U.S. Department of Energy

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program

Topics

FY 2023
Phase I
Release 2

Version 4, December 22, 2022

- Office of Cybersecurity, Energy Security, and Emergency Response
- Office of Defense Nuclear Nonproliferation
- Office of Electricity
- Office of Energy Efficiency and Renewable Energy
- Office of Environmental Management
- Office of Fossil Energy and Carbon Management
- Office of Fusion Energy Sciences
- Office of High Energy Physics
- Office of Nuclear Energy

Schedule

Event	Dates
Topics Released:	Monday, November 7, 2022
Funding Opportunity Announcement Issued:	Monday, December 12, 2022
Letter of Intent Due Date:	Tuesday, January 3, 2023, 5pm ET
Application Due Date:	Thursday, February 23, 2023, 11:59pm ET
Award Notification Date:	Monday, May 15, 2023*
Start of Grant Budget Period:	Monday, June 26, 2023

*** Date Subject to Change**

Table of Changes		
Version	**Date**	**Change**
Ver. 1	Nov. 07, 2022	Original
Ver. 2	Nov. 17, 2022	• Topic C56-10, subtopic c: Updated Subtopic Description • Topic C56-19, subtopic c: Updated Subtopic Description • Topic C56-25: Updated Topic Description • Topic C56-26: Updated Topic Description • Topic C56-27: Updated Topic Description • Topic C56-28: Updated Topic Description
Ver. 3	Dec. 07, 2022	• Topic C56-13: Updated Topic Table
Ver. 4	Dec. 22, 2022	• Schedule: Updated Application Due Date • Topic C56-40, subtopic d: Updated Technical Point of Contact

INTRODUCTION TO DOE SBIR/STTR TOPICS

This SBIR/STTR topics document is issued in advance of the FY 2023 DOE SBIR/STTR Phase I Release 2 Funding Opportunity Announcement scheduled to be issued on December 12, 2022. The purpose of the early release of the topics is to allow applicants an opportunity to identify technology areas of interest and to begin formulating innovative responses and partnerships. Applicants new to the DOE SBIR/STTR programs are encouraged to attend upcoming topic and Funding Opportunity Announcement webinars. Dates for these webinars are listed on our website: https://science.osti.gov/sbir/Funding-Opportunities.

Topics may be modified in the future. Applicants are encouraged to check for future updates to this document, particularly when the Funding Opportunity Announcement is issued. Any changes to topics will be listed at the beginning of this document.

General introductory information about the DOE SBIR/STTR programs can be found online here: http://www.doesbirlearning.com/. Please check out the tutorials--a series of short videos designed to get you up to speed quickly.

COMMERCIALIZATION

Federal statutes governing the SBIR/STTR programs require federal agencies to evaluate the commercial potential of innovations proposed by small business applicants. To address this requirement, the DOE SBIR/STTR programs require applicants to submit commercialization plans as part of their Phase I and II applications. DOE understands that commercialization plans will evolve, sometimes significantly, during the course of the research and development, but investing time in commercialization planning demonstrates a commitment to meeting objectives of the SBIR/STTR programs. During Phase I awards, DOE provides small businesses with technical and business assistance (TABA) either through a DOE-funded and selected contractor or through an awardee-funded and selected vendor(s).

The responsibility for commercialization lies with the small business. DOE's SBIR/STTR topics are drafted by DOE program managers seeking to advance the DOE mission. Therefore, while topics may define important scientific and technical challenges, we look to our small business applicants to define how they will bring commercially viable products or services to market. In cases where applicants are able identify a viable technical solution, but unable to identify a successful commercialization strategy, we recommend that they do not submit an SBIR/STTR application.

TECHNOLOGY TRANSFER OPPORTUNITIES

Selected topic and subtopics contained in this document are designated as **Technology Transfer Opportunities (TTOs)**. The questions and answers below will assist you in understanding how TTO topics and subtopics differ from our regular topics.

What is a TTO?

A TTO is an opportunity to leverage technology that has been developed at a university or DOE National Laboratory. Each TTO will be described in a particular subtopic and additional information may be obtained by using the link in the subtopic to the university or National Laboratory Contractor that has developed the technology. Typically the technology was developed with DOE funding of either basic or applied research and is available for transfer to the private sector. The level of technology maturity will vary and applicants are encouraged to contact the appropriate university or Laboratory Contractor prior to submitting an application.

How would I draft an appropriate project description for a TTO?
For Phase I, you would write a project plan that describes the research or development that you would perform to establish the feasibility of the TTO for a commercial application. The major difference from a regular subtopic is that you will be able to leverage the prior R&D carried out by the university or National Laboratory Contractor and your project plan should reflect this.

How do I draft a subaward?
The technology transfer office of the collaborating university or DOE Laboratory will typically be able to assist with a suitable template.

Am I required to show I have a subaward with the university or National Laboratory Contractor that developed the TTO in my grant application?
No. Your project plan should reflect the most fruitful path forward for developing the technology. In some cases, leveraging expertise or facilities of a university or National Laboratory Contractor via a subaward may help to accelerate the research or development effort. In those cases, the small business may wish to negotiate a subaward with the university or National Laboratory.

Is the university or National Laboratory Contractor required to become a subawardee if requested by the applicant?
No. Collaborations with universities or National Laboratory Contractors must be negotiated between the applicant small business and the research organization. The ability of a university or National Laboratory Contractor to act as a subcontractor may be affected by existing or anticipated commitments of the research staff and its facilities.

Are there patents associated with the TTO?
The TTO will be associated with one or in some cases multiple patent applications or issued patents.

Will the rights to the TTO be exclusive or non-exclusive?
Each TTO will describe whether an exclusive or non-exclusive license to the technology is available for negotiation. Licenses are typically limited to a specific field of use.

If selected for award, what rights will I receive to the technology?
Those selected for award under a TTO subtopic will be granted rights to perform research and development of the technology during their Phase I or Phase II grants. Please note that these are NOT commercial rights which allow you to license, manufacture, or sell, but only rights to perform research and development. In addition, an awardee will be provided a no-cost, six month option to license the technology at the start of the Phase I award. It will be the responsibility of the small business to demonstrate adequate progress towards commercialization and negotiate an extension to the option or convert the option to a license. A copy of an option agreement template will be available at the university or National Laboratory Contractor which owns the TTO.

How many awards will be made to a TTO subtopic?
We anticipate making a maximum of one award per TTO subtopic. If we receive applications to a TTO that address different fields of use, it is possible that more than one award will be made per TTO.

How will applying for an SBIR or STTR grant associated with a TTO benefit me?

By leveraging prior research and patents from a university or National Laboratory Contractor you will have a significant "head start" on bringing a new technology to market. To make greatest use of this advantage it will help for you to have prior knowledge of the application or market for the TTO.

Is the review and selection process for TTO topics different from other topics?
No. Your application will undergo the same review and selection process as other applications.

PROGRAM AREA OVERVIEW: OFFICE OF CYBERSECURITY, ENERGY SECURITY, AND EMERGENCY RESPONSE

The Office of Cybersecurity, Energy Security, and Emergency Response (CESER) leads the Department of Energy's emergency preparedness and coordinated response to disruptions to the energy sector, including physical and cyber-attacks, natural disasters, and man-made events. Risk Management Tools and Technologies (RMT) is a program within the CESER office that works to develop innovative technologies to aid power systems in adapting to and surviving from potential cyberattacks.

The RMT program leverages its partnerships with stakeholders within electricity generation, transmission, and distribution along with entities that represent the secure delivery of natural gas and petroleum to guide technology development that enhances energy systems cybersecurity without impeding normal operations. Research funding is provided to a diverse range of researchers representing asset owners/operators, supply chain vendors, national laboratories, and academia. All RMT funded research is intended for demonstration with an entity that represents the potential user of the technology to aid technology transition into wide area adoption.

For additional information regarding CESER's activities and priorities, click here. Click here to read the CESER Blueprint. Information regarding current RMT' funding can be found here . Note: RMT was formerly called CEDS.

Further information regarding the challenges and needs associated with the cybersecurity of the Nation's energy infrastructure can be found in the 2018 releases of the Department's Multiyear Plan for Energy Sector Cybersecurity.

C56-01. ENERGY SYSTEMS CYBERSECURITY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Research in cybersecurity for energy delivery systems is focused on enhancement of operational technology (OT) that aids power systems to adapt and survive from a cyberattack and continue safe operations. This research topic requests applications to develop proof of concept for unique and innovative solutions that address a need for the cyber security for the energy sector. Selected applications must include a scope of work that will lead up to, but will not include, the development of a demonstration prototype. These solutions can include, but are not limited to, new capabilities for defending critical infrastructure and sensitive networks against cyberattacks and supply chain attacks, improved authentication mechanisms, zero-trust architectures, and better intrusion detection capabilities.

All applications to subtopics under this topic must:

- Clearly provide understanding of current capabilities and outline the novelty of the proposed solution.
- Propose a tightly structured project which includes technical and business milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Demonstrate a clear understanding of the OT process/system that is being protected and how the solution will protect without interrupting reliability and normal operations;
- For any solution intended for onsite installation; fully justify the compatibility with the electro-magnetic and other environmental conditions of the intended site;

- Clearly describe the commercialization potential of the federally-funded effort and provide a detailed path to scale up in potential transition to industry practice.
- Fully justify the future potential for demonstration with an asset owner/operator who is an intended user.

All applications to subtopics under this topic should:

- Prioritize the reduction of catastrophic cyber risk and measures that enhance strategic stability for the nation's energy infrastructure.
- Emphasize technologies that ensure safe, clean, and reliable access to critical functions and safety information systems without obstructing normal operations.
- Clearly define the merit of the proposed innovation compared to competing approaches and the anticipated outcome.
- Be consistent with and have performance metrics (whenever possible) linked to published, authoritative analyses in your technology space.
- Include quantitative projections for price and/or performance improvement that are tied to representative values included in authoritative publications or in comparison to existing products.
- Fully justify all performance claims with thoughtful theoretical predictions and/or experimental data.

Grant applications are sought in the following subtopics:

a. Distributed Energy Resource (DER) Cyber Protection

This subtopic is for the development of capabilities such as tools, techniques, and/or methodologies that address gaps related to **infrastructure/software architecture for securing DERs.** Solutions need to take into consideration reliability requirements and the custom engineered nature of most OT systems. Proposed solutions can include but are not limited to sandbox environments to exercise scenarios, automated and unique cyber guidance development for acquisitions, and solutions that promote self-healing from intrusion or malicious attacks.

Questions – Contact: Joseph Dygert, Joseph.dygert@netl.doe.gov

b. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Joseph Dygert, Joseph.dygert@netl.doe.gov

References:

1. American Petroleum Institute, 2014, State of Operational Technology Cybersecurity in the Oil and Natural Gas Industry, *American Petroleum Institute, April 2014.* p. 82, www.api.org/~/media/Files/Policy/Cybersecurity/Operational-Technologies-Guidance-Doc-Apr14.pdf (October 26, 2022)
2. Locasto, M., Balenson, D., 2019, A Comparative Analysis Approach for Deriving Failure Scenarios in the Natural Gas Distribution Infrastructure, *In: Staggs J., Shenoi S. (eds) Critical Infrastructure Protection XIII. ICCIP 2019. IFIP Advances in Information and Communication Technology, vol 570. Springer, Cham,* https://link.springer.com/chapter/10.1007/978-3-030-34647-8_2 (October 26, 2022)
3. United States Department of Commerce, 2021, NTIA Software Component Transparency, *National Telecommunications and Information Administration, United States Department of Commerce,* https://www.ntia.doc.gov/SoftwareTransparency (October 26, 2022)

4. Proctor, Darrell, 2020, The Energy-Sector Threat: How to Address Cybersecurity Vulnerabilities, *Power Magazine, September 03, 2020,* https://www.powermag.com/the-energy-sector-threat-how-to-address-cybersecurity-vulnerabilities/ (October 26, 2022)
5. US Department of Commerce, 2014, Smart Grid Cybersecurity Strategy, Architecture, and High-Level Requirements, *Guidelines for Smart Grid Cyber Security, Vol. 1-2, NISTIR 7628, p. 668. National Institute of Standards and Technology*, https://nvlpubs.nist.gov/nistpubs/ir/2014/NIST.IR.7628r1.pdf (October 26, 2022)
6. IEEE Standard Cybersecurity Requirements for Substation Automation, Protection, and Control Systems, *IEEE Std C37.240-2014* , vol., no., pp.1-38, 30 Jan. 2015, https://ieeexplore.ieee.org/document/7024885 (October 26, 2022)
7. North American Electric Reliability Corporation, 2018, Reference Document Risks and Mitigations for Losing EMS Functions, *NERC EMSWG, February 27, 2018,* https://www.nerc.com/comm/OC/ReferenceDocumentsDL/Risks_and_Mitigations_for_Losing_EMS_Functions_v2.pdf (October 26, 2022)
8. 2017, Bulk Electric Systems Operations Absent Energy Management System and Supervisory Control and Data Acquisition Capabilities—a Spare Tire Approach, *North American Transmission Forum,* http://www.natf.net/docs/natf/documents/resources/resiliency/natf-bes-operations-absent-ems-and-scada-capabilities---a-spare-tire-approach.pdf (October 26, 2022)

PROGRAM AREA OVERVIEW: OFFICE OF DEFENSE NUCLEAR NONPROLIFERATION RESEARCH AND DEVELOPMENT

The Defense Nuclear Nonproliferation (DNN) mission is to provide policy and technical leadership to limit or prevent the spread of materials, technology, and expertise relating to weapons of mass destruction; advance the technologies to detect the proliferation of weapons of mass destruction worldwide; and eliminate or secure inventories of surplus materials and infrastructure usable for nuclear weapons. It is the organization within the Department of Energy's National Nuclear Security Administration (NNSA) responsible for preventing the spread of materials, technology, and expertise relating to weapons of mass destruction (WMD).

Within DNN, the Defense Nuclear Nonproliferation Research and Development (DNN R&D) program directly contributes to nuclear security by developing capabilities to detect and characterize global nuclear security threats. The DNN R&D program also supports cross-cutting functions and foundational capabilities across nonproliferation, counterterrorism, and emergency response mission areas. Specifically, the DNN R&D program makes these strategic contributions through the innovation of U.S. technical capabilities to detect, identify, locate, and characterize: 1) foreign nuclear material production and weapons development activities; 2) movement and illicit diversion of special nuclear materials; and 3) global nuclear detonations.

To meet national and Departmental nuclear security requirements, DNN R&D leverages the unique facilities and scientific skills of DOE, academia, and industry to perform research and demonstrate advances in capabilities, develop prototypes, and produce sensors for integration into operational systems. DNN R&D has two sub-Offices: Proliferation Detection and Nuclear Detonation Detection.

The Office of Proliferation Detection (PD) develops advanced technical capabilities in support of the following three broad U.S. national nuclear security and nonproliferation objectives: (1) detect, characterize, and monitor foreign production and movement of special nuclear materials; (2) detect, characterize, and monitor foreign development of nuclear weapons and to support the nuclear counterterrorism and incident response mission; and (3) provide enabling capabilities for multi-use applications across the NNSA and interagency community.

The Office of Nuclear Detonation Detection (NDD) performs the following three national nuclear security roles: (1) produce, deliver, and integrate the nation's space-based operational sensors that globally detect and report surface, atmospheric, or space nuclear detonations; (2) advance seismic and radionuclide detection and monitoring capabilities that enable operation of the nation's ground-based nuclear detonation detection networks; and (3) advance analytic nuclear forensics capabilities related to nuclear detonations.

These offices seek grant applications in the following topic areas:

C56-02. ALTERNATIVE RADIOLOGICAL SOURCE TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Office of Proliferation Detection (PD) within Defense Nuclear Nonproliferation Research and Development (DNN R&D) has an objective to reduce the reliance on high-activity commercial and industrial radioactive sources. The office is interested in developing replacements for radioisotopic sources to promote the adoption of non-radioisotopic alternative technologies where technically, operationally, and economically feasible. Grant applications are sought in the following subtopics:

a. Novel Non-Radioisotopic Technology for Portable Calibration Sources

Source-based calibration systems produce radiation fields of known energy and intensity, with little change in uncertainty over a span of years, for calibration of radiation monitoring equipment, dosimeters, and industrial/medical radiation technologies to ensure their accurate operation. These gamma-ray based instruments generally utilize cesium chloride up to Category 2 quantities and are considered essential to the safe use of radiation-generating technology. However, the use of high-activity radioisotope sources, including Cs-137 and Co-60, poses a radiological security risk since the sources could be stolen and used in a radiological dispersal device or radiological exposure device. The risk is significant higher for portable systems.

The 2021 National Academies of Sciences (NAS) study on Radioactive Sources: Applications and Alternative Technologies highlighted a lack of progress in industry adopting alternative technologies for calibration systems due to a lack of viable, comparable, or cost-effective replacements. The report highlighted the monoenergetic beam from Cs-137 versus a broad-spectrum beam from an x-ray generator as one of the major hurdles for alternative technologies. Government and industry end users are willing to examine the possibility of using board spectrum beams for calibration if the process can be validated. However, there are currently no portable x-ray or other non-radioisotopic systems that reach the needed gamma-ray dose rate, repeatability, and stability needed for calibration. The current lack of research and development on a viable alternative to these radioisotopic calibration systems constitutes a notable roadblock to the reduction of safety and security risks associated with Cs-137 worldwide. Further research and development are needed to overcome these deficiencies.

The Office of Proliferation Detection is soliciting the development of novel alternatives capable of replacing the need for radioisotope source-based calibration devices, notably those reliant on Category 2 Cs-137 in the form of cesium chloride. Additionally, portable, low size, weight, and power designs employ novel methods aim to reach dose rates from 0.05 to > 50 cGy/hr in an enclosed area large enough for a large dose rate meter with a stable and repeatable beam sufficient for calibration are also sought-after. The proposed designs need to be capable of providing equivalently valuable calibration capability for major service providers, including the National Institute of Standards and Technology in the U.S. and international equivalent organizations. Some measures of this capability include consistent, reproducible, and verifiable radiation output to a level similar to Cs-137, minimal uncertainty in transferring calibrations, and the ability to produce an energy spectrum that is comparable to Cs-137. The alternative methods must be portable, reliable, capable of sustained operation, robust in challenge environmental conditions (e.g., cold weather, precipitation, dust, etc.), cost-competitive with source-based calibration systems, and should address noted deficiencies (e.g., size, weight, power, speed, etc.).

Questions – Contact: Hank Zhu, hank.zhu@nnsa.doe.gov

b. Improved Vacuum X-Ray Tube Design for Radiological Source Replacement

In many applications, the security risk posed by high-activity radioisotope sources can be mitigated through implementation of non-radioisotopic technologies such as x-ray devices. Self-shielded x-ray machines used for research and blood irradiation are a viable and popular alternative to Cs-137 and Co-60 irradiators. These systems rely on vacuum x-ray tubes to generate radiation. X-ray tubes have also been considered in replacement technologies in other application spaces, including non-destructive testing and calibration. While current commercial offerings, particularly second-generation x-ray tubes, are generally reliable, these tubes have inherently limited usage lifecycles and also can be prohibitively expensive in resource-limited environments. Therefore, a supply of reliable, affordable, and available replacement x-ray tubes is critical to increased global usage of x-ray devices. In addition, there are functional limits on energy levels the x-ray tubes can produce based on their design, which may limit efficiency or application viability. Improvements upon the ease of manufacturing, affordability, storage requirements, lifecycle duration, and effectiveness of x-ray tubes and the devices that rely on them are needed to maximize their efficacy as alternatives to radioisotopes.

The 2021 National Academies of Sciences (NAS) report on Radioactive Sources: Applications and Alternative Technologies outlined the current advantages of x-rays that utilize second-generation versus first-generation x-ray tubes including lower voltage requirements, better heat dissipation, and greater radiation output. However, out of the four manufacturers that produce or distribute x-ray irradiators, only one uses second-generation x-ray tubes. The limited incorporation of improved x-ray tubes results in fewer sustainable and reliable x-ray options available when transitioning to non-radioisotopic technologies.

The Office of Proliferation Detection is soliciting the development of x-ray vacuum tubes capable of improving upon second-generation x-ray tubes developed in 2009 and providing a viable alternative for first-generation x-ray tubes. The device needs to be capable of providing equivalent performance for major service providers at a lower cost than currently available replacement x-rays tubes. Some measures of this capability include maintaining or increasing dose rate to the target, improving average tube lifecycle at standard operation levels, and delivering increased radiation energy with minimal waste heat. Additionally, an x-ray design capable of being configured for multiple systems or fittings would be valuable to minimize vendor redesign for operational systems. The manufacturing process for these tubes should be independent of single point supply chain failures and allows for long storage. Additionally, the x-ray tubes should be reliable, robust, capable of sustained operation similar to current radioisotopes, and lead to affordable capital and maintenance costs in resource-limited environments.

Questions – Contact: Hank Zhu, hank.zhu@nnsa.doe.gov

c. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to subtopic a. and b. are also invited.

Questions – Contact: Hank Zhu, hank.zhu@nnsa.doe.gov

References:

1. National Academies of Sciences, Engineering, and Medicine, 2021, Radioactive Sources: Applications and Alternative Technologies, *Division on Earth and Life Studies; Nuclear and Radiation Studies Board; Committee on Radioactive Sources: Applications and Alternative Technologies, Washington (DC): National Academies Press (US); 2021 Jun 14. PMID: 34524768*, https://nap.nationalacademies.org/read/26121/chapter/1 (October 26, 2022)
2. National Research Council, 2008, Radiation Source Use and Replacement: Abbreviated Version, *Washington, DC: National Academies Press*, 2008, https://nap.nationalacademies.org/catalog/11976/radiation-source-use-and-replacement-abbreviated-version (October 27, 2022)

C56-03. RADIATION DETECTION MATERIALS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Office of Proliferation Detection (PD) within Defense Nuclear Nonproliferation Research and Development (DNN R&D) has an objective to develop new technologies for radiation detection. Meeting this objective requires the improvement of current technology and the development of new materials and tools for radiation detection applications. Grant applications are sought in the following subtopics:

a. High-Yield Growth of High-Performance Radiation Detection Semiconductor Materials

The mission to detect and identify illicit nuclear materials would benefit from the availability of detector materials capable of high energy resolution with high detection efficiency. Low-cost, high-yield radiation detectors are not capable of achieving the high-resolution gamma-ray spectroscopy necessary for the identification of nuclear materials. Over the past decade, significant progress has been made in the development of relatively lower-cost, medium energy resolution inorganic scintillators, such as the elpasolite scintillators, CLLBC for example, but the spectroscopic power of these new scintillators is still unable to match those of the traditional room-temperature semiconductor detectors, such as CZT, either pixelated or coplanar grid. On the other hand, despite significant improvements over the past several decades, CZT technology still suffers from major detrimental defects such as high concentration of tellurium inclusions and sub-grain boundary network/dislocation walls, which adversely impacted the yield of high-quality detectors fabricated from the crystals.

All-inorganic semiconductor materials, such as perovskites and chalcohalides, have a high absorption cross-section to ionizing radiation, can be scaled up to large sizes, and have the potential to achieve high performance without bias-induced performance degradation. Challenges in surface preparation and electrode contact engineering need to be met by developing reliable and scalable methods that can be implemented in a manufacturing setting. In addition, metal deposition and surface preparation need to be optimized to work with these new materials.

The Office of Proliferation Detection is soliciting the development of high-resolution semiconductor gamma-ray detectors with all-inorganic semiconductor compositions capable of operating in a wide range of temperatures from -20°C to 80°C, high stopping power, and stability at photon energies up to 3 MeV. Key requirements of the new semiconductor materials include:

- Energy resolution: better than 2% (1% objective) at 662 keV, 4% at 2 MeV
- Detection efficiency: > 60% at 2 MeV
- High material uniformity over > 4 cm length
- Dark current: < 50 nA/cm^2 at 1000 V/cm
- Radiation survivability: up to 100 Mrad
- Detector yield: > 80%
- Materials cost: 2-5 times lower than the cost of typical spectroscopic CZT (pixelated or coplanar grid), or less than $100/cc ($50/cc objective)

Phase I effort will identify the candidate materials and their potentials, demonstrate pathways for meeting the radiometric and cost performance goals.

Phase II efforts will further develop the selected methodology to produce material samples size from 1.5”x1.5” to 2”x2” for radio-isotope identification device (RIID) at projected cost and targeted energy resolution. Development activities will focus on demonstrating the performance in prototype detectors that accomplish the goals of gamma-ray detection in comparison to existing high performance semiconductor materials, e.g., CZT. The detectors shall not be dependent on post-acquisition analysis of data and shall demonstrate radio-isotopic identification capabilities consistent with N42.34 (areas where the prototype diverges from the standard should be identified). Additional efforts will focus on developing manufacturing and commercialization plans for implementing the research in production and dissemination of the semiconductor materials, respectively.

Questions – Contact: Hank Zhu, hank.zhu@nnsa.doe.gov

b. Other

In addition to the specific subtopic listed above, grant applications in other areas relevant to subtopic a. are also invited, such as other semiconductors or scintillators that can achieve the requirements specified in subtopic a.

Questions – Contact: Hank Zhu, hank.zhu@nnsa.doe.gov

References:

1. Bolotnikov, A.E., Camarda, G.S., Cui, Y., Yang, G., Hossain, A., Kim, K., James, R.B., 2013, Characterization and evaluation of extended defects in CZT crystals for gamma-ray detectors, *J. Crystal Growth* 2013, 379, 46–56, https://www.sciencedirect.com/science/article/pii/S0022024813001012 (October 27, 2022)
2. He, Y. H., Petryk, M., Liu, Z. F., Chica, D. G., Hadar, I., Leak, C., Ke, W., Spanopoulos, I., Lin, W.W., Chung, D. Y., Wessels, B.W., He, Z., Kanatzidis, M.G., 2021, $CsPbBr_3$ Perovskite Detectors with 1.4% Energy Resolution for High-Energy Gamma-Rays, *Nature Photonics* 2021, *15* (1), 36-42, https://scholar.google.com/scholar_url?url=https://www.osti.gov/servlets/purl/1780705&hl=en&sa=X&ei=dH9ZY-HdLoqUy9YPxpG9QA&scisig=AAGBfm2U3KJmLoh7GG-cRXOwsI4kU0V67A&oi=scholarr (October 27, 2022)
3. Johnsen, S., Liu, Z. F., Peters, J. A., Song, J. H., Nguyen, S., Malliakas, C. D., Jin, H., Freeman, A. J., Wessels, B. W., Kanatzidis, M. G., "Thallium Chalcohalides for X-ray and Gamma-Ray Detection", *J. Am. Chem. Soc.* 2011, *133* (26), 10030-10033, https://pubmed.ncbi.nlm.nih.gov/21671681/ (October 27, 2022)
4. 2016, American National Standard Performance Criteria for Hand-Held Instruments for the Detection and Identification of Radionuclides, *ANSI N42.34-2015 (Revision of ANSI N42.34-2006)* , vol., no., pp.1-60, 24 Aug. 2016, doi: 10.1109/IEEESTD.2016.7551091, https://ieeexplore.ieee.org/document/7551091 (October 27, 2022)

C56-04. SEPARATION AND DETECTION TECHNOLOGIES ESPECIALLY FOR RARE EARTH ELEMENTS AND LITHIUM

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Office of Nuclear Detonation Detection (NDD) within the Defense Nuclear Nonproliferation Research and Development (DNN R&D) Office is seeking to improve separation and detection of the specific elements identified below from bulk material. These elements are of interest to nuclear security and have commercial value. Grant applications are sought in the following subtopics:

a. High-Purity Separations of Rare Earth Elements from Bulk Material

The rare earth elements (REEs), consisting of the lanthanides plus yttrium and scandium, are in demand for advanced industrial applications, such as magnets, lasers, energy storage, and optics, due to their distinctive electronic properties [1]. The United States Geological Survey (USGS) and Department of Defense (DoD) have included them, minus promethium, on the critical minerals list and strategic materials list, respectively [2, 3].

The lanthanides are also of interest to the nuclear security complex [4]. Unfortunately, the REEs exhibit nearly identical chemical properties, which present major challenges to interelement separations [1, 4].

The Office of Nuclear Detonation Detection is soliciting applications to develop advanced separation technologies to purify individual REEs from bulk material consisting of various geologic matrices, such as silicon dioxide, monazite, xenotime, and other uranium and thorium bearing minerals. Figures of merit to be considered include process time, decontamination factor from bulk material, decontamination factor from other REEs, and maintenance or operational costs, as improvements above current commercial sector capability. A separation specific to any REE is of interest.

Questions – Contact: Richard Gostic, Richard.Gostic@nnsa.doe.gov

b. Environmental Monitoring of Lithium

Lithium is included on the USGS critical minerals list and DoD's strategic materials list [1, 2]. Portable energy storage for devices such as electric vehicles, mobile phones, and laptops is increasing the demand for lithium [3]. Lithium is also used for nuclear security applications, such as neutron detection and radiation dosimetry [4, 5]. The processing of lithium and production of lithium compounds have historically led to environmental contamination, particularly of surface and groundwater [3, 6, 7].

