FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

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

REDUCING EMISSIONS OF METHANE EVERY DAY OF THE YEAR (REMEDY)

METHANE EMISSIONS ABATEMENT PROGRAM

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002504
CFDA Number 81.135

Funding Opportunity Announcement (FOA) Issue Date:	April 8, 2021
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, May 11, 2021
Submission Deadline for Concept Papers:	9:30 AM ET, May 21, 2021
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	9:30 AM 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 $35 million, subject to the availability of appropriated funds to be shared between FOAs DE-FOA-0002504 and DE-FOA-0002505.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $1M and $5M.

- 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).

- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 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 7 pages in length including graphics, figures, and/or tables (except the required Gantt Chart and the optional LCA and LCCA spreadsheets) and must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities	Mandatory	IV.C	9:30 AM ET, May 21, 2021
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]	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), as further amended by the Energy Act of 2020 (P.L. 116-260) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that—
(i) reduce imports of energy from foreign sources;
(ii) reduce energy-related emissions, including greenhouse gases;
(iii) improve the energy efficiency of all economic sectors;
(iv) provide transformative solutions to improve the management, clean-up, and disposal of radioactive waste and spent nuclear fuel; and
(v) improve the resilience, reliability, and security of infrastructure to produce, deliver, and store energy; 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 its 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 supplemented by 2 C.F.R. Part 910.

ARPA-E funds research on and the development of transformative science and technology solutions to address the energy and environmental missions of the Department. 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 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 an "original investigation undertaken in order to acquire new knowledge…directed primarily towards a specific practical aim or objective" and defines "experimental development" as "creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products or processes or improving existing products or processes."[1] Applicants interested in receiving financial assistance for basic research (defined by the Office of Management and Budget as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts")[2] 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 early-stage R&D for the improvement of technology along defined roadmaps may be more appropriate for support through the DOE applied energy offices including: 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://www.energy.gov/ne/office-nuclear-energy), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

1. INTRODUCTION

REMEDY (Reducing Emissions of Methane Every day of the Year) is a 3-year, $35MM research program to reduce methane emissions from three sources in the oil, gas, and coal value chain. The goal is to reverse the rate of accumulation of methane in the atmosphere, decrease

[1] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.
[2] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.

atmospheric methane concentration, and thus ameliorate climate change. The target sources are:

- Exhaust from natural gas-fired lean-burn engines, used to drive compressors, generate electricity, and increasingly, repower ships;
- Flares required for safe operation of oil and gas facilities; and
- Coal mine ventilation air methane (VAM) exhausted from operating underground mines.

These sources are responsible for at least 10% of US anthropogenic methane emissions.

The REMEDY program seeks highly replicable system-level technical solutions that achieve an overall methane conversion of 99.5%, reduce net greenhouse gas emissions > 87% on a life-cycle basis, have a levelized cost of carbon less than $40/ton CO_2^e, and address techno-economic issues related to commercialization. Systems must incorporate technologies that can operate at lean- and ultra-lean methane concentrations integrated with sensors and/or control algorithms to quantify emission reduction and ensure consistent operation. Stage 1 of the program will be used to screen concepts, and projects selected to continue in Stage 2 will confirm metrics in a limited field test or larger, extended-lab-scale test.

The REMEDY program addresses methane, a powerful greenhouse gas, and complements programs focused on CO_2 reduction. REMEDY metrics will facilitate comparison of methane reduction processes with CO_2 reduction processes.[3,4] REMEDY augments and extends but will not duplicate existing initiatives focused on methane reduction, such as the Environmental Protection Agency (EPA) Natural Gas Star program and Coalbed Methane Outreach Program (CMOP), the DOE Fossil Energy Flare Reduction program, and the Oil and Gas Climate Initiative. Recovery or conversion to high-value products is allowed, provided techno-economic and environmental metrics are met.

2. SCOPE, SCHEDULE, AND BUDGET

ARPA-E's mission includes reducing energy-related emissions. The 2018 EPA Greenhouse Gas Inventory (GHGI) shows anthropogenic methane emissions of 634 MM ton CO_2^e using a greenhouse gas warming potential (GWP) of 25. These methane emissions account for 10% of US anthropogenic greenhouse gas emissions.[5] REMEDY addresses three emission sources associated with the fossil energy value chain: exhaust from natural gas-fired lean-burn engines, flares required for safe operation of oil and gas equipment, and coal mine VAM exhaust, that collectively account for at least 60 MM ton CO_2^e/yr.

[3] See, e.g., https://netl.doe.gov/projects/files/CostandPerformanceofBituminousCoalandNGPlantswithCCSRev4_091020.pdf.
[4] Gillingham, K. and Stock, J.H., "The Cost of Reducing Greenhouse Gas Emissions", J Economic Perspectives, Vol. 32 (4), p. 73-72, Fall 2018.
[5] Inventory of U.S. Greenhouse Gas Emissions Sinks: 1990-2018, *EPA Report*, April 2020, https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf.

The three sources share several common attributes:

- They are an inherent feature of the fossil energy value chain. Natural gas-fired lean-burn engines are used to drive compressors in the oil and gas upstream and midstream sectors; generate electricity at power and combined heat and power facilities; and provide propulsion for ships, ferries, and barges in the marine sector. Flares are required for safe operation of oil and gas facilities. VAM systems are required for safe operation of underground coal mines.

- These sources have a high potential to be addressed with replicate system-level solutions. There are ~50,000 natural gas-fired lean-burn engines, approximately 300,000 flares, and 239 active coal mines with VAM. A solution for one engine, flare, or mine can be readily translated across the entire cohort. REMEDY seeks system-level solutions that leverage replication of engineering, development of product line families, and economies of fabrication/numbers (i.e., making large numbers of similar devices) vs economies of scale (i.e., making larger size units) to drive down unit costs.

- They require technologies that operate in lean- and ultra-lean methane concentration ranges in order to achieve 99.5% methane conversion. The core methane reduction technologies and sensors associated with control algorithms and emission quantification reduction need to operate at methane concentrations below 10,000 parts per million (ppm).

- There has been relatively little R&D investment in reducing methane emissions from these sources.

REMEDY submissions and teams will preferably include: a complete system, technologies that can operate at lean- and ultra-lean methane concentrations, integrated sensors and/or control algorithms to quantify emission reduction and ensure consistent operation, and team members with manufacturing and operations expertise. Commercialization of REMEDY technologies will require that components be integrated to create comprehensive service offerings by parties who are familiar with the respective requirements of their customers. Submissions that do not include a complete system will need to describe their plans for integrating their proposed methane abatement technology into comprehensive systems, through partnerships or other commercialization plans, in order to qualify for the second stage of the program. Teams that lack manufacturing or operations expertise will need to describe their plans to develop and refine capital and operating cost inputs during the execution of the project.

The program has two stages. Submissions need to discuss project plans and budgets for both stages. In Stage 1, performers will test their technology in a lab setting, confirm operation of instruments and control systems, establish that the system meets Stage 1 performance metrics, and address techno-economic issues. For Stage 1, the intent is to fund 10-14 teams for a 12-18 month period, with a budget of $1-2MM per team.

At the conclusion of Stage 1, project teams interested in proceeding to Stage 2 will be required to submit the following to ARPA-E:

- Detailed Stage 2 system engineering specifications/design
- Updated Stage 2 scope/schedule/budget, including status of field test site selection and permitting (if required); and time to procure, build, and install the Stage 2 system.

Deliverables mentioned above will be assessed against the merit review criteria in Section V.A. of the FOA, in consideration of the following:

- Successful achievement of technical and commercialization milestones for Stage 1
- Compliance with all award terms and requirements
- Evidence that the teams are meeting performance metrics and addressing techno-economic issues discussed in Section I.C.5

Projects selected for Stage 2 will test and validate their integrated systems using a limited field test or similarly scaled larger, extended-scale laboratory test. ARPA-E assumes that there may be additional tasks, such as modeling and further lab-based testing, that run in parallel with such testing. The system will be assessed against more stringent Stage 2 metrics, and teams are expected to address the techno-economic issues with more detailed analysis and/or experimental results. The intent is to fund 4-7 teams for a total duration of 36 months (the total of both stages), with an additional budget of $2-3MM per team for Stage 2 (in addition to the respective team's Stage 1 budget).

The scope of the REMEDY program is intended to avoid duplication of current initiatives to reduce methane emissions across the fossil energy value chain. The oil and gas sector have voluntary partnerships such as the EPA's Natural Gas Star and Oil and Gas Climate Initiative. The focus of these programs includes leak detection, reducing fugitive emissions from valves and compressors, eliminating pneumatic vents, and developing best practices for operation and maintenance to reduce process upsets. DOE Fossil Energy has programs to reduce associated gas flaring that results when oil wells are put into production before gas infrastructure is available. Within the coal industry, the EPA's voluntary Coalbed Methane Outreach Program (CMOP) promotes methane recovery/utilization projects and VAM emission reduction using commercial technologies such as state-of-the-art Reversible Thermal Oxidizers (RTO). Submissions covering commercial technology, incremental improvements to existing processes, or duplicating the efforts of these programs are outside the scope of the REMEDY program.

