automated Vehicle Energy Impacts. Remarks at EPA Mobile Sources Technical Review Subcommittee Meeting, December 2014. Available from: http://www.epa.gov/sites/production/files/2014-12/documents/gonder_120914.pdf

Due to well-established patterns of vehicle ownership, reliability and replacement, the incumbent LD vehicle fleet largely turns over in a 10 to 15-year time frame[7], thus requiring that for the next few decades at least, L4 vehicles will have to co-exist on the road with L0-L3 vehicles of higher vehicle weights and reduced levels of safe operation capability. This timeframe is also certainly consistent with the expected longevity of the internal combustion engine-equipped ICVs, HEVs and PHEVs, thus ensuring that at least part of the future fleet will continue to have fuel-consuming engines of varying power capabilities. The reduction of the energy consumption of the entire future vehicle fleet will contribute to our national energy security, economic security and climate change mitigation.

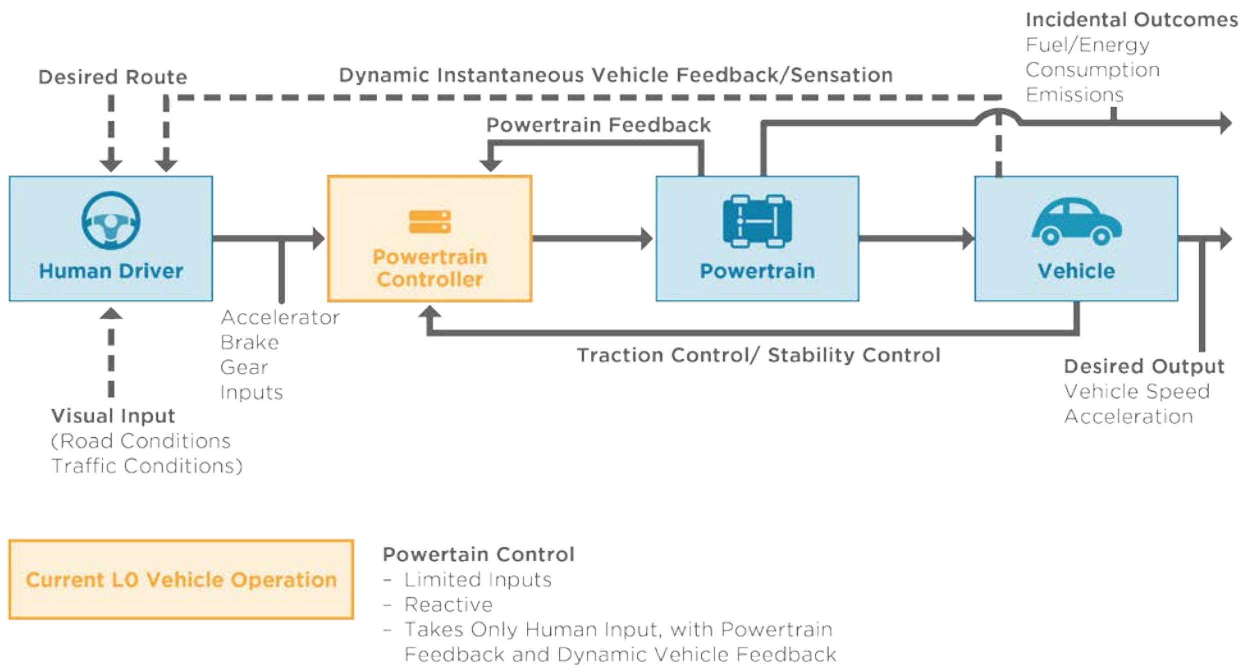

Figure 1: Vehicle dynamic and powertrain control and actuation logic flow diagram for a L0 vehicle.

[7] http://www.rita.dot.gov/bts/. Available from: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_26.html_mfd

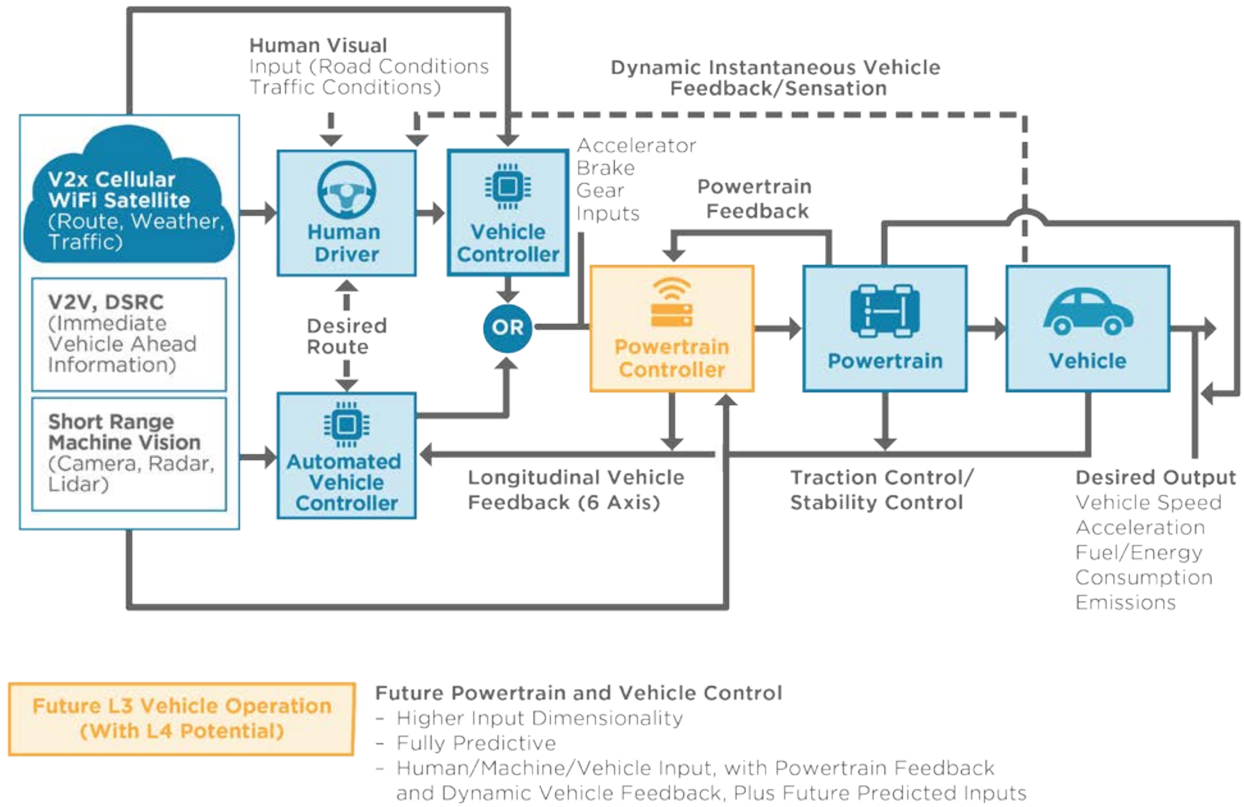

Figure 2: Vehicle dynamic and powertrain control and actuation logic flow diagram for future L3-L4 vehicles. Under the NEXTCAR Program, connectivity will allow the use of additional information inputs to the vehicle and powertrain controllers.

2.2 Current Trends in Powertrain Control

Conventional powertrain control at present is almost exclusively reactive and backward-looking, with limited provision for the incorporation of sensor-based feedback except for crude or indirect measures of combustion efficiency and/or exhaust emissions. As a result, powertrain operation is frequently rendered non-optimal with regard to fuel and energy consumption minimization, and considerable opportunity arises for energy efficiency optimization, with the required computation either performed on-board in real-time or on an off-line basis.

The advent of vehicle connectivity allows for the use of additional, exogenous inputs for improved real-time vehicle and powertrain control. In the near future, in addition to offering advanced levels of collision avoidance and crash prevention, V2V communications (such as DSRC) will facilitate extensive automated collaborative operation between neighboring vehicles – for platooning, cooperative ACC (CACC) and speed-harmonization for congestion mitigation, for example. This connectivity, and the resultant exchange of information, is mainly anticipated by the industry to be between vehicle controllers, as opposed to between powertrain controllers. V2I communications will further allow vehicles (and their on-board controllers) to interact with the road infrastructure, to allow for efficient traffic flows at intersections and traffic signals, for example. Untapped opportunities exist for the efficiency enhancement of future vehicles through optimization of powertrain operation, including real-time powertrain calibration and optimization via connectivity (that allows for over-the-air updates of off-line optimized control software and powertrain calibrations, for example). V2V communication, in addition, effectively equips each vehicle with foreknowledge or a preview of its own future actions, as DSRC gives immediate warnings of the actions and intentions of the vehicles directly ahead in traffic. This knowledge can potentially be used to create a specific time-based trajectory of optimized powertrain control references to minimize the fuel or energy consumption of each individual vehicle across some finite future time horizon, for example, in addition to providing optimal instantaneous vehicle speed (and acceleration) commands for L3 or L4 automation.

The creation or addition of additional high-value information that can be made available through V2X for use in powertrain control systems may also enable significantly higher individual vehicle efficiency through combustion optimization (in the case of ICVs or HEVs), energy storage optimization (in the case of HEVs and BEVs), and route optimization and optimized vehicle dynamic performance for all vehicles. For ICVs or HEVs, the addition of “perfect” information on fuel chemistry, engine and after-treatment conditions, weather and environmental conditions, traffic conditions ahead, and perhaps driver behavior (for example), could lead to meaningful enhancements in the energy efficiency of each and every vehicle under a range of operating conditions and use cases.

One promising enabling technology underlying future vehicle and powertrain control is the development of model-based control algorithms and systems – this will allow powertrain control to be fully predictive and forward-looking, and enhance the effect of real and virtual feedback, as well as utilizing a range of additional information available through connectivity. With this increased information, model-based control using real-time optimization has the potential for useful efficiency gains for individual vehicles, and hence by extension, the entire vehicle fleet. For example, connectivity might allow a vehicle to “know” with some certainty about its future operation across some planned route with respect to the anticipated profiles of acceleration, deceleration, braking (or regeneration) and grade climbing. This look-ahead or preview information can be used in conjunction with the vehicle and powertrain control models to optimize the vehicle energy efficiency over a portion of a trip, or indeed in the case of the availability of “perfect” information, over a full, extended trip. VD&PT control technologies that leverage this information, implemented on either a single vehicle basis, or across a cohort of cooperating vehicles, or even the entire vehicle fleet, could lead to significant fleet energy efficiency improvements.