The Office of Nuclear Detonation Detection is soliciting applications to develop environmental monitoring systems to distinguish trace levels of lithium. These systems should show potential for dual use applications for monitoring environmental contamination from industrial processes, such as lithium-ion battery production, and identify deviations from environmental lithium concentrations. An ideal system would have passive collection and operation and be able to detect lithium at concentrations below the threshold limit values (TLVs®) determined by American Congress of Governmental Industrial Hygienists (ACGIH®) for common lithium compounds. Other figures of merit for an ideal monitoring system to consider include durability in the monitoring environment, high volume sampling, and response rate (i.e., how rapidly the monitor can detect lithium).

Questions – Contact: Richard Gostic, Richard.Gostic@nnsa.doe.gov

c. Other

In addition to the specific subtopics listed above, grant applications are invited in other areas relevant to these subtopics, such as environmental monitoring, environmental sensors, industrial hygiene sensors, and biosensors for other critical minerals or strategic materials.

Questions – Contact: Richard Gostic, Richard.Gostic@nnsa.doe.gov

References: Subtopic a:

1. Cheisson, T., & Schelter, E. J., 2019, Rare earth elements: Mendeleev's bane, modern marvels, *Science*, *363*(6426), 489-493, https://doi.org/10.1126/science.aau7628 (October 28, 2022)
2. Applegate, J. D., 2022, 2022 Final List of Critical Minerals [Memorandum], *Department of the Interior Geological Survey*, https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/2022%20Final%20List%20of%20Critical%20Minerals%20Federal%20Register%20Notice_2222022-F.pdf (October 28, 2022)
3. White House, 2021, *Building resilient supply chains, revitalizing American manufacturing, and fostering broad-based growth*, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf (October 28, 2022)

4. Arrigo, L. M., Jiang, J., Finch, Z. S., Bowen, J. M., Beck, C. L., Friese, J. I., Greenwood, L. R., & Seiner, B. N., 2021, Development of a separation method for rare earth elements using LN resin, *Journal of Radioanalytical and Nuclear Chemistry*, *327*(1), 457-463, https://doi.org/10.1007/s10967-020-07488-9 (October 28, 2022)

References: Subtopic b:
1. Applegate, J. D., 2022, 2022 Final List of Critical Minerals [Memorandum], *Department of the Interior Geological Survey*, https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/media/files/2022%20Final%20List%20of%20Critical%20Minerals%20Federal%20Register%20Notice_2222022-F.pdf (October 28, 2022)
2. White House, 2021, *Building resilient supply chains, revitalizing American manufacturing, and fostering broad-based growth*, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf (October 28, 2022)
3. Bolan, N., Hoang, S. A., Tanveer, M., Wang, L., Bolan, S., Sooriyakumar, P., Robinson, B., Wijesekara, H., Wijesooriya, M., Keerthanan, S. & Rinklebe, J., 2021, From mine to mind and mobiles–Lithium contamination and its risk management, *Environmental Pollution*, *290*, 118067, https://doi.org/10.1016/j.envpol.2021.118067 (October 28, 2022)
4. Mayer, M., Nattress, J., Kukharev, V., Foster, A., Meddeb, A., Trivelpiece, C., Ounaies, Z., & Jovanovic, I., 2015, Development and characterization of a neutron detector based on a lithium glass–polymer composite, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *785*, 117-122, https://doi.org/10.1016/j.nima.2015.03.014 (October 28, 2022)
5. Crittenden, G. C., Townsend, P. D., Gilkes, J., & Wintersgill, M. D., 1974, LiF dosimetry: II. The effects of Mg and Ti on the thermoluminescent emission spectra of LiF. *Journal of Physics D: Applied Physics*, *7*(17), 2410, https://doi.org/10.1088/0022-3727/7/17/316 (October 28, 2022)
6. Kszos, L. A., & Stewart, A. J., 2003, Review of lithium in the aquatic environment: distribution in the United States, toxicity and case example of groundwater contamination. *Ecotoxicology*, *12*(5), 439-447, https://doi.org/10.1023/A:1026112507664 (October 28, 2022)
7. Kuloğlu, S. S., Yalçin, E., Çavuşoğlu, K., & Acar, A., 2022, Dose-dependent toxicity profile and genotoxicity mechanism of lithium carbonate, *Scientific Reports*, *12*(1), 1-12, https://doi.org/10.1038/s41598-022-17838-0 (October 28, 2022)

C56-05. ADVANCED DATA ANALYTICS FOR MULTIPLE MICROSCOPIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Office of Nuclear Detonation Detection (NDD) within the Defense Nuclear Nonproliferation Research and Development (DNN R&D) Office is seeking to improve analyses for large data sets originating from multiple instrumentation, such as optical and electron microscopes and secondary ion mass spectrometry (SIMS). Grant applications are sought in the following subtopics:

a. Graphical Analyses for Material Characterization

Analytical instrumentation provides important radiological, morphological, structural, elemental and/or isotopic characterization information about a bulk material sample. Most of these instruments provide few data processing tools to permit the user to compare features from different materials or samples. Comparative graphical tools become important when analyzing dozens to thousands of observations (e.g., to highlight slight perturbations in crystal structure or trace element variations). Artificial Intelligence/Machine

Learning (AI/ML) graphical analyses have been developed within various microscopy domains [1, 2, 3], but only limited work to date has been applied across multiple microscopies.

The Office of Nuclear Detonation Detection is soliciting applications to develop data processing tools to evaluate data from multiple analytical techniques such as autoradiography, X-ray diffraction (XRD), X-ray fluorescence (XRF), electron microprobe, Raman spectroscopy, Fourier-transform infrared spectroscopy (FTIR), SIMS, electron backscatter diffraction (EBSD), transmission electron microscopy (TEM), and atom probe tomography (APT). Complications may arise from access to raw data files from common instruments or platforms that utilize proprietary software for data analysis. A diverse analytical community would benefit from advanced data processing tools to identify subtle key features or associations that are not readily evident in large data sets. Of interest are data processing tools or platforms that can combine multiple data inputs for a sample, compare with other samples, and identify variations in common characteristics, such as morphology, size, crystal structure, etc., between samples or sample sets without the need for high performance computing. Figures of merit to consider include processing requirements, processing time, data storage requirements, complexity of operation, ease of code modification, and implementation cost.

Questions – Contact: Richard Gostic, Richard.Gostic@nnsa.doe.gov

b. Other

In addition to the specific subtopic listed above, grant applications to this topic are invited in other relevant areas, such as geospatial analyses and biomedical imaging. Quantitative comparisons between data originating from the same sample at different times can measure the effects of different conditions one the subject (e.g., environmental impact on a certain area or the effectiveness of a medical treatment).

Questions – Contact: Richard Gostic, Richard.Gostic@nnsa.doe.gov

References:

1. Kalinin, S. V., Ziatdinov, M., Hinkle, J., Jesse, S., Ghosh, A., Kelley, K. P., Lupini, A. R., Sumpter, B. G., & Vasudevan, R. K., 2021, Automated and autonomous experiments in electron and scanning probe microscopy, *ACS nano*, *15*(8), 12604-12627, https://doi.org/10.1021/acsnano.1c02104 (October 28, 2022)
2. Maksov, A., Kalinin, S. V., Vasudevan, R. K., & Ziatdinov, M., 2020, Deep Machine Learning in Electron and Scanning Probe Microscopy, In *HANDBOOK ON BIG DATA AND MACHINE LEARNING IN THE PHYSICAL SCIENCES: Volume 1. Big Data Methods in Experimental Materials Discovery* (pp. 363-395), https://doi.org/10.1142/9789811204555_0010 (October 28, 2022)
3. Okamoto, K., Sugiyama, M., & Mabu, S., 2020, Importance of Advanced Metrology in Semiconductor Industry and Value-added Creation Using AI/ML, *e-Journal of Surface Science and Nanotechnology*, *18*, 214-222, https://doi.org/10.1380/ejssnt.2020.214 (October 28, 2022)

C56-06. TECHNOLOGY FOR SEISMIC MONITORING SYSTEMS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Office of Nuclear Detonation Detection (NDD) within Defense Nuclear Nonproliferation Research and Development (DNN R&D) has an objective to develop new technologies for seismic monitoring. The growing demand for sensor technologies requires hardware and software development to enable faster data processing approaches capable of processing and managing large amounts of data resulting from sensors with high spatial and temporal resolution, large area coverage, and sensitivity. Data from these sensor systems can potentially support global networks (e.g., the International Monitoring System (IMS)) by filling the gap for inaccessible areas. Grant applications are sought in the following subtopics:

a. Hardware/Software Applications for Distributed Acoustic Sensing (DAS) Data Acquisition and Processing

Distributed Acoustic Sensing (DAS) is a novel tool utilizing laser pulses travelling in fiber-optic cable [1,2]. DAS is an attractive potential nuclear explosion monitoring tool that is affordable and able to collect data even along existing telecommunication cables [3]. However, some characteristics must be overcome with further technological advances in order to fully use DAS technology. For example, the high spatial sampling density (orders-of-magnitude above conventional seismic deployments) results in overwhelming amounts of data to be processed and stored, which is at present an impractical impediment to the near real time use of this information. In fact, the bit rate of a single DAS deployment can exceed that of the entire IMS combined. Furthermore, a DAS system's data are concentrated on a single acquisition system sent from one station, sometimes in a remote location, making data storage and processing a challenge when these data are combined with those of dozens of other stations for data analysis [4]. This results in a computational bottleneck that precludes the possibility of real-time or near real-time data processing. For DAS systems to be used effectively, the seismic monitoring community needs improved ways to gather and process data and reduction of the time lag between data acquisition and data exploitation.

The Office of Nuclear Detonation Detection is soliciting the development of DAS hardware and/or software for faster processing of their data near the sensor, more efficient data compression, and options for hardware-embedded analysis. Systems that fully exploit the strengths of DAS then can be incorporated into new DAS interrogator designs with faster processing hardware architecture [4]. Alternative approaches may include external hardware systems with advanced data processing software that support the data formats of Technical Data Management Streaming (TDMS) (https://www.ni.com/en-us/support/documentation/supplemental/06/the-ni-tdms-file-format.html) and Hierarchical Data Format 5 (HDF5) (https://www.earthdata.nasa.gov/esdis/esco/standards-and-references/hdf5).

Questions – Contact: John Lazarz, John.Lazarz@nnsa.doe.gov

b. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited. These include seismometer improvements (e.g., reduced size, improved sensitivity, reduced power requirements), seismic array improvements, infrasound sensor improvements, hydroacoustic sensor improvements, or other ways to detect acoustic energy underground, on the surface, or in the atmosphere at regional to global distances (>200km). Improvements should substantially enhance capabilities when compared to existing sensors or techniques [5].

Questions – Contact: John Lazarz, John.Lazarz@nnsa.doe.gov

References:

1. Lindsey N. J., E. R. Martin, D. S. Dreger, B. Freifeld, S. Cole , S. R. James, J. B. Ajo-Franklin, 2017, Fiber-Optic Network Observations of Earthquake Wavefields, *Geophysical Research Letters*,44, 11,792–11,799 doi:10.1002/2017GL075722, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL075722 (October 28, 2022)
2. Zhan, Z., 2019, Distributed Acoustic Sensing Turns Fiber-Optic Cables into Sensitive Seismic Antennas, *Seismological Research Letters 91, 1–15*, doi: 10.1785/0220190112, https://pubs.geoscienceworld.org/ssa/srl/article-abstract/91/1/1/579426/Distributed-Acoustic-Sensing-Turns-Fiber-Optic?redirectedFrom=fulltext (October 28, 2022)

3. Li, Y., M. Karrenbach, J. B. Ajo-Franklin, 2021, Distributed Acoustic Sensing in Geophysics: Methods and Applications, *Geophysical Monograph Series*, doi:10.1002/9781119521808, https://www.wiley.com/en-us/Distributed+Acoustic+Sensing+in+Geophysics%3A+Methods+and+Applications-p-9781119521778 (October 28, 2022)
4. Dong B., et al, 2022, Real-time and Post-hoc Compression for Data from Distributed Acoustic Sensing, *Computers & Geosciences*, Volume 166, 2022, 105181, ISSN 0098-3004, doi:10.1016/j.cageo.2022.105181, https://www.sciencedirect.com/science/article/pii/S0098300422001340?dgcid=rss_sd_all (October 28, 2022)
5. Garcia R.F., et al, 2022, Infrasound From Large Earthquakes Recorded on a Network of Balloons in the Stratosphere, *Geophysical Research Letters*, 49 (15), doi.org/10.1029/2022GL098844, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022GL098844 (October 28, 2022)

C56-07. TECHNOLOGY FOR FUTURE RADIONUCLIDE MONITORING SYSTEMS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Office of Nuclear Detonation Detection (NDD) within Defense Nuclear Nonproliferation Research and Development (DNN R&D) has an objective to develop new technologies for atmospheric radionuclide monitoring systems. Present-day monitoring carried out by the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Preparatory Commission (see, for example, https://www.ctbto.org/our-work/monitoring-technologies/radionuclide-monitoring) involves collecting gas samples (i.e., >500 standard cubic meters of air per hour) at regional distances (>200 km) and concentrating the species of interest for measurement (e.g., beta-gamma emissions of radioxenon isotopes). Meeting the NDD objective in local-distance regimes (<200 km) requires the development of new atmospheric radionuclide sensors and techniques capable of lower detection thresholds and better discrimination to distinguish radionuclides from vented underground nuclear tests (1 kT yield or less) among other confounding sources such as medical isotope production or nuclear reactor operations. Grant applications are sought in the following subtopics:

a. Electrostatic Precipitation System for Local-Distance Radionuclide Monitoring

Monitoring effluents present at local distances (<200 km), could entail collecting short-lived isotopes from vented underground nuclear tests [1] which may have larger signals than the current species focused on by IMS radionuclide monitoring technologies. Research of systems based on electrostatic precipitation (ESP) principles show promise for the detection of short-lived particulate radionuclides [2] but using this concept for monitoring at local distances requires reducing size, weight, and power, and increasing collection efficiency [3,4] to become a viable system for mobile applications. Therefore, a primary focus is to improve the collection system.

The Office of Nuclear Detonation Detection is soliciting the development of the mobile particulate detector concept using a low-volume system, collecting 100 standard cubic meters of air per hour, and using an electrostatic precipitator, operating with a collection efficiency of 80% or greater for 0.2 micrometer particles. Overall, this concept would then advance the collection medium into a radiation detector suitable for measuring radionuclides expected at local distances (<200 km) from a vented underground nuclear test of 1 kT yield or less. Applications that address the air flow and collector efficiency specifications, where size and power are minimized to facilitate portability and fielding by a single person, will be prioritized over applications focused on radiation detection performance, which is a secondary design consideration in the overall scheme.

Questions – Contact: Brian Paeth, Brian.Paeth@nnsa.doe.gov

b. Other

In addition to the specific subtopic listed above, grant applications in other areas relevant to this topic are invited. These include development of atmospheric radionuclide sensors or techniques which, when compared against existing sensors or techniques, can be shown to substantially increase performance and reduce uncertainty [1-5]. Applications focused on effluents expected at local distances (<200 km) from a vented underground nuclear test of 1 kT yield or less are welcome.

Questions – Contact: Brian Paeth, Brian.Paeth@nnsa.doe.gov

References: Subtopic a:

1. Schoengold, C R, DeMarre, M E, and Kirkwood, E M., 1996, Radiological effluents released from US continental tests, 1961 through 1992, *United States: DOE/NV-317-Rev.1*, 1996, https://www.osti.gov/biblio/414107 (October 28, 2022)
2. Miley, H, Burnett, J, Chepko, A, Devoy, C, Eslinger P, Forrester, J, Friese, J, Lidey, L, Morris, S, Schrom, B, Stokes, S, Swanwick, M, Smart, J, and Warren, G., 2019, Design Considerations for Future Radionuclide Aerosol Monitoring Systems, *United States: Journal of Environmental Radioactivity 208-209*, 106037, 2019, https://doi.org/10.1016/j.jenvrad.2019.106037 (October 28, 2022)
3. Laskin, A, and Cowin, J.P., 2002, On Deposition Efficiency of Point-to-Plate Electrostatic Precipitator, *United States: Journal of Aerosol Science 33*:405-09, 2002, https://doi.org/10.1016/S0021-8502(01)00183-5 (October 28, 2022)
4. Sharma, A.K., Wallin, H., and Jensen, K.A., 2007, High Volume Electrostatic Field-Sampler for Collection of Fine Particle Bulk Samples, *United States: Atmospheric Environment* 41(2):369-81, 2007, https://doi.org/10.1016/j.atmosenv.2006.07.034 (October 28, 2022)

References: Subtopic b:

1. Sivels, C, et al., 2017, A review of the developments of radioxenon detectors for nuclear explosion monitoring, *United States: Journal of Radioanalytical and Nuclear Chemistry* 314:829–841, 2017, https://doi.org/10.1007/s10967-017-5489-2 (October 28, 2022)
2. Haas, D.A., Eslinger, P.W., Bowyer, T.W., Cameron, I.M., Hayes, J.C., Lowrey, J.D., and Miley, H.S., 2017, Improved performance comparisons of radioxenon systems for low level releases in nuclear explosion monitoring, *United States: Journal of Environmental Radioactivity*, 178–179, 2017, https://doi.org/10.1016/j.jenvrad.2017.08.005 (October 28, 2022)
3. Cooper, M.W., Auer, M., Bowyer, T.W., Casey, L.A., Elmgren, K., Ely, J.H., Foxe, M.P., Gheddou, A., Gohla, H., Hayes, J.C., Johnson, C.M., Kalinowski, M., Klingberg, F.J., Liu, B., Mayer, M.F., McIntyre, J.I., Plenteda, R., Popov, V., and Zahringer, M., 2019, Radioxenon net count calculations revisited. *Hungary: Journal of Radioanalytical and Nuclear Chemistry* 321:369-382, 2019, https://doi.org/10.1007/s10967-019-06565-y (October 28, 2022)
4. Bottenus, D.R., Humble, P.H., Burnett, R., Harper, W., Veldman, T., Powell, M.R., Barclay, J.A., and Ely, J., 2022, Additively manufactured cryogenic microchannel distillation device for air separation, *United States: Journal of Advanced Manufacturing and Processing*, e10139, 2022, https://doi.org/10.1002/amp2.10139 (October 28, 2022)
5. Eslinger, P.W., Ely, J.H., Lowrey, J.D., and Miley, H.S., Projected network performance for multiple isotopes using next-generation xenon monitoring systems, United States: Journal of Environmental Radioactivity, 251–252, 106963, 2022, https://doi.org/10.1016/j.jenvrad.2022.106963 (October 28, 2022)

Back to Table of Contents

PROGRAM AREA OVERVIEW: OFFICE OF ELECTRICITY

The Office of Electricity (OE) leads the Department of Energy's efforts to ensure that the Nation's energy delivery system is reliable, resilient, and secure. Working closely with public and private partners funds the development of new technologies that enhance the infrastructure that delivers electricity at the transmission and distribution levels across North America.

OE recognizes that our Nation's sustained economic prosperity, quality of life, and global competitiveness depend on access to an abundance of reliable, secure, and affordable energy resources. The mission of OE is to drive electric grid modernization and reliability and resiliency in the energy infrastructure. Through a mix of technology and policy solutions, OE will address the changing dynamics and uncertainties in which the electric system will operate. OE leverages effective partnerships, solid research, and best practices to address diverse interests in achieving economic, societal, and environmental objectives.

OE has a broad portfolio of activities that spans technology innovation, institutional support and alignment, and security and resilience. Serving as the lead for the Department of Energy's efforts on grid modernization, OE works closely with diverse stakeholders to ensure that clean energy technologies can be integrated in a safe, reliable, and cost-effective manner.

For additional information regarding OE's activities and priorities, click here.

Further information regarding the challenges and needs associated with the Nation's energy infrastructure can be found in the 2015 releases of the Department's Quadrennial Technology Review.

C56-08. ADVANCED GRID TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Electricity is the lifeblood of modern society, and many of the quality-of-life improvements in human history have been catalyzed by widespread access to affordable electricity. The ability to control, shape, and condition electric power is critical, and requires the use of power electronics. The electric power grid is facing increasing stress due to fundamental changes in both supply-side and demand-side technologies. On the supply-side, there is a shift from large synchronous generators to smaller, lighter units (e.g., gas-fired turbines) and variable invertor-based energy resources (renewables) with utility scale energy storage. On the demand-side, there is a growing number of distributed energy resources, as well as a shift from large induction motors to rapidly increasing use of electronic converters in buildings, industrial equipment, and consumer devices. The monitoring and control systems used for operations are also transitioning from analog systems to systems with increasing data streams and more digital control and communications from systems with a handful of control points at central stations to ones with potentially millions of control points distributed throughout the grid.

Grid modernization will require the adoption of advanced technologies, such as advanced power electronics, smart meters, automated feeder switches, fiber optic and wireless networks, energy storage, and other new hardware. It must also encompass and enable the application of intelligent devices, next-generation components, cybersecurity protections, advanced grid modeling and applications, distributed energy resources, and innovative architectures. Integration of these technologies will require a new communication and control layer to manage a changing mix of supply- and demand-side resources, evolving threats, and to provide new services.

The transition to a modern grid will create new technical challenges for an electric power system that was not designed for today's requirements. Customers have never relied more on electricity, nor been so involved in where and how it is generated, stored, and used. Utilities will continue retrofitting the existing infrastructure with a variety of smart digital devices and communication technologies needed to enable the distributed, two-way flow of information and energy. Reliability, resilience, and security will remain a top priority as aging infrastructure and changing demand, supply, and market structures create new operational challenges.

All applications to this topic should:

- Be consistent with and have performance metrics (whenever possible) linked to published, authoritative analyses in your technology space.
- Clearly define the merit of the proposed innovation compared to competing approaches and the anticipated outcome.
- Emphasize the commercialization potential of the overall effort and provide a path to scale up in potential Phase II follow-on work.
- Include quantitative projections for price and/or performance improvement that are tied to representative values included in authoritative publications or in comparison to existing products.
- Fully justify all performance claims with thoughtful theoretical predictions and/or experimental data.

Grant applications are sought in the following subtopic:

a. Advanced Materials for Power Electronic Components in Medium and High Voltage Grid Applications
The electric grid is going through a modernization process with growing penetration of renewables, multi-directional power flow, and demand-side management based on real-time data. This means a transition from centralized generation-based unidirectional power flow grid to a dynamic and fast-responsive grid with distributed generation, highlighting the critical role of power electronics in the grid modernization.

Power electronics (PE) in this context refers to the broad set of technologies (e.g., materials, components, subsystems, and systems) necessary for the control and conversion of electricity. A power electronic system (PES) is a self-contained, fully functional collection of hardware and software that safely and efficiently converts current-type (e.g., AC to DC, DC to AC), voltage (e.g., DC to DC), frequency (e.g., AC to AC), or any combination thereof, and conditions electric power according to application-specific requirements. PESs are widespread in electric power systems for a variety of applications, highlighting the importance of continued advances in PE.

Materials play a critical role in the design and performance of a PES and associated subsystems. Innovations in semiconductors, magnetics, dielectrics, and conductors can be leveraged across the various key components to develop next-generation systems, reduce cost, improve fundamental properties and capabilities needed for grid applications.

Applications are being sought on material level innovation for power electronic components (e.g., capacitors, transformers, semiconductor devices, inductors) used in medium and high voltage grid applications (e.g., HVDC, Power Flow Controllers). Desired advanced materials for power electronic components are affordable, readily available, and show significant performance improvements over currently available materials. Applications must demonstrate how the advanced material in question provides significant performance improvements over currently available materials, and that it will be applicable to medium and high voltage grid applications.

Questions – Contact: Andre Pereira, andre.pereira@hq.doe.gov

b. Grid-Enhancing Technologies to Reduce Electricity Delivery Losses and Improve T&D Systems Energy Efficiency and Utilization

With the development of the Smart Grid, especially in the distribution grid, and with the possibility of load modeling, control over the peaks of energy demand becomes vital. The peaks of demand are serious problems and present themselves in the electrical system.

Transmission congestion and distribution system overloading have recently become more of an issue as we move to the grid of the future. Congestion occurs when the scheduled or actual flows of electricity are restricted either by physical capacity constraints on a particular device or by operational safety constraints designed to preserve grid reliability. At a load level system overloading occurs when a distribution transformer loading exceeds its design parameters resulting in reduced power quality, premature equipment failure and in some cases can lead to fires.

Another issue that needs to be addressed is that transmission and distribution (including substation) "T&D" have losses of the wires and equipment that the energy passes through. The energy losses greatly depend on the physical characteristics of the system and how is operated. T&D losses between 6% and 8% are currently considered normal. In 2005 according with the data from the Energy Information administration, T&D losses amounted to almost $19.5 billion.

Energy-enhancing technologies would help reduce the line losses, congestion, and equipment losses. Some examples are Flexible AC Transmission Systems (FACTS), technology component to increase distribution transformer efficiency, wide area monitoring system etc.

Energy efficiency is one of the easiest and most cost-effective ways to combat climate change, reduce energy costs for consumers, and improve the competitiveness of U.S. businesses. Energy efficiency is also a vital component in achieving net-zero emissions of carbon dioxide through decarbonization.

Applications are sought on technology impact to reduce wire losses, transmission congestion, distribution system overloading and improve T&D efficiency. Applicants must describe the targeted use-case with sufficient detail their technology will address. Desired technologies are affordable, readily available, and show significant performance improvements over currently available technologies.

Questions – Contact: Fernando Palma, fernando.palma@hq.doe.gov

References: Subtopic a:

1. U.S. Department of Energy, Office of Electricity Delivery & Energy Reliability, 2015, Power Electronics Systems for the Electric Grid, Ensuring the Flexibility, Reliability, and Resilience of The Future Gold, *Power Electronics Factsheet*, March 2015, https://www.energy.gov/sites/prod/files/2016/06/f32/OE%20Factsheet%20Power%20Electronics_0.pdf (October 31, 2022)
2. U.S. Department of Energy, Office of Electricity Delivery & Energy Reliability, 2011, Power Electronics Research and Development, *Program Plan*, April 2011, https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/OE_Power_Electronics_Program_Plan_April_2011.pdf (October 31, 2022)

3. Baliga, B. Jayant, 2015, IGBT Structural Design, *The IGBT Device: Physics, Design and Applications of the Insulated Gate Bipolar Transistor*, 31–116. ScienceDirect: 2015, http://scitechconnect.elsevier.com/wp-content/uploads/2016/02/IGBT-structural-design-chapter-3.pdf (October 31, 2022)
4. Marek, R.S., Hartnett, K., Hayes, J.G., and Egan, M.G., 2009, Magnetic Material Selection for High Power High Frequency Inductors in DC-DC Converters, *2009 Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition (2009):* 2043–2049, https://ieeexplore.ieee.org/document/4802955 (October 31, 2022)
5. Tolbert, L.M., King, T.J., Ozpineci, B., Campbell, J.B., Muralidharan, G., Rizy, D.T., Sabau, A.S., et al, 2005, Power Electronics for Distributed Energy Systems and Transmission and Distribution Applications, *Oak Ridge, TN: U.S. Department of Energy, Oak Ridge National Laboratory*, December 2005, http://web.eecs.utk.edu/~tolbert/publications/ornl_tm_2005_230.pdf (October 31, 2005)
6. McLyman, Colonel W.T., 2017, *Transformer and Inductor Design Handbook*, *CRC press*, https://www.perlego.com/book/1574836/transformer-and-inductor-design-handbook-pdf (October 31, 2022)
7. Tsao, J.Y., Chowdhury, S., Hollis, M.A., et al, 2017, Ultra-Wide-Bandgap Semiconductors: Research Opportunities and Challenges*, Advanced Electronic Materials 4, no. 1* (December 2017), https://onlinelibrary.wiley.com/doi/full/10.1002/aelm.201600501 (October 31, 2022)

Subtopic b:
1. ABB Inc., *Energy Efficiency in the Power Grid*, 2014, http://large.stanford.edu/courses/2014/ph240/singh2/docs/TDEnergyEff.pdf (October 31, 2022)
2. Loschi, H.J., Leon, J., Iano, Y., Filho, E.R., Conte, F.D., Lustosa, T.C. and Freitas, P.O., 2015, Energy Efficiency in Smart Grid: A Prospective Study on Energy Management Systems, Smart Grid and Renewable Energy, 6, 250-259, http://dx.doi.org/10.4236/sgre.2015.68021 (October 31, 2022)

C56-09. ADVANCED POWER CONVERSION SYSTEM FOR GRID-TIED ENERGY STORAGE & ENERGY STORAGE DEPLOYMENT

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The widespread adoption of grid-tied energy storage systems continues to grow, especially due to increasing deployment of renewable energy such as photovoltaic and wind energy systems. Grid-tied energy storage systems add valuable functionality such as renewable firming, frequency regulation, power quality enhancement, and dynamic stability support. Grid storage will ultimately improve the reliability, flexibility, security, and quality of the existing electricity infrastructure in both grid-tied and off-grid systems. The enabling technology that is crucial to these applications is the power conversion system (PCS). The power conversion system controls the power supplied and absorbed from the grid to energy storage device performance while maintaining grid stability. Critical electrical components used in PCS are semiconductors, magnetics such as transformers and inductors, and capacitors. With the advances in wide bandgap semiconductor devices such as SiC and GaN, new topologies for PCSs are emerging due to their high switching frequency, high junction temperature, and high breakdown voltage capabilities.