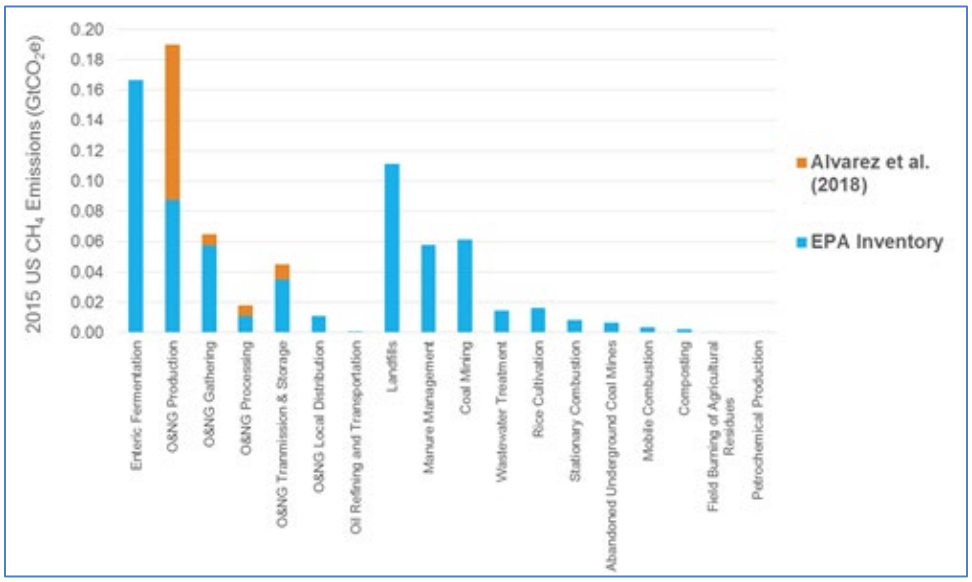
3. IMPACT

The REMEDY program is intended to reduce US anthropogenic methane emissions by 10% in the near term. As noted above, methane is a powerful greenhouse gas. Although ARPA-E uses the EPA's 100-year GWP of 25 for methane, shorter term methane GWP is ~ 80.[6] Using the higher GWP, the REMEDY program targets emissions greater than 150 MM ton/yr CO_2^e.

REMEDY addresses technically challenging methane emissions from the fossil energy (oil, gas, and coal) value chains (production, transmission, distribution, and use). Numerous studies show methane emissions from oil and gas operations may be underestimated during normal operations and as a result of normal and upset conditions.[7,8,9,10] For example, Figure 1, below, shows Alvarez, et al. estimations for oil and gas methane emissions compared to the GHGI.

[6] P. Balcombe, *et al.,* "Methane Emissions: Choosing the Right Climate Metric and Time Horizon", Environ. Sci.: Processes Impacts, Vol. 20, p. 1323–1339, 2018.
[7] Alvarez, *et al*., "Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain", Science, Vol. 361, p. 186-188, 2018.
[8] Pandey, *et al*., "Satellite Observations Reveal Extreme Methane Leakage from a Natural Gas Well Blowout", Proceedings of the National Academy of Sciences, Vol. 116(52), p. 26376-26381, 2019.
[9] Duren, *et al*., "California's Methane Super-emitters", Nature, Vol. 575(7781), p. 180-184, 2019.
[10] Heath, *et al*., https://www.nrel.gov/docs/fy19osti/68478.pdf.

Figure 1 Methane emissions by EPA(5) and Alvarez(7)



The coal value chain also releases methane. VAM emissions, which are not required to be treated, account for 70% of all coal mining methane emissions.[11]

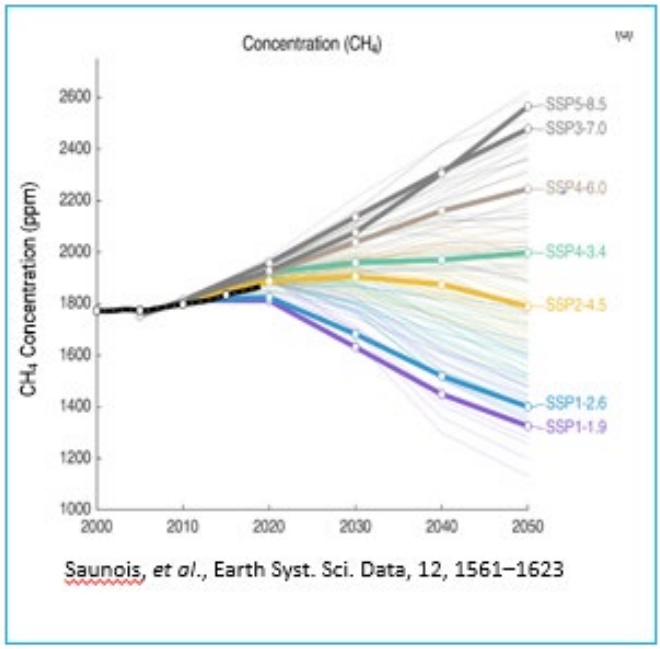
Technologies supported under the REMEDY program should have replicable engineering and hardware design bases; that is, the goal of these technologies is that commercialization should not require bespoke solutions. Rapid commercialization is promoted by economies of fabrication/numbers drive down unit costs. These features will facilitate deployment and a near-term decrease in methane emissions. Consequently, commercialization of REMEDY systems can proceed quickly.

As discussed by Saunois et al., reducing methane emissions 10-20% can begin to reverse the concentration of methane in the atmosphere, as shown in Figure 2, below.[12] The Saunois paper quantifies natural sinks in the atmosphere and soil that remove the majority of methane emissions. Increases in anthropogenic sources since the start of the Industrial Age have resulted in net accumulation of methane in the atmosphere, increasing its concentration 260% to ~2 ppm. Saunois notes that due to natural sinks, stabilization or reduction in methane emissions can lead to a rapid decline in atmospheric methane concentration. Consequently, it is not necessary to eliminate all methane emissions to have an immediate impact on atmospheric methane concentration.

[11] CMOP Webinar - Ventilation Air Methane Projects in the United States: Barriers and Potential Opportunities, Feb 27, 2020, https://www.epa.gov/cmop/ventilation-air-methane-vam-projects-united-states-barriers-and-potential-opportunities.

[12] Saunois, *et al.*, "The Global Methane Budget 2000-2017", Earth Syst. Sci. Data, Vol. 12, p. 1561–1623, 2020, https://doi.org/10.5194/essd-12-1561-2020.

Figure 1 Scenarios to Decrease Atmospheric Methane Concentration (12)



4. State of the Art for Methane Oxidation

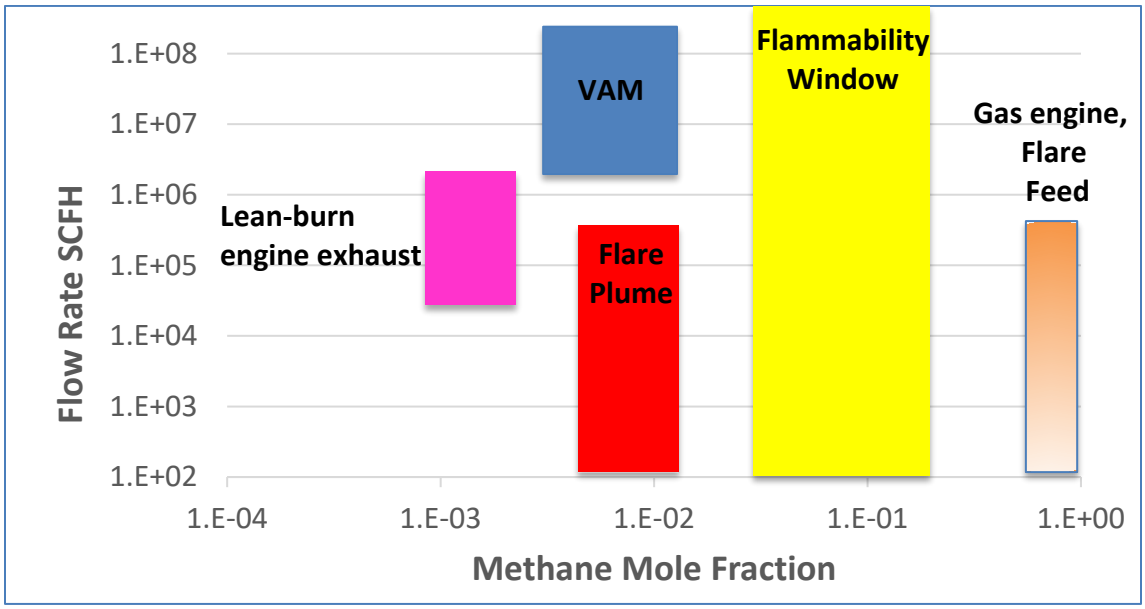
One metric for REMEDY systems is 99.5% methane conversion. The state of the art conversion efficiencies across the three target sources vary. Natural gas-fired lean-burn engines "slip" 2-5% of the inlet fuel into the exhaust gas,[13] resulting in a state of the art conversion efficiency of 95-98%. Per the EPA's AP-42 Compilation of Air Pollutant Emission Factors, flares meeting EPA design specifications are presumed to have 98% combustion efficiency.[14] VAM system are designed for mine safety; methane emissions are not required to be controlled; the state of the art VAM methane conversion is zero.