2.3 Real-World Operation vs. Regulatory Drive Cycles

It is widely acknowledged that regulatory drive cycles used for statutory exhaust emissions and fuel economy measurements are not truly representative of real-world driving, particularly with respect to reproducing typical rates of acceleration and sustained cruise speeds. In fact, in 2005 the EPA conducted a study to compare real-world driving data from instrumented vehicles in Kansas City to the EPA drive cycles (the earliest of which were developed in the 1960s and 70s).[8] Results from this study concluded that the then relatively new US06 cycle (used since 2008 for fuel economy measurement) is a little too aggressive while the UDDS "city" cycle (used since 1972) is not aggressive enough as compared to actual driver behavior. Rather than develop new drive cycles that would quickly become outdated as driver behavior changed further, the EPA developed a modified weighting procedure to combine results from existing drive cycles to produce a representative average for apparent on-road fuel consumption. This weighting procedure was then reflected in the 2008 EPA 5-cycle approach currently used for fuel economy regulation.

While Federal drive cycles have not been modified in recent years even while vehicles have on average become significantly more powerful and are driven more aggressively, much research has been done to develop naturalistic drive cycles, often through a combination of real-world driving data and statistical analyses. For instance, Lee et al.[9] developed a process to characterize PHEV trip characteristics from a limited data set using a stochastic process and statistical analysis. Others have used comprehensive national data sets, such as the National Household Travel Survey (NHTS), or global positioning system (GPS) technology to collect large sets of real-world driving data from which to determine representative real-world operation. Earleywine et al.[10] took this approach and collected GPS data from 783 vehicles operating in Texas to evaluate real-world driving profiles and compare them against EPA drive cycles. They found that UDDS and HWFET cycles provide a limited representation of real world driving, primarily due to the more aggressive driving and higher accelerations evident in the real world. ARPA-E acknowledges the limitations of regulatory drive cycles in reflecting actual vehicle energy consumed under real-world driving operation and as a result *the NEXTCAR Program will utilize testing and validation over a more appropriate set of real-world driving and dynamic operational scenarios (see Section I.D of the FOA).*

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[8] U.S. Environmental Protection Agency, Fuel economy labeling of motor vehicle: revisions to improve calculation of fuel economy estimates, Office of Transportation and Air Quality, Report EPA420-R-06-017, 2006.
[9] Lee et al. Stochastic modeling for studies of real-world PHEV usage: driving schedule and daily temporal distributions, IEEE Transactions on Vehicular Technology, V.61 (4), 2011.
[10] Earleywine et al. Simulated fuel economy and performance of advanced hybrid electric and plug-in hybrid electric vehicles using in-use travel profiles, Vehicle Power and Propulsion Conference (VPPC), IEEE, 2010.

3. MOTIVATION

According to the EIA's Annual Energy Outlook 2015[11], in the United States the existing LD vehicle fleet of roughly 235 million vehicles will travel approximately 2,800 billion miles in calendar year 2016 at an average actual vehicle fuel consumption of 23.0 miles per gallon (mpg) gasoline equivalent. For regulatory compliance purposes the average new vehicle in model year (MY) 2016 will be assigned a CAFE after credits of 33.4 mpg, while their actual on-road, real-world fuel efficiency is projected to be 26.3 mpg. As previously discussed, the discrepancy between assigned (regulatory) fuel economy for CAFE purposes and the adjusted actual real-world fuel economy values are primarily due to the fact that vehicles are typically operated on the road by human drivers at higher speeds and loads (mainly due to higher rates of acceleration) than those covered in the laboratory regulatory cycles used for fuel efficiency determination. Moreover, it is not currently anticipated - due to typical industry and regulatory lead times - that future fuel economy regulations in the 2025 timeframe will take into account the potential benefits of emerging connectivity and automation technologies on individual vehicle fuel consumption. In other words, future testing for the purposes of regulation as currently anticipated is unlikely be capable of accounting for the fuel or energy consumption reductions that will be made possible through individual vehicles making use of connectivity for optimization, or through the effect of multiple vehicles employing automation to cooperate in their collaborative driving behavior for the purposes of reducing their collective fuel or energy efficiency.

As a consequence, it is assumed for the purposes of the NEXTCAR Program that any technology employing connectivity and automation that offers a 20% improvement in the energy efficiency of an individual MY 2016 vehicle today, will likewise offer a (roughly similar) 20% improvement in the energy efficiency of the comparable new vehicle in 2025, even if the future vehicle is significantly more efficient *ab initio,* as explained in Section I.B.2 of the FOA. The energy efficiency improvements to be achieved in this Program will be tested and validated over a range of real-world driving scenarios that are not explicitly captured in current (or future proposed) regulatory fuel efficiency tests (see Section I.D of the FOA).

[11] http://www.eia.gov/forecasts/aeo/

Table 1: Fuel Cost and Technology Payback Analysis by Vehicle Class (VMT, fuel efficiency and fuel costs are notional and approximate).

	Vehicle Class		
	LD	**MD**	**HD**
VMT (mi/yr) (2015)	12,700	35,000	68,000
Fuel Efficiency (mpg) (2015)	27.0	10.0	5.3
Fuel Type	Gasoline	Diesel	Diesel
Fuel Cost ($/gallon) (2015)	$ 2.50	$ 2.50	$ 2.50
Fuel Cost ($/yr) (2015)	$ 1,176	$ 8,750	$ 32,075
20% reduction ($/yr) (2015)	$ 235	$ 1,750	$ 6,415
Current 3 year payback ($)	$ 706	$ 5,250	$ 19,245

Table 1 shows an analysis of vehicle annual fuel costs and the characteristic payback time for a notional advanced technology that offers a 20% reduction in vehicle energy consumption. Considering typical annual VMT by vehicle class, typical fuel consumption rates by vehicle class, and assuming a nominal $2.50 fuel cost per gallon for both gasoline and diesel fuel (roughly the 2015 calendar year average), it can be seen that a 20% energy consumption reduction for LD vehicles, over a 3-year period, results in a $706 energy cost reduction. The same analysis for MD and HD vehicles shows $5,250 and $19,245 fuel cost savings over 3 years respectively – which are both significantly higher than the LD case due to the much lower fuel efficiency of those vehicles and the far higher VMT rates that they undergo on an annualized basis. One conclusion of this analysis is that a nominal $1,000 incremental cost for an added technology that results in a 20% fuel consumption reduction in a LD vehicle incurs a 4.25-year payback period, while a $3,000 technology in HD vehicles is repaid in a mere 6 months of operation.

As previously discussed, the motivation for the development and implementation of vehicle connectivity and automation by the automotive industry has been up to this point primarily for road traffic safety considerations, and the ramifications of these technologies on vehicle or fleet energy consumption has not yet been fully understood or demonstrated. Table 2 shows a summary of recent work on the use of connectivity and automated operation in a number of different real-world operating scenarios with estimates of the resulting reductions in vehicle fuel or energy consumption. Note that Table 2 is not intended to provide a comprehensive review of the state-of-the-art but is provided solely for informational purposes. It should be acknowledged further that the US Department of Transportation (DOT) Applications for the Environment: Real-Time Information Synthesis (AERIS) Program[12] has funded and championed many of the vehicle efficiency studies in this area to date.

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[12] http://www.its.dot.gov/aeris/

Table 2: Examples of vehicle efficiency studies aimed at fuel consumption reduction applicable to CAVs. In most cases, the energy consumption optimization was applied at the vehicle dynamic level with no direct control or coordinated optimization of the powertrain operation.

Reference (Study Type)	Technology or Application	Fuel Consumption or Energy Reduction Potential (%) Summary
Rakha[13] (Simulations)	Eco-routing (network-wide).	3.3% and 9.3% fuel consumption reduction with 4.8% and 3.2% increase in average travel time for Cleveland (OH) and Columbus (OH) networks, respectively.
Rakha[13] (Simulations)	Eco-cruise control (single vehicle).	9.7% fuel consumption reduction with 1.4% increase in travel time and 17.5% fuel consumption reduction with 7.9% increase in travel time for NYC-LA route.
Gonder[14] (Simulations)	Route-based control for HEVs.	2-4% reduction in fuel consumption.
Gonder et al.[15] (Simulations and Testing)	Effect of driver behavior on single vehicle fuel consumption.	30% fuel consumption difference between the most aggressive driver and an energy conscious driver in city driving conditions. 20% difference in highway conditions.
HomChaudhuri et al.[16] (Simulations)	Energy management of connected HEVs using a decentralized hierarchical control structure (two-level controller).	HEV fuel consumption improved from 32.4 mpg to 50.5 mpg (average of a group of 10 vehicles). Energy consumption reduction of 56%.
Mandava et al.[17] (Simulations)	Use of arterial velocity planning algorithms for providing dynamic speed advice to driver.	Energy saving potential of 12-14%.
Lammert et al.[18]	Platooning effects on fuel consumption of Class 8 vehicles as a	Leading truck fuel consumption savings were between 2.7% to 5.3%.

[13] Rakha, H. Overview of VTTI's environmental connected vehicle research activities. Available from: http://www.its.dot.gov/aeris/pdf/12_VTTIsEnvironmentalConnectedVehicleResearchActivities.pdf
[14] Gonder, J. Route-based control for Hybrid Electric Vehicles, SAE 2008-01-1315, 2008.
[15] Gonder et al. Analyzing vehicle fuel saving opportunities through intelligent driver feedback, SAE2012-01-0494, 2012.
[16] HomChadhuri et al. Hierarchical control strategies for energy management of connected hybrid electric vehicles I urban roads, Transportation Research Part C, V.62, 2016.
[17] Mandava et al. Arterial velocity planning based on traffic signal information under light traffic conditions, IEEE Transactions on Intelligent Transportation Systems, 2009.
[18] Lammert et al. Effect of platooning on fuel consumption of class 8 vehicles over a range of speeds, following distances, and mass, SAE International Journal of Commercial Vehicles, V.7(2), 2014.

(Testing)	function of speeds, following distance and gross vehicle weight (GVW).	Trailing vehicle fuel consumption savings ranged from 2.8% to 9.7%.
Ozatay et al.[19] (Simulations and Testing)	Dynamic Programming (DP) algorithm to provide optimal speed trajectory to a driver using traffic and geographical information.	12.6% and 7.4% fuel economy improvement in highway and city driving, respectively.
Ozatay et al.[20] (Simulations)	Generation of optimal velocity trajectory for a given road grade profile versus constant speed cruise control. Results obtained from an analytical solution matched with those from DP algorithm thus enabling real-time onboard implementation.	10.4% improvement in fuel economy by both solutions when compared to constant speed cruise control. Calculation times were 16.2s and 0.05s for DP and analytical solutions, respectively.
Qi et al.[21] (Simulations)	Real-time energy management for PHEVs using DP and Q-learning based blended real-time energy management system.	12% fuel consumption reduction as compared to binary mode control strategy, however 2.9% higher fuel consumption as compared to the DP solution.
Xia et al. [22] (Simulations and Testing)	Eco-approach using Signal Phase and Timing (SPaT).	An average of 14% fuel consumption reduction was achieved.
Barth et al.[23] (Simulations)	Eco-approach and departure at signalized intersections.	5-10% fuel consumption reduction at uncoordinated signal corridors. Coordinated corridors alone result in about 8% fuel savings with an additional 4-5% fuel savings from eco-approach and departure.