Energy storage is a key technology needed to maintain reliability and resource adequacy as the electrical grid transitions to increasing amounts of renewable energy, distributed energy resources, and electrification. While energy storage technologies have seen an increasing number of commercial deployments across a both stationary and transportation-based sectors, the global market for storage capacity is expected to grow approximately three to five times its current size by 2030[1]. Currently in the U.S. pumped hydro-power storage makes up the vast majority of deployed storage capacity, however aggressive decarbonization and electrification scenarios require as much as 3,000 times more non-pumped hydro energy storage technologies such as batteries to be deployed by 2050 compared to current levels[2]. In order to accelerate deployment of storage that can fulfill this market, innovations that can reduce costs, improve value proposition, and reduce deployment barriers are required to allow stakeholders across different sectors and regions to invest in storage solutions at more rapid pace than today.

Grant applications are sought in the following subtopics:

a. High Density Cell-Level Battery Power Converters for Next Generation Grid-Tied Energy Storage Systems

Typical battery energy storage system designs employ a DC-DC converter front-in followed by a grid-tied inverter via a line frequency transformer. Wide bandgap semiconductors are making significant impact on the performance of next-generation power converters. With their high switching frequency and high junction temperature capability, the overall power converter volumetric density can be increased by an order of magnitude. For example, higher switching frequencies can reduce the size of passive components such as magnetics and capacitors. Magnetics and capacitors in conventional designs can take up a disproportionately large piece of the power converter footprint, especially if the design requires a passively cooled thermal management system. Battery cells for grid-tied applications are typically configured in a cylindrical or prismatic format. The basic cell configurations are assembled in series to increase output voltage, or in parallel to increase current carrying capability.

Applications are sought to develop and demonstrate a high-density, high-gain, DC-DC, cell-level power conversion system. The inherent advantage of having a dedicated cell-level converter is that each converter will operate at optimal operating point of each cell and thus improving its performance and eliminating the possibility of dangerous charge and overcharge conditions potentially leading to thermal runaway. In addition, with a controllable high-gain DC output, early cell degradation detection is possible, and the user can either bypass the cell or run it at partial rated power thus maximizing the availability of system power. The advanced cell-level converter must have the same footprint as a prismatic cell (<4 Vdc, >50 Ahr), a DC-gain greater than 100X (i.e., this makes it attractive for 350+ dc-link voltage required by 120V single-phase inverters), the ability to operate in series and/or parallel, and an overall efficiency of greater than 98%. The cell-level converter should connect directly to the positive and negative terminals (typically pole connections) of the prismatic cell. The terminals are located on the top of the cell, which measures approximately 2-3 inches by 5-6 inches. Distances between terminals vary by manufacturer but 3-inch separation can be assumed. The cell-level converter must conform to the terminal face of the cell and be less than 2 inches high. Special considerations should be made to ensure heat generated in the device does not contribute to cell overheating. The cell-level converters will be configured into a standard AC system design (i.e., standard inverter and utility interconnect) with an overall power rating of greater than 2 kW and 120 V single-phase output for remote power applications. The final design should show a significant increase in performance, cost reduction, and decrease in footprint compared to a traditional off-grid power conversion design.

Questions – Contact: Imre Gyuk, imre.gyuk@hq.doe.gov

b. Innovations to Accelerate Energy Storage Deployment

This subtopic is seeking innovations that accelerate deployment of energy storage by enhancing energy storage's ability to provide benefits and reducing current barriers that prevent or delay energy storage from

[1] Energy Storage Grand Challenge Energy Storage Market Report

[2] Storage Futures Study: Economic Potential of Diurnal Storage in the U.S. Power Sector (nrel.gov)

being deployed where they are capable of providing benefits. Innovation areas of interest include:

- Development of enhanced control, communication, or decision-making technologies that improve of customer sited energy storage system's ability to provide benefits to the grid, support customer energy resiliency, support integration of distributed energy resources (DERs), or combinations of these opportunities
- Innovations that reduce amount of time, cost, or other resources needed to integrate energy storage systems into larger systems such as utility grids, microgrids, and building systems

In order to demonstrate real world impacts and near-term benefits, applicants responding to this topic should target innovations that can be demonstrated at or near scale using the funding provided by the SBIR program. Applicants must consider the scale of effort and resources required to demonstrate their concept at scale, including targeting projects that address barriers in appropriate market segments such as multi-dwelling residential and small commercial sectors as opposed to targeting markets that may require large scale storage projects and significant capital outside the scope of what the SBIR program can fund. Applicants are encouraged to identify project partners that will serve as example stakeholders that can benefit from the proposed innovation being deployed in Phase 2 of this opportunity.

Application Requirements:

- Applicants must describe a targeted use-case in sufficient detail that their innovation will address. This can include targeting specific locations, customer types, or other characteristics that would specifically benefit from the proposed innovation.
- The proposed innovation must leverage mature storage technologies that can be safely used at the specified site and adhere to all necessary codes and standards.
- Applicants will describe how any newly developed technologies or methods to control, coordinate, monitor or otherwise interface with the energy storage system or site infrastructure will be conceptually designed in Phase 1 and validated in Phase 2 if awarded.

Phase 1 Objectives:

- Approach and Feasibility: Initial analysis, scoping, and design of the concept that will show that the described innovation can be successfully implemented and validated using up to $1.1 million (amount provided by SBIR Phase 2 funding) or less and fulfill all outlined objectives.
- Benefits Analysis: Detailed project economic model, techno-economic analysis, or other evidence of benefits that explains the relevant economic and non-economic benefits that will come from this innovation.
- Market Impact Analysis of Potential Beneficiaries: Will quantify how the developed innovation will accelerate the amount of storage deployed as well as the economic and societal benefits the concept can provide to its target market.

Phase 2 Objectives:

- Concept Validation: Project performer will identify actual or representative site that they will conduct a full hardware, controls, software, etc. demonstration and validate the that the innovation can be successfully deployed in their target market and use case using the funding provided (up to $1.1 million) from Phase 2.

Areas specifically not of interest include:

- R&D of new materials or components for the storage block component of energy storage technologies (as defined by the ESGC Cost and Performance Report[3]) that are not yet commercial
- Activities that support deployment of energy storage in already developed markets such as deployment of PV and Storage for residential utility bill management
- Applications which consist of entities looking for financial support for purchasing energy storage systems that could otherwise be acquired in a traditional procurement process

Questions – Contact: Vinod Siberry, vinod.siberry@hq.doe.gov

References: Subtopic a:

1. Silva, W., Donoso-Garcia, P.F., Seleme Jr., S.I., Oliveria, T., 2013, Study of the application of bidirectional dual active bridge converters in dc nanogrid energy storage system, 2013 Brazilian Power Electronics Conference (COBEP 2013), Oct. 2013, https://ieeexplore.ieee.org/document/6785178 (October 31, 2022)
2. Mishima, T., Hiraki, E., Nakaoka, M., 2010, A high frequency-link bidirectional DC-DC converter for super capacitor-based automotive auxiliary electric power systems, *Journal of Power Electronics*, Jan 2010, https://www.researchgate.net/publication/239586683_A_High_Frequency-Link_Bidirectional_DC-DC_Converter_for_Super_Capacitor-Based_Automotive_Auxiliary_Electric_Power_Systems (October 31, 2022)
3. Pragallapai, N., Ranade, S.J., Moonem, M.A., Atcitty, S., 2018, Distributed Power Processing based Cell-level Battery Energy Storage System, *2018 9th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG*), 2018, pp. 1-7, doi: 10.1109/PEDG.2018.8447709, https://ieeexplore.ieee.org/document/8447709 (October 31, 2022)
4. Xiaodong, L., Ashoka, K.S., 2009, Analysis and Design of High-Frequency Isolated Dual-Bridge Series Resonant DC/DC Converter, *IEEE Transaction on Power Electronics*, Vol. 25, No. 4, April, 2010, https://ieeexplore.ieee.org/document/5288618 (October 31, 2022)
5. Shen, Y., Wang, H., Blaabjerg, F., Al Durra, A., Sun, X., 2017, A fixed-frequency bidirectional resonant DC-DC converter suitable for wide voltage range, *2017 IEEE Applied Power Electronics Conference and Exposition (APEC*), 2017, pp. 2084-2090, doi: 10.1109/APEC.2017.7930986, https://ieeexplore.ieee.org/document/7930986 (October 31, 2022)

References: Subtopic b:

1. Frazier, A., Cole, W., Denholm, P., Machen, S., Gates, N., & Blair, N., 2021, Storage Futures Study: Economic Potential of Diurnal Storage in the U.S. Power Sector, Golden, CO: National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy21osti/77449.pdf (October 31, 2022)
2. Mongird, K., Viswanathan, V., Alam, J., Vartanian, C., & Sprenkle, V., 2020, 2020 Grid Energy Storage Technology Cost and Performance Assessment, *Technical Report, Publication No. DOE/PA-0204*, December 2020, https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf (October 31, 2022)
3. U.S. Department of Energy, 2020, Energy Storage Grand Challenge: Energy Storage Market Report, Technical Report, NREL/TP-5400-78461, DOE/GO-102020-5497, December 2020, https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Market%20Report%202020_0.pdf (October 31, 2022)

[3] Final - ESGC Cost Performance Report 12-11-2020.pdf (pnnl.gov)

Back to Table of Contents

PROGRAM AREA OVERVIEW: OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

The Office of Energy Efficiency and Renewable Energy (EERE) accelerates the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050, creating good paying jobs, and ensuring the clean energy economy benefits all Americans, especially workers and communities impacted by the energy transition and those historically underserved by the energy system and overburdened by pollution.

Achieving this goal in an equitable manner will require leveraging the expertise and talents of small businesses. EERE's FY 2022 Phase I SBIR/STTR topics are focused on five investment areas that are central pillars of the U.S. greenhouse gas (GHG) profile:

- *Decarbonizing the electricity sector*. To initiate a path to achieve a carbon pollution-free electricity sector no later than 2035, EERE's focus is to support technologies that will allow us to generate all electricity from clean, renewable sources. To transition to a carbon-free power sector, advancements are needed to continue to make major strides to integrate more renewable energy generation onto the grid, while ensuring it is reliable, secure, and resilient, even as it evolves.
- *Decarbonizing transportation across all modes: air, sea, rail, and road.* The transportation sector has historically relied heavily on petroleum, which supports over 90 percent of the sector's energy needs today; as a result, the sector has surpassed electricity generation to become the largest source of CO_2 emissions in the country. This investment area aims to develop and enable new zero emission light-duty vehicle sales; address the Nation's sustainable aviation fuel demands; and increase the commercial viability of hydrogen fuel cells for long-haul heavy-duty trucks.
- *Decarbonizing energy-intensive industries.* Industrial processes currently contribute as much as 20 percent of the Nation's carbon emissions. To phase out emissions, EERE will support approaches that rely on renewable energy and fuels such as hydrogen to power industrial processes, capture and use carbon emissions, and vastly improve efficiency.
- *Reducing the carbon footprint of buildings.* EERE supports efforts to reduce the carbon footprint of the U.S. building stock by 50% by 2035. Such advances will be made while maintaining or improving affordability, comfort, and performance.
- *Decarbonizing the agriculture sector, specifically focused on the nexus between energy and water.* Agriculture represents nearly 10 percent of the Nation's carbon emissions, and EERE looks to make investments that drive a cleaner agriculture sector.

Please note that each topic and subtopics may have unique requirements for responsive application submissions; review the requirements for each topic and subtopic carefully to ensure you are responsive to requirements where applicable.

Technical and Business Assistance (TABA) Program and the American-Made Network

Applicants are encouraged to take advantage of the Technical and Business Assistance (TABA) Program, which provides funding for commercialization activities in addition to SBIR/STTR research funding. Please read all sections of this FOA with more information about this program and how to apply for this additional funding opportunity. The American-Made Network is an excellent resource for finding commercialization-assistance providers and vendors with specific expertise across EERE's technology sectors. The Network helps accelerate innovations through a diverse and powerful group of entities that includes National Laboratories, energy incubators, investors, prototyping and testing facilities, and other industry partners from across the United States who engage, connect, mentor, and amplify the efforts of small businesses. The Network can help companies solve pressing technology challenges, forge connections, and advance potentially game-changing ideas and innovations.

Back to Table of Contents

C56-10. JOINT TOPIC: DECARBONIZATION OF AGRICULTURE, BUILDINGS, TRANSPORT, INDUSTRY AND THEIR COMMUNITIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The objectives of this topic on decarbonization of Agriculture, Buildings, Transport, and Industry are to enable major reductions in carbon emissions in these sectors to help meet the Biden Administration greenhouse gas (GHG) reduction objectives—50 percent reduction by 2030 and net-zero carbon economy by 2050.[4]

This joint topic is a collaboration among U.S. Department of Energy's Advanced Materials & Manufacturing Technologies (AMMTO), Building Technologies (BTO), Bioenergy Technologies (BETO), Industrial Efficiency and Decarbonization (IEDO), Vehicle Technologies (VTO), and Water Power Technologies (WPTO) Offices.[5] This topic is not intended to comprehensively cover all aspects of decarbonization, rather, this joint topic generally supplements individual office topics with those aspects of decarbonization R&D best suited to joint efforts.

All applications to this topic must:

- Clearly indicate the subtopic and area of interest;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions-- Justify all performance claims with theoretical predictions and/or relevant experimental data.
- Propose a tightly structured program which includes clearly defined, relevant materials and manufacturing RD&D metrics (including energy savings where applicable). The program should include quantitative technical milestones, timelines, and expected deliverables that demonstrate aggressive but achievable progress;
- Provide evidence that the proposer has relevant materials and or manufacturing experience and capability; and
- Explain applications of project output and potential for future commercialization including projections for cost and/or performance improvements that are tied to a clearly defined baseline.

In addition to reducing carbon emissions to net zero in all sectors by 2050, the Biden-Harris Administration seeks a more immediate equitable economic recovery that requires the expertise and talents of small businesses. While increasing equity is a concern for the topic in general, one way to advance equity as well as accelerate carbon reduction is to develop equitable and inclusive innovative technology solutions through a

[4] Under Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," (Executive Office of the President. (2021). Executive Order 14008, https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad) the President set a national goal of reducing greenhouse gas emissions to net-zero by 2050. Under the Paris Agreement, the United States set a Nationally Determined Contribution of reducing GHGs 50-52 percent by 2030, and confirmed the goal to reach net-zero GHG emissions by 2050 (U.S. (2021). USA NDA at https://unfccc.int/sites/default/files/NDC/2022-06/United%20States%20NDC%20April%2021%202021%20Final.pdf). Executive Order 13990 declared that the federal government must be guided by the best science to improve public health, protect our environment, reduce GHG emissions, ensure access to clean air and water, prioritize environmental justice, and create well-paying union jobs (The White House. (2021). Executive Order 13990, "Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis". https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-protecting-public-health-and-environment-and-restoring-science-to-tackle-climate-crisis/).

[5] For more information on all of the DOE applied energy programs supporting this topic and subtopics, see the following websites for Tech Offices within DOE's Office of Efficiency and Renewable Energy (EERE): Advanced Manufacturing Group (https://energy.gov/eere/amo), Advanced Materials and Manufacturing Technologies (AMMTO) Building Technologies Office (BTO) (https://energy.gov/eere/buildings), Industrial Efficiency and Decarbonization Office (IEDO); the Vehicle Technologies Office (VTO) (https://www.energy.gov/eere/vehicles/vehicle-technologies-office); and the Water Power Technologies Office (WPTO) (http://energy.gov/eere/water/water-power-program)

community partnership approach. The requirements below, however, are only for the specific community areas of interest under each subtopic:

Crosscutting Community-Driven Decarbonization Areas of Interest
The offices are, under each of the subtopics, soliciting in a specific area of interest for applications from small businesses that are focused on community partnerships. Such partnerships are critical to achieving the national goal of net-zero carbon emissions as technology deployment depends on communities exercising agency in the integration of innovative technologies. These areas of interest under each subtopic support technology integration into communities through informed decision-making, community-centered research, and engagement at the local, state, and/or regional levels. They are specifically intended to assist new technologies that face cultural, economic, and societal hurdles to responsible and accelerated deployment. Trusted and community-driven research is fundamental to multiple stakeholders including rule makers, environmental regulators, clean energy industry developers, technology researchers and developers, and, most importantly, communities. These areas of interest encourage small business technology developers to incorporate community needs and inputs to the extent possible into their decarbonization R&D.

Additionally, these areas of interest encourage the participation of small businesses from disadvantaged communities, and/or with extensive, substantive partnerships with disadvantaged communities. Applicants are encouraged to review the guidance and definitions for communities, disadvantaged, and direct benefits outlined in M-21-28, the Interim Guidance for the Justice40 Initiative to understand about potentially impacted persons or communities of interest for this topic. Partnering is co-beneficial for both the small businesses and the disadvantaged communities that have often been left out in the initial stages of clean energy and climate technology development.

Specifically for the community-driven decarbonization areas of interest all applications must:

- Demonstrate innovation in technology as well as community partnering. The community engagement should be treated as an R&D component of the project, with a design package and a robust implementation and evaluation plan (detailing the method and level of involvement from members of the disadvantaged community organization partner(s)) and will be reviewed based on the "Scientific/Technical Approach" review criteria.
- Provide evidence that the team has sufficient experience, expertise, and/or capability in working in, or with disadvantaged communities;
- Include an organization representing at least one disadvantaged community and/or non-federal government entity.
- Provide a letter of support/commitment from the partnering community organization(s) towards participation in the project;
- Include an initial analysis of the applications' value to the community partner.
- Emphasize in Phase I end-user and community partnerships for the proposed concept by collecting end-user/ community requirements; converting collected requirements into system design requirements; using those design requirements to inform preliminary prototype design; and performing preliminary proof-of-concept testing or modeling of system components.
- For Phase II, small businesses should demonstrate the system design based on findings from Phase I and perform a pilot of the community-driven technological solution.

The following 4 subtopics and corresponding areas of interest contain further details and requirements. Applications outside of the following subtopics and areas will not be considered.

a. Agricultural Decarbonization

Back to Table of Contents

This subtopic is focused on decarbonizing the agriculture sector, specifically focused on the nexus between energy and water. Agriculture represents nearly 10 percent of the Nation's carbon emissions, and EERE looks to make investments that drive a cleaner agriculture sector. This subtopic is being led by the Bioenergy Technologies Office (BETO) with contribution from other offices. BETO advances technologies that convert domestic biomass and other waste resources into cost effective, low-carbon biofuels and bioproducts. These technologies hold the promise of enabling a transition to a clean energy economy, creating high-quality jobs, supporting rural economies, and spurring innovation in renewable energy and chemicals production as part of the bioeconomy. This subtopic solicits innovative research and development (R&D) applications for decarbonization of Agriculture in the following three areas of interest:

1. Agricultural Decarbonization through Alternate Proteins and Amino Acids to Reduce Livestock-Associated Emissions
   The EPA has previously estimated that 37% of methane emissions from human activity are the direct result of our livestock and agricultural practices [1]. One of the largest GHG contributors associated with livestock production comes from methane associated with enteric fermentation which accounted for 175.2 MMT CO2eq, or about 30% of all US agricultural emissions in 2020. Enteric fermentation results in methane emissions as a byproduct of livestock digestion processes (particularly cattle and other ruminants). Beef cattle accounted for 72% of methane emissions in the US in 2020 associated with enteric fermentation [2].

   BETO is seeking applications aimed at the production of novel alternative proteins and/or precursor amino acids from biomass that can be used as plant-based substitutes for animal-based food products. Target technologies should demonstrate the potential to reduce GHG emissions and other environmental impacts associated with livestock.

   Applications specifically focused on currently commercial commodity proteins are not of interest. Preference will be given to technologies with the lowest overall carbon intensity scores.

2. Agricultural Power Decarbonization
   This area of interest aims to support small businesses that advance technologies in agricultural opportunities related to irrigation modernization and other alternative opportunities in hydropower in agricultural communities. By harvesting power from the flow of water through irrigation canals and pipes, irrigation water suppliers and users can self-supply clean energy while reducing or eliminating the need for diesel pumps. Modernization also allows for the adoption of precision agriculture and other practices that support decarbonization, such as crop changes and reduced use of fertilizer. Areas of interest include hardware and/or software tools to enable harvesting water power from irrigation canals and pipes and/or otherwise modernize agricultural systems through water power technologies [3].

3. Community-Driven Agricultural Decarbonization for a Just and Equitable Energy Transition
   This area of interest aims to support small businesses that advance agricultural decarbonization technology by integrating opportunities for advancing equity. Specific areas of interest include:
   - Emission-reducing technologies/strategies for agricultural operations.
   - A conversion process transforming local sources of agricultural biomass (including waste biomass) to net negative emissions fuels and fuel intermediates (e.g., Sustainable Aviation Fuels, alternative marine/rail fuels) or net negative emission bioproducts and chemicals.
   - Opportunities for use of the resulting product(s) within or for the benefit of the agricultural communities.

- Soil carbon storage technologies/strategies that can be implemented and/or monitored at the community scale.
- Advanced waste reduction and utilization technologies and processes (e.g., on-farm waste utilization to reduce need for inputs, such as fertilizer, diesel, etc.)
- Bioenergy production strategies and/or technologies that innovatively maximize participation of and/or benefit to communities directly.

Questions – Contact: Andrea Bailey, Bioenergy Technologies Office, Andrea.Bailey@ee.doe.gov and Elizabeth Burrows, Bioenergy Technologies Office, Elizabeth.Burrows@ee.doe.gov

b. Buildings Decarbonization

The DOE supports efforts to reduce the carbon footprint of the U.S. building stock by 50% by 2035. Such advances will be made while maintaining or improving affordability, comfort, and performance. This subtopic is led by EERE's Building Technologies Office (BTO) with contribution from other offices. It solicits innovative research and development (R&D) applications for decarbonization of Buildings in the following two areas of interest:

1. Decarbonizing Buildings HVAC Direct Air Capture (DAC) systems
   This topic solicits applications to advance the development of efficient and cost-effective heating, ventilation, air-conditioning (HVAC) direct air capture systems for existing and new buildings. BTO seeks to accelerate the development of next generation heating of HVAC systems with direct air capture capabilities. HVAC is the largest energy end-use for U.S. buildings, consuming approximately 38% (14.3 Quads) of total building energy in 2021, 35% of building electricity use, and a very large share of peak power demand. Water heating (3.6 Quads) is primarily a residential function (81% of all water heating energy use). Today's HVAC systems are already moving air to heat or cooling a building. According to the IEA [1], air conditioning (AC) accounts for nearly 20% of the global electricity used in buildings around the world today, as well as driving up emissions. With the utilization of DAC technology, HVAC systems can be leveraged to directly decarbonize the heating and cooling of buildings as general AC usage is increasing globally.

   There are two main air sources to remove carbon (CO_2) from inside or outside air. Removing carbon from indoor air is a filtration task, advanced filtration [2]. By removing carbon as well as humidity from conditioned air, less fresh air is required to be introduced thereby limiting the load on the HVAC system. The energy savings are larger when the difference between indoor and outdoor temperatures are great, in extreme summer and winter weather conditions. The other air source is outside air. This HVAC DAC system would operate just like a traditional DAC system except that size of the system is small and HVAC system have fans that move air dissipate (AC function) or extract heat (heating, heat pump system) from the environment.

   The main thrust for this topic is enable the use of DAC technology in HVAC systems and leverage their air circulation capabilities. This subtopic seeks innovative solutions that will integrate direct air capture (DAC) in HVAC systems; develop new technologies that are effective at capturing carbon dioxide from dilute HVAV indoor and outdoor air sources and enable cost-effective solutions. This subtopic will also focus on the applied R&D needed to integrate DAC technology into existing buildings on a significant scale. To reduce emissions and advance energy efficiency, the BTO pursues solutions that are systems-

Back to Table of Contents

oriented to optimize energy use in the entire building. Improved HVAC technologies with DAC capabilities offer significant opportunity for energy and emission savings.

Applicants should clearly describe how new HVAC DAC can be integrated in existing and new buildings and deliver direct as well as life-cycle energy, carbon, and comfort advantages. Applicants should describe how the CO2 can be stored and moved offsite for long term storage or utilized by industry, the energy input needed for both HVAC and DAC operation, and the overall system economics. The objective is to advance the development of applications to advance the development of efficient and cost-effective heating, ventilation, air-conditioning (HVAC) direct air capture systems for existing and new buildings.

All applicants must include metrics for carbon reduction, energy efficiency improvements, and emissions reduction.

Objective/ Goal	**Metric**	**Target**	**Stretch Target**	**Baseline Performance**
Payback period, cost effectiveness	years	≤ 5 years	≤ 3 years	*Applicant Defined*
Energy efficiency improvements, HVAC	COP	5%, increase	15%, increase	*Applicant Defined*
Size and/or weight increases relative to today's current state of the art units. Volume important for system on the ground and weight critical for roof-based systems.	Volume (ft^3, m^3) or Weight (lbs., kg)	<50%, increase in volume and/or weight	<30%, increase in volume and/or weight	*Applicant Defined*
Carbon Capture metric	tCO_2/year	1.5 * rated system AC tonnage	2.0 * rated system AC tonnage	*Applicant Defined*
Lifetime	years	≥ 12	≥ 15	*Applicant Defined*
Service to maintain as-new performance	Yes/No	Little to no increase as compared to state-of-the-art HVAC design		*Applicant Defined*

2. Community-Driven Building Decarbonization for a Just and Equitable Energy Transition
This area of interest aims to support small businesses that advance building decarbonization technology by integrating opportunities for advancing equity and meeting all the requirements for this area specified before the beginning of the subtopics.

Questions – Contact: Tony Bouza, Building Technologies Office, Antonio.Bouza@ee.doe.gov and Tina Kaarsberg, Advanced Materials and Manufacturing Technologies Office Tina.Kaarsberg@ee.doe.gov

c. Transportation Decarbonization

Back to Table of Contents

The transportation sector has historically relied heavily on petroleum, which supports over 90 percent of the sector's energy needs today; as a result, the sector has surpassed electricity generation to become the largest source of CO_2 emissions in the country. This DOE subtopic aims to address the Nation's sustainable aviation fuel demands; develop and enable new zero emission light-duty vehicle sales; and increase the commercial viability of hydrogen fuel cells for long-haul heavy-duty trucks. In collaboration with other offices, this subtopic is being led by DOE's Bioenergy Technologies Office (BETO), which advances technologies that convert domestic biomass and other waste resources into cost effective, low-carbon biofuels and bioproducts. These technologies hold the promise of enabling a transition to a clean energy economy, creating high-quality jobs, supporting rural economies, and spurring innovation in renewable energy and chemicals production as part of the bioeconomy. This subtopic solicits innovative research and development (R&D) applications for decarbonization of Transportation in the following areas of interest:

1. Low-Carbon Liquid Biofuels for the Aviation, Maritime, Rail, and Medium-to-Heavy Duty Transportation Sectors
   As part of the Government's comprehensive strategy to decarbonize all modes of transportation, BETO is primarily focused on RD&D to produce "drop-in" biofuels from renewable biomass and waste resources that are compatible with existing fueling infrastructure and difficult-to-electrify modes of transportation including aviation, maritime, rail, and medium-to-heavy duty vehicles (on and off-road). This multi-faceted approach is part of the Administration's strategy to spur the development of homegrown renewable biofuels, which is critical to expanding Americans' options for affordable fuel in the short-term and to building real energy independence in the medium- to long-term by reducing our reliance on fossil fuels.

   This topic seeks applications that aim to investigate new liquid low-carbon biofuel production pathways with at least a 70% green house gas (GHG) decrease on a life-cycle basis as compared to equivalent petroleum-based fuels for the aviation, maritime, rail, and/or medium-to-heavy duty transportation sectors. Anticipated approaches can include, but are not limited to:
   - The development of new renewable biofuel(s) or biofuel intermediate(s) technology pathways harnessing underutilized biomass, waste resources, oil-seed cover crops, algae, or other biobased feedstocks;
   - Novel blending of biobased feedstocks, intermediates, or precursors that can be upgraded into finished fuels through commercially available methods;
   - Novel upgrading techniques that harness up and coming biobased intermediates; and
   - Improving the carbon conversion efficiency and/or reduction in the GHG emissions during the production of commercially available renewable biofuels (such as ethanol and biodiesel).

   Of particular interest, is R&D on biofuel pathways that will lead to a 100% "drop-in" biofuel that will not require any blending with petroleum fuels or additives. The biofuel will not need to meet 100% "drop-in" specification by the end of Phase I or II, especially since regulatory approval may limit the blend ratio to ≤50%, but the biofuel(s) should show potential for meeting applicable specifications to displace the incumbent and provide at least a 70% GHG reduction.