To achieve 99.5% methane conversion, REMEDY systems will need to react methane in lean- and ultra-lean conditions. Figure 3, below, shows methane concentration and flow rates for the three sources. The colors in Figure 3 are intended to reflect temperature: VAM at ambient temperature, engine exhaust 450-500 °C, and flare plume > 1000 °C. Methane emission concentrations fall below the lower flammability limit for all three sources. Meeting this 99.5% methane conversion metric will require extending oxidation or conversion reactions to lean- or ultra-lean conditions.

[13] Stenersen, *et al.*, "GHG and NOx Emissions from Gas Fueled Engines", Report from SINTEF Ocean AS, 2017.
[14] See https://www3.epa.gov/ttnchie1/ap42/ch13/final/c13s05.pdf.

Figure 3 also shows that gas flow rates can range over a wide range for each of the three sources, suggesting that multiple system designs may be required for each of the three sources.

Figure 2 Methane Concentration and Gas Flow Rate for Lean-burn Engines, Flares, and VAM



Air permits place limits on criteria pollutants[15], but methane is specifically excluded from limits on volatile organic compounds (VOC) in Federal[16] and most state regulations, with the notable exception of California. Given the limited legal/regulatory emphasis on methane emissions, there has been little incentive to reduce methane emissions from the target sources, or to develop new technologies. In parallel, there have been relatively few related R&D programs. Consequently, there are no commercial technologies that guarantee 99.5% methane conversion for gas-fired lean-burn engines, flares, or VAM.

Technical approaches to oxidize methane in lean and ultra-lean conditions include catalysts, reactive additives, and increasing temperature, which can be used individually and in combination. In parallel there has been significant progress in the partial oxidation of methane under rich conditions to high-value products and the oxidation of VOCs under lean and ultra-lean conditions. These approaches and advances may inform options for REMEDY systems.

For example, VOC catalysts are deployed today on lean-burn engines. The catalysts typically use platinum group metals (PGM) such as Pd on Al_2O_3. VOC catalysts require operating temperatures greater than 550 ^oC to attain >70% methane oxidation. Lean-burn engine exhaust is cooler (450-500 ^oC) due to the high air/fuel ratio. To compensate for the lower

[15] See https://www.epa.gov/stationary-engines/compliance-requirements-stationary-engines.
[16] See, e.g., 40 CFR Part 51 Section 51.100.

temperature, the precious metal loading is increased to ~100-200 g Pd/ft^3, increasing catalyst costs.[17] Despite the higher loading, methane oxidation is still limited to ~70% conversion at these lower temperatures. An alternative approach is increasing the exhaust temperature by thermal and electric means[18], which incurs CAPEX and OPEX penalties.

PGM catalysts are sensitive to several poisons, including water, which is inherent in the exhaust gas.[19] Sulfur, for example, has a detrimental effect on methane oxidation conversion.[20] Catalysts can be thermally regenerated, for example, by varying the air/fuel ratio. However, thermal cycling can cause Pd sintering, affect the structural stability of the catalyst support, and increase the light-off temperature, lowering methane oxidation.[20,21,22]

Mixed oxide catalysts such as $NiCo_2O_4$ are promising cost-effective catalyst candidates for methane oxidation in the temperature range of 350 – 550 ^oC.[23] An optimal mix of Co and Ni at 50% each promotes the highest activity among transition metals for methane oxidation.[24] A Co_3O_4/CeO_2 nanocomposite catalyst demonstrated high methane oxidation rates at 200-500 ^oC.[25]

The literature on partial methane oxidation may provide insights on catalysts for total methane oxidation. Significant progress has been reported in using metal-exchanged zeolites for methane oxidation into liquid fuels.[26] Pd/zeolite composites are being investigated to promote

[17] Raj, A., "Methane Emission Control", Johnson-Matthey Technology Review, Vol. 60(4), p. 228-235, 2016.
[18] Liu, *et al.*, "Catalytic Combustion of Lean Methane Assisted by Electric Field over Pd/Co3O4 Catalysts at Low Temperature", J. Shanghai Jiaotong Univ. (Sci.), Vol. 23, p. 8–17, 2018.
[19] Yoshifuru Nitta, Yudai Yamasaki, Evaluation of Effective Active Site on Pd Methane Oxidation Catalyst in Exhaust Gas of Lean Burn Gas Engine, ICEF2019-7152, V001T04A003; 12 pages (2019).
[20] Lampert, *et al.*, "Palladium Catalyst Performance for Methane Emissions Abatement from Lean Burn Natural Gas Vehicles", Applied Catalyst B: Environmental 14, 211-223, 1997.
[21] Kinnunen, *et al.*, "Case Study of a Modern Lean Burn Methane Combustion Catalyst for Automotive Applications: What are the Deactivation and Degradation Mechanisms", Applied Catalysis B: Environmental 207, 114-119, 2017.
[22] Auvinen, *et al.*, "Development of a Rapid Ageing Technique for Modern Methane Catalysts in the Laboratory: Why does SO2 Concentration Play an Essential Role", Applied Catalysis B: Environmental 258, 117976, 2019.
[23] Tao, *et al.*, "Understanding complete oxidation of methane on spinel oxides at a molecular level", Nature Communications 6, 7798, 2015.
[24] Tae Hwan Lim, *et al.*, "Effect of Co/Ni ratios in cobalt nickel mixed oxide catalysts on methane combustion", Applied Catalysis A: General, Vol. 505, p. 62-69, 2015.
[25] Dou, *et al.*, "Complete Oxidation of Methane on Co_3O_4/CeO_2 Nanocomposite: A Synergic Effect", Catalyst Today, Vol. 311, p. 48-55, Aug 1, 2018.
[26] Yua, *et al.*, "Conversion of Methane into Liquid Fuels – Bridging Thermal Catalysts with Electrocatalysis", Advanced Energy Materials, Vol. 10(40), p. 2002154, 2020.

methane oxidation as well.[27] Technological advancements in photocatalysis[28], electro-catalysis[29] and plasma catalysis[30] also show promise for methane oxidation to CO_2.

Additives, such as H_2[31] and ethane[32] enhance methane oxidation. Studies show that ozone (O_3) promotes natural gas ignition in pre-mixed natural gas engines, reducing hydrocarbon and CO emissions at low engine load conditions.[33] However, ozone also has the potential to create trace amounts of oxygenated hazardous air pollutants (HAPs), increase NO_x, or enter the atmosphere. Hydroxyl radicals (OH) are part of the reaction mechanism for tropospheric methane oxidation.[34] OH radicals may result in HAPs, CO and/or O_3 emissions.[35]

5. TECHNO-ECONOMIC ISSUES

The three target sources share several techno-economic issues, which must be addressed by all submissions. Impacts need to be quantified in the provided Life Cycle Analysis (LCA) and Levelized Cost of Carbon Abatement (LCCA) spreadsheets. The LCA and LCCA must be calculated over the life of the equipment.

- Historically, methane emission reduction was not a primary design objective for equipment used in these three sources. Gas-fired engines are sized for specific loads with expectations for fuel efficiency and reliability. Flares and VAM units are safety devices. Proposed REMEDY systems must identify and address impacts to other operating criteria, including equipment performance (capacity, output, efficiency, downtime), emissions other than methane, and safety. Impact on externalities, including water use, noise, view shed (e.g., flare luminosity) must also be addressed.

- System-level solutions share similar challenges for all three sources. The design of the core methane oxidation chemistry/process design may involve similar catalysts,

[27] Losch, *et al.*, "Modular Pd/Zeolite Composites Demonstrating the Key Role of Support Hydrophobic/Hydrophilic Character in Methane Catalytic Combustion", ACS Catalysis, Vol. 9(6), p. 4742-4753, 2019.
[28] Yu, *et al.*, "Selective photocatalytic conversion of methane into carbon monoxide over zinc-hetero-polyacid-titania nanocomposites", Nature Communications, Vol. 10(700), 2019.
[29] Boyd, *et al.*, "Electro-Oxidation of Methane on Platinum under Ambient Conditions", ACS Catalysis, Vol. 9(8), p. 7578-7587, 2019.
[30] Zhou, *et al.*, "Light-driven methane dry reforming with single atomic site antenna-reactor plasmonic photocatalysts", Nature Energy, Vol. 5, p. 61-70, 2020.
[31] Soltic, *et al.*, "Efficiency and Raw Emissions Benefits from Hydrogen Addition to Methane in a Pre-chamber Equipped Engine", International Journal of Hydrogen Energy, Vol. 45, p. 23638-23652, 2020.
[32] Ahmad, *et al.,* "Impact of Ethane Enrichment on Diesel-Methane Dual-Fuel Combustion," SAE Technical Paper 2020-01-0305, 2020, https://doi.org/10.4271/2020-01-0305.
[33] Mohammadi, *et al.*, "Study on Combustion Control in Natural Gas PCCI Engines With Ozone Addition to Intake Gas", SAE Technical Paper 2006-01-0419, 2006.
[34] Rigby, *et al.*, "Role of atmospheric oxidation in recent methane growth", PNAS, Vol. 114(21), p. 5373-377, 2017.
[35] Tie, *et al.*, "Net yield of OH, CO and O_3 from the oxidation of atmospheric methane", Atmospheric Environment. Part A General Topics, Vol. 26(1), p. 125-136, 1992.

computational fluid dynamics and heat transfer, and materials issues. Control systems and required methane reduction quantification will require flow measurement (or a surrogate), possibly upstream feed gas analysis (species or overall calorific content) and downstream sensors for methane concentration. Minor or trace species could be an issue for all three sources, although possibly for different reasons.