[19] Ozatay et al. Cloud-based velocity profile optimization for everyday driving: A dynamic-programming-based solution, IEEE Transaction on Intelligent Transportation Systems, V.15(6), 2014.

[20] Ozatay et al. Analytical solution to the minimum energy consumption based velocity profile optimization problem with variable road grade, 19th World Congress, The International Federation of Automatic Control, V.19(1), 2014.

[21] Qi et al. Novel blended real-time energy management strategy for plug-in hybrid electric vehicle commute trips, IEEE Transactions of Intelligent Transportation Systems, 2015.

[22] Xia et al. Field operational testing of Eco-approach technology at a fixed-time signalized intersection, IEEE Transactions of Intelligent Transportation Systems, 2012.

[23] Barth et al. Eco-approach and departure at signalized intersections: preliminary modeling results. Available from: http://www.its.dot.gov/aeris/pdf/UCR_eco-approach_final2.pdf

Wu et al. [24] (Simulations)	Optimal velocity trajectory is generated with the knowledge of vehicle location, roadway characteristics and real-time traffic information and used to determine battery charge depletion control.	10-15% fuel consumption reduction as compared to binary mode control strategy.

Table 2 above indicates the type of each study and whether the energy efficiency achieved for each individual technology was validated in Simulation or via real-world Testing (either on-road or on a chassis dynamometer) or both. As Sciarretta et al.[25] point out, there is a dearth of real-life test validation data for many proposed advanced vehicle energy efficiency strategies. Also, significant effort is needed to realize and implement these strategies in real-time on-board vehicles due to the complex nature of the control strategies required, and the real-time computational effort required. In many cases the controls problems have an innate multiple-input-multiple-output (MIMO) structure which is not amenable to closed-form solution. Dynamic programming (DP) algorithms have been proposed as a useful methodology to solve some of these complex real-time vehicle control and optimization problems, but these algorithms are not yet capable of allowing real-time predictions under the computational time constraints posed by city driving conditions. Sciarretta et al. have reviewed several analytical solutions for onboard vehicle dynamics optimization for eco-driving and reported a 14% reduction in energy consumption for a BEV. Similarly, onboard vehicle dynamics optimization of truck operation resulted in a fuel consumption reduction of up to 6% with a less than 2% penalty on the trip time through the use of online DP optimization. It must be noted that most often in these test cases, driver behavior is not modeled and hence is not taken into consideration in the optimization scenarios. As a result, many of the cases given above represent optimistic assessments of the achievable fuel consumption by assuming that the driver (human or automated) follows the optimal speed profiles exactly as generated by the optimization techniques (a known shortcoming of dynamometer-based driving and testing, for example).

Another significant technical gap that exists in this area is the co-optimization of vehicle dynamics and powertrain systems, which is an additional area of interest of this Program. It is envisioned that, as a part of the control system, a variety of useful additional *exogenous information* will be made available to vehicles through V2X connectivity, beyond that which is currently available. This additional information could include parameters such as traffic information (traffic density, route congestion, signal information etc.), topology (road curves, road grade etc.), weather (temperature, humidity etc.), road surface conditions (coefficient of friction etc.), fuel quality (heat of vaporization, knock resistance as indicated by octane number etc.) and others. A range of *endogenous information* is already available on-board vehicles, and this includes information such as powertrain states (engine state, battery state of charge,

[24] Wu et al. Development and evaluation of an intelligent energy-management strategy for plug-in hybrid electric vehicles, IEEE Transactions of Intelligent Transportation Systems, 2014.
[25] Sciarretta et al. Optimal ecodriving control, IEEE Control Systems Magazine, October 2015.

transmission states etc.), after-treatment states, fuel quality (in the case of flex-fuel vehicles), HVAC operation and other parasitic loads (available via real or virtual sensing) that is valuable for powertrain optimization. The combined use of these two types of information opens up a plethora of VD&PT optimization opportunities for real-time energy consumption and emissions reduction. The optimal velocity, torque and acceleration profiles as obtained by the 'higher-level' vehicle dynamic controller can be communicated to the 'lower-level' powertrain optimizer so that the latter can calculate the optimal reference set-points for fuel-system, air-handling, ignition, exhaust management, after-treatment, energy storage and electric drive sub-systems that can be met by the powertrain controller with minimal tracking error, to maximize the resultant vehicle energy efficiency. *ARPA-E sees a tremendous opportunity in this technical area that is currently void of any fully-deployed solution that utilizes cooperation across the vehicle longitudinal dynamics and powertrain optimization domains, utilizing connectivity for information and varying levels of automation for vehicle control.*

Early developmental examples of such vehicle- and powertrain-level cooperative solutions include the Bosch Electronic Horizon[26] and AVL Connected Powertrain™ [27]. For example, the Bosch Electronic Horizon, with the addition of limited exogenous information, predicts 5%, 6% and 8% CO_2 emissions reduction potentials for ICVs, HEVs and PHEVs, respectively, in real-world drive cycles using route and topographical information. In the case of ICVs, the energy consumption reduction is obtained from powertrain optimization purely using start-stop and coasting systems. In HEVs, the combustion engine and electric drive are co-optimized for further efficiency enhancements, including the optimization of regenerative braking strategies. An interesting example cited in Ref. 27 is that of eco-routing with and without diesel particulate filter (DPF) regeneration where the efficiency results can be different for the two scenarios as catalyst regeneration accounts for a significant penalty in fuel consumption. A similar approach whereby the powertrain operation is included within the energy efficiency optimization loop for the operation of a Chevrolet Volt PHEV can be found in the work of Gonder et al.[28]

Recently, ARPA-E released a Request for Information (RFI) on energy efficiency optimization for connected and automated vehicles[29]. Based on the responses received, there was a general consensus that the operation of L0-L3 vehicles with connectivity and "perfect" information for VD&PT control and optimization could lead to a 5-20% energy consumption reduction at the vehicle level. For L0-L3 vehicles, it was agreed further that advanced driving assistance systems (ADAS) and powertrain optimization with predictive features (using information obtained

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[26] Bulander, R. Powertrain optimization using a comprehensive systems approach, 36th International Vienna Motor Symposium, 2015. Available from: http://www.bosch-presse.de/presseforum/download/BroschuereA5_Wiener_Motorensymposium_2015_EN.pdf

[27] Prenninger, P. Integrated open development platform. Available from: http://www.a3ps.at/site/sites/default/files/downloads/5_20141211_a3ps_workshop_prenninger_adas_overview_avl02.pdf

[28] Gonder et al. Connectivity-enhanced route selection and adaptive control for the Chevrolet Volt, 21st World Congress for Intelligent Transportation Systems, 2014. Available from: http://www.nrel.gov/docs/fy14osti/60960.pdf

[29] https://arpa-e-foa.energy.gov/Default.aspx?Archive=1#FoaId0853ef67-002d-4773-b11d-064b9168ae70

through both on-board sensing and external connectivity) would improve vehicle fuel or energy efficiency appreciably. The need for robust and adaptive algorithms for embedded vehicle and powertrain control technologies was also recognized in the responses.

It is further apparent that the time-scales for the information available via connectivity that is necessary for powertrain optimization may vary between vehicle and powertrain control sub-systems and the type of deployed CAV application. For example, a look-ahead time window of 5 to 15 seconds might be appropriate for the optimization of powertrain control while vehicle-level eco-routing would need a much longer time horizon (e.g., 5-15 minutes). Even at the powertrain level, there is a multiplicity of time-scales, as the fuel system of an ICV has a characteristic response time-scale of milliseconds, while the air-handling dynamics (filling of a manifold, turbocharger and exhaust gas recirculation or EGR dynamics) display time-scales of 1-2 seconds or more. Exhaust catalytic after-treatment systems have even longer typical time-scales due to transient thermal and chemical effects that can range from seconds to minutes. The optimized control of a PHEV may require a much longer time-scale, such as the entire trip time, in order to allow for a fully balanced battery state of charge (SOC). The identification of suitable sampling rates (for the data acquired via connectivity), controller computational times and data transmission rates that are appropriate for each vehicle sub-system is a necessary part of the successful integration of vehicle and powertrain control strategies. HEVs and PHEVs by definition incorporate both a fuel-consuming system (such as an ICV) and an energy storage system (ESS) (typically electro-chemical in nature). It is widely acknowledged that the overall efficiency of a hybrid vehicle can vary significantly as a result of the integrated effect of the relative energy flows from the engine and to or from the ESS (during propulsion or regenerative braking). It is anticipated that connectivity will allow for the incorporation of a range of new high-value information into the optimization calculations and cost or objective functions that determine the optimal energy flows and splits under real-world driving operation. In fact, connectivity and partial or full automation may allow the full (and hitherto unfulfilled) energy savings potential of hybrid vehicles to be captured under a range of real-world driving scenarios, thereby improving the economics of their purchase, payback and use.

The vision of the ARPA-E NEXTCAR Program is to reduce the energy consumption of a status-quo (2016 baseline) light-, medium- or heavy-duty vehicle by at least 20% by taking advantage of connectivity and automation (of up to L3 capability), without explicitly requiring extensive powertrain architecture or vehicle hardware modifications. Moreover, the connectivity and automation technologies required for the implementation of the NEXTCAR technologies developed in this Program will be assumed to be available on the future target vehicles. Applicants may choose to employ advanced real (or virtual) sensing, as demanded by their powertrain and vehicle controls architecture, as long as all the incremental hardware, controls and software modifications meet the system cost target of the FOA as shown in Section I.E. It is acknowledged that the technical solutions developed in the NEXTCAR Program could ultimately be extended to future L4 vehicles, which themselves provide further potential for energy consumption and emissions reductions (mainly due to the effect of extensive light-weighting and by removing the effect of the human driver). *However, purely L4 applications are considered beyond the immediate scope of this Program.*

C. <u>Program Objectives</u>

The overall objective of the NEXTCAR Program is to develop optimized, coordinated vehicle dynamic and powertrain (VD&PT) control technologies that will improve the energy efficiency of each individual vehicle in the future automotive fleet, by utilizing emerging technologies and strategies in sensing, communications, connectivity, information, decision-making, control and automation. In essence, the co-optimization of vehicle-level (vehicle dynamic) and powertrain-level operations is sought in order to maximize future reductions in vehicle energy consumption.