   By the end of Phase II awards, the subject biofuel(s) production technologies should be able to show proof of concept by demonstrating technical feasibility using alpha prototype(s) or integration and testing of components. The pathway to commercialization of these novel technologies should be through subsequent scale-up by combining technology components, unit operations, or subsystems, testing under integrated operations, producing sufficient biofuels for downstream testing, and verifying the integrated process at various scales. Successful Phase II awards are encouraged to apply for additional scale-up funding via BETO's annual Scale-Up FOA [3], which is subject to future appropriations.

2. Energy Efficient Mobility Systems (EEMS) Decarbonizing Transportation through Shared Mobility
This area of interest is led by the Vehicle Technologies Office (VTO) which funds early-stage, high-risk research that develops new, affordable, efficient, and clean transportation options that increase domestic economic opportunities. EEMS is one of the major programs within VTO and conducts early-stage research and development (R&D) at the vehicle, traveler, and system levels, creating knowledge, insights, tools, and technology solutions that increase mobility energy productivity for individuals and businesses. This multi-level approach is critical to understanding the opportunities that exist for optimizing the overall transportation system. The EEMS Program uses this approach to develop tools and capabilities to evaluate the energy impacts of new mobility solutions, and to create new technologies that provide economic benefits to all Americans through enhanced mobility.

An overview of the EEMS program is best provided through the VTO Annual Merit Review database [1] and through Annual Progress Reports [2]. For this SBIR area of interest, the EEMS program welcomes applications that focus on developing *innovative* solutions that **improve shared mobility**. Examples of technologies of interest *include, but are not limited to*:

- Technologies that improve transit optimization
- Technologies to enable First-mile/last-mile connectivity
- Pooled ride-share
- Micro-transit

Successful applications should:

- Clearly describe the shared mobility and transportation problems and challenges they seek to address
- Clearly describe what *novel* shared mobility solution they seek to develop and apply
- Clearly describe the *baseline carbon emissions* of the problem space they seek to address and propose relevant metrics to be able to quantify BOTH the mobility benefits AND the potential for decarbonization of the proposed solutions.

Applications that use or seek to further develop automated technologies to enable shared mobility are encouraged; however, automated technology solutions are not required for this area of interest.

Applications that are not of interest are straightforward implementations of existing technologies and solutions; this sub-topic seeks innovative ideas. Applications that are primarily focused on procurement are also discouraged.

EEMS recognizes that smartphone applications ("apps") may be a part of any shared mobility solution. However, applications whose primary effort appears to be in app development will also be discouraged.

Applications deemed to be duplicative of research that is already in progress by VTO, as well as by other agencies, including state and local governments, and by the private sector, will not be funded; therefore, all submissions should clearly explain how the proposed work differs from other work in the field. Note that the area of improving shared mobility is an area of active research and where many jurisdictions have many "pilot" programs. The intent of this SBIR subtopic is to *complement* these efforts.

Back to Table of Contents

Questions – Contact: Ben Simon, Bioenergy Technologies Office, Ben.Simon@ee.doe.gov and Energy Efficient Mobility Systems (EEMS) eems@ee.doe.gov

d. Industrial Decarbonization

Industry represents 30% of U.S. primary energy-related CO_2 emissions, or 1360 million MT CO_2 (2020) [1]. To phase out emissions, DOE will support approaches that rely on electrification of process heating operations, biomanufacturing, and vastly improved efficiencies. This subtopic is being led by EERE's Industrial Efficiency and Decarbonization office (IEDO), which is part of a larger EERE/DOE effort to research, develop, and demonstrate energy efficiency and GHG emissions reduction technologies to reach net zero carbon emissions nationwide by 2050. The IEDO focuses on emerging industrial technologies, pilot-demonstrations, and technology partnerships to drive U.S. industrial decarbonization, productivity, and economic competitiveness. This subtopic reflects DOE's support for activities that address decarbonization in energy- and emissions-intensive industries, cross-sector industrial emissions technologies, as well as technical assistance and partnerships. Innovative research and development (R&D) applications to decarbonize industrial processes will contribute to DOE goals of strengthening domestic manufacturing and achieving resiliency in the industrial sector.

This subtopic is also being supported by EERE's Bioenergy Technology Office (BETO), which supports development of low-carbon fuels and energy through focus on alternative feedstocks (e.g., biomass, waste, CO_2) and process improvements through biomanufacturing.

Applications must address one of the following areas of interest:

1. Industrial Energy Efficiency through Conductivity-enhanced materials
   Energy efficiency is a crosscutting approach to achieve carbon emissions and cost reductions across the industrial sector. While some efficiency gains can be made via optimization of processes, innovative materials R&D also is needed to achieve more ambitious emissions and cost reductions. DOE also supports development of new technologies to improve material efficiency—i.e., reduce the amount of material needed to provide the same service—reducing waste and improving yield.

   Given the importance of electrification for industrial decarbonization, this area of interest seeks innovative materials and systems that will reduce energy use of electrified processes. In particular, it seeks new conductor materials—and processes to make them cost-effectively— whose system performance is enhanced above those of today's commercial conductors such as copper (Cu) or aluminum (Al) used in electrical and thermal electrification applications. Applications are sought for characterization and/or theory, modelling and simulation to improve fabrication of enhanced conductivity materials. This area of interest encompasses both metal-based [2, 3, 4, 5, 6] and non-metal-based approaches where the enhanced conductivity material to be studied meets minimum thresholds for electrical and thermal conductivity enhancements. The proposed metal conductivity enhancement must be more than 5 MS/m above the present baseline/minimum and the proposed enhanced thermal conductivity should be above the range of 10 W/mK (watts per meter-Kelvin).

   Small businesses should seek partnerships with research institutes that have leading-edge expertise and capabilities in characterization and/or theory/modelling /simulation that is relevant to enhanced conductivity. While small businesses that also have expertise in these areas also are encouraged to apply, the main requirement for the small business is that they have the materials fabrication know how to translate information from the research institutes into process improvements for fabrication of enhanced conductivity materials. Applications are sought that could lead to breakthrough changes in current manufacturing processes that further improve the conductivity, affordability, non-conductivity performance and manufacturability of the enhanced conductivity material. While an application may be either a pure characterization – or a pure theory/modelling/simulation focused – application, all applications must clearly describe the connection between the project focus and either theory/modelling/simulation or characterization and how one supports the other. In describing these connections, applicants must provide details of proposed research institute partners included in the accompanying Table. Applications also should clearly state the application space and targeted industries, as well as present a feasible integration plan into industrial applications. Material efficiency technologies of interest also should include where applicable use of smart manufacturing [7] including advanced sensors and controls, data analytics, enabling technology for Internet of Things (IoT), information and communications technology (ICT) equipment, and digital twins, among others.

Table 1. Research Institutes/Facilities with which potential partnerships are encouraged include but are not limited to:

- The five Nanoscale Science Research Centers (NSRCs) are DOE's premier user centers for interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. Each center has particular expertise and capabilities in selected theme areas. While all NSRCs have CABLE-relevant offerings, those of particular interest to this CABLE topic include synthesis and characterization of nanomaterials; theory, modeling and simulation; electronic materials; imaging and spectroscopy; and nanoscale integration. NSRC user facilities laboratories contain clean rooms, nanofabrication resources, one-of-a-kind signature instruments, and other instruments not generally available except at major user facilities. NSRC resources and capabilities are available to small businesses with research projects that compete successfully in a peer-reviewed process [8].
- Pacific Northwest National Laboratory's ShAPE™ tool and associated facilities as well as facilities for testing electrical conductivity, modeling metallic and non-metallic composite conductivity [9].
- National Energy Technology Laboratory's Auburn campus' industrial scale metallurgy furnaces and covetics expertise and capability [10].
- Argonne National Laboratory's Advanced Photon Source and MERF [11] and
- Argonne National Laboratory's Chemical Deposition expertise, facilities, and capabilities [12].
- Oak Ridge National Laboratory's Manufacturing Demonstration Facility (MDF) expertise, facilities, and capabilities for both metals and non-metals (e.g., carbon fiber CFDF [13, 14].
- Ames National Laboratory metal powder production facilities, expertise, and capabilities [15].

2. Industrial Heat Pumps to Enable Electrification

This area of interest seeks to reduce the carbon emissions associated with process heat by enabling industrial electrification. Industrial process heating is ubiquitous in almost all major industrial subsectors and is largely fossil-fuel based. Process heating consumes more energy than any other manufacturing end use and is responsible for 9% of all domestic emissions. [16]. Electrification of industrial processes has the potential to achieve deep decarbonization across multiple industries and is aligned with the Biden administration's goal of a clean electricity grid by 2035 [17]. Novel process heat operations also have the potential to provide important co-benefits to industrial processes: improved control, decreased waste, reduced energy usage, among others [18].

Specifically, this area of interest solicits applications for cost-effective Industrial Heat Pump (IHP) systems, focusing on industrial process heating. Heat pump technology is a key decarbonizing technology. Instead of burning a fuel, heat pumps work by moving heat and upgrading low-temperature heat (heat source) to higher-temperature (heat sink). Although heat pumping technology has advanced in other sectors with the development of advanced compressors, low-GWP refrigerants and better heat exchangers, low fossil fuel prices and non-standardized solutions are impeding IHP widespread adoption in the US. In the building sector for example, DOE R&D has demonstrated cost effective cold climate heat pump technology that can operate and provide heat from ambient temperatures (heat source) as low as -25°C (-13°F), focusing on the heat source side. For IHP, the research focus shifts towards the heat sink side of the heat pump system where very little research has taken place.

IHP solutions are available today with sink temperatures in the range of 90 to 150°C. This subtopic seeks IHP applications that go up to 200°C. This higher temperature range is a technical challenge but covers more of the range for industrial processes for waste heat recovery include drying, sterilization, papermaking, food preparation and preheating applications. There is substantial overlap between this technical challenge and applications that offer the opportunity to decarbonize. For example, European statistics show that 67% of the process heat demand between 100°C and 200°C was directly supplied by fossil fuels. From this, a considerable application potential for industrial heat pumps and their associated emission reductions can be derived by pushing the IHP range up to 200°C.

In the US, “Accelerating Decarbonization of the U.S. Energy System” report by National Academies of Sciences, Engineering, and Medicine calls for deploying 1−2 GW of advanced industrial heat pumps (IHPs), with early development/demonstrations at industrial clusters to lower barriers, for a range of process heat, drying, evaporator trains, and other applications lowering CO2 emissions with the electricity coming from low-carbon sources. IHPs can contribute to GHG emissions reductions both directly through refrigerant emissions reductions, as well as indirectly by reducing emissions from power generation through energy efficiency. Refrigerants are essential in vapor compression cycles: they absorb heat at a relatively low temperature in the evaporator and releases it at a higher temperature in the condenser. Low global warming potential (GWP) refrigerants are required in new IHPs since a transition is taking place towards them. Given the importance of both refrigerant emissions and efficiency requirements for IHPs, both direct and indirect emissions targets are included for this subtopic.

The focus in this area of interest is integration of IHP technology into existing industrial processes, supplying heat at or below 200°C. Integration of IHPs in existing industrial processes will require a systems approach, because waste heat is not constant during operation and application. Research advances are required in all heat pump components, including better heat exchangers and compressors and potentially new materials, refrigerants and non-refrigerant based solutions (e.g., non-vapor compression solutions, functional materials).

Given the wide range of technology suitable for this subtopic, specific application targets are not defined but proposed innovations must exceed the state-of-the-art performance significantly. Applications must demonstrate progress in Phase I and achievement in Phase II of the following performance and cost targets:

Requirements	Targets
Payback period, cost effectiveness	≤ 3 years
Physical size	Can be integrated into existing manufacturing systems
Lifetime	≥ 12 years
Service to maintain as-new performance	Little to no increase as compared to state-of-the-art heat pump designs
Low global warming potential (GWP) refrigerants, direct emissions	≤ 150 GWP value
Indirect emissions, energy efficiency	≥ 50% reduction
Coefficient of performance (COP) @ Highest Supply Temperature	≥ 45% Carnot COP
CO_2 equivalent emissions reductions	85%

Applications may also pursue enabling technologies to utilize electricity such as thermal storage, and enhanced controls and management. Applications should clearly state the temperature ranges and application spaces of their proposed technologies.

3. Decarbonization and Biomanufacturing
In September 2022, the White House released an Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy. As part of this Executive Order the Department of Energy is directed to:

> *"[…] invest in infrastructure to accelerate bioenergy and bioproduct science advances, biotechnology and bioinformatics tool development, and to reduce the hurdles to commercialization, including through incentivizing the engineering scale-up of promising biotechnologies and the expansion of biomanufacturing capacity."*

To advance this goal, BETO seeks applications developing novel chemicals from biomass that will achieve a reduction in GHG emissions over incumbent products and exhibit the potential to be scaled up to demonstration scale. Preference will be given to products that address markets facing challenges with domestic production and products with the lowest overall carbon intensity scores.

4. Community-Driven Industrial Decarbonization for a Just and Equitable Energy Transition
This topic aims to support small businesses that advance industrial decarbonization technology by integrating opportunities for advancing equity. Specific areas of interest include Industrial Decarbonization for local food, chemicals, steel or cement manufacturers. Applications to this area must meet the requirements for community-driven projects in the Topic before the subtopics begin.

Questions – Contact: Emmeline Kao, Industrial Efficiency and Decarbonization, Emmeline.Kao@ee.doe.gov and Tina Kaarsberg, Advanced Materials and Manufacturing Technologies, Tina.Kaarsberg@ee.doe.gov

References: Subtopic a:

1. United States Environmental Protection Agency. *Agriculture and Aquaculture: Food for Thought*. 2020. Accessible at: https://www.epa.gov/snep/agriculture-and-aquaculture-food-thought

2. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020, Chapter 5: Agriculture. United States Environmental Protection Agency. 2022. Accessible at: https://www.epa.gov/system/files/documents/2022-04/us-ghg-inventory-2022-chapter-5-agriculture.pdf
3. “National Labs Lend Expertise to Overhaul Circulatory System of the American West.” *INL*, https://inl.gov/article/circulatory-systems-of-the-american-west/

References: Subtopic b:

1. IEA (2018), The Future of Cooling, IEA, Paris https://www.iea.org/reports/the-future-of-cooling
2. *Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems Month Year.* 2017. Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems

References: Subtopic c:

1. “Annual Merit Review Presentations.” *Energy.gov*, https://www.energy.gov/eere/vehicles/annual-merit-review-presentations
2. *Energy Efficient Mobility Systems 2021 Annual Progress Report Vehicle Technologies Office*. https://www.energy.gov/sites/default/files/2022-10/VTO_2021_APR_EEMS_REPORT_FINAL_compliant.pdf

References: Subtopic d:

1. “DOE Industrial Decarbonization Roadmap.” *Energy.gov*, www.energy.gov/eere/doe-industrial-decarbonization-roadmap. https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap
2. Occo, R., Somers, K., Speelman, E., and Witteveen, M. “Plugging in: What Electrification Can Do for Industry, McKinsey and Company.” 2020. www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry
3. Cao, M., Xiong, D.B. “Ultrahigh Electrical Conductivity of Graphene Embedded in Metals, Adv. Funct. Mater.” 2019, 29, 1806792 DOI: 10.1002/adfm.201806792, Ultrahigh Electrical Conductivity of Graphene Embedded in Metals | Request PDF (researchgate.net) https://www.researchgate.net/publication/331403006_Ultrahigh_Electrical_Conductivity_of_Graphene_Embedded_in_Metals
4. Kappagantula, K., et al, 2020, “Better” Copper Means Higher-Efficiency Electric Motors, Pacific Northwest National Laboratory, https://www.pnnl.gov/news-media/better-copper-means-higher-efficiency-electric-motors
5. Subramanian C., et al, 2013, One-Hundred-Fold Increase in Current Carrying Capacity in a Carbon Nanotube–Copper Composite, Nature Communications, 4 2202 [DOI: 10.1038/ncomms3202 |www.nature.com/naturecommunications]. Jul 23, 2013 https://www.nature.com/articles/ncomms3202
6. Rogers, Ethan, et al. *Intelligent Efficiency: Opportunities, Barriers, and Solutions*. 2013. Intelligent Efficiency: Opportunities, Barriers, and Solutions (aceee.org)
7. The DOE Office of Science, Basic Energy Sciences’ Nanoscale Science Research Centers (NSRCs) Research Centers are described, and contact information can be found at https://science.osti.gov/bes/suf/User-Facilities/Nanoscale-Science-Research-Centers NSRC Portal: https://nsrcportal.sandia.gov/
8. Bystricky P., Lashmore D., Kalus-Bystricky I., 2018, Metal Matrix Composite Comprising Nanotubes and Methods of Producing Same, onAcademic, IPN: WO2018/126191 A1 p.1. Jul 5, 2018. https://www.onacademic.com/detail/patent_1800001606361499_a1e2.html
9. A summary of most of these techniques and where they best can be applied can be found in: EAG Laboratories, 2020, EAG SMART (Spectroscopy and Microscopy Analytical Resolution Tool), https://www.eag.com/techniques/
10. Kappagantula, K.S., et al, 2021, Available Technical Resources for Enhanced Conductivity Material Development, Pacific Northwest National Laboratory, CABLE Workshop April 7-9, 2021, https://chptap.lbl.gov/profile/420/CABLE_3-2-2_01_Kappagantula_v2.pdf

11. Jablonski, P.D., Detrois, M., et al., 2021, Melt Processing of Covetic Materials, NETL, U.S. DOE, CABLE Big Idea Workshop April 7-9, 2021, https://www.energy.gov/sites/prod/files/2015/06/f23/P3%20-%20Melt%20Processing%20of%20Covetic%20Materials%20NETL%20May%202015.pdf
12. Gould, B., Eastman, J., et al., 2021, Using the Advanced Photon Source to Investigating the Interface of Metal Nano-Carbon Composites (MNCC), Argonne National Laboratory, CABLE Workshop April 7-9, 2021, https://anl.box.com/s/gqsvzsijygzj5apeegtpm7vm1uhwno67
13. "Materials Engineering Research Facility | Argonne National Laboratory." *Www.anl.gov*, https://www.anl.gov/amd/materials-engineering-research-facility
14. Elam, J., 2021, Controlling The Carbon-Metal Interface Through Chemical Vapor Functionalization, Argonne National Laboratory, CABLE Big Idea Workshop April 7-9, 2021, https://anl.box.com/s/y2m439shhc4t1dr5dzpu3q67h34hnlam
15. "Manufacturing Energy and Carbon Footprints (2018 MECS)." *Energy.gov*, Manufacturing Energy and Carbon Footprints (2018 MECS) | Department of Energy
16. "FACT SHEET: Biden-Harris Administration Races to Deploy Clean Energy That Creates Jobs and Lowers Costs." *The White House*, 12 Jan. 2022, FACT SHEET: Biden-Harris Administration Races to Deploy Clean Energy that Creates Jobs and Lowers Costs - The White House
17. Rightor, E., Whitlock, A., Elliot, N., Beneficial Electrification in Industry | ACEEE. July 2020. https://www.aceee.org/research-report/ie2002

C56-11. JOINT AMMTO/HFTO/IEDO TOPIC: FUEL CELL AND ELECTROLYZER RECYCLING

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

EERE's Advanced Materials and Manufacturing Technologies Office (AMMTO) researches, develops, and demonstrates next-generation materials and manufacturing technologies needed to improve Americans' quality of life, increase U.S. industrial competitiveness and drive economy-wide decarbonization. AMMTO supports the national plan to revitalize American manufacturing, secure critical supply chains, and develop diverse innovation ecosystems leading to new manufacturing jobs and increased economic strength of the nation. AMMTO provides planning, management, and direction necessary for a balanced program of research, development, demonstration, and workforce development to support domestic manufacturing that is critical to achieving a clean, decarbonized economy.

The Hydrogen and Fuel Cell Technologies Office (HFTO) is part of DOE's comprehensive energy portfolio aimed at building a clean and equitable energy economy and addressing the climate crisis, which is a top priority of the Biden Administration [1].

The activities to be funded by HFTO will support the goals of DOE's Hydrogen Shot [2], which targets affordable clean hydrogen production at $1/kg within the decade, and the H2@Scale Initiative [3], which aims to advance affordable hydrogen production, transport, storage, and utilization to enable decarbonization and revenue opportunities across multiple sectors. Additionally, activities will address the new clean hydrogen provisions of the November 2021 Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL). It includes provisions for the investment by DOE of $9.5 billion over five years in the research, development and demonstration of clean hydrogen production, storage, distribution, and end use technologies. Section 40314 includes $8 billion for establishment of at least four Regional Clean Hydrogen Hubs, $500 million for Clean Hydrogen Technology Manufacturing and Recycling, and $1 billion for Clean Hydrogen Electrolysis Program [4]. Applications are sought to address the overarching program goal of facilitating wide-spread adoption of hydrogen and fuel cells across sectors and the DOE national clean hydrogen strategy and roadmap. The HFTO efforts include research, development, and demonstration, including reducing the cost and improving the performance and durability of fuel cells, as well as developing affordable and efficient technologies for hydrogen production, delivery, and storage.

The Industrial Efficiency and Decarbonization Office (IEDO) is part of a larger EERE/DOE effort to research, develop, and demonstrate energy efficiency and GHG emissions reduction technologies to reach net zero carbon emissions nationwide by 2050 [5]. The IEDO focuses on emerging industrial technologies, pilot-demonstrations, and technology partnerships to drive U.S. industrial decarbonization, productivity, and economic competitiveness. This topic reflects DOE's support for activities that address decarbonization in energy- and emissions-intensive industries, cross-sector industrial emissions technologies, as well as technical assistance and partnerships.

This Topic reflects DOE's support for activities that develop Manufacturing Technologies, Secure and Sustainable Materials, and Clean Energy Technology.

All applications to this topic must:

- Clearly indicate the subtopic and area of interest;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions using appropriate metrics, key performance parameters, or properties – Justify all performance claims with theoretical predictions and/or relevant experimental data;
- Propose a tightly structured program which includes clearly defined, relevant materials and manufacturing RD&D metrics (including energy savings where applicable). The program should include quantitative technical milestones, timelines, and expected deliverables that demonstrate aggressive but achievable progress towards meeting performance parameter targets;
- Provide evidence that the proposer has relevant materials and or manufacturing experience and capability; and
- Explain applications of project output and potential for future commercialization including projections for cost and/or performance improvements that are tied to a clearly defined baseline.

Recycling of H_2 fuel cells and electrolyzers is a key pathway toward securing a domestic supply chain for a potential 2050 U.S. H_2 market of 100 MMT/yr of H_2. The Water Electrolyzers and Fuel Cells Supply Chain [6] & Platinum Group Metal Catalyst Supply Chain Deep Dive Assessments [7], written in response to Executive Order 14017, found that recycling infrastructure for these electrochemical systems can significantly reduce demand for new mines and secure the domestic supply chain. However, there are significant technical challenges that arise in recycling – recovered useful components such as membranes and catalysts are subject to degradation and toxic emissions. To date, there exists little infrastructure for specialized fuel cell and electrolyzer recycling. As found in the SBIR commercial potential evaluation on recovery of platinum metals, a commercially viable process for fuel cell recovery that does not release hydrogen fluoride is key to realizing a robust recycling infrastructure [8].

a. Efficient and Sustainable Recovery and Reuse of Materials from Manufacturing Scrap in Fuel Cell and Electrolyzer

Hydrogen production from no/low carbon electricity via proton exchange membrane (PEM) water electrolysis along with carbon-free electric power generation via hydrogen PEM fuel cells is a rapidly growing approach that will figure prominently in a variety of decarbonization efforts. Both electrolyzers and fuel cells contain similar (in some cases identical) membrane materials, and each manufacturing step yields meaningful quantities of unused scrap as the membranes are cut and processed. Recycling and/or reprocessing this scrap material will ease environmental and supply chain concerns, as these are fluorinated components and can

Back to Table of Contents

lead to unwanted emissions with conventional end-of-life processing. Addressing the reuse/recycling of scraps presents a starting point for developing more complex recycling methods relevant for end-of-life recycling of fuel cell and electrolyzer stacks. This subtopic seeks novel processes that are capable of reprocessing membrane scrap such that reuse in a new membrane (or other suitable application, e.g., ionomer in the catalyst layer) is possible with minimal degradation. Processes capable of facile conversion to or integration with end-of-life membrane recycling while avoiding complete material destruction (such as incineration) are encouraged.

Requirements	Targets
Recovery and reuse of scrap membrane material	50%
Recovery of PGMs	90%
Performance of recovered/reused scrap membrane material relative to performance of virgin membrane material	90%

Questions – Contact: Donna Ho, donna.ho@ee.doe.gov, Hydrogen and Fuel Cell Technologies Office

b. Reducing Hazardous Substances in Fuel Cells and Electrolyzer Recycling

As hydrogen fuel cells and electrolyzers increase in prominence as a decarbonization technology [9], processes for efficiently recycling rare platinum group metals (PGMs) such as platinum and iridium and useful components such as ionomers are needed. However, fluorinated components within fuel cells and electrolyzers create challenges in recycling these technologies without releasing toxic gasses and by-products [10]. For example, pyrometallurgical procedures for PGM recycling, which apply direct thermal energy to the fuel cell in order to concentrate PGMs, release toxic hydrogen fluoride gas in the process [11]. Hydrometallurgical procedures utilize strong acids and oxidizers that can react with fluorinated compounds leading to large amounts of hydrofluoric acid, hydrogen fluoride, and other hazardous gasses [12]. As the SBIR Commercial Potential Evaluation on Recovery of Platinum Group Metals from PEMFC found, mitigation of hazardous chemicals produced in the recycling process is key to increasing the viability of recycling fuel cells and electrolyzers [13]. This subtopic seeks efficient processes that use environmentally friendly solvents, reduce the production of hazardous by-products, or manage hazardous by-products in the recycling of fuel cells and electrolyzers.

Requirements	Targets
Reduction of Hazardous Substances	80%
PGM recovery	90%

Questions – Contact: Emmeline Kao; emmeline.kao@ee.doe.gov, Industrial Efficiency and Decarbonization Office

References:

1. Executive Order 14008, “Tackling the Climate Crisis at Home and Abroad,” January 27, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/
2. Hydrogen Shot | Department of Energy, https://www.energy.gov/eere/fuelcells/hydrogen-shot
3. H2@Scale | Department of Energy, https://www.energy.gov/eere/fuelcells/h2scale
4. H2IQ webinar presentation “DOE Update on Hydrogen Shot, RFI Results, and Summary of Hydrogen Provisions in the Bipartisan Infrastructure Law,” December 8, 2021, https://www.energy.gov/sites/default/files/2021-12/h2iq-12082021.pdf

5. DOE National Clean Hydrogen Strategy and Roadmap, September 22, 2022 DRAFT, https://www.hydrogen.energy.gov/roadmaps_vision.html
6. Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," Executive Office of the President. (2021). Executive Order 14008, https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad
7. Water Electrolyzers and Fuel Cells Supply Chain Deep Dive Assessment. 2021. https://www.energy.gov/sites/default/files/2022-02/Fuel%20Cells%20%26%20Electrolyzers%20Supply%20Chain%20Report%20-%20Final.pdf
8. Platinum Group Metal Catalyst Supply Chain Deep Dive Assessment. 2021. https://www.energy.gov/sites/default/files/2022-02/PGM%20catalyst%20supply%20chain%20report%20-%20final%20draft%202.25.22.pdf
9. SBIR Market Research Studies. Recovery of Platinum Metal September 2022. https://science.osti.gov/-/media/sbir/pdf/Market-Research/AMO---Recovery-of-Platinum-September-2022-Public.pdf
10. DOE Industrial Decarbonization Roadmap, 2022, https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap
11. Towards circular fuel cells: overcoming 3 challenges, Umicore. https://www.umicore.com/en/newsroom/news/fuel-cells-challenges-for-circularity/
12. New Research Project BReCycle - Fraunhofer IWKS https://www.iwks.fraunhofer.de/en/press-and-media/pressreleases/press-and-media-releases-2020/new-research-project-brecycle.html
13. Recycling of platinum group metals from energy storage devices: a techno-economical business plan analysis https://open-research-europe.ec.europa.eu/articles/2-92/v1

C56-12. VEHICLE TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Last year, vehicles transported 11 billion tons of freight, more than $32 billion worth of goods each day, and moved people more than 3 trillion vehicle-miles. The U.S. Department of Energy's Vehicle Technologies Office (VTO) provides low cost, secure, and clean energy technologies to move people and goods across America. VTO (https://www.energy.gov/eere/vehicles/vehicle-technologies-office) focuses on reducing the cost and improving the performance of vehicle technologies that can reduce petroleum dependency, including advanced batteries, electric traction drive systems, lightweight materials, advanced combustion engines, and advanced fuels and lubricants. VTO supports the development and deployment of advanced vehicle technologies, including advances in electric vehicles, engine efficiency, and lightweight materials. Since 2008, the Department of Energy has helped reduced the costs of producing electric vehicle batteries by more than 75%. DOE has also pioneered improved combustion engines that have saved billions of gallons of petroleum fuel, while making diesel vehicles as clean as gasoline-fueled vehicles.