- The sites are typically remote, resulting in high costs for utilities and operation and maintenance (O&M) costs. Due to remoteness, it is typically not economical to recover or monetize the methane. Systems that propose to monetize methane must address the economics for marketing their product(s), and demonstrate a market that would use at least 1 billion cubic feet methane/yr.

- Robust processes are required. Engine and VAM flow rates typically vary over a factor of two, and flare flow rates can vary by more than an order of magnitude. Gas composition, including methane concentration, can vary, often in an unpredictable manner. Trace components which impact operations and/or corrosion can vary with time and across sites. Downtime is expensive, due to high O&M costs and potential need to shut down equipment and lose operating revenue. Operating problems may also result in high methane emissions. Test programs need to demonstrate performance over the full range of flow rate and concentration, address trace species, and show the process can load follow and be compatible with upstream equipment.

- System performance may change over time, due to a variety of causes (e.g., catalyst deactivation, corrosion/material fatigue, instrument calibration, etc.). Test programs need to discuss how equipment maintenance intervals and service life will be determined, and how changes in performance with time will be quantified.

The following sections summarize specific techno-economic issues that must be addressed for submissions targeting specific sources.

5.A. LEAN-BURN ENGINE TECHNO-ECONOMIC ISSUES

Natural gas-fired engines are found across the oil and gas value chain. Reciprocating internal combustion engines (RICE) are the dominant engine type. There are more than 60,000 RICE units in the upstream/midstream oil and gas sector,[36] where they are used to drive compressors, pumps, and other hardware. The 2014 GHGI includes 52,000 compressor drives in the upstream sector.[37] There are another 6000 engines of various configurations used by

[36] Technical communications with a high horse-power original equipment manufacturer.
[37] EPA Office of Air Quality Planning and Standards (OAQPS), "Oil and Natural Gas Sector Compressors", April 2014, http://www.ourenergypolicy.org/wp-content/uploads/2014/04/epa-compressors.pdf.

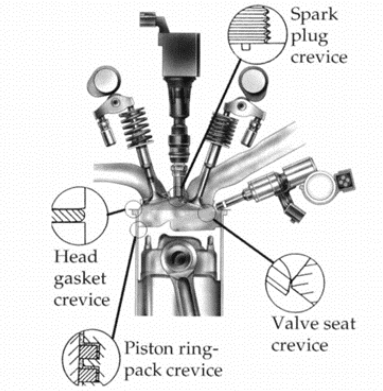
interstate pipelines.[38] Natural gas-fired engines are also used to generate electricity. EIA's 2019 inventory includes ~1100 RICE units which generated 5.2 GW of electricity.[39] EPA identifies 2000 RICE units with 2.3 GW capacity used in combined heat and power (CHP) facilities.[40]

RICE units can be classified as rich-burn (stoichiometric) or lean-burn (diesel or spark-ignited natural gas). REMEDY is focused on natural gas-fired lean-burn engines. The majority of RICE units used in oil and and upstream/midstream, electric generation, and CHP are natural gas-fired lean-burn engines. Liquified natural gas (LNG) powered marine vessels are a rapidly emerging market for very large lean-burn engines. There are approximately 500 marine vessels that use lean-burn engines.[41]

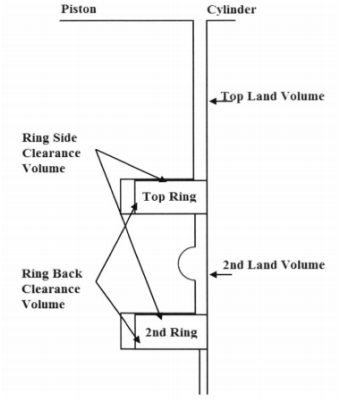
As noted above, methane emissions, also called methane slip, from lean-burn natural gas engines ranges from 2-5% of the inlet fuel volume. [13] Although there are large number of engine models, all lean burn engines share common features that result in very similar composition of exhaust gas. In lean-burn engines methane slip results from gas by-passing the combustion zone. As shown in Figure 3, below, the air/fuel mixture entering the engine can pass though crevice volumes located within the cylinder components of the engine. Examples include the area between cylinder head and piston liner, between piston top land and cylinder liner and behind the anti-polishing ring. [42] Unburned hydrocarbon emissions from the piston top land and the cylinder liner are reported to be significant among the three sources of methane slip from the engine cylinders.

[38] Hohn, K. et al., Final Report: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines, 2011 https://www.osti.gov/servlets/purl/1032856.
[39] See https://www.eia.gov/outlooks/steo/data/browser.
[40] See https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies_section_2._technology_characterization_-_reciprocating_internal_combustion_engines.pdf.
[41] ICCT Working Paper, "The climate implications of using LNG as a marine fuel", January 2020, https://theicct.org/sites/default/files/publications/Climate_implications_LNG_marinefuel_01282020.pdf.

Figure 4 Lean Burn Engine Crevices[42]



Different Engine Crevices in a Spark Ignited Engine



Piston-Ring Pack Crevices

Methane slip from lean-burn engines is likely underestimated in the GHGI. The Greenhouse Gas Reporting Program (GHGRP) requires GHG emission reporting for oil and gas facilities that emit >25,000 ton CO_2/yr.[43] Facilities would need to include multiple engines and/or other CO_2 source to meet this reporting threshold. In addition, emission factors for lean-burn engines may underestimate methane slip. Based on the number of lean-burn engines in the oil and gas, electric generation, and CHP sectors, and assuming 2% methane slip, methane emissions from such engines are likely greater than 15 MM ton CO_2^e/yr.

The marine sector could become a large source of methane emissions, as fleets convert from bunker fuel to LNG. LNG reduces sulfur, black carbon, and CO_2 emissions; however, methane slip is an emerging concern.[44] The ~500 marine lean-burn engines in service today have the potential to emit an estimated 5.4 MM ton CO_2^e/yr. Methane emissions are estimated to increase to 17 MM ton by 2030 as additional LNG-powered vessels enter into service. **Error! Bookmark not defined.** The marine industry anticipates converting one third of the fleet to LNG

[42] Smith, P., "Crevice volume effect on spark ignition efficiency", Master's Thesis, MIT, 2013.
[43] Greenhouse Gas Reporting Program, https://www.epa.gov/ghgreporting
[44] Fourth IMO GHG Study 2020 – Final report, MEPC 75/7/15, https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx.

with lean-burn engines,[45] which could result in more than 60 MM ton CO_2^e/yr methane emissions.

There are several issues for systems addressing methane emissions from lean-burn engines:

- One approach is to replace all lean-burn engines with technologies that do not emit methane, such as electric drives, rich-burn engines, etc. While technically feasible, the cost would be very high, and the time to replace all the engines could be decades. REMEDY is seeking alternatives to engine replacement that would have significantly lower cost and faster implementation.

- A second approach is reducing or eliminating crevice volumes. Coincident with reducing methane slip, engineering designs suggest reducing the crevice volumes in piston top land could increase efficiency 2.3-3.5% per 1000 m^3 of displacement within the cylinder.[42] This option may be interesting for new engines. However, it would not likely impact methane emissions for many years since the existing fleet of lean-burn engines has a long service life, in many cases exceeding 50 years.[46] Submissions for retrofitting engines to reduce crevice volume need to demonstrate a market of at least 5000 amenable engines and address timing for retrofits to be implemented.

- Engines are typically at remote sites. Utilities (electricity, water) may be limited, and requiring these inputs must include and justify their costs. Delivering consumables (i.e., reagents) could be expensive. Technologies that require consumables (for analogy, diesel exhaust fluid required for Selective Catalytic Reduction (SCR) units) need to include the delivered cost of the consumables as well as cost for storage and environmental/permitting issues. O&M labor costs will typically exceed $200/hr. Maintenance intervals for the proposed system must be specified, particularly maintenance intervals that differ from standard maintenance requirements for lean-burn engines.

- Submissions must address the impact of engine load cycles, which can result in start/stop heating cooling cycles, and variable operating rates which change inlet and exhaust flow rates, composition, and temperature.