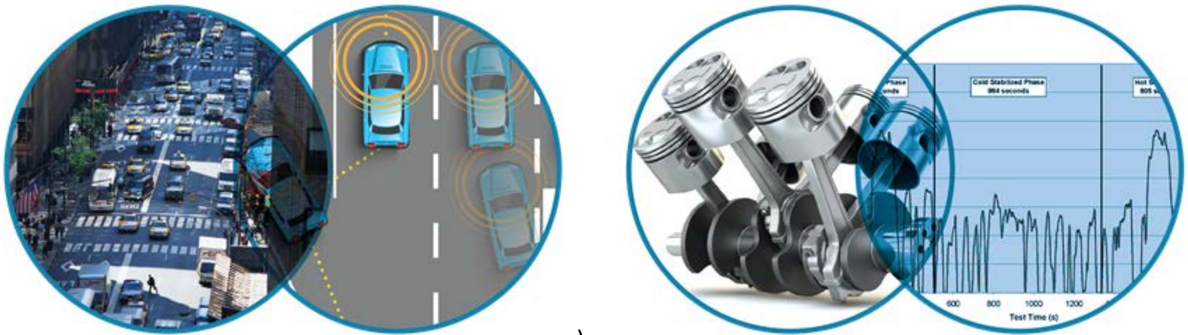
The vision of the ARPA-E NEXTCAR Program is to reduce the energy consumption of a status-quo (2016 baseline) LD, MD- or HD vehicle by at least 20% by taking advantage of connectivity and automation (of up to L3 capability), without explicitly requiring extensive powertrain architecture or vehicle hardware modifications.

The proposed VD&PT control technologies are required to be capable of meeting the prevailing regulated vehicle emissions levels at the expected time of commercial deployment, and must ultimately result in equivalent (or at least acceptable) vehicle performance, utility, total cost of ownership and operation, functionality, drivability, power and energy storage density, reliability and maintainability, without compromise. The ultimate goal of this Program is the future commercialization and deployment, at scale, of energy efficiency optimization technologies for the future vehicle fleet that take advantage of advances in vehicle connectivity and automation (where the vehicle connectivity and automation technologies required are assumed already to exist). Given below are specific objectives of the NEXTCAR Program:

- **Reduce energy consumption:** The primary objective of the NEXTCAR Program is to fund the development of deployable VD&PT control technologies that can achieve, through the use of connectivity and automation, at least a 20% reduction in the energy consumption of LD, MD and HD vehicles under real-world operation, when compared to a 2016 baseline vehicle. Vehicle efficiency improvements should be achieved with minimal or no powertrain or vehicle hardware improvements or modifications beyond those offered by the 2016 baseline vehicle. The total cost of the technology improvements (both hardware and software) must meet the cost metric as outlined in Section I.E of the FOA. It is assumed that the connectivity and automation systems required for the implementation of the NEXTCAR technologies either currently exist or will be deployed by the time of commercialization of these new VD&PT control technologies.
- **System target cost:** There are limits prescribed on the final commercial cost of the proposed NEXTCAR VD&PT control technologies at varying production scales for the LD, MD and HD markets. ARPA-E is interested in cost-effective solutions for minimizing fuel

consumption, which will accelerate Original Equipment Manufacturer (OEM) acceptance and increase the fleet penetration of CAVs**. The anticipated NEXTCAR target system cost excludes the additional cost of any hardware and software required to provide the connectivity and/or automation required for its implementation in the target vehicle.** It is to be assumed, for the purposes of assessing costs (with justification where appropriate) that all of the required hardware and software that is needed to enable connectivity and automation is (i) currently available, or (ii) likely to be available before 2025, or (iii) available on-board the target vehicle at no additional or incremental cost.

- **Emissions:** The proposed vehicle technology must be compliant with all applicable emissions regulations for that vehicle class at the time of deployment, which is expected to be in the 2025 and beyond timeframe.
- **Target vehicle utility:** The NEXTCAR Program will only fund the development of technologies that either meet, or show the potential to meet, all applicable Federal Motor Vehicle Safety Standards (FMVSS) and other Federal and State safety and exhaust emissions requirements. As a result, the technologies, when deployed, should be compatible with all vehicle regulatory drive cycle and customer performance requirements, including acceleration, top speed, gradeability, startability, operating temperature range, NVH, and driveability. In this Program, it must be demonstrated that the proposed vehicle technology does not result in any degradation of the performance of the 2016 baseline vehicle with respect to the performance and emissions parameters and characteristics listed above.
- **Collaborative vehicle and powertrain solution:** One objective that the ARPA-E NEXTCAR Program aims to achieve is to enhance the collaboration between the vehicle dynamics control, transportation analytics and powertrain communities to formulate solutions for minimizing the energy consumption of future CAVs. To date, ARPA-E recognizes that there have been two independent approaches for improving vehicle energy efficiency (or reducing energy consumption): a purely connectivity-driven approach (such as the one undertaken under the auspices of the DOT AERIS Program) and a regulation-driven approach, such as CAFE and NHTSA/EPA Phase 2 fuel-efficiency and GHG emissions regulations. ARPA-E seeks integrated solution approaches that can leverage the efforts of the aforementioned research communities working together in unison. In schematic form, Figure 3(a) shows the status-quo of independent vehicle and powertrain level research, and Figure 3(b) shows the vision and the objective of the ARPA-E NEXTCAR Program in bridging the gap between the two independent approaches.



a)

b)

Figure 3: (a) Status-quo showing two separate and independent efforts for improving vehicle energy efficiency and (b) the NEXTCAR Program vision for maximizing vehicle energy efficiency through a cooperative effort from all communities.

It is acknowledged that the prediction of human driver behavior (for both an individual target vehicle and for neighboring vehicles) is an important artifact that can impact any solution for minimizing vehicle energy consumption; however, this is not an area of interest under the NEXTCAR Program.

D. TECHNICAL CATEGORY OF INTEREST

The ARPA-E NEXTCAR Program seeks to fund the development of technologies that **reduce future vehicle energy consumption by developing new co-optimized vehicle dynamic and powertrain control and optimization techniques, facilitated by the use of connectivity and vehicle automation**.

ARPA-E is specifically interested in supporting the development of new and emerging VD&PT control technologies that employ vehicle connectivity to extend beyond the automation of *vehicle dynamic control* functions, to the *powertrain control* level, for the purposes of reducing overall vehicle energy consumption.

Application Scenarios for Technology Design, Development, Testing and Validation:

The VD&PT control technologies to be developed must apply to the operation of a single vehicle in isolation (undergoing operation on uncongested roadways, as well as in traffic) as well as to the operation of the same vehicle in a group of collaborating vehicles (under a range of traffic conditions). **The technologies to be developed should be appropriate for, and simulated and tested across, a range of CAV operating applications (listed in column A of Table 3). The range of appropriate operational factors that should be considered for either the simulation or testing of the technologies is shown in column B, while a description of the field testing and validation requirements of the proposed VD&PT control technologies is shown in column C below.**

Table 3: Example CAV applications and test factors that are pertinent to the VD&PT control technologies to be developed under the ARPA-E NEXTCAR Program.

(A) CAV Applications	(B) Simulation or Testing Factors	(C) Field Testing and Validation
• Platooning/ Cooperative Adaptive Cruise Control (CACC) • Speed Harmonization (SPD-HARM) • Eco-Approach and Departure at Signalized Intersections • Eco-Routing • City Driving and Highway Cruise Operation • ……	• Technology Penetration Rate • Level of Congestion • Lane Utilization Scheme • Facility Type • Number of vehicles in the cooperating cohort • …..	• Field testing must include VD&PT control technologies addressing at least two CAV applications, and more than one simulation or testing factor

Table 3 is not intended to be a fully comprehensive or prescriptive list of vehicle operational applications and simulation and testing factors, and it is up to the Applicant to expand on the information listed in the Table, or to state where deviations from those recommended applications, simulation or testing scenarios are justified.

The CAV applications[30,31] listed above are defined as follows for the purposes of this FOA:

- **Platooning/Cooperative Adaptive Cruise Control (CACC) Application**: This cooperative energy-saving behavior is enabled via V2V for a platoon of vehicles, wherein the lead vehicle informs the following vehicle(s) of its instantaneous location, speed, and acceleration, allowing the follower(s) to follow the leader safely with smaller inter-vehicle spacing. The follower(s) can safely and quickly respond to speed and acceleration changes by the vehicles ahead, thereby reducing the risk of rear-end collisions and string instability[32]. This application enables platooning, in which a train of vehicles cooperate to reduce their combined aerodynamic drag, and hence energy consumed. This type of application can be considered an example of cooperative vehicle behavior in which the total fuel or energy consumption of the cohort of vehicles is reduced compared to the sum of the energy usage of the individual vehicles operating alone.
- **Speed Harmonization (SPD-HARM) Application:** The speed harmonization application determines optimal vehicle speeds based on traffic conditions and the state of the surrounding roads. The purpose of speed harmonization is to vary the speed of traffic on roadways that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect traffic flow. Speed harmonization of a collection of vehicles assists in maintaining traffic flow, reducing unnecessary stops and starts, and maintaining consistent vehicle speeds to reduce congestion. This application utilizes V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate an appropriate response plan and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to CAVs. Speed recommendations are sent to an in-vehicle display for driver-operated vehicles or are used to automatically adjust speed (via ACC for example) for automated (L1-L4) vehicles.
- **Eco-Approach and Departure at Signalized Intersections Application (Eco-AND):** This application, located in a vehicle, collects signal phase and timing (SPaT) and Geographic Information Description (GID) messages using V2I communications as well as data from nearby vehicles using V2V communications. Upon receiving these messages, the application calculates each vehicle's optimal speed to allow it to pass through the next traffic signal unimpeded on a green light or to cause the vehicle to decelerate to a stop in the most energy efficient manner (using regeneration, for example, in the case of

[30] http://www.its.dot.gov/aeris/
[31] http://www.its.dot.gov/dma/
[32] Swaroop, D.V.A.H.G. String stability of interconnected systems: an application to platooning in automated highway systems. PhD Dissertation, University of California- Berkeley, 1994.

HEVs). This information is then sent to the longitudinal vehicle dynamics control system in each vehicle in support of partial automation operation (L1-L3).

- **Eco-Routing Application:** This application determines the most energy efficient route, in terms of minimum fuel or energy consumption and/or emissions, for individual vehicles. This application is similar to current navigation applications, which determine the route based on the shortest path or minimum trip time. Eco-routing can also recommend routes that result in the lowest total fuel or energy consumption or emissions based on historical, real-time, and predicted traffic and environmental data, by incorporating energy usage in the calculation of a cost, objective or optimization function, for example.
- **City Driving and Highway Cruise Operation:** This application includes normal vehicle operation at a range of vehicle speeds and accelerations that closely mimics city driving and highway cruise operation. These modes of operation may be conducted in isolation or in a cohort of collaborating vehicles.