Applications may be submitted to any one of the subtopics listed below but all applications must:

- Propose a tightly structured program which includes technical milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Include projections for price and/or performance improvements that are tied to a baseline (i.e. Multi-Year Program Plan (MYPP) or Roadmap targets and/or state of the art products or practices);
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include a preliminary cost analysis;

- Justify all performance claims with theoretical predictions and/or relevant experimental data;
- Applications that duplicate research already in progress will not be funded; all submissions therefore should clearly explain how the proposed work differs from other work in the field.

Grant applications are sought in the following subtopics:

a. Innovative Electric Vehicle Battery Cells and Components

Applications are sought to develop electrochemical energy storage technologies that support commercialization of electric vehicles, including innovative battery cells and battery components. Specific improvements of interest include: significant improvement in specific energy (Wh/kg) or energy density (Wh/L), for example, through Li metal batteries and/or solid-state batteries; cells/components based on low-cost and earth-abundant materials (e.g., S cathodes, Na-ion cells, etc.); improvements in manufacturing processes for the above materials and demonstration of their incorporation into a cell deliverable; improved cell design minimizing inactive material; and improved safety. Applications must clearly demonstrate how they advance the current state of the art and meet the relevant performance metrics for transportation or stationary energy storage. Development, processing, and recycling of Ni- and Co-containing cathodes are not of interest for this topic.

When appropriate, the technology should be evaluated in accordance with applicable test procedures or recommended practices as published by the Department of Energy (DOE) and the US Advanced Battery Consortium (USABC). These test procedures can be found on the USABC website [1]. The work must focus on battery material and cell-level innovations; pack-level work is not of interest, including demonstrations of battery pack integration in vehicles. Phase I feasibility studies must be evaluated in full cells (not half-cells) ≥200 mAh capacity, and Phase II technologies should be demonstrated in full cells ≥1 Ah capacity. All submissions should clearly explain how the proposed work differs from other work in the field and should not be duplicative of ongoing projects.

Questions – Contact: Simon Thompson, Simon.Thompson@ee.doe.gov
USABC Manuals, United States Council for Automotive Research, LLC. www.uscar.org/usabc

b. Novel Integrated Power Electronics Solutions for High Frequency Power Conversion in EV Fast Charging Systems

Continued advancements in wide-bandgap (WBG) power semiconductors and power magnetics have introduced higher frequency, higher power, and more power dense power electronics, reducing the total footprint of high-power direct current fast chargers (DCFCs) for electric vehicles (EVs). High switching frequency power electronics (PEs) solutions reduce the size of required passive components and eliminate the necessity for bulky and expensive low frequency isolation transformers [1]. High frequency solid-state transformers (SSTs) have shown promise to replace conventional systems to step down the grid voltage from medium voltage (MV ~13 kVAC) to a low voltage (LV = 480VAC) input for DCFCs while also providing the isolation critical for protecting the electrical grid. These solutions utilize medium voltage level isolated power electronics with high frequency transformers to provide the isolation, as well as to step-down the bus voltage to the voltage range necessary for EV charging.

Current state-of-the-art (SOA) high frequency power conversion stages for DCFCs utilize an AC-DC conversion for the utility front end, either through passive or active rectification, followed by an isolated DC-DC conversion to interface with the charging head. These high-power systems (>150kW) require a parallel connection of power conversions stages to meet the total output power demand for fast charging of EVs. This allows for commonality of devices as well as modularity of the power conversion stages to increase capacity as necessary. These high frequency topologies however still introduce parasitic passive elements such as capacitances, inductances, and resistances due to wiring and proximity of components, increasing the likelihood of Electromagnetic Interference (EMI) when using WBG power semiconductors, as well as contributing to greater power losses and thus lower efficiencies. Additionally, the proximity of components, such as the power modules and high frequency transformers lower the total power density of the power converters. It is therefore critical to determine cost-effective, and innovative solutions to advance the potential for integrated power components and passive elements suitable for implementation in modular high power DCFCs and other applications.

This topic intends to find innovative, low-cost, efficient, and power dense solutions to improve integrated power module and high frequency passive element designs for utilization in grid tied SSTs.

Proposed innovations may include but are not limited to:

- Integration of power semiconductors with planar magnetics
- Integrated DC bus capacitance
- Integration of filters and sensors with power conversion stages.

Applications must: clearly demonstrate:

- How the proposed work will improve on the SOA performance
- Cost-effective pathways for commercial adoption in DCFCs.

In Phase 1, projects should aim to design and simulate/model a ≥160-kVA prototype Dual Active Bridge (DAB) converter for a MV-to-LV EV DCFC with 150-kW output rating utilizing the proposed technology. Projects should also aim to utilize ≥1.2 kV SiC power semiconductors for the switching elements in the design. Phase I should include in-depth analysis of the electrical and thermal properties of the proposed innovation to demonstrate technology viability, with plans to prototype and test one unit in Phase II.

Questions – Contact: Fernando Salcedo, fernando.salcedo@ee.doe.gov

c. Recycling of Polymer Composites for Vehicle Decarbonization

Vehicle lightweighting provides opportunities to increase electric vehicle (EV) drive range, reduce battery size and cost, and decrease carbon emissions. EVs are driving significant strides in the decarbonization of the nation's transportation system, this burgeoning demand places ever greater importance on the development of lightweight and low carbon footprint materials. A paradigm shift in polymer composites design and manufacturing is urgently needed to enable vehicle decarbonization via low carbon emissions recycling of polymer composites.

Recycled polymer composites are an important class of materials with exceptional recyclability and low carbon footprint. Recyclable polymeric materials can be reinforced with natural or recycled/reclaimed high-performance fibers to make composites more eco-friendly and sustainable. Such recycled polymer composites have the potential to replace traditional nonrecyclable petroleum-based composite materials and other metallic materials such as steels and aluminum.

This subtopic seeks innovative technologies for recycling/reintegrating carbon fiber and other high-performance fibers of polymer composites into the U.S. vehicle supply chain to reduce carbon footprint over vehicle lifecycle. Low cost and low carbon emissions recycling/upcycling processes are required. Recycled/upcycled polymer composites with multifunctionalities are also of interest. For example, recycled polymer composites need to possess pristine composites properties over multiple (3+) lives to dramatically reduce green house gas (GHG) emissions and costs associated with fibers and composites manufacturing. Recycling processes and resultant composites must align with VTO Materials Program goals of the total composites costing less than $5/kg-saved weight on their subsequent lives. Novel matrices and/or reinforcements that significantly reduce the embodied energy of vehicle components and carbon footprint of composites manufacturing are encouraged.

Furthermore, recyclable dissimilar materials may be hybridized to simultaneously achieve lighter weight, lower cost, less carbon emissions, and/or more multifunctionalities for vehicle structures. Multifunctional composites for EVs can be tailored to carry mechanical loads of battery management system, reduce NVH, improve thermal management, enhance battery performance, and enable health monitoring. Recyclable dissimilar materials could also be optimized via artificial intelligence/machine learning to realize unprecedented lightweighting, carbon- and cost-reduction, and functionalities.

Questions – Contact: Felix Wu, felix.wu@ee.doe.gov

References: Subtopic b:

1. "Electrical and Electronics Technical Team Roadmap." USDrive, October 2017 https://www.energy.gov/sites/prod/files/2017/11/f39/EETT%20Roadmap%2010-27-17.pdf

C56-13. VEHICLE TECHNOLOGIES (FAST-TRACK ONLY)

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: NO	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: YES	Accepting STTR Fast-Track Applications: YES

Fast-Track grants are opportunities to expedite the decision and award of SBIR and STTR Phase I and II funding for scientifically meritorious applications that have a high potential for commercialization. Fast-Track incorporates a submission and review process in which both Phase I and Phase II grant applications are combined into one application and submitted and reviewed together.

Last year, vehicles transported 11 billion tons of freight, more than $32 billion worth of goods each day, and moved people more than 3 trillion vehicle-miles. The U.S. Department of Energy's Vehicle Technologies Office (VTO) provides low cost, secure, and clean energy technologies to move people and goods across America. VTO (https://www.energy.gov/eere/vehicles/vehicle-technologies-office) focuses on reducing the cost and improving the performance of vehicle technologies that can reduce petroleum dependency, including advanced batteries, electric traction drive systems, lightweight materials, advanced combustion engines, and advanced fuels and lubricants. VTO supports the development and deployment of advanced vehicle technologies, including advances in electric vehicles, engine efficiency, and lightweight materials. Since 2008, the Department of Energy has helped reduced the costs of producing electric vehicle batteries by more than 75%. DOE has also pioneered improved combustion engines that have saved billions of gallons of petroleum fuel, while making diesel vehicles as clean as gasoline-fueled vehicles.

Applications may be submitted to any one of the subtopics listed below but all applications must:

- Propose a tightly structured program which includes technical milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Include projections for price and/or performance improvements that are tied to a baseline (i.e. Multi-Year Program Plan (MYPP) or Roadmap targets and/or state of the art products or practices);
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include a preliminary cost analysis;

- Justify all performance claims with theoretical predictions and/or relevant experimental data;
- Applications that duplicate research already in progress will not be funded; all submissions therefore should clearly explain how the proposed work differs from other work in the field.

Grant applications are sought in the following subtopics:

a. Advanced Separations and Processing Technologies for Battery Critical Materials

Today, the U.S. is reliant on other countries for much of its battery critical minerals processing, which poses risk of disruption to domestic supply chain. Many of the materials needed to supply the next generation of batteries for electric vehicles and stationary storage are not produced domestically in the quantities and the costs needed to keep up with the increasing downstream U.S. demand. Advanced, cost-competitive separation and processing technologies offer a critical opportunity for development of a robust U.S. battery supply chain.

This subtopic seeks innovative technologies for separating and processing critical materials necessary for high-capacity batteries. Technologies should advance the state of the art and have a clear pathway towards commercialization and competitiveness in the domestic market. Critical minerals of interest for batteries include but are not limited to lithium, nickel, cobalt, manganese, fluorine, and graphite.

Technologies of interest to this subtopic include the following:

- Advanced processing methods that lower costs, improve efficiencies (such as water or energy use), and/or lead to decarbonization
- Separations of minerals from novel/unconventional sources, for example mine tailings
- Minerals extraction from brine sources (i.e. geothermal, oil field, continental)
- Co-production of critical minerals from sources

Small-scale demonstration or validation of technologies is within scope of this subtopic.

Questions – Contact: Mallory Clites, mallory.clites@doe.gov, Manufacturing & Energy Supply Chains

b. Advanced Critical Minerals Mapping Technologies

Today, the U.S. is reliant on other countries for much of its battery critical minerals processing, which poses risk of disruption to domestic supply chain. In order to realize a strong domestic supply of critical minerals to feed the growing energy sector industrial base, a greater understanding of domestic mineral resources is needed. This subtopic seeks innovative technologies that advance the capabilities of minerals mapping tools to help locate new critical mineral sources and support the development of a robust domestic supply chain. Technological advances in this area include advanced hardware and software for higher fidelity resource mapping, as well as innovative solutions to reduce the cost and time for resource mapping tools.

Questions – Contact: Mallory Clites, mallory.clites@doe.gov, Manufacturing & Energy Supply Chains

References:

1. "BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH" A Report by the White House. June 2021. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

Back to Table of Contents

C56-14. WATER POWER TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The U.S. Department of Energy's (DOE) Water Power Technologies Office (WPTO) enables research, development, and testing of new technologies to advance marine energy as well as next-generation hydropower and pumped storage systems for a flexible, reliable grid. To reduce marine energy costs and fully leverage hydropower's contribution to the grid, WPTO invests in research and technology design; validates performance and reliability for new technologies; develops and enables access to necessary testing infrastructure; and disseminates objective information and data for technology developers and decision makers.

WPTO is seeking SBIR and STTR applications related to both Hydropower and Marine Energy technologies, and details are described below.

In addition to the technical considerations described in the subtopic descriptions, ALL applications in this topic must:

- Propose a structured program which includes technical milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Include projections for price and/or performance improvements that are tied to a baseline;
- Differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include a preliminary cost analysis; and
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

The five subtopics supported in the Water Power Technologies this year are:

a. Innovations in Water Data
b. Advanced Coatings and Geomembrane Liners
c. Identification of Cybersecurity Threats and Research and Development of Mitigation Strategies for Hydropower and Dams' Operations
d. Co-Development of Marine Energy Technologies (CMET)
e. Marine Energy Supply Chain Development

In addition to the subtopics, applicants are strongly encouraged to review the EERE-wide Joint Topic on Decarbonization for subtopics related to irrigation modernization and maritime decarbonization.

a. Innovations in Water Data

Background

The collection, preparation, storage, processing, and interpretation data as it relates to water is foundational to 1) understanding the resilience of hydropower to changing basin-scale and climate conditions and 2) strategizing new marine renewable energy projects. This subtopic seeks novel and/or opportunistic approaches in water-related data that could open new areas of opportunity or bring greater efficiency or capabilities to hydropower and/or marine energy applications.

The goals of this cross-cutting hydropower and marine energy topic are:

- Encourage private sector approaches to solving gaps and challenges in synthesizing marine and freshwater data. In recent years, commercial data applications have rapidly expanded across climate change research, hydrologic and ocean data collection, and data applications. Example solutions may include resource characterization for marine renewable energy or new, advanced sensors for water quantity or quality monitoring for surface water resources on a basin-scale.

- Support startups and other small businesses focused on new approaches to data collection (e.g., AUVs, sensor platforms, and remote sensing) and processing (e.g., artificial intelligence/machine learning, data processing for decision-making, data assimilation, or other innovative data science platforms). Specifically, WPTO encourages novel commercial platforms, technologies, tools, or other approaches to benefit marine energy and hydropower industries with advanced data analysis, information, and knowledge. For example, one possible solution may involve AUVs for collecting ocean or reservoir/lake data or tools for analyzing "big data" to forecast wave and streamflow resources.
- Encourage community-based and/or citizen-science approaches where applicable. Focusing on traditional knowledge gaps, interdisciplinary and inclusive approaches, and global to local data are encouraged, especially where discovery or collection of this data drives downstream knowledge, products, and methods. For example, including new data types or approaches to data collection that incorporates social or economic data into data platforms.

Areas of Potential Interest*:

Marine Energy Applications	Hydropower Applications
• Resource characterization • Powering the Blue Economy • Environmental impacts and permitting • Disaster reduction, response, and relief • Spatial planning for testing and deployment	• Water quality, quantity, or demand monitoring • Watershed-scale sensor networks • Remote sensing • Greenhouse gas detection
Cross-cutting Applications	
• Artificial intelligence and machine learning • Decision support tools • Citizen science • Interdisciplinary research • Qualitative and quantitative approaches • Modeling • Forecasting	

* Themes of interest are deliberately broad to allow for unanticipated application approaches and topic areas that may have great value to the Water Power Technologies Office.

Applications must involve research, development, and demonstration in one or more of the two opportunity area below:

1. ***Data Gaps and Collection:*** Products and services integrating multiple data streams or databases
2. ***Data Processing and Analysis:*** Technologies, data, information, or tools that support the integration and/or usability of science-based tools and information in assessing hazard risk, vulnerability, and resilience
    a. Technologies that promote ecosystem management
    b. Tools that improve geospatial frameworks, increase accuracy of products and services, enhance decision support tools, or provide timely and accurate predictive information
    c. Technologies that facilitate greater understanding of the effects of marine energy on the health of humans and marine life

Back to Table of Contents

Application Requirements

In addition to the requirements for all Water Power Technologies projects described earlier in the topic description, competitive applicants for Phase I in this subtopic must describe in their applications how they will:

- If developing a data collection system:
    - Clearly define the landscape of the system including but not limited to:
        - the solution's applicability to hydropower/riverine systems or marine energy/ocean systems,
        - pervasiveness of applicability,
        - alternate solution that currently exist, and
        - articulate the value proposition beyond the state of the art;
    - Establish firm characteristics of the data collected along with the means of storing and/or transmitting this data
    - Document concerns and limitations of the application of the solution to the target demographics including water security, power supply, and communications;
    - Research the commercial potential for development of through practical use cases of said solution;
    - Outline the lifespan and temporal resolution of the solution;
    - Establish applicable standards committees or other relevant bodies to ensure industry uptake;
    - Prepare a preliminary design of the testing equipment needed;
    - Clearly define the accuracy, uncertainty, and adaptability of the solutions to datasets outside of the bounds of the initial data leveraged to develop the solution.
- If developing a data processing or analysis tool:
    - Clearly define the landscape of the system including but not limited to:
        - the tool's applicability to the broad hydropower/riverine system or marine energy/ocean systems,
        - pervasiveness of applicability,
        - alternate solution that currently exist, and
        - articulate the value proposition beyond the state of the art;

Phase II applications should state how awardees will:

- If developing a data collection system:
    - Finalize the design of the sensor along with any necessary system support;
    - Develop the sensor solution as outlined in Phase I;
    - Perform a series of testing on the sensor solution over a range of operational conditions;
    - Complete the research on the commercial potential of the solution;
    - Develop a report with recommendations on data collection needs of the industry and how/the extent to which the solution developed mitigates these. This report should also detail the commercial potential and a path forward to commercialize the solution and identify a process for industry uptake.
- If developing a data processing or analysis tool:
    - Finalize the design of the processing and/or analysis solution, along with any necessary coding, user information or guides;
    - Perform a wide range of sensitivity tests to ensure accuracy and precision and quantify uncertainty. This may include varying inputs and parameters such as temporal-spatial resolution, geographic location, data quality, data range and/or data sources;

- Develop a report with recommendations on data processing needs of the industry and the extent to which the solution developed mitigates these. This report should also detail the commercial potential and a path forward to commercialize the solution and identify a process for industry uptake.

Questions – Contact: water.sbir@ee.doe.gov

b. Advanced Coatings and Geomembrane Liners

Background

This subtopic identifies two areas of interest for innovation related to advanced materials to support new and existing hydropower and pumped storage hydropower (PSH). The Water Power Technologies Office has identified in the Multi-Year Program Plan (DOE 2022) that there are opportunities to leverage advanced manufacturing and materials to enable cost savings and/or improved performance for hydropower components and facilities. Current efforts are on-going to identify the top priorities for the highest impact. Based on industry feedback, two areas with potential impacts include:

Opportunity Area 1: Coatings for Hydropower

Due to the harsh conditions typical for hydropower facilities, coatings are frequently leveraged for a variety of applications. Additionally, increased efforts to ensure minimal environmental impacts, some traditional coatings may no longer be acceptable for use. Alternatives often have higher costs and/or shorter lifespans which is impacting the industry.

Recent efforts by Oak Ridge National Laboratory have focused on identifying key challenges and opportunities for advanced manufacturing and materials to apply to hydropower. Industry stakeholders have identified a real need and interest in all types of coatings for hydropower applications. Common issues for concrete and metal components tend to include, but are not limited to:

- Friction loss,
- Corrosion,
- Cracking,
- Insulation,
- Seepage loss, and
- Biofouling.

Applicants should consider novel coatings that can address one or more of these concerns; this can include coatings completely novel or adopted from other industries. The application method (paint, spray, roll-to-roll, dip etc.) and requirements associated such as clearance/access and surface prep should be described. In-situ repair and application capabilities are of interest. Additionally, the types of components and facilities where the coating is applicable should also be described to ensure a broad market opportunity. Potential for environmental and water quality impacts should also be considered for coating selection; appropriate standards should be follows. Anticipated testing should validate the use for hydropower applications and likely include in-situ testing.

Opportunity Area 2: Reservoir Liners

Pumped storage hydropower (PSH) is a highly efficient way of storing electrical energy, which is becoming more and more necessary to support the integration of variable renewable energy resources like wind and solar. The 2021 edition of the Hydropower Market Report (DOE, 2021) lists 43 PSH plants in the US, which account for 95% of all the utility scale energy storage of the nation. A PSH plant includes a connected upper and lower reservoir. Energy is used to pump water to the upper reservoir for storage. When needed, the water flows down from the upper reservoir to the lower reservoir through a penstock. These reservoirs are generally subjected to cycles of rapid drawdown and filling cycles as the water pumped and released for storing and producing energy. Therefore, the reservoirs of PSH plants must consider the slope stability during rapid draw-down and filling cycles. Additionally, efforts to minimize water loss due to seepage are important for conservation of water used for the energy production and protection of groundwater resources.

Geomembrane lining systems are one of several lining systems that can be considered for the impervious lining of PSH reservoirs and there are a number of geomembrane materials available in the marketplace that may be suitable for PSH application, yet as of (Hedien et al., 2022) no new PSH facilities have been constructed in the United States that have utilized geomembrane lining systems. No PSH specific design guidelines or regulation for geomembrane lining systems could be identified in the literature search conducted for (Hedien et al., 2022). Because of the growing need for energy storage, PSH reservoir liners present an opportunity for innovation related to geomembrane reservoir liners as well as adoption from other industries. Applicants are challenged to develop polymeric geomembrane liners that have properties that are relevant to PSH reservoirs. Factors to consider include seepage rates, soil retention, greenhouse gas emission reductions, installation, cost, and durability.

Application Requirements

In addition to the requirements for all Water Power Technologies subtopics described at the beginning of this topic, competitive applicants to both opportunity areas for Phase I of this subtopic must describe in their application:

- Demonstrate knowledge, experience, and/or capabilities in developing coatings, membranes, and/or hydropower technologies;
- A conceptual design of the proposed system with estimated physical dimensions and a clear description on how the system would operate – this may include a drawing or schematic of the proposed system;
- The state-of-the-art for incumbent technologies and/or typical industry practice for the current coating or liner and how the proposed design is an improvement in performance or reduction in cost;
- How the innovative technologies will improve operational performance relative to current components or structures, construction methods, or installation methods, given that reductions of cost, time, materials, etc. are the desired outcomes – combinations of cost reduction and operational performance improvements for existing component refurbishments are also encouraged;
- How the innovation relates to various types of dams or PSH projects (i.e. concrete arch, concrete gravity, earth fill, or combinations);
- The selection of a suitable location for demonstration of the technology and obtain necessary permits if needed;
- How the applicant will research, design, and develop innovative coating or geomembrane lining systems for the particular location and demonstrate understanding of the specific requirements for deployment at that site;
- Illustrate the integration of the innovative system and/or improvement within a project (i.e. how the innovation will interface with a whole hydropower project);
- Perform a customer discovery and analysis to understand the potential for commercialization and scaling-up of the solution to multiple locations globally.
- Other relevant details of work to be performed in Phase I including resources required and intended performance targets;
- Initial description of Phase II work including the scale of the prototype, the intended test location or facility, and ideally, end-user partners;

Phase I proof-of-concept work may include component or sub-system testing in a laboratory or natural environment as well as computer modeling and simulation.

Additionally, during Phase II, awardees will:

- Refine system designs based on the findings from Phase I towards building a functional prototype;
- Build, test, and demonstrate the technology developed during Phase I at the location identified in Phase I. Note that the applicant will be responsible to obtain any permits required in a timely manner;
- Present a detailed plan for technology commercialization including identification and engagement of end-users, near-term and long-term market opportunities, future demonstration and deployment plans, manufacturing and supply chain requirements.

Questions – Contact: water.sbir@ee.doe.gov

c. Identification of Cybersecurity Threats and Research and Development of Mitigation Strategies for Hydropower and Dams' Operations

Background

U.S. hydropower plants and their associated dam infrastructure play critical roles in both the evolution of a carbon-free electrical system and the safety and livelihoods of local communities and ecosystems. Dams may serve many purposes and provide important community services like flood safety, drinking water quality, ecosystem health, and energy reliability.

The current fleet of U.S. hydropower plants and dams needs to be modernized and digitalized due to hydropower's increasing role in the integration of variable renewables, the need for grid resilience services like black start and frequency regulation, aging dam infrastructure, the need for effective maintenance that supports new operating regimes, and other factors. As these facilities become increasingly interconnected to better enable remote operation and optimization within and across multiple plants, they become more vulnerable to cybersecurity threats, particularly in operational technology (OT) environments. This has been increasingly apparent worldwide. For example, data breaches have grown significantly with more than 40 documented cyber-attacks on hydropower plants and water infrastructure globally in the past 20 years[1]. Without the necessary cybersecurity measures, these attacks have the potential to reduce the reliability of the grid and hinder the safe operation of facilities.

Hydropower is a unique resource due to the diversity of plant configurations across the fleet and the mixture of legacy and modern technologies across information technology (IT) and OT environments. A recent WPTO funded effort by Pacific Northwest National Laboratory surveyed 275 hydropower plants and, while the approaches to control and digitalization varied widely, the team was able to identify nine common configurations for hydropower cyber-physical systems[2]. This analysis helped identify the common cybersecurity needs across the diverse hydropower fleet; solutions must be developed to address these needs, particularly for legacy industrial control systems that lack modern protection. WPTO seeks cost-effective cybersecurity solutions that also minimize implementation and maintenance efforts by the plant operator.

WPTO is seeking SBIR and STTR applications that provide solutions for hydropower-specific cybersecurity challenges across a range of plant configurations. These could be novel solutions or existing technologies that could be adapted for hydropower facilities and dams. For instance, successful solutions may include, but are not limited to, communication monitoring devices, threat detection and mitigation software (including OT asset management systems), depth-in-defense approaches, supervisory control and data acquisition (SCADA) system protections, and remote operation platforms.

Back to Table of Contents

Application Requirements

In addition to the requirements for all Water Power Technologies subtopics described at the beginning of this topic, for Phase I applications, competitive applicants should:

- Demonstrate knowledge, experience, and capabilities in hydropower IT/OT systems and/or energy-related cybersecurity practices.
- Identify existing critical cybersecurity threats that may interrupt hydropower and dam operations, known threats currently impacting related industries that may affect hydropower and dam operations in the future, and any other new or emerging threats.
- Describe how they will research and prioritize cybersecurity threats to hydropower systems (building upon existing research from WPTO-funded activities and others as appropriate).
- Conceptualize and design a cybersecurity solution to combat one or more high-priority threats or provide actionable information for plant operators.
- Identify how the cybersecurity solution will apply to a variety of hydropower plants and/or systems.
- Identify the scope of the proposed solution in terms of:
  - Where the solution fits into the cyber-physical system (considering how this placement may change in different plant configurations[2])
  - What systems or components the solution protects (e.g., using the Purdue model for Industrial Control System (ICS) security[3])
  - What threats are mitigated by the solution
- Work with at least one hydro-plant owner/operator, and preferably multiple owners/operators as an end-user whose considerations may influence the design and operation of the solution
- Work with the selected industry stakeholder(s) to select a site for a demonstration of the solution, obtain the appropriate approvals and permits, and scope the Phase II pilot-scale demonstration activities.
- Describe how they will quantify the commercial viability of their solutions through a clear and quantifiable value proposition to hydropower stakeholders.
- Perform customer discovery to understand the potential for commercialization and scaling-up of the solution in the global hydropower market and assess the transferability to other relevant energy markets.
- Conduct initial cost analysis to quantify the approximate value proposition of the solution to customers, including the costs of implementation, the cyber-event risk reduction, and the expected costs/savings from a cyber-event.

During Phase II the applicants will:

- Develop and implement the cybersecurity solution at the selected demonstration site. If a full-scale pilot is not feasible, this implementation may rely on lab-scale cyber test ranges and or partial designs (component or sub-system).
- Demonstrate the mitigation of risk by conducting and documenting tests of the solution, such as red team tests, to ensure proper operation in the case of a cyber-attack.
- Create a detailed commercialization plan, such as a business model canvas, to highlight key partners, customers, costs, revenues, resources, and other relevant activities.

Questions – Contact: water.sbir@ee.doe.gov

d. Co-Development of Marine Energy Technologies (CMET)

Background

Back to Table of Contents

The Co-Development of Marine Energy Technologies (CMET) subtopic seeks applications for the development and design of new marine energy prototypes specific to the needs of an identified end user in the blue economy. Applicants may be technology developers and/or end users.

CMET seeks to advance near-term marine energy opportunities in the blue economy by supporting the development of solutions tightly coupled to end-user needs. Specifically, this subtopic seeks to support the development of industry projects that link marine energy technologies together with blue economy energy end users to co-develop solutions specific to energy constraints.

A common underlying input for many of the activities in the blue economy is energy: fuel for ships, batteries for underwater vehicles, or high-pressure seawater for desalination systems. While some activities have access to cheap and reliable sources of energy, others do not. Energy inaccessibility limits operations and adds unnecessary costs. Removing or reducing these energy constraints through energy innovation could open new pathways for sustainable economic development.

Recognizing this opportunity and the potential for marine energy to ease energy constraints, WPTO released a report in 2019 titled "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets". The report describes a non-exhaustive set of non-grid applications where marine energy could provide consistent, reliable power, and is the foundation for the Powering the Blue Economy (PBE) Initiative for non-grid applications of marine energy. These applications of marine energy are not limited to electricity generation and can include marine energy for propulsion or pumping.