- Submissions must address potential poisons/trace species that could impact catalyst and/or corrosion. The trace species could be part of the fuel gas (i.e., H_2S, heavy hydrocarbons), exhaust stream (H_2O, NOx, SOx, particulates), or originate from the engine oil (P, Zn).

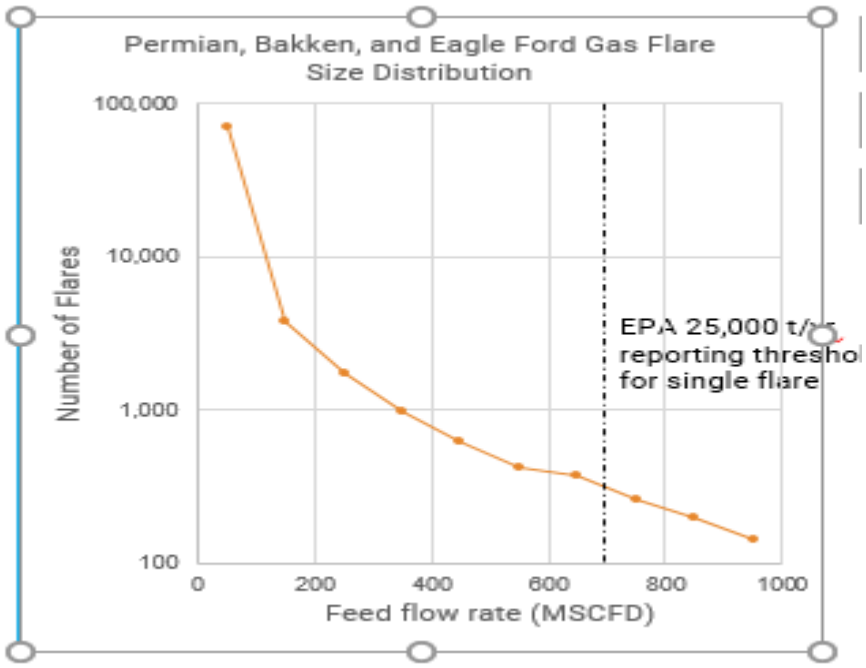
[45] DNV-GL Maritime Forecast to 2050, https://eto.dnvgl.com/2018/maritime.
[46] S. Clowney, Compressor and Pump Station Research, DOT/PRCI Pipeline R&D Forum, December 11-12, 2003 Washington, DC.

5.B. FLARE TECHNO-ECONOMIC ISSUES

Flares are used throughout the oil and gas upstream and midstream sectors. Although the number of flares is unknown, an extrapolation can be made based on the 100,000 flares in Texas, per a report by DOE Fossil Energy.[47] Texas produces 41% of US oil[48] and has 30% of US oil and gas wells.[49] Extrapolation suggests the existence of 250,000-500,000 flares in the US. The National Energy Technology Lab gas flaring report documents 78,000 flares in the Permian (Texas), Bakken (North Dakota) and Eagleford (Texas) basins.[50] Figure 5, below, shows that the distribution of flare sizes follows a rough power-law distribution, with a large number of smaller flares and fewer large flares. It also shows that more than 90% of flares are below the GHGRP threshold of 25,000 ton/yr CO_2, which may partially account for the lack of data on the number of flares.[43]

[47] Natural Gas Flaring and Venting: State and Federal Regulatory Overview, Trends, and Impacts, June 2019.
[48] https://www.eia.gov/energyexplained/oil-and-petroleum-products/where-our-oil-comes-from.php.
[49] The Distribution of U.S. Oil and Natural Gas Wells by Production Rate, December 2020, https://www.eia.gov/petroleum/wells/pdf/full_report.pdf.
[50] Flaring Fact Sheets by Basins in US, National Energy Technology Laboratory (NETL), 2020.

Figure 5 Flares in the Permian (TX), Bakken (ND) and Eagleford (TX) Basins[50]



There is considerable debate regarding methane emissions from flares. As noted above, flares that meet EPA design specifications are presumed to achieve 98% combustion efficiency. Using the data from the NETL and DOE reports, and assuming 98% combustion efficiency, 2018 calculated methane emissions for the three regions was 8 MM ton CO_2^e. The smaller flares account for the majority of flared gas volume: 27% of total flared gas from the smallest flares, more than 50% from flares < 300,000 SCFD, and less than 5% from the largest flares. As noted above, the combustion efficiency for smaller flares is more sensitive to operating conditions. Consequently, and perhaps counterintuitively, improved design for smaller flares has the highest potential for reducing methane emissions.

Extrapolating methane emissions from the three regions across all US associated gas fields is difficult, but a conservative estimate is an additional 5-10 MM ton CO_2^e/yr based on the total volumes of associated gas produced, and adjusting for the higher rates of flaring in the three regions. However, several factors support that contention that flare methane emissions may be larger than 13-18 MM ton/yr CO_2^e calculated assuming 98% combustion efficiency.

The presumed 98% efficiency may not apply to methane in flares used in the oil and gas sectors. EPA regulations require flares be qualified using a propylene/propane mixture under the assumption that propylene is more difficult to combust than methane.[51] Propylene is not present in oil and gas feeds to flares, and the ignition temperature for propylene is 120 °C lower

[51] See https://www.epa.gov/sites/production/files/2020-11/documents/report_ef_ong_2018.pdf.

than methane. The database used to define the EPA allowable operating parameters for flares has limited data for methane.[52]

Currently oil and gas flares are exempted from field testing/verification. Consequently, the actual methane emission rates for flares have a high degree of uncertainty. Several studies indicate that actual emissions are higher than expected when assuming 98% combustion efficiency. The Fossil Energy report discusses under-reporting for very large flares based on satellite data.[45] Smaller flares, which account for a relatively large fraction of total flared gas volume, are known to be more susceptible to wind and gas composition.[53] While a 2014 aerial survey of 11 flares showed very high combustion efficiencies,[54] more recent aerial surveys covering a larger number of facilities with better instruments have observed flares operating below 98% combustion efficiency, and in some cases flares not lit and venting.[55,56]

New flare designs, including enclosed ground flares and high-pressure multi-point ground flares, which operate outside the prior EPA design window, have been reviewed by the EPA.[57,58] EPA issued approval for these as an Alternative Means of Emission Limitation at specific sites. These recent advances suggest that new operating windows may be available for alternative flare designs.

There are several issues for systems addressing methane emissions from flares:

- Advances in indirect flare emission measurements, including LiDAR, multi-spectral IR, pFTIR and DIAL, have the potential to measure flare plume emissions more accurately than previous analytical techniques that required directly sampling the flare plume. Applicants need to discuss the precision and accuracy of methods they will consider for establishing flare combustion efficiency in Stage 1 and Stage 2.

- Flares need to meet combustion efficiency and "no smoke" criteria. In some cases these two objectives are incompatible. For example, over-steaming or over-airing eliminates smoke but can decrease combustion efficiency. Proposed systems must show they can meet both criteria.

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[52] Evans, S., "It's Time to Re-Think Flare Velocity Limits", WPCA News, Fall 2018.
[53] Matthew Johnson, "Flare Efficiency & Emissions: Past & current research", Carleton Univ., Dec. 2008, https://www.globalmethane.org/documents/events_oilgas_20081203_oilgas-5Dec08_johnson.pdf.
[54] Caulton, *et al.*, "Methane Destruction Efficiency of Natural Gas Flares Associated with Shale Formation Wells", Environ. Sci. Technol., Vol. 48, p. 9548−9554, 2014, dx.doi.org/10.1021/es500511w.
[55] Gvakharia, *et al.*, "Methane, Black Carbon, and Ethane Emissions from Natural Gas Flares in the Bakken Shale, North Dakota", Environmental Science and Technology, Vol. 51, p. 5317-5325, 2017, doi.org/10.1021/acs.est.6b05183.
[56] See https://www.daily-times.com/story/money/industries/oil-gas/2020/12/21/new-mexico-permian-san-juan-basins-methane-leaks-increase/3997573001/.
[57] See AP 42 Chapter 13.5 Industrial Flares, 2-18, https://www.epa.gov/sites/production/files/2020-10/documents/13.5_industrial_flares.pdf.
[58] See https://www.epa.gov/sites/production/files/2020-11/documents/report_ef_ong_2018.pdf.

- Most flares are small, and costs for measurement and control hardware could be prohibitive. Applicants must describe approaches for qualifying designs or family of designs for small flares that provide assurance that performance targets will be achieved under the full range of field conditions if instruments are not economical, for example using designs based on computational fluid dynamics and/or control algorithms that are confirmed with field tests.