The effectiveness of each proposed NEXTCAR VD&PT control Technology will be evaluated in each CAV application with a range of simulation or testing deployment factors. These factors are listed in column B of Table 3 and are as follows:

- **CAV Technology Penetration Rate:** The percentage of vehicles that are equipped with the proposed CAV technology in the traffic stream. For example, three rates could be considered: 10% (low penetration), 50% (medium penetration), and 100% (high level of penetration).
- **Level of Congestion:** The overall number of vehicles in the proposed vehicle test roadway compared to the number of vehicles encountered on an average given day. Three levels could be considered, namely uncongested traffic or low traffic density, average traffic conditions, and a congested traffic condition.
- **Lane Utilization Scheme:** Many CAV applications (such as platooning) can be used in a specific traffic lane, dedicated for that purpose, or can be applied on an ad hoc, temporary basis in any travel lane. Two schemes are to be considered: dedicated lane usage and free lane selection usage for the technology developed.
- **Facility Type:** The type of roadway or corridor used for the technology validation and testing. Three broad types are considered applicable in the context of this Program, namely freeways, arterial roads and city streets.
- **Number of vehicles in the cooperating cohort:** The total number of vehicles in a cooperating unit, such as a platoon. A range of collaborative vehicles could be considered, namely a single isolated vehicle operating alone, a small cohort of cooperating vehicles (say 5 CAVs), and a larger group of cooperating vehicles (10 CAVs, for example).

The Technology to be developed under this Program must be designed, simulated, physically implemented, and ultimately tested and validated (either in a vehicle on the road or on a chassis dynamometer), in such a manner that will allow its future deployment over the full

extent of applications in Column A of Table 3, and for the specified range of corresponding testing scenarios in Column B.
For the purposes of simulation, the performance and efficiency of the Technology must be simulated across as wide a range of CAV applications and simulation and testing factors in Table 3 as is possible.
Actual field testing and validation must include at least two CAV applications, and at least two testing factors. For example, Applicants could first simulate and then ultimately test their proposed Technology on a CACC application for a technology penetration level of 100%, in a highly-congested corridor, using a dedicated lane setup for CAVs in a platoon with a maximum number of 5 vehicles on a freeway section. Depending upon the test factor used (for example, use in a highly-congested corridor with no platooning vs. non-congested corridor with 3 vehicles in a platoon) and the type of the powertrain architecture selected (ICVs, HEVs, BEVs etc.), the Technology to be developed should minimize the total vehicle energy consumption by at least 20% relative to the 2016 baseline vehicle for a range of appropriate vehicle speed, wheel torque and acceleration requirements. Table 3 is not intended to be a fully prescriptive list of simulation, validation and testing applications and factors, and it is up to each Applicant to expand on the information listed in the Table, or to state where deviations from those recommended test and validation scenarios are justified.

ARPA-E also encourages applications stemming from ideas that still require proof-of-concept R&D efforts. Submissions requiring proof-of-concept development and demonstration may propose a project with the final deliverable being an extremely creative, but partial solution. However, Applicants are required to provide a convincing vision as to how these partial solutions would enable the realization of the full Program metrics with further development.

All Submissions should contain an appropriate cost estimate, project duration and a project plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. Proof-of-concept (or partial) solutions must at the very least demonstrate a 10% reduction in energy consumption over a comparable 2016 baseline vehicle (with a defined vehicle class, powertrain configuration and fuel), using connectivity and automation. ARPA-E may make one, multiple or no awards that will qualify as partial solutions, and only a small portion of the total amount to be awarded under the NEXTCAR Program is likely to be allocated to partial solutions.

E. Technical Performance Targets

Only transformational Technologies with the potential to meet or exceed all NEXTCAR Program targets will be considered for funding. Applicant teams must propose to meet the following targets, or state where their Technology will not meet or deviate from these targets. Funded Applicants will be required to demonstrate via real-world testing that these targets have been met by their Technologies, by the end of the award period.

ID	Description	Target
1.1	Target Vehicle Applications/Operating Scenarios	All reasonable scenarios of vehicle operation. See Table 3 for representative descriptions of CAV applications and testing factors. Applicants must develop a Simulation, Testing and Validation Plan using the CAV applications and testing factors described in Table 3, or describe how their proposed Plan deviates from this.
1.2	Target Vehicle Emissions	Must demonstrate no degradation in tail-pipe out exhaust emission levels over the 2016 Federal regulations and a pathway for significant future reductions.
1.3	Target Vehicle Utility	Must meet current applicable Federal vehicle regulatory drive cycle and customer performance requirements, including acceleration, top speed, gradeability, startability, operating temperature range, NVH, driveability and ease of use.
1.4	Customer Acceptability	The operation of the Technology must be transparent to the user or driver.
1.5	Energy Consumption Reduction Target over a 2016 Baseline Vehicle*	≥20%**
1.6	System Cost Target	**$1,000** for a LD vehicle, **$2,000** for a MD vehicle, and **$3,000** for a HD vehicle, upon full commercialization of the Technology. Vehicle classes are as defined in Appendix 1 of the FOA.

***Baseline Vehicle**: Applicants must select a baseline 2016 vehicle and specify and describe the following: Vehicle class (LD, MD or HD), powertrain type (e.g. engine-only, hybrid electric, battery-only, etc.) and fuel/energy type. The above mentioned characteristics of the baseline vehicle cannot be modified to achieve the metrics of this Program. However, for the purposes of cost assessments, Applicants may assume that the baseline vehicle will be equipped for and capable of operation up to the L3 level of operation through the use of enabling technologies such as DSRC, stereoscopic cameras for machine vision, radar, LIDAR, and acoustic/ultrasonic sensors, etc. In other words, it is to be assumed that all of the required hardware that is needed to enable the required connectivity and automation is available at no incremental cost. For example, the baseline 2016 vehicle may be equipped only with a L0 level of automation but the CAV Technology implementation can assume a L1-L3 level of capability provided the Applicant provides justification that the technologies for enabling the connectivity and automation are either (i) currently available, or (ii) likely to be available on all vehicles before 2025, or (iii) are or will be available at no incremental cost. Any additional hardware beyond that described above should be justified from a technology and cost point of view.

**Due to the technical advances that are likely to be implemented in vehicles as a consequence of the implementation of pending future fuel efficiency standards, it is recognized that a 20% reduction in the energy usage of a 2025 vehicle will necessarily result in a lower total absolute amount of energy saved than the corresponding 20% reduction for a 2016 baseline vehicle. The energy reduction potential of the Technologies to be developed under this Program is anticipated to be additive to, and independent of, those energy reductions already expected to be implemented in future vehicles (due to future fuel efficiency regulations, for example).

<u>**Supplementary Explanations of Targets**</u>

1.1 The Technology proposed to be developed in the NEXTCAR Program must be designed, simulated, physically implemented, and ultimately tested and validated (either in a vehicle on the road or on a chassis dynamometer), in such a manner that will allow its future deployment over the full extent of applications in Column A of Table 3, and for the specified range of corresponding testing factors in Column B. For the purposes of simulation, the performance and efficiency of the Technology must be simulated across as wide a range of CAV applications and testing factors in Table 3 as is possible. Actual field testing must include at least two CAV applications, and at least two testing factors as described in Table 3, or an alternative CAV approach with justification should be proposed.

1.2 The Technology proposed must not degrade the Target Vehicle's certified emissions below those of the 2016 baseline vehicle. Additionally, the Technology must allow for the relevant class-appropriate future emissions regulations (including those for NOx, CO, HC, PM and CO_2) to be met in the 2025 timeframe, without significant further development or cost.

1.3 The Technology proposed must deliver full vehicle utility comparable to that of the 2016 baseline vehicle. This utility includes, but is not limited to, regulatory drive cycle performance, acceleration time, top speed, gradeability, startability, operating temperature range, NVH, driveability and ease of use.

1.4 To ensure full customer acceptance and the successful eventual commercialization of the Technology, the Technology must be easy for the driver to operate and understand, if required.

1.5 The Technology must deliver a ≥20% reduction in energy consumption without changing the defining features of the 2016 baseline vehicle, including vehicle class, powertrain type and fuel type. (For instance, if the 2016 baseline vehicle is a light duty PHEV with a nominal all-electric range of 40 miles that operates on gasoline, the improved vehicle should at a minimum retain those characteristics).

Method of Verification: A ≥20% reduction in energy consumption relative to the baseline 2016 vehicle must, by the end of the Program, be demonstrated to ARPA-E over each of the real-world scenarios selected by the Applicant from Table 3 and validated first through simulation, and ultimately through real-world testing (on a chassis dynamometer or on-road, as applicable).

1.6 Applicants must demonstrate the achievement of the applicable system cost target through techno-economic analysis for 100,000 units of production for LD vehicles, 20,000 units for MD vehicles and 10,000 units for HD vehicles, depending upon the vehicle class selected by the Applicant. Applicants may assume that the baseline vehicle will be equipped for and capable of operation up to the L3 level of operation provided the Applicant provides justification that the technologies for enabling the connectivity and automation are either (i) currently available, or (ii) likely to be available on all vehicles before 2025, or (iii) are or will be available at no incremental cost. Any additional hardware beyond that described above should be justified from a technology and cost point of view.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $30 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 6-10 awards under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $250,000 and $10 million.

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be February 2017, or as negotiated.

ARPA-E encourages applications stemming from ideas that still require proof-of-concept R&D efforts as well as those for which some proof-of-concept demonstration already exists.

Applications requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metrics at the conclusion of the period of performance. These applications should contain an appropriate cost and project duration plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration. Alternatively, applications requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

Applicants proposing projects for which some initial proof-of-concept demonstration already exists should submit concrete data that supports the probability of success of the proposed project.

ARPA-E will provide support at the highest funding level only for applications with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

ARPA-E will accept only new applications under this FOA. Applicants may not seek renewal or supplementation of their existing awards through this FOA.

ARPA-E plans to fully fund your negotiated budget at the time of award.

B. ARPA-E Funding Agreements

Through Cooperative Agreements, Technology Investment Agreements, and similar agreements, ARPA-E provides financial and other support to projects that have the potential to realize ARPA-E's statutory mission. ARPA-E does not use such agreements to acquire property or services for the direct benefit or use of the U.S. Government.

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[33] Accordingly, ARPA-E has substantial involvement in the direction of every project, as described in Section II.C below.

1. Cooperative Agreements

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[34]

Cooperative Agreements involve the provision of financial or other support to accomplish a public purpose of support or stimulation authorized by Federal statute. Under Cooperative Agreements, the Government and Prime Recipients share responsibility for the direction of projects.