Blue economy markets and coastal communities present multiple opportunities and applications for marine energy technology developers; upfront engagement with blue economy end-users and coastal communities is essential to successful technology integration. The CMET topic is market agnostic but requires SBIR/STTR Phase I applicants to make a case for their proposed application through an initial analysis of the market's value and broader impact in their application. Should the project be awarded, a more refined market analysis will be required as a deliverable during the period of performance.

In addition to open-ended blue economy applications for marine energy systems, particular areas of interest for FY23 include:

1. Applications that incorporate aquaculture systems or marine carbon dioxide removal (mCDR) with marine energy systems. Marine energy applications for aquaculture systems could include, but are not limited to, those related to monitoring, precision farming, robotic and submerged cages, towing and transportation, feeding, health and disease prevention, and/or underwater drones and autonomous vehicles. Marine energy applications for marine carbon dioxide removal could include technology designed for various removal methods, such as electrochemistry, alkalinity enhancement, and/or seaweed and aquaculture farming, as well as for monitoring, reporting, and verification (MRV) of mCDR efforts.
2. Applications that seek to further develop innovations related to recent WPTO Powering the Blue Economy Prizes, i.e., the Waves to Water Prize focusing on wave-powered desalination, and the Ocean Observing Prize focused on marine energy powered ocean observing systems, including autonomous underwater vehicles.

WPTO strongly encourages engaging with end users to understand their power requirements and the functional requirements required, therefore applicants must identify and demonstrate at least one end-user whom they will work with during the project. The identified end-use partner(s) may be listed as project participant(s). Applicants must demonstrate that a prototype, with an identified partner, can be designed, built, and tested with funds provided in Phase II. As an example of the type of engagements the program has done with end-users, please see recently funded CMET and CMETSS SBIR projects and the published report "Enabling Power at Sea: Opportunities for Expanded Ocean Observations through Marine Renewable Energy Integration".

Application Requirements

In addition to the requirements for all Water Power Technologies subtopics described at the beginning of this topic, for Phase I applications, competitive applicants should demonstrate knowledge, experience, and/or capabilities in developing marine technologies and include the following in their applications:

- A preliminary design of the proposed system with estimated physical dimensions;
- A clear description on how the system would function;
- Identification of the marine energy resource that would be utilized;
- The end-user or customers that will be engaged during the project;
- Plan to incorporate customer needs based on interviews, workshops, expert panels, literature searches, and other methods;
- The method(s) by which customer needs will be converted into design requirements or specifications;
- The process by which design requirements will be converted to preliminary prototype designs;
- Table of design specifications for the system and how each relates to a customer need.
- Plan for preliminary proof-of-concept testing or modeling of system components;
- Identification and description of the proposed performance metrics which will be used to assess the system in comparison to incumbent technologies, such as levelized cost of energy, levelized avoided cost of energy, or other similar metrics – please refer to "Existing Ocean Energy Performance Metrics" for examples;
- A description of the intended deployment location(s) and the available energy in the chosen marine energy resource, including identification of any key environmental, social, and regulatory challenges;
- The state-of-the-art for incumbent technologies and how the proposed design is an improvement in performance or reduction in cost;
- How the solution can be applied to other applications or end-uses;
- Relevance of this project to DOE's climate change goals including through advancing clean energy and decarbonization, specifically how this project will advance increased availability of renewable energy, decrease fossil fuel emissions, and/or its potential to meet specific DOE technical targets or other relevant performance targets;
- Description of how this project will enable climate and energy justice;
- Details of work to be performed in Phase I including resources required and intended performance targets; and
- Initial description of Phase II work including the scale of the demonstration prototype, the intended test location or facility, and potential end-user partners.

Phase II applications should state how awardees will:

- Refine system designs based on the findings from Phase I towards building a functional prototype;
- Build, test, and demonstrate a functioning prototype in a realistic environment;
- Iterate system design based on ongoing laboratory and in-water experiments;
- Present a detailed plan for technology commercialization including identification and engagement of end-users, near-term and long-term market opportunities, future demonstration and deployment plans, manufacturing and supply chain requirements;

Questions – Contact: water.sbir@ee.doe.gov

e. Marine Energy Supply Chain Development

Back to Table of Contents

Background

Marine energy, including energy generated from waves, tides, currents, and temperature and pressure gradients is an emerging energy source for the U.S., given its reliability and long-term forecast-ability. While marine energy technologies are currently not at cost-parity with other sources of renewable energy, lessons from the development and deployment of solar and wind technologies show that supply chain optimization can play an important role towards cost reductions for the industry.

Currently there is no clustered or established marine energy supply chain in the US. The geographical areas with the most-near term opportunities for marine energy supply chain co-location are related to the offshore oil and gas industry in the Gulf of Mexico, thousands of miles away from the existing marine energy sites along the west and east coasts. Existing fleets of marine vessels with the ability to deploy energy infrastructure in the ocean are primarily contracted by offshore wind and/or offshore oil and gas, and are cost-prohibitive for the current marine energy industry.

The objective of this subtopic is therefore to spur the development of innovative systems or prototypes that will improve the logistics and supply chain capabilities (i.e., faster, cheaper more resilient, more secure, more adaptive) necessary for the deployment of marine energy technologies on a commercial scale. These innovations will be critical in delivery of operations, specialized manufacturing, and other supporting services such as environmental monitoring & impact assessment, certification, and project management. Successful projects in this subtopic will:

- Engage with at least one marine energy developer in the private or public sector, or a relevant research institution.
- Conduct research and development to accelerate ME supply chain development in US, to prepare for future tidal, wave and other marine energy deployments for the electric grid or non-grid blue economy applications.
- Target specific near-term to long-term areas for supply chain development, including manufacturing, repair, storage, distribution, transportation, planning, and disposal.

Application Requirements

In addition to the requirements for all Water Power Technologies subtopics described at the beginning of this topic, for Phase I applications, competitive applicants should:

- Identify the marine energy developer or institution that will be engaged during the project;
- Describe how marine energy developers' and/or institutions' considerations will be incorporated including through possible stakeholder mapping;
- Develop partnerships to address specific supply chain challenge areas like moorings, installation, operations, and maintenance challenges, and high-voltage / dynamic cables,
- Demonstrate knowledge of and experience with the challenges faced in tidal, wave, or other marine energy systems':
    - manufacturing,
    - device fabrication,
    - installations including electrical cables,
    - power take-off components,
    - composites, and
    - other materials designed for the marine environment;
- Demonstrate the impact that improvements to the supply chain will have on cost reduction trajectories, including addressing challenges identified and faced in the sector;
- Describe how they will develop business mechanisms for companies to pivot technologies and/or services currently utilized in offshore oil and gas and similar sectors towards marine energy;

- Describe how they will investigate and develop creative opportunities for developers to access and/or modify existing maritime infrastructure including fishing vessels, piers, platforms, cables, moorings, shipping containers, etc., to deploy marine energy systems,
- Describe project outputs which may be software tools, databases, reports, etc.

For Phase II applications, applicants will:
- Describe how they will work with marine energy developers and/or institutions, as well as supply chain experts to implement a supply chain improvement pilot program;
- Develop methods to scale their supply chain improvements, including through industry surveys;
- Describe how they will engage at least five (5) developers and / or institutions to provide feedback and input into the eventual deployment of their supply chain improvement solution;
- Describe how the solution can integrate with other current and potential future solutions, and how it can be sustainable;
- Describe their commercialization plan to make the tools and/or systems developed accessible and useful to the marine energy industry overall.

Questions – Contact: water.sbir@ee.doe.gov

References: Subtopic b:

1. "*Water Power Technologies Office: Multi-Year Program Plan.*" October 2022. Water Power Technologies Office Multi-Year Program Plan (energy.gov)
2. "*U.S. Hydropower Market Report.*" January 2021. https://www.energy.gov/sites/default/files/2021/01/f82/us-hydropower-market-report-full-2021.pdf
3. Hedien, J.; Altinakar, M.; DeNeale, S.; Koritarov, V. "*Reservoir Lining for Pumped Storage Hydropower: Scoping Study of Geomembrane Lining Systems*." 2022 https://publications.anl.gov/anlpubs/2022/05/175341.pdf

References: Subtopic c:

1. Ham, KD, C Eppinger, D Thorsen, C Powell, P Boyd, A Somani, M Ingram, V Koritarov. *"Hydropower Cyber-Physical Configurations: A typology for understanding the fleet of hydropower plants."* 2021 https://www.osti.gov/servlets/purl/1893701
2. *"What Is the Purdue Model for ICS Security?"* Zscaler, 23 Oct. 2020, https://www.zscaler.com/resources/security-terms-glossary/what-is-purdue-model-ics-security

References: Subtopic d:

1. "Powering the Blue Economy Report." Energy.gov, https://www.energy.gov/eere/water/articles/powering-blue-economy-report
2. Green, Rebecca, et al. "Enabling Power at Sea: Opportunities for Expanded Ocean Observations through Marine Renewable Energy Integration Preprint." 2019. https://www.nrel.gov/docs/fy20osti/74459.pdf
3. "Combating the Climate Crisis." Energy.gov, https://www.energy.gov/combating-climate-crisis
4. "Promoting Energy Justice." Energy.gov, https://www.energy.gov/promoting-energy-justice

C56-15. SOLAR ENERGY TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: YES	Accepting STTR Fast-Track Applications: YES

Back to Table of Contents

The goal of the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) [1] is to accelerate the development and deployment of solar technology to support an equitable transition to a decarbonized electricity system by 2035 and decarbonized energy sector by 2050. Achieving this goal will support the nationwide effort to meet the threat of climate change and ensure that all Americans benefit from the transition to a clean energy economy. In 2021, DOE released the Solar Futures Study [2], a report that explores the role of solar energy in achieving these goals. SETO supports solar energy research, development, demonstration and technical assistance in five areas—photovoltaics (PV), concentrating solar-thermal power (CSP), systems integration, manufacturing and competitiveness, and soft costs—to improve the affordability, reliability, and domestic benefit of solar technologies on the electric grid.

The amount of U.S. electricity that is generated by solar technology is increasing. In 2010, less than 0.1% of U.S. electricity generation came from solar energy; today this fraction is 4%. In California, solar accounts for more than 20% of all electricity generated, with 11 states generating more than 6% from solar energy. [3] At the same time, the cost of solar electricity is decreasing, driven by global economies of scale, technology innovation, and greater confidence in PV technology. The levelized cost of energy (LCOE) benchmarks and actual power purchase agreement (PPA) prices for utility-scale PV systems have decreased more than 80% since 2010. [4] These low costs have driven the deployment of over 90 gigawatts alternating current (GWAC) of solar capacity in the United States as of the end of 2021. [3] Over half of this capacity was installed after 2017. [5]

Historically, SETO has supported the commercialization of solar innovations through funding opportunities and other programs that relate to one another but have their own unique attributes [6]. SETO uses the SBIR/STTR program encourage U.S. small businesses to engage in high-risk, innovative research and technology development with the potential for future commercialization. Other programs include the American-Made Solar Prize [7], the Incubator topic area in SETO FOAs [8], and the Technology Commercialization Fund [9]. Please review SETO's webpage to find the best program for the technology readiness of your proposed technology and to make sure that the application aligns with the program's goals and objectives and our open funding opportunities.

This topic is open to both SBIR and STTR applications. SETO also has an additional topic open only to STTR applications. This topic is also open to SBIR and STTR Fast-Track applications.

Fast-Track grants are opportunities to expedite the decision and award of SBIR and STTR Phase I and II funding for scientifically meritorious applications that have a high potential for commercialization. Fast-Track incorporates a submission and review process in which both Phase I and Phase II grant applications are combined into one application and submitted and reviewed together. DOE reserves the right to award only the Phase I application deferring funding of Phase II.

Technical and Business Assistance (TABA)

Applicants are encouraged to take advantage of the TABA Program, which provides funding for commercialization activities in addition to the SBIR/STTR research funding. Please read the FOA with more information about this program and how to apply for this extra funding.

The American-Made Network [9] is a great resource for finding commercialization-assistance providers and vendors with specific expertise in the solar space. The Network helps accelerate solar innovations through a diverse and powerful group of entities that includes National Laboratories, energy incubators, investors, prototyping and testing facilities, and other industry partners from across the United States who engage, connect, mentor, and amplify the efforts of small businesses. The Network can help companies solve pressing technology challenges, forge connections, and advance potentially game-changing ideas and innovations.

Application Guidelines

Within this SBIR/STTR topic, applications submitted to any one of the subtopics listed below must:

- Propose a tightly structured program that includes quantitative technical and business objectives that demonstrate a clear progression in development and are aggressive but achievable;
- Include projections for price and/or performance improvements that are referenced to a benchmark;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include a preliminary cost analysis that clearly identifies assumptions and sources of input data;
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

Applications must include a clear assessment of the state of the art and how the proposed technology would represent a significant improvement, along with a basic cost-model analysis showing a path to becoming cost-competitive with current state of the art and the potential to increase solar generation on the grid.

Phase I awards part of this topic will be made in the form of a grant; SETO anticipates that Phase II awards will be made in the form of a cooperative agreement. In a cooperative agreement, DOE maintains substantial involvement in the definition of the scope, goals, and objectives of the project.

Applicants are strongly encouraged to use the table below to include a summary of objectives they expect to achieve by the end of the Phase I period of performance. A similar table will be required in a Phase II application. DOE may negotiate project milestones with entities selected for a Phase II award. The table contains examples of each objective type, to guide you as you prepare your application. Each application should include technical, business, and stakeholder engagement-related objectives with clear, quantifiable, measurable, verifiable, aggressive yet realistic success metrics, and clear definitions of how completion of an objective will be assessed. Completion of a task or activity is not an objective. The table should be organized chronologically.

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
1	2	Cell efficiency	> 25% efficiency	Average, standard deviation. At least 10 cells measured under standard conditions. Standard deviation < 1% (absolute efficiency).	Raw data and graphs included in the progress / final report submitted to DOE according to the FARC.	The success value was chosen based on initial cost modeling. Efficiency lower than 25% makes this material not competitive with current state of the art.
2	3	Circuit model curation	> 30 models, of which at least 20 are suitable	Count. 30 realistic and anonymized candidate distribution circuit models identified, of which at least 20 are	Description of circuit models, load models, impedances, and connectivity characteristics	Load models, impedances, and connectivity characteristics must be included in the report to assess the

Back to Table of Contents

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
			for testing	suitable for detailed testing.	included in the progress / final report submitted to DOE according to the FARC.	feasibility of the proposed circuits.
3	4	Feedback	> 10 potential users	Count. A minimum of 10 potential users of the tool will undergo a demo of the software (in-person or webinar) and provide feedback. Users must provide specific feedback as to the minimum availability and response time they require for their specific use case.	Documentation of feedback and a justified plan to implement or reject recommendations from potential users included in the progress / final report submitted to DOE according to the FARC.	User feedback is a critical part of an iterative development cycle to ensure the solution is useful to potential off-takers.
4	4	Module lifetime	> 30 years	Accelerated testing conducted according to testing procedures listed in IEC 1234.	Raw data and graphs included in the progress / final report submitted to DOE according to the FARC.	IEC 1234 is the industry-used module degradation test.
5	5	Heliostat installed cost	≤ $\$50/m^2$	Average expected accuracy range is +20%/-15%.	Cost model with description of assumptions used for input parameters, methodology for the sensitivity analysis, supporting documents used to determine the bill of materials included in the progress / final report submitted to DOE according to the FARC.	Success metrics defined in the FOA.

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
6	5	Letters of Support	5 letters	Count. A minimum of 5 letters of support from domestic manufacturers. Includes one module producer with capacity over 200MW annually.	Letters included in the progress / final report submitted to DOE according to the FARC.	Engaging with a large domestic module manufacturer is essential to show there are interested technology off-takers.
7	6	Simulation validation	Single feeder simulation	Power flows validated on a single realistic distribution feeder in simulation. Phasor tracking shows agreement with expected power flows at every circuit node to better than 5%.	Quantitative simulation results included in the progress / final report submitted to DOE according to the FARC.	5% agreement is required to assess the quality of the simulation tools.
8	8	Independent expert review of security architecture	Third-party review	Report by independent third-party cybersecurity expert reviewing the architecture and providing feedback on potential weaknesses.	Security review report included in the progress / final report submitted to DOE according to the FARC.	Implications of new platform architecture in the context of new cybersecurity concerns must be investigated and mitigated if necessary.
9	9	Module efficiency	> 25% efficiency	Average, standard deviation. At least 10 modules measured under standard conditions. Standard deviation < 1% (absolute efficiency).	Raw data, graphs, and report from testing facility included in the progress / final report submitted to DOE according to the FARC.	The success value was chosen based on initial cost modeling. Efficiency lower than 25% makes this technology not competitive with current state of the art.
10	9	Binding letters of intent	2 letters	Count. A minimum of 2 letters of intent from relevant stakeholders committing to fabricate and test a	Letters included in the progress / final report submitted to DOE according to the FARC.	Success of the award will be measured by successful technology transfer to private entities.

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
				large-scale prototype of this technology.		
11	9	Contract	> 1	Count. At least one agreement with a non-team-member to share data and beta test the solution.	Agreement included in the progress / final report submitted to DOE according to the FARC.	Success of the award will be measured by successful technology transfer to private entities.

Applications are sought in the following subtopics:

a. Wide-Bandgap-Based Power Electronics for Solar Inverters, Converters, and Multi-Port Systems that Integrate Solar Generation with Energy Storage and/or Electric Vehicle Charging

This subtopic solicits applications for the development of the next generation of power-electronic systems for the solar industry that integrate and leverage the greater efficiencies, improved performance, lower size/weight, automated manufacturability, and other advantages of devices and designs based on wide-bandgap semiconductor materials, such as silicon carbide (SiC) or gallium nitride (GaN). Systems of interest are solar inverters, DC/DC converters/optimizers, and multi-port devices designed to integrate and optimize distributed energy resources—in particular solar generation—with energy storage capabilities and infrastructure for electric vehicle charging. The goal of this subtopic is to support ideas and prototype development of technologies that can accelerate decarbonization of the electricity and transportation systems.

As solar electricity costs continue to decrease, the percentage of solar photovoltaic generation (both from distributed and utility-scale systems) in the U.S. increases. This opens up new challenges and opportunities for the development of novel technologies that can enable low-cost, dispatchable solar generation that can be integrated and operated flexibly to better match solar electricity with demand while also having the ability to provide operating support services to the electricity grid. At the same time, wide bandgap materials hold great promise to outperform traditional silicon-based devices in power electronic applications and in particular silicon carbide (SiC) and gallium nitride (GaN) devices have reached a level of maturity that allows them to become the device of choice in many applications. The growing market demand for SiC-based power electronics is driven by the rising adoption of SiC devices by original equipment manufacturers (OEMs) of electric vehicles and hybrid vehicles (EVs), which is leading to their de-risking and widespread adoption. This creates an opportunity for their use in power-electronics components for the solar industry in a cost-competitive way compared to incumbent technologies. Furthermore, the United States is a pre-eminent supplier of high-quality SiC wafers and chips, which—when used with advanced inverter/converter topologies that facilitate pick-and-place manufacturing—make a compelling case for domestic manufacturing.

This subtopic solicits applications for new power-electronic equipment that leverage the dropping costs of SiC and/or GaN grown on SiC wafers and implements innovative topologies, which may include transformerless designs, to create cost-competitive, high-performance alternatives to today's industry-standard silicon-based equipment. Additionally, this subtopic solicits applications that incorporate improvements to the state of the art in planar transformer designs and/or build processes for high-frequency-switching applications. This must be considered in conjunction with new SiC and/or GaN-based power electronics, given that planar magnetic components are very well suited for use with emerging GaN and SiC devices. In addition to inverter, SETO is seeking highly integrated systems that consist of distributed PV paired with energy storage systems (ESS) and/or electric vehicle charging (EVC) systems—including vehicle-to-grid (V2G) and vehicle-to-home (V2H) functionalities. By leveraging the inherent flexibility of ESS and EVC technology, the integrated systems can reduce the total capital and operational costs of these distributed energy resource assets. They also have the potential to provide grid services, including on-demand energy, capacity, reliability, and resiliency. SETO is specifically interested in innovative ESS technologies that could be co-located with PV systems and are fully compatible with the characteristics of the typical output of a solar inverter (medium-low voltage, variable generation). SETO is especially interested in novel thermal, mechanical, or chemical storage technologies that can demonstrate clear non-incremental differentiation from the current state of the art. Solutions that also integrate EVC should be capable of delivering power necessary for high-power direct-current fast charging.

The lack of holistic designs and standard interfaces can result in added integration costs and operational complexity. Applications should address issues of control coordination, interoperability, communication, component obsolescence, and scalability. Technologies proposed should leverage attributes specific to solar PV generation technologies while addressing current integration gaps and challenges. Applications must demonstrate potential to increase the utilization of solar PV generation in the grid and include a basic cost-model analysis showing a path to be cost-competitive with current state of the art. Storage functionalities at any time scale will be considered (minutes, hours, days, seasonal). However, the application should clearly discuss which energy value stream this technology will target, if successful.

Applications must include a clear assessment of the potential for domestic manufacturing. Proposed technologies must balance any power conversion cost increases with clear and substantiated value propositions from improved efficiency, performance, or reliability.

Applications focused on power conversion or integrated systems without including or incorporating wide-bandgap-based devices into the power conversion topology will be considered nonresponsive and declined without external merit review.

Applications will be considered nonresponsive and declined without external merit review if they address self-consumption optimization exclusively.

Questions – Contact: solar.sbir@ee.doe.gov

b. Photovoltaic Recycling

End-of-life management for photovoltaics (PV) refers to the processes that occur when solar panels and all other components are retired from operation [1]. This subtopic intends to support ideas and prototype development of new materials, designs, technologies, and practices that can help reduce PV manufacturing's environmental impact by minimizing waste, energy use, negative effects on human health, and pollution.

Back to Table of Contents

This subtopic solicits applications for technologies that can improve the overall recyclability and refurbishment of PV modules and/or other hardware or balance-of-system components of a solar system. As installed capacity of solar generation increases, end-of-life handling will become a larger consideration. Methods for extending the life of existing panels, as well as effectively recycling decommissioned modules, could be increasingly important. In addition, reclamation of key materials could ameliorate supply chain issues and further reduce overall environmental impact of the photovoltaic industry.

Specific areas of interest include but are not limited to:

- Module designs for improved ease of recycling and reclamation (materials separation, processing, etc.);
- Module designs for reduced recycling burden (lower materials usage, improved materials, etc.);
- Methods, processes, and equipment to lower the cost of the recycling or refurbishing process;
- Methods for effective refurbishing of modules and system components that facilitate the market for refurbished modules.

Proposed technologies must balance any module cost increases with clear, substantiated value propositions from improved recyclability and materials reclamation. Proposed technologies must not degrade module efficiency; applications must include a techno-economic analysis showing that any reductions in operational life expectancy when offset by savings in the recycling process are net positive.

Applications focused exclusively on resale platforms or software/web platforms to facilitate a secondhand hardware market will be considered nonresponsive and declined without external merit review.

Questions – Contact: solar.sbir@ee.doe.gov

c. Solar Systems Resilient to Weather-related or Cyber Threats

In this subtopic, SETO seeks innovative applications to improve the ability of solar assets or electronic devices associated with solar energy generation (such as inverters, direct current (DC)-DC optimizers, and smart meters) and systems to quickly recover in response to weather-related or cyber threats [1].

One of SETO's priorities is to enhance the ability of solar energy technologies to contribute to grid reliability and resilience, including the security and resilience of the nation's critical infrastructure. Infrastructure systems, including the electrical grid and solar generation assets, are vulnerable to weather-related threats, cyberattacks, and other disruptive events. Increased asset resilience presents opportunities to maximize operability and energy availability and minimize restoration costs following these occurrences.

Applications to this subtopic may address specific component or system designs that improve survival; improve recovery time; ensure access control, confidentiality, integrity, availability, or non-repudiation of assets; and minimize cost associated with disruptive events. Component or system designs may achieve these goals passively (e.g., via more robust designs or configurations) or actively (e.g., via "hardened" components, including any component that is connected in a smart power systems injection/absorption role).

Applications must include a basic cost-model analysis showing the cost/benefit of the proposed solution in comparison to current state of the art. Proposed solutions should discuss the component(s) being addressed, potential threats that will be deterred, method of integration (especially clarifying if it is part of a traditional PV component for integration at install or a retrofit for a fielded device), how interoperability with other components is considered, and how compromises or attempted compromises are conveyed to the relevant parties. Applications should also identify a possible case use by defining the time to recover the system's full functionalities and provide substantiated estimates for the capabilities of the proposed approach.

Examples of targets and metrics for hardened solar system performance include, but are not limited to:

- Percent of system operable after a disruptive event (applications should specify type and intensity of the threat);
- Time to full system operability after extreme event (restoration time);
- Reduction in system restoration cost following disruptive event;
- Level of functionality without grid support following extreme event (islanding).

Applications will be considered nonresponsive and declined without external merit review if they do not demonstrate clear innovation compared to the current state of the art, particularly in regard to microgrid and/or islanding behaviors.

Questions – Contact: solar.sbir@ee.doe.gov

d. Heliostat Components and Systems for Low-Cost, Autonomous, and High-Concentration Solar Collectors

This subtopic seeks applications for the design of heliostat components to support SETO's goals of low-cost solar-thermal energy for both high-temperature industrial process heating, as well as high-efficiency electricity production, coupled with thermal energy storage.

Achieving a decarbonized energy sector by 2050 will require the development of cost-effective technologies beyond today's commercial technologies. Increased deployment of solar technology, in particular, will require the deployment of flexible and dispatchable generation and energy storage technologies, like concentrating solar-thermal power (CSP) with thermal energy storage, to ensure reliability of the grid.[1] Achieving this transition requires that the industry achieve SETO's 2030 cost targets, which would halve the cost of solar power from 2020-2030, to $0.05 per kWh for CSP plants with 12 or more hours of thermal energy storage. Achieving this target will depend heavily on reducing the cost of heliostats – which track the sun and reflect light, concentrating it on a receiver – to $50/m^2, while improving technical performance. To advance heliostat technology development, SETO has established a National Laboratory-led consortium on heliostat technology, HelioCon.[2] In September 2022, HelioCon released a detailed Roadmap[3] describing the key technical gaps and promising strategies to achieve low-cost, high-performance heliostat systems.

In support of the HelioCon Roadmap, SETO seeks to advance the state of the art for the next generation of heliostats by improving their technoeconomic performance through, for example, enhanced pointing accuracy, increased average reflectivity, reduced backlash and performance under wind loads, new collector and field topologies and better long-term durability. These objectives may be achieved through solutions such as improved drives and closed-loop control systems, optimization of mirror washing methods, and advanced manufacturing techniques.

Applicants are expected to include the design, feasibility, subscale testing, and cost validation of new or improved components and subsystems during their Phase I application; lab scale testing, and prototype manufacturing of such components, lifetime performance, and feasibility of scale-up is of interest in Phase II applications.

Current commercial heliostat costs are approximately $96-$127/m^2. SETO is seeking to reduce the cost of heliostats by either developing novel designs or focusing on reducing the costs of heliostat components. All efforts in this subtopic should address cost reductions as a major requirement, or significantly, and cost effectively, increase technical performance. The heliostat is a highly integrated system, and therefore, concept improvements in an individual component, should not negatively affect cost or quality in other components or the overall system.

High Level Heliostat Operational Targets

- Total installed cost <$50/m^2, or a positive increase of technoeconomic impact for the plant
- Total error < 2 mrad total RMS
- Lifetime > 30 years
- Autonomy: Increased autonomy during normal operations and calibration
- Weather: Wind and hail survivability in both the operational and stowed positions

Components

- Heliostat Structure. Replacing the heliostat support structure with new materials including composite materials may provide an opportunity to reduce costs. New materials replacing the steel structure typically used in a heliostat must meet the above operational targets. SETO seeks to advance the use of low-cost composite materials in heliostats.
- Mirror Facets. The reflective surface of a heliostat is made up of 1 or more mirrored facets. These facets are often comprised of a mirror and a structural backing. SETO is seeking a composite sandwich facet design with 2 mm or less of highly reflective glass mirror or other reflective material, capable of meeting the heliostat operational targets as well as the optical requirements below:
  - Average Reflectivity > 95.5%
  - Precision < 1.5 mrad total RMS
- Mirror Facets Alignment Systems. Larger heliostats, with many mirror facets, typically require in-situ adjustment just after installation and periodically require recalibration. SETO is seeking facet designs or mirror facet to structure interfaces that allow for infield canting adjustments in less than 15 minutes.
- Wireless Control Systems. Maturing wireless control systems to a commercial off-the-shelf product would ultimately provide tremendous risk and cost reduction, eliminating the need for heliostat designers to take on the software development. SETO seeks to mature the heliostat wireless control system and meet the following goals:
  - Flexible – database or variable driven. Adaptable to multiple heliostat fields
  - Closed loop – Calibration and Normal Operations
  - Secure – Secure from attack (DOS, Control Interference)
  - Safe – Fail-safe, fault-tolerant architecture. Free of common cause failure
- Heliostat Drives. The drive systems represent the largest component cost of a heliostat. SETO seeks to advance drive technologies, while reducing total cost (combination of initial cost, power requirement, accuracy, expected lifetime, and maintenance over the desired 30-year life of a CSP tower system).