5.C. VENTILATED AIR METHANE (VAM) TECHNO-ECONOMIC ISSUES

VAM systems are designed for mine safety. VAM methane emissions are recognized, but not required to be controlled, despite the fact that ventilation air methane is the largest source of methane emissions from coal mines.[59,60] Methane concentration in the mine needs to be maintained below the lower explosive limit (~4%), and typically range from 0.2-2%. The CMOP 2010 report provides details on VAM concentrations and flow rates for mines by Mine Safety and Health Administration (MSHA) district.[61] The 2018 EPA GHGI has net methane emission from VAM at 39 MM ton CO_2^e.[5]

There are few commercial options for VAM gas. In some US mines, conventional coal bed methane wells recover methane ahead of the mining operations, preventing emissions by capturing 19 MM ton CO_2^e methane in 2018.[62] The only commercial technology deployed in the US is Regenerative Thermal Oxidation (RTO), which can achieve 97% methane conversion during normal operations.[63] The Department of Energy funded an RTO study and pilot plant from 2002-2009.[64] There were multiple projects planned in the 2010 timeframe in anticipation of enactment of a carbon trading requirement in the United States.[65] Globally, at least six RTO commercial projects were reported to have run by 2019.[66] Unfortunately, the US and global markets for these technologies have not matured. As of 2020 there is only one operating RTO project in the US, and two others outside the US.[66]

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[59] Carothers, F. P. & Deo, M., "Technical and economic assessment: Mitigation of methane emissions from coal mine ventilation air," Washington, DC: EPA, 2000.
[60] Somers, J.M. & H.L. Schultz, Thermal oxidation of coal mine ventilation air methane, U.S./North American Mine Ventilation Symposium, Reno, NV, 2008,https://swap.stanford.edu/20130415225046/http://www.epa.gov/cmop/docs/2008_mine_vent_symp.pdf.
[61] U.S. Underground Coal Mine Ventilation Air Methane Exhaust Characterization, July 2010 https://www.fs.usda.gov/nfs/11558/www/nepa/68608_FSPLT2_126053.pdf.
[62] EPA Green House Gas Inventory, 2018.
[63] D. Kay, Vamox®RTO Technology, CMOP Program Webinar Feb 27, 2020.
[64] Capture and Use of Coal Mine Ventilation Air Methane, Final Report of Work Performed October 1, 2002 through October 31, 2008. https://www.fs.usda.gov/nfs/11558/www/nepa/68608_FSPLT2_126051.pdf
[65] J.M. Somers and H.L Schultz, Coal mine ventilation air emissions: project development planning and mitigation technologies, 13th United States/North American Mine Ventilation Symposium, 2010 – Hardcastle & McKinnon (Eds.)
[66] Ventilation Air Methane (VAM) Utilization Technologies, U.S. EPA Report, July 2019, https://www.epa.gov/sites/production/files/2017-01/documents/vam_technologies-1-2017.pdf.pdf.

Karacan, *et al.,*[67] and the EPA[59] reviewed the state of the art. Several concepts have been discussed, including using novel reactors.[68,69,70] and incorporating catalysts in RTO to make a Regenerative Catalytic Oxidizer (RCO) [71,72] or a Catalytic Recuperative Oxidizer (CRO),[73] which are used commercially for VOC reduction.

Recent advances in other fields may be applicable to VAM systems. The state of the art discussion above outlined several catalysts and reactive additives that can enhance reactions under lean- and ultra-lean conditions, reduce methane oxidation temperatures below 1000 °C required for RTOs and 600-800 °C required for RCO/CROs, and may reduce H_2O inhibition.

Interest in medium- and high-temperature thermal storage has led to development of new phase-change metals and metallic compounds with significantly higher heat capacities and thermal conductivity than ceramics used in RTO/RCO.[74,75] These materials could increase the system's thermal inertia and thermal conductivity, create more uniform temperature distributions, reduce cycle times, and increase tolerance to variable gas flow rates and methane concentration. There are also new thermal storage design concepts and computational models that could be used for advanced control algorithms.[76,77,78]

There are several issues for systems addressing methane emissions from VAM:

- VAM methane concentrations can fluctuate from 0.2% to 1.5% due to short term fluctuations and long-term changes in mining operation. Applicants need to discuss how their technology addresses the wide range of inlet concentrations.

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[67] C.O. Karacan, *et al.*, "Coal mine methane: a review of capture and utilization practices with benefits to mining safety and to greenhouse gas reduction", Int. J Coal Geology, Vol. 86, p. 121-156, 2011.
[68] Fernandez, J., *et al.*, "Combustion of coal mine ventilation air methane in a regenerative combustor with integrated adsorption: Reactor design and optimization," Applied Therm. Eng, Vol. 102, p. 167-175, 2016.
[69] Fu-xun, Z., "Catalytic deoxygenating characteristics of oxygen-bearing coal mine methane in the fluidized bed reactor," J Fuel Chem Technol, Vol. 4, p. 523−529, 2013.
[70] Lan, B. and Li, Y., "Numerical study on thermal oxidation of lean coal mine methane in a thermal flow-reversal reactor," Chem. Eng. J., Vol. 351, p. 922-929, 2018.
[71] Marin, P., *et al.*, "Control of Regenerative catalytic oxidizers Used in Coal Mine Ventilation Air Methane Exploitation," Process Safety and Environ Protection, Vol. 134, p. 333-342, 2020.
[72] Coal Mine Methane Developments in the US, EPA, February 2019. https://www.epa.gov/sites/production/files/2016-03/documents/cmm_developments_in_the_us_2013.pdf.
[73] P Hinde, *et al.,* "COMET® - A New VAM Abatement Technology", Johnson Matthey Technol. Rev., Vol. 60(3), p. 211–221, 2016.
[74] Y. Zhao, *et al.,* "Medium- and high-temperature latent and thermochemical heat storage using metals and metallic compounds as heat storage media; a technical review", Applied Energy, Vol. 280, p. 115950, 2020.
[75] Sharar, D., *et al.*, "High-capacity high-power thermal energy storage using solid-solid martensitic transformations," Appl. Therm. Eng., Vol. 187, p. 116490, 2021.
[76] M. Johnson*, et al.,* "Design of high temperature thermal energy storage for high power levels", Sustainable Cities and Society, Vol. 35, p. 758-763, Nov. 2017.
[77] G. Zanganeh, *et al.*, "Design of packed bed thermal energy storage systems for high-temperature industrial process heat", Applied Energy, Vol. 137, p. 812-822, January 1, 2015.
[78] L. Amiri, *et al.*, "Numerical evaluation of the transient performance of rock-pile seasonal thermal energy storage systems coupled with exhaust heat recovery, Appl. Sci., Vol. 10, p. 7771, 2020, doi:10.3390/app10217771.

- VAM systems are regulated by MSHA, which will also need to approve methane reduction systems. The approval process requires careful consideration of safety impacts. Proposed systems must discuss safety issues and mitigation strategies.

- VAM systems are inherently large. Applicants must address what scale of testing is required to address critical issues for system design, and how modeling results will be verified experimentally.

C. PROGRAM OBJECTIVES

The goal of the REMEDY program is to support the development of technologies that will reduce methane emissions from the three targeted sources. REMEDY seeks highly replicable system-level solutions that meet the performance metrics described in Section I.F. and address the techno-economic issues described above. Systems must integrate methane reduction technologies with sensors and/or control algorithms to quantify emission reduction and ensure consistent operation. Solutions must demonstrate ability to replicate engineering, develop product line families, and achieve low costs through economies of fabrication/numbers (i.e., making large numbers of similar devices) versus economies of scale (i.e., making larger size units).

Stage 2 testing is intended to de-risk the proposed systems such that the private sector or other government agencies would be willing to fund the next stages of commercialization.

Successful REMEDY systems will likely require diverse skill sets, and may benefit from adopting technologies developed for other applications. ARPA-E seeks to bring diverse communities of expertise together. REMEDY encourages teams with broad competencies, including:

- Methane reduction technology(ies) that operate in lean- and ultra-lean conditions, incorporating computational fluid dynamics, heat/mass transfer, and kinetics; hardware design; and design of experiments;

- Instrument and control systems, including methane sensors, measurement of feed and exhaust gas components/ poisons, control logic/digital twins;

- Systems Engineering, ideally with an identified commercialization party to do system integration/packaging;

- Sector domain expertise (engine, flare, VAM) to support market analysis and customer outreach; and

- Customer/operator expertise, to validate inputs to the LCCA spreadsheet.

The REMEDY program will accept submissions that do not include a complete system, provided Applicants can explain how their methane abatement approach will meet the technical criteria and the key integration issues for the system aspects that are not part of their submission. These Applicants will also need to describe their plans for integrating their products into a system that could be tested in Stage 2, how their approach will ultimately be commercialized, and submit a Stage 2 budget that incorporates system-level testing. ARPA-E strongly encourages diverse teams with complementary skills. Teams that lack manufacturing or operations expertise will need to discuss how they will develop capital and operating cost inputs for Stage 1 and refine these costs inputs in Stage 2. All Applicants need to provide details for the Tech-to-Market scope and schedule, outlining intellectual property sale/licensing, partnering, and/or other commercialization plans

D. TECHNICAL CATEGORIES OF INTEREST

The critical factors for proposed REMEDY systems include such systems' ability to meet performance metrics, address techno-economic issues, and achieve scale. Example approaches include, but are not limited to:

- Natural gas-fired lean-burn engines: catalytic reactors treating exhaust gas; and additives to enhance methane combustion reaction rates, which preferably can be produced on-site;

- Flares: novel open or enclosed combustor designs, likely outside the EPA proscribed operating parameters; and additives or catalysts to ensure high combustion efficiency; and

- VAM: systems incorporating novel materials with enhanced properties (high thermal capacity and/or thermal conductivity) and/or catalysts.