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at http://arpa-e.energy.gov/arpa-e-site-page/award-guidance.

2. Funding Agreements with FFRDCs/DOE Labs, GOGOs, and Federal Instrumentalities

Any Federally Funded Research and Development Centers (FFRDC) involved as a member of a

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[33] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).

[34] The Prime Recipient is the signatory to the funding agreement with ARPA-E.

Project Team must provide the information requested in the "FFRDC Lab Authorization" and "Field Work Proposal" section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

When a FFRDC/DOE Lab (including the National Energy Technology Laboratory or NETL) is the *lead organization* for a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the rest of the Project Team. Notwithstanding the use of multiple agreements, the FFRDC/DOE Lab is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

When a FFRDC/DOE Lab is a *member* of a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the rest of the Project Team. Notwithstanding the use of multiple agreements, the Prime Recipient under the Cooperative Agreement is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S. Government and the Laboratory. Any funding agreement with a FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (http://arpa-e.energy.gov/arpa-e-site-page/award-guidance).

Non-DOE GOGOs and Federal agencies may be proposed to provide support to the project team members on an Applicant's project, through a Cooperative Research and Development Agreement (CRADA) or similar agreement.

3. Technology Investment Agreements

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 or DOE's "other transactions" authority under the Energy Policy Act of 2005 to enter into Technology Investment Agreements (TIAs) with Prime Recipients. ARPA-E may negotiate a TIA when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

A TIA is more flexible than a traditional financial assistance agreement. In using a TIA, ARPA-E may modify standard Government terms and conditions. See 10 C.F.R. § 603.105 for a description of a TIA.

In general, TIAs require a cost share of 50%. See Section III.B.2 of the FOA.

C. STATEMENT OF SUBSTANTIAL INVOLVEMENT

ARPA-E is substantially involved in the direction of projects from inception to completion. For the purposes of an ARPA-E project, substantial involvement means:

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion – renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.338 and 200.339.
- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

III. Eligibility Information

A. Eligible Applicants

1. Individuals

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[35] as the lead for a Project Team,[36] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. Domestic Entities

For-profit entities, educational institutions, and nonprofits[37] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs/DOE Labs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team that includes institutions of higher education, companies, research foundations, or trade and industry research collaborations, but not as a Standalone Applicant.

State, local, and tribal government entities are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

Federal agencies and instrumentalities (other than DOE) are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

3. Foreign Entities

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or otherwise formed or to be formed) under the laws of a State or territory of the United States to

[35] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[36] The term "Project Team" is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.
[37] Nonprofit organizations described in section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Prime Recipient or Subrecipient.

receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Project Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

Unincorporated consortia must provide the Contracting Officer with a collaboration agreement, commonly referred to as the articles of collaboration, which sets out the rights and responsibilities of each consortium member. This collaboration agreement binds the individual consortium members together and shall include the consortium's:

- Management structure;
- Method of making payments to consortium members;
- Means of ensuring and overseeing members' efforts on the project;
- Provisions for members' cost sharing contributions; and
- Provisions for ownership and rights in intellectual property developed previously or under the agreement.

B. COST SHARING[38]

Applicants are bound by the cost share proposed in their Full Applications.

[38] Please refer to Section VI.B of the FOA for guidance on cost share payments and reporting.

1. BASE COST SHARE REQUIREMENT

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.B.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[39] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[40]

2. INCREASED COST SHARE REQUIREMENT

Large businesses are strongly encouraged to provide more than 20% of the Total Project Cost as cost share. ARPA-E may consider the amount of cost share proposed when selecting applications for award negotiations (see Section V.B.1 of the FOA).
Under a Technology Investment Agreement, the Prime Recipient must provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this minimum cost share requirement, as appropriate.

3. REDUCED COST SHARE REQUIREMENT

ARPA-E has reduced the minimum cost share requirement for the following types of projects:

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is required to provide at least 5% of the Total Project Cost as cost share.

- Small businesses – or consortia of small businesses - will provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[41] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80%, but less than 100%, of the total work under the funding agreement (as measured by the Total Project Cost) the Project Team are

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[39] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs and FFRDCs.
[40] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.
[41] Small businesses are generally defined as domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.[42]

- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs are required to provide at least 5% of the Total Project Cost as cost share.

- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs perform greater than or equal to 80%, of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.

- Projects that do not meet any of the above criteria are subject to the minimum cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. LEGAL RESPONSIBILITY

Although the cost share requirement applies to the Project Team as a whole, the funding agreement makes the Prime Recipient legally responsible for paying the entire cost share. The Prime Recipient's cost share obligation is expressed in the funding agreement as a static amount in U.S. dollars (cost share amount) and as a percentage of the Total Project Cost (cost share percentage). If the funding agreement is terminated prior to the end of the period of performance, the Prime Recipient is required to contribute at least the cost share percentage of total expenditures incurred through the date of termination.

The Prime Recipient is solely responsible for managing cost share contributions by the Project Team and enforcing cost share obligations assumed by Project Team members in subawards or related agreements.

5. COST SHARE ALLOCATION

Each Project Team is free to determine how much each Project Team member will contribute towards the cost share requirement. The amount contributed by individual Project Team members may vary, as long as the cost share requirement for the project as a whole is met.

[42] See the information provided in previous footnote.

6. Cost Share Types and Allowability

Every cost share contribution must be allowable under the applicable Federal cost principles, as described in Section IV.G of the FOA.

Project Teams may provide cost share in the form of cash or in-kind contributions. Cash contributions may be provided by the Prime Recipient or Subrecipients. Allowable in-kind contributions include but are not limited to personnel costs, indirect costs, facilities and administrative costs, rental value of buildings or equipment, and the value of a service, other resource, or third party in-kind contribution. Project Teams may use funding or property received from State or local governments to meet the cost share requirement, so long as the funding or property was not provided to the State or local government by the Federal Government.

The Prime Recipient may not use the following sources to meet its cost share obligations:

- Revenues or royalties from the prospective operation of an activity beyond the period of performance;
- Proceeds from the prospective sale of an asset of an activity;
- Federal funding or property (e.g., Federal grants, equipment owned by the Federal Government); or
- Expenditures that were reimbursed under a separate Federal program.

In addition, Project Teams may not use independent research and development (IR&D) funds[43] to meet their cost share obligations under cooperative agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under Technology Investment Agreements.

Project Teams may not use the same cash or in-kind contributions to meet cost share requirements for more than one project or program.

Cost share contributions must be specified in the project budget, verifiable from the Prime Recipient's records, and necessary and reasonable for proper and efficient accomplishment of the project. Every cost share contribution must be reviewed and approved in advance by the Contracting Officer and incorporated into the project budget before the expenditures are incurred.

[43] As defined in Federal Acquisition Regulation Subsection 31.205-18.

Applicants may wish to refer to 2 C.F.R. Parts 200 and 910, and 10 C.F.R Part 603 for additional guidance on cost sharing, specifically 2 C.F.R. §§ 200.306 and 910.130, and 10 C.F.R. §§ 603.525-555.

7. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

Because FFRDCs are funded by the Federal Government, costs incurred by FFRDCs generally may not be used to meet the cost share requirement. FFRDCs may contribute cost share only if the contributions are paid directly from the contractor's Management Fee or a non-Federal source.

Because GOGOs/Federal Agencies are funded by the Federal Government, GOGOs/Federal Agencies may not provide cost share for the proposed project. However, the GOGO/Agency costs would be included in Total Project Costs for purposes of calculating the cost-sharing requirements of the Applicant.

8. COST SHARE VERIFICATION

Upon selection for award negotiations, Applicants are required to provide information and documentation regarding their cost share contributions. Please refer to Section VI.B of the FOA for guidance on the requisite cost share information and documentation.

C. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper complies with the content and form requirements in Section IV.C of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Concept Papers found to be noncompliant will not be merit reviewed or considered for award. ARPA-E will not review or consider noncompliant Concept Papers, including Concept Papers submitted through other means, Concept Papers submitted after the applicable deadline, and incomplete Concept Papers. A Concept Paper is incomplete if it does not include required information. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Full Applications are deemed compliant if:

- The Applicant submitted a compliant and responsive Concept Paper;
- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.D of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Full Applications found to be noncompliant will not be merit reviewed or considered for award. ARPA-E will not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploads its response to ARPA-E eXCHANGE by the deadline stated in the FOA.
- The Replies to Reviewer Comments comply with the content and form requirements of Section IV.E of the FOA.

ARPA-E will not review or consider noncompliant Replies to Reviewer Comments, including Replies submitted through other means and Replies submitted after the applicable deadline. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information due to server/connection congestion. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be noncompliant.

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Concept Papers and Full Applications. The following types of submissions may be deemed nonresponsive and may not be reviewed or considered:

- Submissions that fall outside the technical parameters specified in Section I.E of the FOA

- Submissions that have been submitted in response to other currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from those submitted in response to other currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.
- Submissions that describe a technology but do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. Submissions Specifically not of Interest

Submissions that propose the following will be deemed nonresponsive and will not be merit reviewed or considered:

- Technologies already well understood or commercially implemented,
- Technologies that rely solely on modification of vehicular propulsion systems, or the development or improvement of engines, transmissions, energy conversion devices, energy storage technologies, components or advanced computational capability alone,
- Technologies that offer fuel or energy efficiency improvements through (human) driving behavior modification alone,
- Energy efficiency optimization as applied to a L4 vehicle,
- Solutions that only take into account vehicle-level longitudinal (or vehicle dynamic) control or driver behavior optimization without regard for optimized powertrain operation,
- Technologies that rely solely upon collaborative vehicle behavior, such as platooning, without the modification of individual vehicle and powertrain energy efficiency,
- Technologies that rely solely upon enhanced navigation, such as eco-routing or congestion avoidance, without the modification of individual vehicle and powertrain energy efficiency,

- Technologies that rely upon mobility sharing services, ridesharing, shared ownership or 'mobility on demand' services,
- Technologies such as transportation mode shifting, transportation network optimization, air travel, rail, transit services or marine transportation,
- Technologies for reducing individual vehicle fuel or energy consumption, such as hybridization, electrification, fuel shifting or alternative fuel substitution, weight reduction, aerodynamic drag reduction, rolling resistance improvements, waste energy recovery and parasitic load and friction reduction,
- Technologies that use vehicle connectivity exclusively for safety, accident avoidance, navigation, driver notification, congestion mitigation, traffic management system operation or interaction, or infotainment, without any energy efficiency implications, or
- Technologies pertaining to cybersecurity, policy issues, human factors or the human machine interface (HMI).