Questions – Contact: solar.sbir@ee.doe.gov

e. Concentrating Solar-Thermal Power Technologies for Gen3 CSP or Industrial Decarbonization

While PV has dominated the U.S. solar market, with over 90 GW deployed by the end of 2020, CSP technologies offer a unique value as a renewable energy resource that can readily deliver high-temperature heat and inherently incorporates storage for on-demand solar energy. There are nearly 100 CSP plants in commercial operation worldwide, representing almost 7 GW of capacity. Existing CSP plants have already demonstrated long durations of daily storage, up to 15 hours, which increases their value to the grid. With integrated TES, CSP plants can produce consistent amounts of electricity on demand, regardless of the time of day or amount of cloud cover. Continued development of this technology will improve the performance, reliability, and cost of future CSP plants, which have the potential to provide between 25 and 160 GW of U.S. capacity by 2050. [1]

Additionally, achieving a net-zero carbon economy by 2050 will require the adoption of clean energy technologies in sectors beyond electricity generation. Technologies are required that can eliminate the need to burn fossil fuels for heat-driven processes that produce electricity, essential commodities, refined products, and other goods. Even with increasing amounts of available renewable electricity, many industrial processes will be difficult to electrify because they require high temperatures or have other unique process characteristics.

For next-generation CSP plants, SETO has set a target to lower the cost of electricity from baseload plants, with greater than 12 hours of storage, to $0.05/kWh by 2030. This represents, approximately, a 50% reduction of existing costs. Although this target is aggressive, there are multiple pathways to achieve it.[2] The primary technical strategy being pursued to achieve this goal is to raise the temperature of the heat that next-generation CSP plants deliver to the power cycle, thereby increasing plant efficiency. Specifically, 'Generation 3 Concentrating Solar Power Systems[3] (Gen3 CSP) targets the development of high-temperature components and develop integrated designs with thermal energy storage that can reach operating temperatures greater than 700° Celsius (1,290° Fahrenheit). In March of 2021, SETO announced the selection of a Gen3 CSP pathway based on solid particle heat transfer media, led by Sandia National Laboratories, to receive approximately $25 million to build a megawatt-scale integrated test facility to validate the performance of this system.

Beyond CSP for electricity, SETO works to make solar industrial process heat (SIPH) a cost-effective alternative to conventional fuels. SETO pursues cost reductions and process integration improvements for a range of temperatures and industrial applications. Developing scalable, low-cost solutions for this variety of applications is a key challenge. Candidate applications for SIPH includes both low-temperature processes, such as enhanced oil recovery, food processing, and water desalination, and high-temperature processes, such as calcination to produce cement, thermochemical water splitting for producing solar fuels, and ammonia synthesis for producing fertilizer.

This subtopic seeks the development of CSP technologies, components, systems, and materials relevant to either low-cost electricity production or the decarbonization of industrial thermal processes.

Questions – Contact: solar.sbir@ee.doe.gov

f. Solar Hardware and Software Technologies: Affordability, Reliability, Performance, and Manufacturing

This subtopic solicits applications for solutions that can advance solar energy technologies by lowering cost and facilitate the secure integration into the Nation's energy grid. Applications must fall within one of these areas: advanced solar systems integration technologies, concentrating solar thermal power technologies, or photovoltaic technologies.

Specific areas of interest include, but are not limited to:

1. Innovative software solutions that will increase the competitiveness of the U.S. solar industry. This may include but is not limited to decreasing solar deployment barriers, expanding to new solar markets, reducing non-hardware costs of installations such as permitting, system design, or interconnection, and/or enabling new business models.
2. Technologies that reduce the manufacturing costs of solar energy system components or subcomponents to boost domestic energy manufacturing and increase U.S. manufacturing competitiveness;
3. Technologies that can measure, validate, or increase outdoor PV system reliability;

4. Technologies which improve operation and maintenance of PV systems. Can include self contained smart PV systems with sensors which detect actual or imminent power loss, or mobile instrumentation for low cost field diagnostics.
5. Technologies enhancing the ability of solar energy systems to contribute to grid reliability, resiliency, and security;
6. Technologies or solutions that reduce the balance-of-system costs of a PV system;
7. Technologies that build on other SETO programs and/or leverage results and infrastructure developed through these programs. In the past few years, SETO has funded several programs to support multi-stakeholder teams as they research and develop solutions to reduce significant barriers to solar energy adoption through innovative models, technologies, and real-world data sets. The areas of interest, analysis, taxonomies, and best practices developed from these programs can be leveraged as the impetus for small-business innovation.
8. Technology components and systems for application-specific needs such as integration with vehicles or agriculture, or special climates.

Applications must include a clear assessment of the state of the art and how the proposed technology would represent a significant improvement, along with a basic cost-model analysis showing a path to becoming cost-competitive with current state of the art and the potential to increase solar generation on the grid.

Applications will be considered nonresponsive and declined without external merit review if they are not based on sound scientific principles, are within the scope of any other of the subtopic listed under the Solar Energy Technologies topic, or do any of the following:

- Focus exclusively on HVAC or water heating applications;
- Propose products or projects for satellite or other space applications;
- Propose development of concentrated PV or solar spectrum splitting technologies;
- Propose development of technologies with very low possibility of being manufactured domestically at a competitive cost (e.g., PV modules based on copper zinc tin sulfide (CZTS) or amorphous silicon thin films; technologies assuming incorporation of functional materials, such as quantum dots or luminescent solar concentrators);
- Propose technologies to improve the shade tolerance of PV modules;
- Business plans or proofs of concept that do not include documentation supporting their necessity or benefit. Competitive approaches in this application segment should be clearly defined in the application;
- Undifferentiated products, incremental advances, or duplicative products;
- Projects lacking substantial impact from federal funds. This subtopic intends to support projects where federal funds will provide a clear and measurable impact (e.g., retiring risk sufficiently for follow-on investment or catalyzing development). Projects that have sufficient monies and resources to be executed regardless of federal funds are not of interest;
- Duplicative software solutions with many existing competitors in the market, including software to facilitate system design or system monitoring and any software solution to improve customer acquisition processes;
- Propose development of ideas or technologies that have already received federal support for the same technology at the same technology readiness level.

This subtopic seeks to assist independent, growing small businesses that will successfully bring a new technology to the market and identify a profitable, self-sustaining business opportunity based on their innovation. This subtopic is not intended for creating a product, organization, service, or other entity or item that requires continued government support.

Back to Table of Contents

Questions – Contact: solar.sbir@ee.doe.gov

References:

1. U.S. Department of Energy, 2021, Solar Energy Technologies Office, US DOE, Solar Energy Technologies Office, https://energy.gov/solar-office (November 3, 2021)
2. U.S. Department of Energy, 2021, Solar Futures Study, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/solar-futures-study (November 4, 2021)
3. Feldman, D., Margolis, R., 2021 Spring Solar Industry Update, https://www.nrel.gov/docs/fy22osti/82854.pdf
4. Feldman, D., et al, 2021, U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020, National Renewable Energy Laboratory, NREL/TP-6A20-77324, https://www.nrel.gov/docs/fy21osti/77324.pdf (November 4, 2021)
5. Feldman, D., Margolis, R., 2020, Q2/Q3 2020 Solar Industry Update, NREL/PR-6A20-78625, https://www.nrel.gov/docs/fy21osti/78625.pdf (November 4, 2021)
6. U.S. Department of Energy, 2021, Manufacturing and Competitiveness, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/manufacturing-and-competitiveness (November 4, 2021)
7. U.S. Department of Energy, 2021, American-Made Solar Prize, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/american-made-solar-prize (November 4, 2021)
8. U.S. Department of Energy, 2022, Solar Energy Technologies Office Fiscal Year 2022 Solar Manufacturing Incubator, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/articles/funding-notice-fiscal-year-2022-solar-manufacturing-incubator (October 14, 2022)
9. U.S. Department of Energy, 2021, Technology Commercialization Fund, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/technology-commercialization-fund (November 4, 2021)
10. Funding Opportunities, Department of Energy, Solar Energy technologies Office. https://www.energy.gov/eere/solar/funding-opportunities (October 14, 2022)
11. The American-Made Challenges, https://network.americanmadechallenges.org/ (October 14, 2022)

References: Subtopic b:

1. "End-of-life Management for Solar Photovoltaics." Energy.gov, https://www.energy.gov/eere/solar/end-life-management-s"olar-photovoltaics

References: Subtopic c:

1. "Multiyear Plan for Energy Sector Cybersecurity." Energy.gov. March 2018 https://www.energy.gov/sites/prod/files/2018/05/f51/DOE%20Multiyear%20Plan%20for%20Energy%20Sector%20Cybersecurity%20_0.pdf

References: Subtopic d:

1. Augustine, Chad, Craig Turchi, and Mark Mehos. 2021. The Role of Concentrating Solar Thermal Technologies in a Decarbonized U.S. Grid. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-80574. https://www.nrel.gov/docs/fy21osti/80574.pdf
2. "HelioCon Heliostat Consortium for Concentrating Solar-Thermal Power." *Heliocon.org*, https://heliocon.org/
3. "HelioCon Heliostat Consortium for Concentrating Solar-Thermal Power." *Heliocon.org*, https://heliocon.org/roadmap_report_release.html

References: Subtopic e:

1. C. Murphy, Y. Sun, W. Cole, G. Maclaurin, C. Turchi, and M. Mehos. "The Potential Role of Concentrating Solar Power within the Context of DOE's 2030 Solar Cost Targets." 2019. https://www.nrel.gov/docs/fy19osti/71912.pdf
2. 2030 Solar Cost Targets. SETO, Energy.gov. https://www.energy.gov/eere/solar/articles/2030-solar-cost-targets
3. SETO. "Generation 3 Concentrating Solar Power Systems (Gen3 CSP)." https://www.energy.gov/eere/solar/generation-3-concentrating-solar-power-systems-gen3-csp

C56-16. SOLAR ENERGY TECHNOLOGIES (STTR ONLY)

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: NO	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: YES

The goal of the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) [1] is to accelerate the development and deployment of solar technology to support an equitable transition to a decarbonized electricity system by 2035 and decarbonized energy sector by 2050. Achieving this goal will support the nationwide effort to meet the threat of climate change and ensure that all Americans benefit from the transition to a clean energy economy. In 2021, DOE released the Solar Futures Study [2], a report that explores the role of solar energy in achieving these goals. SETO supports solar energy research, development, demonstration and technical assistance in five areas—photovoltaics (PV), concentrating solar-thermal power (CSP), systems integration, manufacturing and competitiveness, and soft costs—to improve the affordability, reliability, and domestic benefit of solar technologies on the electric grid.

The amount of U.S. electricity that is generated by solar technology is increasing. In 2010, less than 0.1% of U.S. electricity generation came from solar energy; today this fraction is 4%. In California, solar accounts for more than 20% of all electricity generated, with 11 states generating more than 6% from solar energy. [3] At the same time, the cost of solar electricity is decreasing, driven by global economies of scale, technology innovation, and greater confidence in PV technology. The levelized cost of energy (LCOE) benchmarks and actual power purchase agreement (PPA) prices for utility-scale PV systems have decreased more than 80% since 2010. [4] These low costs have driven the deployment of over 90 gigawatts alternating current (GWAC) of solar capacity in the United States as of the end of 2021. [3] Over half of this capacity was installed after 2017. [5]

Historically, SETO has supported the commercialization of solar innovations through funding opportunities and other programs that relate to one another but have their own unique attributes [6]. SETO uses the SBIR/STTR program encourage U.S. small businesses to engage in high-risk, innovative research and technology development with the potential for future commercialization. Other programs include the American-Made Solar Prize [7], the Incubator topic area in SETO FOAs [8], and the Technology Commercialization Fund [9]. Please review SETO's webpage to find the best program for the technology readiness of your proposed technology and to make sure that the application aligns with the program's goals and objectives and our open funding opportunities.

This topic is open only to STTR Phase I applications and STTR Fast-Track applications.

Fast-Track grants are opportunities to expedite the decision and award of SBIR and STTR Phase I and II funding for scientifically meritorious applications that have a high potential for commercialization. Fast-Track incorporates a submission and review process in which both Phase I and Phase II grant applications are combined into one application and submitted and reviewed together. DOE reserves the right to award only the Phase I application deferring funding of Phase II.

Technical and Business Assistance (TABA)

Applicants are encouraged to take advantage of the Technical and Business Assistance (TABA) program, which provides funding for commercialization activities in addition to the STTR research funding. Examples of allowable commercialization services include: product sales, intellectual property protections, market research, market validation, development of certifications and regulatory plans, development of manufacturing plans. If you wish to utilize your own TABA provider(s), you are required to include this as one or more subcontracts or consultants in your budget and to provide a detailed budget justification. Please read the FOA [10] with more information about this program and how to apply for this extra funding.

The American-Made Network [11] is a great resource for finding TABA providers and vendors with specific expertise in the solar space. The Network helps accelerate solar innovations through a diverse and powerful group of entities that includes national laboratories, energy incubators, investors, prototyping and testing facilities, and other industry partners from across the United States who engage, connect, mentor, and amplify the efforts of small businesses. The Network can help companies solve pressing technology challenges, forge connections, and advance potentially game-changing ideas and innovations.

Application Guidelines

Within this STTR Topic, applications submitted to any one of the subtopics listed below must:

- Propose a tightly structured program that includes quantitative technical and business objectives that demonstrate a clear progression in development and are aggressive but achievable;
- Include projections for price and/or performance improvements that are referenced to a benchmark;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include a preliminary cost analysis that clearly identifies assumptions and sources of input data;
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

Applications must include a clear assessment of the state of the art and how the proposed technology would represent a significant improvement, along with a basic cost-model analysis showing a path to becoming cost-competitive with current state of the art and the potential to increase solar generation on the grid.

Phase I awards part of this topic will be made in the form of a grant; SETO anticipates that Phase II awards will be made in the form of a cooperative agreement. In a cooperative agreement, DOE maintains substantial involvement in the definition of the scope, goals, and objectives of the project.

Applicants are strongly encouraged to use the table below to include a summary of objectives they expect to achieve by the end of the Phase I period of performance. A similar table will be required in a Phase II application. DOE may negotiate project milestones with entities selected for a Phase II award. The table contains examples of each objective type, to guide you as you prepare your application. Each application should include technical, business, and stakeholder engagement-related objectives with clear, quantifiable, measurable, verifiable, aggressive yet realistic success metrics, and clear definitions of how completion of an objective will be assessed. Completion of a task or activity is not an objective. The table should be organized chronologically.

Back to Table of Contents

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
1	2	Cell efficiency	> 25% efficiency	Average, standard deviation. At least 10 cells measured under standard conditions. Standard deviation < 1% (absolute efficiency).	Raw data and graphs included in the progress / final report submitted to DOE according to the FARC.	The success value was chosen based on initial cost modeling. Efficiency lower than 25% makes this material not competitive with current state of the art.
2	3	Circuit model curation	> 30 models, of which at least 20 are suitable for testing	Count. 30 realistic and anonymized candidate distribution circuit models identified, of which at least 20 are suitable for detailed testing.	Description of circuit models, load models, impedances, and connectivity characteristics included in the progress / final report submitted to DOE according to the FARC.	Load models, impedances, and connectivity characteristics must be included in the report to assess the feasibility of the proposed circuits.
3	4	Feedback	> 10 potential users	Count. A minimum of 10 potential users of the tool will undergo a demo of the software (in-person or webinar) and provide feedback. Users must provide specific feedback as to the minimum availability and response time they require for	Documentation of feedback and a justified plan to implement or reject recommendations from potential users included in the progress / final report submitted to DOE according to the FARC.	User feedback is a critical part of an iterative development cycle to ensure the solution is useful to potential off-takers.

Back to Table of Contents

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.

#	Month of completion	Performance Metric	Success Value	Assessment Tool / Method of Measuring Success Value	Verification Process	Metric Justification, Additional Notes
				their specific use case.		
4	4	Module lifetime	> 30 years	Accelerated testing conducted according to testing procedures listed in IEC 1234.	Raw data and graphs included in the progress / final report submitted to DOE according to the FARC.	IEC 1234 is the industry-used module degradation test.
5	5	Heliostat installed cost	≤ $50/m^2$	Average expected accuracy range is +20%/-15%.	Cost model with description of assumptions used for input parameters, methodology for the sensitivity analysis, supporting documents used to determine the bill of materials included in the progress / final report submitted to DOE according to the FARC.	Success metrics defined in the FOA.
6	5	Letters of Support	5 letters	Count. A minimum of 5 letters of support from domestic manufacturers. Includes one module producer with capacity over	Letters included in the progress / final report submitted to DOE according to the FARC.	Engaging with a large domestic module manufacturer is essential to show there are interested technology off-takers.

Back to Table of Contents

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
				200MW annually.		
7	6	Simulation validation	Single feeder simulation	Power flows validated on a single realistic distribution feeder in simulation. Phasor tracking shows agreement with expected power flows at every circuit node to better than 5%.	Quantitative simulation results included in the progress / final report submitted to DOE according to the FARC.	5% agreement is required to assess the quality of the simulation tools.
8	8	Independent expert review of security architecture	Third-party review	Report by independent third-party cybersecurity expert reviewing the architecture and providing feedback on potential weaknesses.	Security review report included in the progress / final report submitted to DOE according to the FARC.	Implications of new platform architecture in the context of new cybersecurity concerns must be investigated and mitigated if necessary.
9	9	Module efficiency	> 25% efficiency	Average, standard deviation. At least 10 modules measured under standard conditions. Standard deviation < 1% (absolute efficiency).	Raw data, graphs, and report from testing facility included in the progress / final report submitted to DOE according to the FARC.	The success value was chosen based on initial cost modeling. Efficiency lower than 25% makes this technology not competitive with current state of the art.
10	9	Binding letters of intent	2 letters	Count. A minimum of 2 letters of intent from relevant stakeholders committing to	Letters included in the progress / final report submitted to	Success of the award will be measured by successful technology

Back to Table of Contents

PERFORMANCE METRICS AND SUCCESS VALUES IN THIS TABLE ARE ONLY EXAMPLES AND DO NOT NECESSARILY REPRESENT OFFICE GOALS OR SUCCESS METRICS FOR THIS TOPIC.						
#	**Month of completion**	**Performance Metric**	**Success Value**	**Assessment Tool / Method of Measuring Success Value**	**Verification Process**	**Metric Justification, Additional Notes**
				fabricate and test a large-scale prototype of this technology.	DOE according to the FARC.	transfer to private entities.
11	9	Contract	> 1	Count. At least one agreement with a non-team-member to share data and beta test the solution.	Agreement included in the progress / final report submitted to DOE according to the FARC.	Success of the award will be measured by successful technology transfer to private entities.

Applications are sought in the following subtopics:

a. Transferring Novel Solar Technologies from Research Laboratories to the Market

This subtopic intends to support technology transfer from research institutions (universities and national laboratories) to the market. SETO recognizes that a lot of interesting technologies are developed in research laboratories and do not have enough support to be spun out into independent companies. At the same time, research institutions have unique expertise, know-how, and infrastructure that can be valuable to a start-up. The STTR program is a vehicle to support the creation of new, for-profit entities that will work closely with a research institution.

This subtopic solicits applications for spinning out solutions from research institutions with the goal of advancing solar energy technologies by lowering cost [1], increasing domestic content in solar hardware [2], and facilitating its secure integration into the nation's energy grid. Applications must fall within one of these areas: advanced solar systems integration technologies, concentrating solar-thermal power technologies, photovoltaic technologies, or technologies to reduce soft costs. Applications can include hardware and / or software innovation.

Specific areas of interest include but are not limited to:

- Technologies that reduce the manufacturing costs of solar energy system components or subcomponents to boost domestic energy manufacturing and increase U.S. manufacturing competitiveness;
- Technologies to enable fast quality-control processes both in the manufacturing lines and in the field;
- Advanced metrology for scaled PV manufacturing;
- Optical annealing technologies for PV module manufacturing (including thin films and emerging materials, such as perovskites);
- Technologies enhancing the ability of solar energy systems to contribute to grid reliability, resiliency, and security;
- Technologies or solutions that reduce the balance-of-system costs of a PV system;

- Technologies that build on other SETO programs and/or leverage results and infrastructure developed through these programs. [3] In the past few years, SETO has funded several programs to support multi-stakeholder teams as they research and develop solutions to reduce significant barriers to solar energy adoption through innovative models, technologies, and real-world data sets. The areas of interest, analysis, taxonomies, and best practices developed from these programs can be leveraged as the impetus for small-business innovation.

Applications must include a clear assessment of the state of the art and how the proposed technology would represent a significant improvement, along with a basic cost-model analysis showing a path to becoming cost-competitive with the current state of the art and the potential to increase solar generation on the grid.

Applications will be considered nonresponsive and declined without external merit review if they are not based on sound scientific principles, are within the scope of any other of the subtopic listed under the Solar Energy Technologies topic, or do any of the following:

- Focus exclusively on HVAC or water heating applications;
- Propose development of concentrated PV or solar spectrum splitting technologies;
- Propose development of technologies with very low possibility of being manufactured domestically at a competitive cost (e.g., PV modules based on copper zinc tin sulfide (CZTS) or amorphous silicon thin films; technologies assuming incorporation of functional materials, such as quantum dots or luminescent solar concentrators);
- Propose technologies to improve the shade tolerance of PV modules;
- Business plans or proofs of concept that do not include documentation supporting their necessity or benefit. Competitive approaches in this application segment should be clearly defined in the application;
- Undifferentiated products, incremental advances, or duplicative products;
- Projects without a clear and measurable impact on the solar industry (e.g., retiring risk sufficiently for follow-on investment or catalyzing development);
- Duplicative software solutions with many existing competitors in the market, including software to facilitate system design or system monitoring and any software solution to improve customer acquisition processes;
- Propose development of ideas or technologies that have already received federal support for the same technology at the same technology readiness level.

This subtopic seeks to assist independent, growing small businesses that will successfully bring a new technology to the market and identify a profitable, self-sustaining business opportunity based on their innovation. This subtopic is not intended for creating a product, organization, service, or other entity or item that requires continued government support.

Questions – Contact: solar.sbir@ee.doe.gov

To be fair to all potential applicants, SETO will collect all questions received and make all answers public on this page: https://energy.gov/solar-office/sbir. The name of the person or organization asking the question will not be made public. SETO will not provide individual feedback or comments to specific potential projects or applications. Please do not include any business-sensitive or confidential information in your question.

References:

1. U.S. Department of Energy, 2021, Solar Energy Technologies Office, US DOE, Solar Energy Technologies Office, https://energy.gov/solar-office (November 3, 2021)

2. U.S. Department of Energy, 2021, Solar Futures Study, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/solar-futures-study (November 4, 2021)
3. Feldman, D., Margolis, R., 2021 Spring Solar Industry Update, https://www.nrel.gov/docs/fy22osti/82854.pdf
4. Feldman, D., et al, 2021, U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020, National Renewable Energy Laboratory, NREL/TP-6A20-77324, https://www.nrel.gov/docs/fy21osti/77324.pdf (November 4, 2021)
5. Feldman, D., Margolis, R., 2020, Q2/Q3 2020 Solar Industry Update, NREL/PR-6A20-78625, https://www.nrel.gov/docs/fy21osti/78625.pdf (November 4, 2021)
6. U.S. Department of Energy, 2021, Manufacturing and Competitiveness, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/manufacturing-and-competitiveness (November 4, 2021)
7. U.S. Department of Energy, 2021, American-Made Solar Prize, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/american-made-solar-prize (November 4, 2021)
8. U.S. Department of Energy, 2022, Solar Energy Technologies Office Fiscal Year 2022 Solar Manufacturing Incubator, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/articles/funding-notice-fiscal-year-2022-solar-manufacturing-incubator (October 14, 2022)
9. U.S. Department of Energy, 2021, Technology Commercialization Fund, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/technology-commercialization-fund (November 4, 2021)
10. Funding Opportunities, Department of Energy, Solar Energy technologies Office. https://www.energy.gov/eere/solar/funding-opportunities (October 14, 2022)
11. The American-Made Challenges, https://network.americanmadechallenges.org/ (October 14, 2022)

References: Subtopic a:

1. U.S. Department of Energy, 2021, 2030 Solar Cost Targets, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/articles/2030-solar-cost-targets (November 4, 2021)
2. U.S. Department of Energy, 2021, Solar Energy Technologies Office Multi-Year Program Plan, US DOE, Solar Energy Technologies Office, https://www.energy.gov/eere/solar/articles/solar-energy-technologies-office-multi-year-program-plan (November 4, 2021)
3. U.S. Department of Energy, 2021, Solar Energy Research Database, U.S. DOE, Office of Energy Efficiency and Renewable Energy, https://www.energy.gov/eere/solar/solar-projects-map (November 4, 2021)

C56-17. WIND ENERGY TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

EERE's Wind Energy Technologies Office (WETO) (https://energy.gov/eere/wind) drives innovation through research, development, and testing of advanced wind energy technologies. WETO plans and executes a diversified portfolio of early-stage research and development (R&D) to advance technologies for offshore, land-based, and distributed wind energy, and its integration with the electric grid. The Office also supports research on siting and environmental challenges and analysis and modeling. This work aims to drive down the cost of wind energy through competitively selected, cost-shared projects, carried out in collaboration with industry, universities, research institutions, and other stakeholders.

WETO emphasizes three common and overarching themes:

- Reduce the cost of wind energy for all wind applications (offshore, land-based utility-scale, and distributed).

Back to Table of Contents

- Enable and facilitate the interconnection and integration of substantial amounts of wind energy into the dynamic and rapidly evolving energy system, that is cost-effective, cyber-secure, reliable, and resilient, and includes systems integrated with other energy technologies, energy storage, and offshore and inter-regional transmission planning.
- Accelerate the deployment of wind energy through siting and environmental solutions to reduce environmental impacts, minimizing timetables for wind energy project development, and facilitating responsible, sustainable, and equitable development and delivery of wind energy resources.

Wind power capacity grew at a near record pace in 2021 (second only to 2020), with $20 billion invested and 13,413 megawatts (MW) of new capacity added in the United States, totaling a cumulative installed capacity of 135,886 MW. Additions were supported by the industry's primary federal incentive—the PTC—technology improvements and cost reductions, as well as state-level policies, but the PTC expired at the end of 2021 creating market uncertainty. In August 2022, the Inflation Reduction Act (IRA) was signed into law which makes the single largest investment in climate and energy in American history, enabling America to tackle the climate crisis, advancing environmental justice, securing America's position as a world leader in domestic clean energy manufacturing, and putting the United States on a pathway to achieving the Biden Administration's climate goals, including a net-zero economy by 2050 [1]. The IRA is poised to have a significant impact on the future of wind energy.

Wind power represented the second largest source of U.S. electric-generating capacity additions in 2021 (behind solar), constituting 32% of all capacity additions. Domestic wind-related jobs grew to a record number in 2021, with more than 120,000 Americans now working in the wind industry. According to the Bureau of Labor Statistics, wind turbine service technicians are the second fastest growing U.S. job of the decade [2].

The offshore wind industry is just beginning to develop in the United States, driven by the attraction of robust offshore wind resources, falling offshore wind turbine costs, technological advances, accelerated Federal offshore wind lease auctions, and complementary state policies and commitments. Offshore wind development in U.S. waters has been slowed, however, by several challenges, including its comparatively high-cost, an array of unique weather, wildlife, environmental, radar and other siting challenges, and no clear path yet for integrating vast amounts of new power onto an existing shore-based grid. Fixed-bottom technology, as developed abroad, can be adapted to U.S. waters, but the technology for floating offshore wind is a "new frontier". The promise of offshore wind is great, but there is more work to be done.
Global offshore wind installations in 2021 had a record year for deployment with 17,398 MW of new projects commissioned, pushing global installed capacity past 50 GW. Three floating offshore wind projects came online in 2021, totaling 57.1 MW, including the largest floating offshore wind project built to date—the 50 MW Kincardine Offshore Wind Farm in Scotland. With these additions, the total global pipeline for floating offshore wind energy grew by 12% in 2021 to 60,746 MW.

Falling offshore wind prices, state-level commitments, and an unprecedented expansion into new leasing areas drove the U.S. offshore wind pipeline to grow 13% over the previous year, with 40,083 MW now in various stages of development. The pipeline includes two projects in operation totaling 42 MW, two projects under construction totaling 800 MW, and 18 projects in the permitting phase totaling 18,581 MW. Over the last year, the Biden administration significantly expanded areas of the country available to offshore wind development, with six new lease areas auctioned in New York Bight, two new lease areas auctioned in Carolina Bay, and plans to lease new areas in California, Gulf of Mexico, Central Atlantic, Oregon, and Gulf of Maine [3].