ARPA-E anticipates Applicants will consider how novel thermal integration concepts, emerging manufacturing techniques, advanced control algorithms, and emerging methane sensors can enhance the performance of their systems.

Oxidation of methane to CO_2 is sufficient. REMEDY metrics incorporate the value proposition for processes that propose to monetize methane by capturing it for use or converting it to higher-value products. However, REMEDY does not prioritize monetization of methane over oxidation. As noted previously, submissions based on monetizing methane must demonstrate an amenable market, addressing impact of site locations/remoteness, volume of saleable product(s), and net revenue after delivering product(s) to market.

E. TECHNICAL PERFORMANCE REQUIREMENTS

Proposed systems must meet the performance metrics and address the techno-economic issues identified in Section I.C.5.

7.1 Performance Metrics

The Stage 1 and Stage 2 performance metrics are:

Stage 1 (Lab demonstration)

- Economics (per LCCA spreadsheet)
  - \$40-50/ton CO_2^e levelized cost of carbon
- Environmental (per LCA spreadsheet)
  - 98-99.5% methane conversion efficiency
  - 85-87% Life Cycle Analysis (LCA) CO_2^e reduction
  - No adverse environmental impacts

Stage 2 (Systems-level solution in field/emulated-field setup)

- Economics (per LCCA spreadsheet)
  - \$40/ton CO_2^e levelized cost
- Environmental (per LCA spreadsheet)
  - 99.5% methane conversion efficiency
  - 87% LCA CO_2^e reduction
  - No adverse environmental impacts

The performance metrics are quantified in the attached spreadsheet. Note that the attached spreadsheets GHG calculations currently include only carbon dioxide and methane. More detailed calculations for all incremental GHG emissions will be required during program execution. For purposes of calculating GHG emissions in a submission to this FOA, the GWPs for CH_4, CO, and N_2O are assumed to be 25, 3, and 298, respectively.

Applicants are expected to provide best estimates and justify their inputs in the application process. ARPA-E recognizes that initial inputs to the LCA and LCCA spreadsheets may have large ranges due to lack of data, need for improved experimental techniques, missing information, etc. Consequently, the target values for Stage 1 allow for a larger range. Awardees will be required to update the spreadsheets as they progress through Stage 1. The expectation is the continued refinement of cost and performance data, with decreasing error bands for all input parameters.

Processes are expected to meet all applicable permitting requirements, e.g., New Source Performance Standards (NSPS); National Pollutant Discharge Elimination System (NPDES);

noise; light; etc.). Applicants must identify other potential environmental impacts and approaches to mitigate them.

Applicants must discuss how the proposed test programs will provide the data to support the inputs to the spreadsheets. The experimental program must address baseline conditions and an appropriate range of operating conditions/system parameters. It should quantify factors that may cause performance declines or equipment downtime.

ARPA-E recognizes that on-stream time for methane abatement technologies is critical. Applicants must address operating plans if methane control equipment is not operating. Ideally the maintenance schedule and on-stream time for the methane abatement technology will coincide with that for the upstream processes. If the methane control equipment requires maintenance when upstream equipment is operating, Applicants must specify if the upstream equipment will be shut down or continue to operate with uncontrolled methane emissions. If the upstream equipment will continue to operate, the uncontrolled methane emissions must be quantified in the LCA. If the upstream equipment will be shut down, the lost revenue must be quantified in the LCCA.

The base case conditions and ranges for operating parameters for engines, flares, and VAM units are listed in the following Tables:

Table 1 Natural Gas-fired Lean-Burn Engine Baseline Parameters

Parameter	**Baseline Value**	**Comments/ Variable range**
Rated Output	1000 bkW	50% - 100% of rated load
Rated Speed	1400 RPM	50% - 100% of rated speed
Exhaust gas flowrate	260 m^3/min	Full load
Exhaust gas temperature	530C	Full load
Fuel consumption	10.3 MJ/bkW-hr	fuel @38 MJ/m^3
Methane concentration	87%	
Methane Number	80	70-100
Sulfur	%	TBD
Relative Humidity	30%	
On-stream availability	85%	
CH4	4.2 g/bkW-hr	Assume 2.5% methane slip 50-100% rated load
NOx	0.7 g/bkW-hr	Assume constant over 50-100% rated load
CO	3.3 g/bkW-hr	Assume constant over 50-100% rated load
VOC	0.6 g/bkW-hr	Assume constant over 50-100% rated load
Baseline GHG emission from methane slip and methane combustion	4147 tonnes CO_2^e /yr	Simplified analysis if no other emissions change
Controlled GHG emission from methane slip and methane combustion	3589 tonnes CO_2^e /yr	99.5% (engine + technology)
Incremental methane reduction	558 tonnes CO_2^e/yr	

Table 2 Flare Baseline Parameters

Parameter	Value	Comments
Design Capacity	100,000 scf/day	majority of flares in smallest size range
Average Capacity	50%	30-100%
On-stream availability	100%	
Flare gas composition		
Methane	65%	50-80%
Ethane	20%	
Propane	10%	
Butane	5%	
Baseline methane combustion efficiency (mole basis)	98%	Per EPA
NOx	0.068 lb/MMBtu	AP42
CO	0.37 lb/MMBtu	AP42
VOC	0.14 lb/MMBtu	AP42
Baseline GHG emission from methane slip and methane combustion	714 tonnes CO_2^e /yr	Simplified analysis if no other emissions change
Controlled GHG emission from methane slip and methane combustion	639 tonnes CO_2^e /yr	99.5% methane reduction
Incremental methane reduction	75 tonnes CO_2^e/yr	

Table 3 VAM Baseline Parameters

Parameter	Value	Comments
Location	Eastern US	
Capacity	100,000 scfm	
Average capacity	80%	50-100%
On-stream availability	95%	
Methane concentration	0.6%	0.2-1.6%
NOx	<0.2 ppm	West Liberty pilot test
CO	<1.5 ppm	West Liberty pilot test
VOC	0	West Liberty pilot test
Baseline GHG emission from methane slip and methane combustion	112,854 tonnes CO_2^e /yr	Simplified analysis if no other emissions change
Controlled GHG emission from methane slip and methane combustion	12,916 tonnes CO_2^e /yr	99.5% methane reduction
Incremental methane reduction	99,938 tonnes CO_2^e/yr	

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $35 million available for new awards, to be shared between FOAs DE-FOA-0002505 and DE-FOA-0002505, subject to the availability of appropriated funds. ARPA-E anticipates selecting 10-14 Stage 1 teams, and down-selecting 4-7 Stage 2 teams under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $1M and $5M in Federal share.

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be February 2022, or as negotiated.

ARPA-E encourages submissions 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.

Submissions requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metric at the conclusion of the period of performance. These submissions must 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, submissions requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the 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 submissions with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

ARPA-E will accept only new submissions 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. RENEWAL AWARDS

At ARPA-E's sole discretion, awards resulting from this FOA may be renewed by adding one or more budget periods, extending the period of performance of the initial award, or issuing new award. Renewal funding is contingent on: (1) availability of funds appropriated by Congress for the purpose of this program; (2) substantial progress towards meeting the objectives of the approved application; (3) submittal of required reports; (4) compliance with the terms and conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by ARPA-E at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

Through cooperative agreements, other transactions, 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."[79] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, 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.[80]

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 https://arpa-e.energy.gov/technologies/project-guidance.

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

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

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 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 lead entity for 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 Prime Recipient, the lead entity for 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 an FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements).

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. OTHER TRANSACTIONS AUTHORITY

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 to enter into an other transaction agreement with Prime Recipients, on a case-by-case basis.

ARPA-E may negotiate an other transaction agreement when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

In general, an other transaction agreement normally requires a minimum cost share of 50%. See Section III.B.2 of the FOA.

D. 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.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or technical milestones and deliverables.
- 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. §§ 200.339 and 200.340.
- 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[81] 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.

[81] The term "nonprofit organization" or "nonprofit" is defined in Section IX.

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

This FOA is open to U.S. universities, national laboratories, industry and individuals.

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[82] as the lead for a Project Team,[83] 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[84], educational institutions[85], and nonprofits[86] 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.

[82] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[83] A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.
[84] For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.
[85] Institutions of Higher Education (or educational institutions): Has the meaning set forth at 20 U.S.C. 1001.
[86] 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.

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 receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. All work under the ARPA-E award must be performed in the United States. 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/ (see "View Template Application Documents"). 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[87]

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

[87] Please refer to Section VI.B.3-4 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.C.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[88] as cost share, except as provided in Sections III.B2 or III.B.3 below.[89]

2. INCREASED COST SHARE REQUIREMENT

Large businesses[90] 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 an "other transaction" agreement, the Prime Recipient is normally expected to provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this cost share requirement, as appropriate.