4. Limitation on Number of Applications

ARPA-E is not limiting the number of applications that may be submitted by Applicants. Applicants may submit more than one application to this FOA, provided that each application is scientifically distinct.

IV. Application and Submission Information

A. Application Process Overview

1. Registration in ARPA-E eXCHANGE

The first step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.H.1 of the FOA and the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. Concept Papers

Applicants must submit a Concept Paper by the deadline stated in the FOA. Section IV.C of the FOA provides instructions on submitting a Concept Paper.

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Concept Papers found to be noncompliant or nonresponsive will not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria in Section V.A.1 of the FOA.

ARPA-E will encourage a subset of Applicants to submit Full Applications. Other Applicants will be discouraged from submitting a Full Application in order to save them the time and expense of preparing an submission that is unlikely to be selected for award negotiations. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

3. Full Applications

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 30 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Full Applications found to be noncompliant or nonresponsive will not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria in Section V.A.2 of the FOA.

4. Reply to Reviewer Comments

Once ARPA-E has completed its review of Full Applications, reviewer comments on compliant and responsive Full Applications are made available to Applicants via ARPA-E eXCHANGE. Applicants may submit an optional Reply to Reviewer Comments, which must be submitted by the deadline stated in the FOA. Section IV.E of the FOA provides instructions on submitting a Reply to Reviewer Comments.

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.C.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

5. Pre-Selection Clarifications and "Down-Select" Process

Once ARPA-E completes its review of Full Applications and Replies to Reviewer Comments, it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings and site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for funding and make awards without pre-selection meetings and site visits. Participation in a pre-selection meeting or site visit with ARPA-E does not signify that Applicants have been selected for award negotiations.

6. SELECTION FOR AWARD NEGOTIATIONS

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

7. MANDATORY WEBINAR

All selected Applicants, including the Principal Investigator and the financial manager for the project, are required to participate in a webinar that is held within approximately one week of the selection notification. During the webinar, ARPA-E officials present important information on the award negotiation process, including deadlines for the completion of certain actions.

B. APPLICATION FORMS

Required forms for Full Applications are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov), including the SF-424 and Budget Justification Workbook/SF-424A. A sample Summary Slide is available on ARPA-E eXCHANGE. Applicants may use the templates available on ARPA-E eXCHANGE, including the template for the Concept Paper, the template for the Technical Volume of the Full Application, the template for the Summary Slide, the template for the Summary for Public Release, the template for the Reply to Reviewer Comments, and the template for the Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form is available on ARPA-E eXCHANGE.

C. Content and Form of Concept Papers

The Concept Paper is mandatory (i.e. in order to submit a Full Application, a compliant and responsive Concept Paper must have been submitted) and must conform to the following formatting requirements:

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11-inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.
- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category, Proposed Funding Requested (Federal and Cost Share), and Project Duration.

Concept Papers found to be noncompliant or nonresponsive will not be merit reviewed or considered for award (see Section III.C of the FOA).

Each Concept Paper should be limited to a single concept or technology. Unrelated concepts and technologies should not be consolidated into a single Concept Paper.

A fillable Concept Paper template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

Concept Papers must conform to the content requirements described below. If Applicants exceed the maximum page length indicated above, ARPA-E will review only the authorized number of pages and disregard any additional pages:

1. Concept Paper

a. Concept Summary

- Describe (with minimal jargon) the proposed concept for the vehicle dynamic and powertrain (VD&PT) control technology (the "Technology") to be developed for connected and automated vehicles under the NEXTCAR Program, and explain how it addresses the Program Objectives of the FOA.

b. INNOVATION

- Clearly identify the particular vehicle energy consumption problem to be solved with the proposed Technology.
- Describe how the proposed Technology represents an innovative and potentially transformational solution to the technical challenges posed by the FOA.
- Explain how the Technology will utilize vehicle connectivity and automation to achieve the projected vehicle energy consumption improvements required, for the selected target baseline vehicle and class.
- To the extent possible, provide quantitative metrics (in a table) that compare the proposed Technology to current technologies and to the technical performance targets in Section I.E of the FOA.
- Applicants must focus on describing their specific technological innovation for achieving the Technical Performance Targets specified in Section I.E of the FOA. (The energy savings and CO_2 reduction potential of CAVs are well established and should not be addressed).
- Applicants should not compare the energy efficiency of different vehicle technology types; the technical impact of any proposed Technology should be evaluated relative to the chosen 2016 baseline vehicle (for example, an application proposing a VD&PT controls Technology for an EV should not draw a comparison with an ICV).

c. PROPOSED WORK

- Describe the final deliverable(s) for the project and the overall technical approach that will be used to achieve the project objectives.
- Describe the anticipated overall Technology development effort including a brief description of all the tasks required to be performed for the successful design and development of the Technology.
- Describe how simulation, testing and validation of the Technology will be performed, including detail on the resources available for these tasks.

- Describe why the proposed effort is a significant technical challenge and describe the key technical risks to the project. Describe how technical risk will be mitigated.

- Identify techno-economic challenges to be overcome for the proposed Technology to be commercially relevant and viable. Provide an estimate for the final anticipated commercial cost of the Technology, upon deployment.

d. Team Organization and Capabilities

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.

- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.

- Identify key capabilities (including experience in automotive control technology, design, development, testing, validation and commercialization) provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.

- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort

D. Content and Form of Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

E. Content and Form of Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

F. Intergovernmental Review

This Program is not subject to Executive Order 12372 (Intergovernmental Review of Federal Programs).

G. Funding Restrictions

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Concept Papers, Full Applications, and Replies to Reviewer Comments must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E will not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications will be deemed noncompliant (see Section III.C.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;
- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

ARPA-E urges Applicants to carefully review their applications and to allow sufficient time for the submission of required information and documents.

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Concept Papers and Full Applications to determine whether they are compliant and responsive (see Section III.C of the FOA). ARPA-E also performs a preliminary review of Replies to Reviewer Comments to determine whether they are compliant.

ARPA-E considers a mix of quantitative and qualitative criteria in determining whether to encourage the submission of a Full Application and whether to select a Full Application for award negotiations.

1. CRITERIA FOR CONCEPT PAPERS

(1) *Impact of the Proposed Technology Relative to FOA Targets* (50%) - This criterion involves consideration of the following:

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- The extent to which the proposed concept is innovative and will achieve the Technical Performance Targets defined in Section I.E of the FOA; and

- The extent to which the Applicant demonstrates awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

(2) *Overall Scientific and Technical Merit* (50%) - This criterion involves consideration of the following factors:

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;

- The extent to which the Applicant proposes a sound technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;

- The extent to which project outcomes and final deliverables are clearly defined;

- The extent to which the Applicant identifies techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and

- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement. The above criteria will be weighted as follows:

Impact of the Proposed Technology Relative to FOA Targets	50%
Overall Scientific and Technical Merit	50%

2. Criteria for Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

3. Criteria for Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

B. Review and Selection Process

1. Program Policy Factors

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Concept Papers to encourage to submit a Full Application and which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity (including gender) of technical personnel in the proposed Project Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;
   e. Technical or commercialization risk; or
   f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
   a. Reduction of US dependence on foreign energy sources;
   b. Stimulation of domestic manufacturing;
   c. Reduction of energy-related emissions;
   d. Increase in U.S. energy efficiency;
   e. Enhancement of U.S. economic and energy security; or
   f. Promotion of U.S. advanced energy technologies competitiveness.

III. **Synergy of Public and Private Efforts**.
   a. Avoids duplication and overlap with other publicly or privately funded projects;
   b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
   c. Increases unique research collaborations.

IV. **Low likelihood of other sources of funding.** High technical and/or financial uncertainty that results in the non-availability of other public, private or internal funding or resources to support the project.

V. **High-Leveraging of Federal Funds**. Project leverages Federal funds to optimize advancement of programmatic goals by proposing cost share above the required minimum or otherwise accessing scarce or unique resources.

VI. **High Project Impact Relative to Project Cost.**

2. ARPA-E Reviewers

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

3. ARPA-E Support Contractor

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. Anticipated Announcement and Award Dates

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

VI. Award Administration Information

A. Award Notices

1. Rejected Submissions

Noncompliant and nonresponsive Concept Papers and Full Applications are rejected by the Contracting Officer and are not merit reviewed or considered for award. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Concept Paper or Full Application was rejected.

2. Concept Paper Notifications

ARPA-E promptly notifies Applicants of its determination to encourage or discourage the submission of a Full Application. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. ARPA-E provides feedback in the notification letter in order to guide further development of the proposed technology.

Applicants may submit a Full Application even if they receive a notification discouraging them from doing so. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. The purpose of the Concept Paper phase is to save Applicants the considerable time and expense of preparing a Full Application that is unlikely to be selected for award negotiations.

A notification letter encouraging the submission of a Full Application does not authorize the Applicant to commence performance of the project. Please refer to Section IV.G. of the FOA for guidance on pre-award costs.

3. Full Application Notifications

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN JULY 2016]

VII. Agency Contacts

A. Communications with ARPA-E

Upon the issuance of a FOA, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- ARPA-E will cease to accept questions approximately 5 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted approximately one business day in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- Responses are posted to "Questions and Answers" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants as necessary and appropriate. As described in Section VII.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. ARPA-E provides Applicants with a notification encouraging or discouraging the submission of a Full Application based on ARPA-E's assessment of the Concept Paper. In addition, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. Other Information

A. FOAs and FOA Modifications

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

B. Obligation of Public Funds

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

C. Requirement for Full And Complete Disclosure

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Concept Paper, Full Application, and/or Reply to Reviewer Comments;
- The termination of award negotiations;
- The modification, suspension, and/or termination of a funding agreement;
- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and
- Civil and/or criminal penalties.

D. RETENTION OF SUBMISSIONS

ARPA-E expects to retain copies of all Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

E. MARKING OF CONFIDENTIAL INFORMATION

ARPA-E will use data and other information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information must be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Concept Paper, Full Application, Reply to Reviewer Comments, or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

> Notice of Restriction on Disclosure and Use of Data:
>
> Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

F. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions. If they elect to retain title, they must file a patent application in a timely fashion.

- All other parties: The Federal Non-Nuclear Energy Act of 1974, 42. U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below)*.

- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues "class patent waivers" under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20% may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.

- GOGOs are subject to the requirements of 37 CFR Part 501.

G. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. GOVERNMENT USE LICENSE

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. MARCH-IN RIGHTS

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;
- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner;
- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner; or
- The U.S. Manufacturing requirement has not been met.

3. U.S. Manufacturing Requirement

ARPA-E requires that awards address whether products embodying or produced through the use of subject inventions (i.e., inventions conceived or first actually reduced to practice under ARPA-E funding agreements) are to be substantially manufactured in the United States by Project Teams and their licensees. The requirement varies depending upon whether an awardee is a small business, University or other type of awardee. The Applicant may request a modification or waiver of the U.S. Manufacturing Requirement.

H. Rights in Technical Data

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

I. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

Applicants may not include any Protected Personally Identifiable Information (Protected PII) in their submissions to ARPA-E. Protected PII is defined as data that, if compromised, could cause harm to an individual such as identity theft. Listed below are examples of Protected PII that Applicants must not include in their submissions.

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;
- Mother's maiden name associated with an individual;
- Biometric record associated with an individual;
- Fingerprint;
- Iris scan;
- DNA;
- Medical history information associated with an individual;
- Medical conditions, including history of disease;
- Metric information, e.g. weight, height, blood pressure;
- Criminal history associated with an individual;
- Ratings;
- Disciplinary actions;
- Performance elements and standards (or work expectations) are PII when they are so intertwined with performance appraisals that their disclosure would reveal an individual's performance appraisal;
- Financial information associated with an individual;
- Credit card numbers;
- Bank account numbers; and
- Security clearance history or related information (not including actual clearances held).

J. COMPLIANCE AUDIT REQUIREMENT

A prime recipient organized as a for-profit entity expending $750,000 or more of DOE funds in the entity's fiscal year (including funds expended as a Subrecipient) must have an annual compliance audit performed at the completion of its fiscal year. For additional information, refer to Subpart F of: (i) 2 C.F.R. Part 200, and (ii) 2 C.F.R. Part 910.

If an educational institution, non-profit organization, or state/local government is either a Prime Recipient or a Subrecipient, and has expended $750,000 or more of Federal funds in the entity's fiscal year, the entity must have an annual compliance audit performed at the completion of its fiscal year. For additional information refer to Subpart F of 2 C.F.R. Part 200.

IX. Glossary

Applicant: The entity that submits the application to ARPA-E. In the case of a Project Team, the Applicant is the lead organization listed on the application.

Application: The entire submission received by ARPA-E, including the Concept Paper, Full Application, and Reply to Reviewer Comments.

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency within the U.S. Department of Energy.

Cost Sharing: is the portion of project costs from non-Federal sources that are borne by the Prime Recipient (or non-Federal third parties on behalf of the Prime Recipient), rather than by the Federal Government.

Deliverable: A deliverable is the quantifiable goods or services that will be provided upon the successful completion of a project task or sub-task.

DOE: U.S. Department of Energy.

DOE/NNSA: U.S. Department of Energy/National Nuclear Security Administration

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

GOCOs: U.S. Government Owned, Contractor Operated laboratories.

GOGOs: U.S. Government Owned, Government Operated laboratories.

Milestone: A milestone is the tangible, observable measurement that will be provided upon the successful completion of a project task or sub-task.

Prime Recipient: The signatory to the funding agreement with ARPA-E.

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing inventive supportive work that is part of an ARPA-E project.

Standalone Applicant: An Applicant that applies for funding on its own, not as part of a Project Team.

Subject Invention: Any invention conceived or first actually reduced to practice under an ARPA-E funding agreement.

Task: A task is an operation or segment of the work plan that requires both effort and resources. Each task (or sub-task) is connected to the overall objective of the project, via the achievement of a milestone or a deliverable.

Total Project Cost: The sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

TT&O: Technology Transfer and Outreach. (See Section IV.G. of the FOA for more information).

X. APPENDIX 1

1.1 List of Abbreviations

ACC	adaptive cruise control
ADAS	advanced driver assistance systems
AERIS	Applications for the Environment: Real-time Information Synthesis
ARPA-E	Advanced Research Projects Agency - Energy
BEV	battery electric vehicle
CACC	cooperative adaptive cruise control
CAFE	corporate average fuel economy
CAVs	connected and automated vehicles
CO	carbon monoxide
CO_2	carbon dioxide
DOE	Department of Energy
DOT	Department of Transportation
DP	dynamic programming
DPF	diesel particulate filter
DSRC	dedicated short range communications
Eco-AND	eco-approach and departure at signalized intersections application
EIA	Energy Information Administration
EGR	exhaust gas recirculation
EPA	Environmental Protection Agency
ESS	energy storage system
FOA	Funding Opportunity Announcement
FCV	fuel cell vehicle
FMVSS	Federal Motor Vehicle Safety Standards
GHG	greenhouse gas
GID	geographic information description
GPS	global positioning system
GVW	gross vehicle weight
HC	hydrocarbons
HD	heavy duty
HEV	hybrid electric vehicle
HMI	human machine interface
HWFET	highway fuel economy test
ICV	internal combustion vehicle
L0	no automation (see the appropriate DOT/NHTSA definition)

L1	function-specific automation (see the appropriate DOT/NHTSA definition)
L2	combined function automation (see the appropriate DOT/NHTSA definition)
L3	limited self-driving automation (see the appropriate DOT/NHTSA definition)
L4	full self-driving automation (see the appropriate DOT/NHTSA definition)
LD	light-duty
LIDAR	light detection and ranging
MD	medium-duty
MIMO	multiple-input-multiple-output
MPG	miles per gallon
MY	model year
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NOx	nitrogen oxides
NVH	noise vibration and harshness
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
RFI	request for information
SOC	state of charge
SPaT	signal phase and timing
SPD-HARM	speed harmonization
TEA	techno-economic analysis
UDDS	Urban Dynamometer Driving Schedule
V2C	vehicle-to-cloud communications
V2I	vehicle-to-infrastructure communications
V2V	vehicle-to-vehicle communications
V2X	vehicle-to-vehicle, vehicle-to-infrastructure & vehicle-to-cloud communications
VD&PT	vehicle dynamic and powertrain
VMT	vehicle miles traveled

1.2 Nomenclature

- **Powertrain** can include a vehicle's engine, transmission, and any propulsive electric machine(s) and associated energy storage and conversion systems, where applicable.
- **Powertrain control** refers to the control of powertrain systems to produce the required output power, performance, efficiency and (potentially) emissions over a range of timescales and environmental and operating conditions. For example, in HEVs or PHEVs, powertrain control would include the operation of the engine, the electric machines for

propulsion or energy regeneration, and the resultant energy and power flows to and from the energy storage system, including through regenerative braking.

- **Optimization** refers in this context to the minimization of instantaneous and/or integrated energy usage or emissions, subject to a number of constraints in operation.
- **Full vehicle control** (or **vehicle dynamic control**) refers to the control of vehicle longitudinal and lateral dynamics through the operation of safety critical inputs such as accelerator (throttle), brake, transmission control and steering. It also includes such active dynamic control features as vehicle stability control and traction control.
- **Vehicle efficiency** refers to the reduction in the total amount of energy utilized by a vehicle to perform a certain operation or duty cycle. This energy may either be derived from a liquid or gaseous fuel or some other form of energy generated or stored on-board the vehicle. 'Fuel efficiency' typically applies to conventional ICVs or FCVs, while 'energy efficiency' may be applicable to HEVs, PHEVs, BEVs and FCVs.
- **Connectivity** in the context of this FOA includes the communication of high bandwidth, localized information such as that obtained through vehicle-to-vehicle (V2V) communication protocols such as DSRC (Dedicated Short Range Communications), and/or higher latency information obtained through vehicle-to-infrastructure communications (V2I). Vehicle connectivity is at present being developed primarily for safety and collision avoidance (in the case of V2V) and navigation and infotainment (for V2X). Connectivity, along with enhanced on-board sensors (primarily to allow for machine vision and proximity sensing of fixed or moving objects), will allow for advanced levels of vehicle dynamic control automation. V2V is considered to include high bandwidth, low latency communications for secure, safety critical short- to medium-range information exchange, such as DSRC. V2X is considered to include vehicle-to-cloud (V2C) communications, at higher bandwidths but with greater latency, and is assumed to include cellular, Wi-Fi and satellite communications.
- **Automation**. Applicants are referred to the NHTSA definitions[44] of vehicle **automation** levels, viz., L0 (no automation), L1 (function-specific automation), L2 (combined function automation), L3 (limited self-driving automation) and L4 (full self-driving automation) are adopted in this FOA. Automated vehicles are assumed to rely on an array of on-board sensors (such as stereoscopic cameras for machine vision, radar, LIDAR, and acoustic/ultrasonic sensors) and additional off-board-derived information to enable fully automated machine-derived decision-making, operation and navigation.
- **Connected and Automated Vehicle (CAV) Operation**. Using a combination of advanced sensors and controls, connectivity, and mapping and navigation technologies, CAVs are able to employ communication and automation capabilities in support of a specific set of vehicle operating applications. A more detailed treatise on various operating applications within the CAV framework such as platooning, eco-routing, dynamic speed harmonization (SPD-HARM), cooperative adaptive cruise control (CACC), eco-signal

[44] http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf

compliance, eco-approach and departure at signalized intersections, and many more can be found in Hill[45] (and in Tables 1 and 2 below).

- **Cooperative (Collaborative) Vehicle Operation**: The combination of advanced connectivity, machine vision, sophisticated data fusion methods and machine-based decision-making will facilitate the automation of individual vehicle dynamic controls. A further set of computational and communications advancements will allow a group or cohort of vehicles in close proximity to collaborate in their operation, in order to facilitate improved traffic flow, for example. In one case, a target vehicle may communicate with a collection of N surrounding vehicles that are performing a shared or cooperative task, where the task being performed depends on the application set (e.g., SPD-HARM) and the type of infrastructure (roadway) being utilized.
- **Individual (Isolated) Vehicle Operation**: The target vehicle operates based on a specific target (e.g., maintaining a desired speed on a specific roadway) and reacts to the actions of surrounding vehicles without performing a shared task with those vehicles.
- **LD, MD and HD Vehicles**: The Federal Highway Administration (FHWA) classifies vehicles as LD, MD and HD based on Gross Vehicle Weight Rating (GVWR)[46]. LD vehicles include vehicles in Class-1 (<6,000 lbs) and Class-2 (6,001-10,000 lbs). MD vehicles include vehicles in Class-3 (10,001-14,000 lbs), Class-4 (14,001-16,000 lbs), Class-5 (16,001-19500 lbs) and Class-6 (19,501-26,000 lbs). Finally, HD vehicles include vehicles in Class-7 (26,001-33,000 lbs) and Class-8 (>33,000 lbs). EPA has an extensive classification of vehicles for emission regulation and fuel economy certification purposes, which fall under two generic vehicle classes i.e. LD vehicles and HD vehicles and engines[5]. All of the above vehicle classes (LD, MD and HD) will be considered in this Program.

[45] https://www.pcb.its.dot.gov/eprimer/documents/module13.pdf
[46] http://www.afdc.energy.gov/data/10380