3. REDUCED COST SHARE REQUIREMENT

ARPA-E has reduced the base 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.
- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs/DOE Labs/Federal agencies and instrumentalities (other than DOE) are required to provide at least 5% of the Total Project Cost as cost share.Small businesses – or consortia of small businesses – may provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[91] 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% of the total work under the funding agreement (as measured by the Total Project Cost) are entitled to the same cost

[88] 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.
[89] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988(c)
[90] The term "For-Profit Organizations (Other than Small Businesses)" or "large business" is defined in Section IX.
[91] The term "small business" is defined in Section IX.

share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.

- 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 base 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, or ensuring payment of 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.

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;
- Appropriated 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[92] to meet their cost share obligations under Cooperative Agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under "other transaction" 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.

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.

[92] As defined in Federal Acquisition Regulation SubSection 31.205-18.

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.3 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 may not be merit reviewed or considered for award. ARPA-E may 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 may not be merit reviewed or considered for award. ARPA-E may 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; and
- 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 this FOA.
- Submissions that have been submitted in response to currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to 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 distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by other government agencies or the private sector.

- Submissions that 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.
- Submissions that do not propose both Stage 1 and Stage 2.

3. SUBMISSIONS SPECIFICALLY NOT OF INTEREST

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

- Theoretical studies, analysis of existing processes, or lab-based experimental investigations of methane reduction technologies that do not establish how the proposed technology can be developed into a complete system.
- Submissions with a primary focus on methane leak detection, methane emission quantification, and/or methane sensor development. Note that methane sensor development is allowed in the context of a REMEDY system development effort, but methane sensor development cannot be the primary focus of the submission.
- Submissions that focus on oil and gas methane emissions from valves, compressors (versus the gas-fired lean-burn engines used as prime movers for compressors), or fugitive emissions that are can be addressed by routine maintenance and/or improvements in best practices.
- Submissions that focus on operations best practices, versus novel systems/hardware, to reduce methane emissions from the three sources.
- Submissions focused on engine retrofits, unless they can demonstrate scalability to more than 5000 engines, the economics of the retrofit in the LCCA, and justify the carbon footprint of materials used for the retrofit in the LCA.
- Flare reduction programs focused on associated gas flaring due to lack of natural gas takeaway capacity.
- Mine methane recovery projects addressing methane drainage ahead of mining.
- Energy recovery projects that require substantial inputs of external energy to monetize the lean methane found in any of the three sources (i.e., augmenting VAM to run a boiler or gas turbine).

4. LIMITATION ON NUMBER OF SUBMISSIONS

ARPA-E is not limiting the number of submissions from 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 may 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 and program policy factors in Sections V.A.1 and V.B.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 application 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 45 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 may 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 and program policy factors in Sections V.A.2 and V.B.1 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 or site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for award negotiations 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.

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 seven (7) pages in length including graphics, figures, and/or tables (except the required Gannt Chart and the optional LCA and LCCA spreadsheets, provided in the FOA, which will not count as part of the 7 pages).
- 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 may not be merit reviewed or considered for award (see Section III.F of the FOA).

Each Concept Paper must be limited to a single concept or technology. Unrelated concepts and technologies must 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 the proposed system with minimal jargon, and identify the methane source(s) the proposed solution will address
- Address the general and specific techno-economic issues in Section I.C.5 relevant for the system and methane sources.
- If the submission does not include a complete system, explain to what extent the proposed technology addresses the general and specific Techno-economic issues in Section 5. Identify the additional components needed to form a complete system, and the critical system integration issues. Discuss plans for incorporating the proposed technology into a system.

b. INNOVATION AND IMPACT

- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA compared to existing technologies and their incremental improvement, or emerging technologies.
- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach can meet the performance metrics. Provide specific examples of model results, supporting data, and/or appropriate citations to the scientific and technical literature.
- Optional – LCA and LCCA Spreadsheets. To the extent possible, provide quantitative inputs to the LCA and LCCA spreadsheets in the Technical Performance Requirements in Section I.F of the FOA. Applicants must justify the cost inputs to the model, including discussing sources for capital and operating costs (e.g. CAPEX, OPEX, and maintenance inputs supported by commercial experience of Team members, etc.). Costs must be based on US-sourced equipment and fabrication. Applicants must discuss how they intend to develop/refine cost inputs if they do not have a commercialization partner and/or customer/user on their team.

c. PROPOSED WORK

- Describe the key technical risks for the project. Identify if the approach requires one or more entirely new technical developments to be commercialized.
- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.
- Discuss key schedule risks for the project.
- Describe the proposed scope of work/schedule, list key milestones, and provide a Gannt chart. Discuss how the scope/tasks addresses the above technical risks, techno-economic challenges, and schedule risks.
- Discuss the scale of the Stage 1 and Stage 2 tests, if/how modeling will support scale-up, and how the scale of testing is relevant to the test objectives. Address scale-up risks, and how the proposed test scale will be relevant to commercial-scale equipment.
- Discuss technical risks that will not be addressed by the scope of work and how these will be mitigated.
- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.
- If the submission does not include a complete system, describe the plan for integrating the proposed technology into a system that could be tested in Stage 2. Provide details for the Tech-to-Market scope and schedule, outlining intellectual property sale/licensing, partnering, and/or other commercialization routes to support system-level development.

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 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.
- Identify any gaps in the Project Team, and how and when these gaps will be addressed. Teams that lack manufacturing or operations expertise need to discuss how they will develop capital and operating cost inputs for Stage 1 and refine these costs in Stage 2.

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]

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 JUNE 2021]

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 Applicant 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 may not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications may 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 (40%)

This criterion involves consideration of the following:

- Demonstration of awareness of competing commercial and emerging technologies and justification that the proposed concept/technology provides significant improvement over existing solutions.
- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies; and
- Ability to meet the program metrics and addressing the Techno-economic issues.

(2) Program Plan (40%)

This criterion involves consideration of the following:

- The feasibility of the proposed tasks, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;
- Sufficiency of technical approach to address the key technical risks and techno-economic challenges;
- Clearly defined milestones and ability to meet them; and
- If the proposal does not include a complete system, plans for integrating the proposed technology into a system that could be tested in Stage 2.

(3) Project Team (20%)

This criterion involves consideration of the following:

- The demonstrated capabilities of the individuals and their organizations;
- The key roles, responsibilities, and contributions of the organizations comprising the Project Team
- Letters of Intent from Team members
- if applicable, previous collaborations among team members supporting the proposed project.
- Plans to address any gaps in the Project Team, including how and when these gaps will be addressed.

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement.

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]

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 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 U.S. dependence on foreign energy sources;
   b. Stimulation of U.S. manufacturing and/or software development

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.**

VII. **Qualified Opportunity Zone (QOZ).** Whether the entity is located in an urban and economically distressed area including a Qualified Opportunity Zone (QOZ) or the proposed project will occur in a QOZ or otherwise advance the goals of QOZ. The goals include spurring economic development and job creation in distressed communities throughout the United States. For a list or map of QOZs go to: https://www.cdfifund.gov/opportunity-zones.

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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 contractors 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 JUNE 2021]

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 JUNE 2021]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN JUNE 2021]

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 that have not already been addressed at the link above. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- ARPA-E will cease to accept questions approximately 10 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 published in a document specific to this FOA under "CURRENT FUNDING OPPORTUNITIES – FAQS" 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 IV.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. 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 Prime Recipients/Subrecipients elect to retain title, they must file a patent application in a timely fashion, generally one year from election of title, though: a) extensions can be granted, and b) earlier filing is required for certain situations ("statutory bars," governed by 35 U.S.C. § 102) involving publication, sale, or public use of the subject invention.
- All other parties: The Federal Non-Nuclear Energy Research and Development 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 C.F.R. Part 501.
- Determination of Exceptional Circumstances (DEC): DOE has determined that exceptional circumstances exist that warrant the modification of the standard patent rights clause for small businesses and non-profit awardees under Bayh-Dole to maximize the manufacture of technologies supported by ARPA-E awards in the United States. The DEC, including a right of appeal, is dated September 9, 2013 and is available at the following link: http://energy.gov/gc/downloads/determination-exceptional-circumstances-under-bayh-dole-act-energy-efficiency-renewable. Please see Section IV.D and VI.B for more information on U.S. Manufacturing Requirements.

B. 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.

C. 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.

D. 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).

E. 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.

F. 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.

G. 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.

H. 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.

I. 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 should 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.

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 Preliminary Application, Full Application, Reply to Reviewer Comments, and Small Business Grant Application (if applicable).

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency of 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

For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.

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

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

Institutions of Higher Education (or *educational institutions*): Has the meaning set forth at 20 U.S.C. 1001.

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

Nonprofit Organizations (or *nonprofits*): Has the meaning set forth at 2 C.F.R. § 200.70.

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 or otherwise supporting work under an ARPA-E funding agreement.

Small Business: Small businesses are 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).

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.8 of the FOA for more information).