Wind energy's growth has brought attention to the need for advanced technology and controls to support grid resilience and integration of wind with other energy technologies. WETO aims to advance scientific knowledge

Back to Table of Contents

and technological innovation to enable clean, low-cost wind energy options nationwide. With continued research and technology innovation to drive down wind energy costs and overcome grid integration, environmental and siting, and workforce development challenges, wind energy has the potential to serve as a key building block of an affordable, reliable, and secure energy future.

All applications must:

- Include technical, business, and stakeholder engagement-related objectives with clear, quantifiable, measurable, verifiable, aggressive, yet realistic, success metrics, and clear definitions of how completion of an objective will be assessed, supported by literature-based articulation of the baseline and quantitative success metrics, where feasible.
- Include projections for price and/or performance improvements that are tied to a baseline (i.e., DOE *Wind Vision* [4] or market reports and/or state-of-the-art products or practices).
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions expressing how the technical advancements will advance the state of the art.
- Include a preliminary cost analysis and justify all performance claims with theoretical predictions and/or relevant experimental data.
- Include a strong justification of the need for such technical advancements from the perspective of wind research and development, or energy siting and permitting.

Where applicable, applications should demonstrate interest from wind energy original equipment manufacturers and/or owner/operators regarding potential use of the technologies or where the end user is a regulatory body. The nature of that interest in and/or support of that body regarding the products of the research project should also be identified.

a. Open Topic

WETO invites applications for technology innovations that address technology gaps for distributed, land-based, and offshore wind with the potential to enable wind power to generate electricity in all 50 states cost competitively with other sources of generation.

This is an open call. Areas of specific interest include, but are not limited to, the following:

- Technology solutions to mitigate siting and environmental impacts for land-based and/or offshore wind plants [5].
    - Evaluating or minimizing impacts on coastal communities (e.g., fishing communities), historic properties and settings, cultural landscapes, and co-users of ocean space.
    - Innovative wildlife tags with a focus on alternatives to radio tags (e.g., GPS tags with or without remote data transfer).
    - Software technologies aimed at improving audio and/or image recognition of wildlife impacted by wind that function in adverse conditions which can differentiate between groups of wildlife and species.
    - Wind turbine radar interference reduction technologies [6]
- Technology for offshore wind resource characterization
    - Measurement of turbulence intensity and thermodynamic profiles across the rotor layer at sea [7]
- Wind turbine manufacturing, installation, and innovation [8, 9]
    - Increased automation in wind turbine blade manufacturing and maintenance
    - Non-destructive evaluation technologies for in-process qualification of manufactured wind components

  - Innovative installation technologies for extreme scales and complex terrain
  - Operations and maintenance decision-making tools
  - Wind turbine component recycling technologies
  - Anchoring and mooring concepts
- Grid Integration and Energy Storage [10]
  - Tools that address bulk power system wind interconnection needs [11]
  - Wind plant model validation
  - STTR: Tool to simplify state and local regulatory requirements for electric transmission project development [12]

Questions – Contact: Ben Hallissy, benjamin.hallissy@ee.doe.gov

References:

1. The White House. 2022. *Executive Order on the Implementation of the Energy and Infrastructure Provisions of the Inflation Reduction Act of 2022*. https://www.whitehouse.gov/briefing-room/presidential-actions/2022/09/12/executive-order-on-the-implementation-of-the-energy-and-infrastructure-provisions-of-the-inflation-reduction-act-of-2022/
2. Wiser, R., M. Bolinger, et al. 2022. *Land-Based Wind Market Report: 2022 Edition*. Washington, D.C. U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/wind/wind-market-reports-2021-edition#wind
3. Musial, W., Spitsen, P, et. al. 2022. *Offshore Wind Market Report: 2022 Edition*. Washington, D.C. U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/wind/wind-market-reports-2021-edition#offshore
4. U.S. Department of Energy. 2015. *Wind Vision: A New Era for Wind Power in the United States*. doi:10.2172/1220428 https://www.energy.gov/eere/wind/maps/wind-vision
5. U.S. Department of Energy Wind Energy Technologies Office. 2022. *Environmental Impacts and Siting of Wind Projects*. https://www.energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects
6. P. Gilman, Husser, L. Miller, B. Peterson, L. 2016. *Federal Interagency Wind Turbine Radar Interference Mitigation Strategy*. https://www.energy.gov/sites/default/files/2016/06/f32/Federal-Interagency-Wind-Turbine-Radar-Interference-Mitigation-Strategy-02092016rev.pdf
7. Shaw, W., et al., *Scientific Challenges to Characterizing the Wind Resource in the Marine Atmospheric Boundary Layer*, Wind Energy Sci. Discuss. [preprint], https://doi.org/10.5194/wes-2021-156, in review, 2022
8. U.S. Department of Energy Wind Energy Technologies Office. 2022. *Wind Manufacturing and Supply Chain*. https://www.energy.gov/eere/wind/wind-manufacturing-and-supply-chain
9. Veers, P., et al., *Grand Challenges in the Design, Manufacture, and Operation of Future Wind Turbine Systems*, Wind Energy Sci. Discuss. [preprint], https://doi.org/10.5194/wes-2022-32, in review, 2022
10. U.S. Department of Energy Wind Energy Technologies Office. 2022. *Renewable Systems Integration*. https://www.energy.gov/eere/wind/renewable-systems-integration
11. Tools could include hosting capacity tools such as the one EPRI developed "How Much Renewable Energy Can a Power Transmission System Accommodate? - EPRI Journal | EPRI Journal"
12. MISO has on POI analysis https://giqueue.misoenergy.org/PoiAnalysis/index.html
13. National Renewable Energy Laboratory. Regulatory and Permitting Information Desktop Toolkit. https://openei.org/wiki/RAPID

C56-18. HYDROGEN AND FUEL CELL TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES

Back to Table of Contents

Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Hydrogen and Fuel Cell Technologies Office (HFTO) is part of DOE's comprehensive energy portfolio aimed at building a sustainable energy economy and addressing the climate crisis, which is a top priority of the Biden Administration. The goals are to achieve carbon pollution-free electricity by 2035 and to "deliver an equitable, clean energy future, and put the United States on a path to achieve net-zero emissions, economy-wide, by no later than 2050" [1] to the benefit of all Americans.

The activities to be funded by HFTO will support the goals of DOE's Hydrogen Shot [2], which targets affordable clean hydrogen production at $1/kg within the decade, and the H2@Scale Initiative [3], which aims to advance affordable hydrogen production, transport, storage, and utilization to enable decarbonization and revenue opportunities across multiple sectors.

Additionally, activities will address the new clean hydrogen provisions of the November 2021 Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL). It includes provisions for the investment by DOE of $9.5 billion over five years in the research, development and demonstration of clean hydrogen production, storage, distribution, and end use technologies. Section 40314 includes $8 billion for establishment of at least four Regional Clean Hydrogen Hubs, $500 million for Clean Hydrogen Technology Manufacturing and Recycling, and $1 billion for Clean Hydrogen Electrolysis Program [4].

Applications are sought to address the overarching program goal of facilitating wide-spread adoption of hydrogen and fuel cells across sectors and the DOE national clean hydrogen strategy and roadmap [5] required in the BIL. The roadmap prioritizes three key strategies to ensure that clean hydrogen is developed and adopted as an effective decarbonization tool and for maximum benefits for the United States: (1) Target strategic, high impact uses for clean hydrogen. This will ensure that clean hydrogen will be utilized in the highest value applications, where limited deep decarbonization alternatives exist. Specific markets include the industrial sector, heavy-duty transportation, and long-duration energy storage to enable a clean grid. Long-term opportunities include the potential for exporting clean hydrogen or hydrogen carriers and enabling energy security for our allies; (2) Reduce the cost of clean hydrogen, aligned with Hydrogen Shot to catalyze both innovation and scale, stimulating private sector investments, spurring development across the hydrogen supply chain, and dramatically reducing the cost of clean hydrogen; and (3) Focus on regional networks. This includes regional clean hydrogen hubs to enable large-scale clean hydrogen production and end-use in proximity, enabling critical mass infrastructure. Priorities will include near term impact, creating jobs - including good paying union jobs - and jumpstarting domestic manufacturing and private sector investment.

As part of all these activities, HFTO efforts include research, development, and demonstration, including reducing the cost and improving the performance and durability of fuel cells, as well as developing affordable and efficient technologies for hydrogen production, delivery, and storage.

Applications submitted to any of these subtopics must:

- Propose a tightly structured program including technical milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative
- Include projections for performance and/or cost improvements that are tied to a baseline
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions
- Include a preliminary cost analysis and justify all performance claims with theoretical predictions and/or relevant experimental data

Back to Table of Contents

HFTO seeks applications in the following subtopics:

Base Appropriation

a. Low-Temperature Reversible Fuel Cells
b. Advanced Thermal Management Technologies for Fuel Cell Heavy-Duty Vehicle Applications
c. Fast Response Flow Control Valves for Gaseous Hydrogen Fueling of Fuel Cell Vehicles
d. Hydrogen Leak Quantification Technologies for Environmental Monitoring
e. Hydrogen Fuel Cell Powered Urban Air Mobility Feasibility Study
f. Hydrogen Sustainability Assessment Methods for Project Development

BIL Funding

g. Liquid Hydrogen Fueling and Delivery Components
h. Fuel Cell and Electrolyzer Manufacturing Quality Methods
i. Power Electronics Manufacturing Improvements for Heavy-Duty Fuel Cell Vehicle Applications
j. Fuel Cell Bipolar Plate Protective Coating Manufacturing and Refurbishment Development
k. Non-PFSA Membranes for Electrolyzers and Fuel Cells
l. Electrolyzers for Impure Water Operation
m. Alkaline Exchange Membranes for Water Electrolyzers

a. Low-Temperature Reversible Fuel Cells

This subtopic solicits applications for low temperature reversible fuel cells (RFCs) for energy storage applications and addresses the challenges RFCs face within those applications.

RFCs can operate in both fuel cell and electrolyzer modes and are a promising way to store large amounts of energy at a low cost. These systems, when combined into a single stack, need to maintain high performance in both operating modes and achieve a high roundtrip efficiency (RTE) to be cost competitive. If they can achieve such targets, they can be used for co-located energy storage and power generation. These RFCs could mitigate intermittency issues that are inherent to renewable energy, such as solar and wind [1]. These systems would need to reliably generate hydrogen during excess power generation (via electrolyzer mode) and use hydrogen to generate electricity (via fuel cell mode) during peak demand.

However, to date, RFCs typically suffer in one of the modes, depending on which operating mode the cell is most optimized for. Fabricating a stack that can satisfy the optimal requirements for both fuel cells and electrolyzers is difficult, due to the different demands. If an RFC can achieve high RTE, the system can be used as an energy storage device with the energy stored as hydrogen gas and provide long term energy resiliency.

Phase I applications should demonstrate an RFC with a high RTE with improved durability obtained from the same MEA operating in both fuel cell and electrolyzer modes, moving towards the 2030 targets given in the below table [2], and focused on a specific energy storage application. Cost analysis and projections for the specific application should be part of the research plan to move towards a lower levelized cost of storage set by DOE. Additional important areas to consider and are encouraged to apply under this subtopic includes water management to achieve high RTEs, bifunctional catalyst integration into RFCs, and other low-temperature materials, such as anion-exchange membrane systems. The goal of this subtopic is to reach high performing RFCs for low-cost energy storage applications.

Requirements[6] (1 or more)	Units	2020 Status	2030 Targets
Cell Performance/Roundtrip Efficiency at 0.5 A/cm^2 FC; 1 A/cm^2 EL	%	52	55

Total Cell PGM Loading	mg/cm^2	1.3	1.0
Cell Durability/Degradation Rate	%/1000 hr	-	0.25
Levelized Cost of Storage (for a system)	$/kWh	1.60	0.20

Questions – Contact: David Peterson, David.Peterson@ee.doe.gov or Julie Fornaciari, Julie.Fornaciari@ee.doe.gov

b. Advanced Thermal Management Technologies for Fuel Cell Heavy-Duty Vehicle Applications
This subtopic solicits novel and innovative thermal management concepts that advance the performance and durability of heavy-duty fuel cell vehicle systems.

Medium- and heavy-duty proton exchange membrane (PEM) fuel cell electric vehicles operating on hydrogen offer several advantages over incumbent combustion technologies, including higher efficiency, reduced emissions, higher torque, and no noise pollution. Medium- and heavy-duty truck applications require a lifetime of up to one million miles (e.g., 100,000 miles/year over 10 years), and therefore require fuel cells with innovative components with enhanced durability, while also maintaining low cost. Significantly longer vehicle lifetimes and range requirements also mean that hydrogen fuel costs comprise a greater proportion of vehicle lifecycle cost. As such, fuel cell efficiency is a key parameter for economic viability [1]. Offroad-equipment and vehicles powered via hydrogen fuel cells are frequently tailored to specific applications (e.g., mining trucks, agricultural equipment, construction equipment, etc.), with high power operation often at low speed, thus requiring large, high-power cooling fans to generate sufficient air flow over radiator fins. A recent offroad workshop report lists fuel cell cooling as a key challenge, with potential solutions arising from additional radiators, increased fan power, higher fuel cell stack operating temperatures, and/or more efficient heat rejection equipment [2]. Equipment addition results in a gravimetric and/or volumetric cost by lowering system energy/power density and/or further restricting the vehicle area/volume for heat rejection and fuel storage. Thus, equipment addition must be carefully weighed against potential benefits.

PEM fuel cell stacks generally operate at temperatures ranging from 65 - 95°C with most operation near 80°C, which optimizes stack performance and durability. System designers must balance higher heat rejection rates at higher stack temperatures against more rapid degradation at the membrane and electrode level. Many of the degradation mechanisms responsible for shortening PEM fuel cell lifetimes are thermally activated, with rates that increase exponentially with temperature. As a result, small increases in stack operating temperature can lead to large reductions in stack lifetime. Operating the stack below 80°C reduces cell current density due to lower conductivities and slower reaction rates and reduces the temperature differential for heat rejection to the ambient environment, which further constrains the system due to limited vehicle area for radiator inclusion.

Optimization of the thermal management system is critical for meeting the 2030 DOE heavy duty fuel cell targets for durability (25,000 hours), system cost ($80/kW), and efficiency (68% peak) [3]. Novel approaches to thermal management and heat rejection may provide distinct advantages over conventional approaches.

Phase I applications should develop a model capable of capturing the PEM fuel cell thermal management system dynamics and assessing the impact of thermal management component improvements on overall heat rejection and reduced average stack operating temperature over simulated drive cycles. Applicants are not restricted in their approach to improved thermal management but must include analysis comparing the projected improvement(s) in fuel cell system benefits against any additional component costs as well as gravimetric, volumetric, and efficiency penalties. Novel thermal management component performance must be validated via bench test in Phase I. Commercial off the shelf components may be modeled using manufacturer specifications. Phase II efforts must demonstrate the novel component(s) at the bench scale, and validate the model developed during Phase I. Applications developing novel heat exchangers, coolant flow paths, coolant composition(s), phase change materials, hybridized systems, and other approaches are encouraged.

Questions – Contact: Will Gibbons, William.Gibbons@ee.doe.gov

c. Fast Response Flow Control Valves for Gaseous Hydrogen Fueling of Fuel Cell Vehicles

This subtopic solicits applications to develop gas flow control valves for use at hydrogen fueling stations serving medium- and heavy-duty fuel cell vehicles. These vehicles are expected to have on-board hydrogen capacities up to 100 kg and the targeted fueling time is under 10 minutes, yielding expected average flow rates of 10+ kg/min (20+ kg/min peak). Additionally, supply (inlet) pressure to the flow control valve can increase significantly and rapidly due to supply tank switching. These flow conditions challenge the performance of currently available flow control valves. This topic seeks research and develop of valves or other flow control approaches that can maintain set point accuracy under large and rapid inlet pressure increases. Depending on the station hydrogen storage configuration, inlet pressure could rise by several hundred bar in only a few seconds. Operating conditions include a rated pressure of 1000 to 1380 bar and hydrogen gas temperature of -40 to 85°C. The flow control valve will need to connect to hydrogen supply tubing of at least 9/16-inch outer diameter.

For additional information, HFTO funded activities at the National Renewable Energy Laboratory have demonstrated high flow fueling test capabilities and generated test data concerning potential flow rates [1] and inlet pressure swings [2].

Phase I applications must describe the current status of the gas flow control technology or approach being developed and innovations targeted to maintain set point accuracy under large and rapid inlet pressure changes. Applications must also describe bench-scale testing that will be completed to assess the likelihood of the proposed concept maintaining accuracy under varied inlet pressure conditions.

Questions – Contact: Mark Richards, Mark.Richards@ee.doe.gov

d. Hydrogen Leak Quantification Technologies for Environmental Monitoring

In this subtopic, HFTO seeks applications for novel concepts that can quantify hydrogen leakage for in-situ environmental monitoring at hydrogen production, delivery, storage, or end-use locations.

In March 2022, HFTO and the European Commission co-hosted the "Clean Hydrogen JU Expert Workshop on Environmental Impacts of Hydrogen" to identify technical needs and next steps for monitoring and mitigating hydrogen releases into the atmosphere [1]. To mitigate environmental impacts of hydrogen leakage, as well as to inform future hydrogen technology development and risk assessment efforts, further understanding is needed on the amount of hydrogen that is released if a leak occurs. Previous work by the National Renewable Energy Laboratory has provided a benchmark for current hydrogen leak detection technologies [2]. Currently commercially available hydrogen leak detection systems have been designed to alert operators of hydrogen leaks at momentary levels that pose safety risks, rather than quantify the total amount lost through leakage. Quantification of hydrogen losses from infrastructure currently rely on system mass flow measurements rather than in-situ measurement at the site of the leak.

Phase I applications must include concept design to quantify hydrogen leakage in-situ at least a parts per million sensitivity and should detail plans to advance the detection capability to a parts per billion level in Phase II. Concepts proposed may either be stand-alone, with a detection component, or they may be integrated with existing detection technology, as a modular system. Phase I is expected to involve an in-depth analysis that includes preliminary design, research, and development of the selected component(s) or strategy, as well as identification of the specific application or use case being targeted. If reasonable within the Phase I budget, applications may include proof-of-concept testing of any new components or processes to show that they have the potential to quantify hydrogen leakage in-situ.
Phase II should focus on prototype development and testing at a scale relevant to demonstrate the viability of the concept for the specific application or use case identified. Phase II should include refining the sensitivity of the technology to quantify hydrogen leaks at a parts per billion level. Identification of service life and replacement criteria, commercialization strategies, market analysis, and cost comparison to existing hydrogen sensor technologies should also be included in Phase II.

Questions – Contact: Laura Hill, Laura.Hill@ee.doe.gov

e. Hydrogen Fuel Cell Powered Urban Air Mobility Feasibility Study

The objective of this topic is to perform a technical economic analysis (TEA), conceptual and preliminary designs, model scale development and test of a hydrogen fuel cell powered Urban Air Mobility (UAM) aircraft utilizing Vertical Take Off Landing (VTOL) based on the air taxi use case comparing it to comparable internal combustion engine and battery rotor craft to determine the following key metrics [1]:

- Greenhouse Gases (GHGs) abatement potential
- Total Cost of Ownership
- Technology Readiness Level – Fuel Cell Power Train, H2 Storage, Vehicle
- Performance versus baseline incumbent technology – internal combustion engine rotor craft and battery powered rotor craft.

Urban and highway roads are increasingly more hindered with traffic jams reducing the ability of passengers to get to local destinations in urban areas. UAM includes VTOL aircraft designed to expand transportation networks beyond ground-based technologies to aviation enabling short flight networks for the movement of people and goods around metropolitan areas. Air taxis use VTOL aircraft technologies and are starting to be used in urban areas for short flights to move passengers reducing the number of ground vehicles and traffic congestion [2]. Fewer vehicles on road result in reduced traffic congestion, a decrease in noise, and with hydrogen fuel cell zero emission UAM, a reduction in vehicular GHGs [3]. Present propulsion systems either lack sufficient range (e.g., batteries) or contribute to greenhouse gas emissions (e.g., internal combustion engines). The global air taxi market size is projected to reach $6.63 billion by 2030 [4].

This SBIR topic seeks innovative concepts for a hydrogen fuel cell powered UAM vehicle and the feasibility study to support its development. The feasibility study should include a technical economic analysis (TEA) of a UAM VTOL based on the air taxi use case comparing it to comparable internal combustion engine rotor craft. The effort should align with previous efforts performed by national labs in terms of technical specifications and targets [5].

Operational and conceptual design specifications for the design study should feature a UAM VTOL:

- With an average one-way trip range of 50 miles (the average urban commute is 8.5 miles, and the average mega commute is 93 miles)
- Carrying a payload of between two and four revenue passengers
- Capable of operating in all environments for cities located at elevations as high as Denver, CO
- Onboard storage of hydrogen should include a provision for a 20-minute reserve

Back to Table of Contents

- UAM to be piloted (though in the future, autonomous flight is a likely evolution of the aircraft)

The design study should include the expected cost of hydrogen fuel. To determine hydrogen consumption values used in the study, the topic seeks development of a powertrain dynamic model, confirmed by powertrain testing, for a UAM air taxi. The model should include take-off, ascent, horizontal flight, hovering, descent, and landing operations typical of a daily duty cycle of multiple trips, passenger loading/unloading, takeoffs and landings, and fueling.

PHASE I: Perform and document a feasibility study of fuel cell UAMs based on the development of a TEA (including comparison with baseline incumbent technology – internal combustion engine and battery power) including conceptual and preliminary design specification. Develop a Phase II plan to validate the findings of the feasibility study and conceptual and preliminary design using a scale VTOL model.

PHASE II: Build a scale and operate a scale UAM VTOL with fuel cell power train and onboard hydrogen storage system validation of results from the PHASE I study. The Technology Readiness Level target for end of Phase II is TRL 6 as defined by NASA to be system/subsystem model or prototype demonstration in a relevant environment (ground or space) [6].

The resulting findings and final report from this Topic should serve as a guide for aircraft manufactures and operators of hydrogen fuel cell UAM air taxi in development of full-scale development and placement into revenue service.

Questions – Contact: Pete Devlin, Peter.Devlin@ee.doe.gov

f. Hydrogen Sustainability Assessment Methods for Project Development

In this subtopic, HFTO seeks applications for improved methods to assess the sustainability of commercial hydrogen projects and energy systems. The assessment approach will incorporate a broad range of sustainability metrics, covering all relevant social, environmental, and economic indicators, and allow for application to real-world projects deployed within the next 1-3 years. To the degree possible, the assessment approach should leverage both DOE and other public resources relevant to various hydrogen sustainability indicators, as well as assessment methods and communication or interface platforms used to assess other civil infrastructure, energy utility, or transportation system projects (examples are provided below). One of the goals of the assessment process is to improve stakeholder engagement and development decisions related to sustainability performance over the project life cycle, from early planning through execution and operation. To the degree possible, the assessment approach should address the needs of one or more primary stakeholder groups (e.g., environmental/energy justice), and address opportunities or impacts relevant to utilities, energy companies, government organizations, and relevant industrial and transportation sector stakeholders.

While applicable to a wide range of hydrogen projects, including hydrogen production, storage, delivery, and end-use technologies, the assessment approach should be consistent with practices that are readily recognized and accepted by the sustainability assessment community. A successful approach and framework will be easily integrated with assessment methods already in use by various stakeholder groups, government and non-government agencies, and industry, energy utility, or transportation organizations. Examples include project-based rating systems, such as Envision [1], CEEQUAL [2], or the IS rating scheme [3], sector-specific tools such as SOLVE [4], as well as, potentially, broader frameworks such as GRI [5] or the Natural Capital Protocol [6]. Results from applying the assessment should accelerate, support, and feed into various sustainability certifications or rating systems, depending upon the project type and application. Assessment results will include both quantitative and qualitative indicators, with emphasis on those mostly closely related to attributes unique to hydrogen energy systems and end-use applications.

Phase I applications must include full description of the assessment approach, including analytical approach, qualitative methods, indicator results, and all potentially relevant input and project-specific data sources. Integration and commensurability with existing frameworks and assessment methods used by government and other stakeholder types should be described in detail. The framework should be integrated with capabilities and results provided by relevant tools currently relied upon by DOE or other federal agencies, with no duplication of analytic capabilities. Examples of relevant existing tools include the GREET model [7], AWARE model [8], EPA's EJScreen [9], and the H2A [10], HDRSAM [11], and H2FAST [12] cost and financial analysis models. Given that these existing tools address a subset of core indicators, such as lifecycle GHG emissions, new capabilities should focus on other sustainability indicators, such as community benefits, stakeholder engagement, air quality benefits, land use management, or energy resilience. Unique strengths and value-added benefits of the approach should be highlighted with respect to hydrogen projects developed in the near term. Capabilities to engage external stakeholders in the decision-making process directly should be integrated into the framework. Options for ongoing institutional management and accessibility of the assessment framework for use by the general public should be discussed.

Phase I deliverables will include full conceptional development of the assessment framework and encourages preliminary scoping of 1-3 case studies. This initial framework will draw upon appropriate data sources and will be integrated with existing relevant tools and frameworks, as discussed above. Phase II would include full development of the framework, extensive stakeholder engagement and review, followed by rollout of the framework and additional case studies and best practices.

Questions – Contact: Marc Melaina, Marc.Melaina@ee.doe.gov

g. Liquid Hydrogen Fueling and Delivery Components

Advancement of hydrogen and fuel cell technologies for off-road transportation applications, such as rail and mining as well as in on-road medium- and heavy-duty vehicles, requires a reduction in the cost of hydrogen fuel. While hydrogen fueling stations for light-duty vehicles typically dispense the fuel as a pressurized gas, stations that can dispense hydrogen as a liquid may be viable in the medium- or heavy-duty and off-road segments due to their potential to achieve lower cost [1], enable fast fills, and enable large amounts of hydrogen storage onboard the vehicles [2].

This topic seeks to develop components and approaches that can be used to deliver liquefied hydrogen. These include dispenser components (nozzles, hoses, breakaway valves, and flow meters), cryopumps or other devices or methods for transfer, and other transfer components (vacuum jacketed lines, fittings, flanges, etc.).

Proposed components and approaches should target: (1) flow rates of at least 10 kg/min, with higher flow rates encouraged [3], (2) cycle life in the thousands while accounting for materials compatibility effects of thermal and pressure cycling [4], and (3) commercial viability based on cost and manufacturability (e.g., avoid the use of specialized high-cost materials or manufacturing processes). Components should also be usable with minimal to no personal protective equipment (PPE), mitigate hydrogen losses through leaks and boil off, and mitigate the need for purging.

Phase I applications should focus on assessing proof of concept through component design, initial assessment of component cost, and/or initial materials and prototype testing. Phase II applications will be expected to develop and test prototypes at scale and evaluate performance.

Questions – Contact: Mark Richards, Mark.Richards@ee.doe.gov

h. Fuel Cell and Electrolyzer Manufacturing Quality Methods

This subtopic solicits applications for novel and innovative concepts that address challenges to maintaining requisite quality standards and tolerances associated with high-volume manufacturing of membrane electrode assembly (MEA) components and raw materials, MEAs, and full-cell assemblies for polymer electrolyte membrane (PEM) heavy-duty fuel cells and water electrolyzers, as an enabler for moving the needle on increasing fuel cell and electrolyzer manufacturing throughput and reducing costs.

Medium- and heavy-duty PEM fuel cell electric vehicles operating on hydrogen offer several advantages over incumbent technologies, including higher efficiency, reduced emissions, higher torque, and no noise pollution. Medium- and heavy-duty truck applications require a lifetime of up to one million miles, and therefore require advancements to facilitate enhanced durability. PEM electrolyzers split water into hydrogen and oxygen electrochemically using electricity that can be produced from diverse domestic resources. The large-scale production of hydrogen from water by electrolysis is a key enabler of EERE's H2@Scale vision of affordable hydrogen production, distribution, storage, and use across multiple applications from fueling to industrial uses. The current high system cost and general lack of domestic manufacturing facilities for both of these technologies remain as critical challenges impeding widespread adoption. Part of these high costs comes from the lack of rapid, highly accurate, and where applicable in-line and real-time quality methods, tools, and diagnostics to facilitate scaling to higher-throughput manufacturing processes [1, 2].

HFTO seeks to assist the hydrogen community in establishing manufacturing capacities that enable near-term production targets of 20,000 stacks/year for heavy-duty fuel cells and 1 GW/year for PEM water electrolyzers. These targets are first steps toward the production volumes needed to meet ultimate cost targets for both technologies. Part of this overall goal is to ensure that high-volume manufacturing methods for PEM raw materials, components, MEAs and cells are supported by associated tools that enable high quality.

Phase I applications should provide details of the quality technology concept, the approach to validating feasibility at a prototype scale using relevant materials, and evidence of how the concept will facilitate increased manufacturing throughput and/or higher accuracy quality measurement.

Questions – Contact: Michael Ulsh, michael.ulsh@ee.doe.gov

i. Power Electronics Manufacturing Improvements for Heavy-Duty Fuel Cell Vehicle Applications

This subtopic solicits concepts that promote standardization and manufacturing of power electronics for heavy-duty fuel cell applications. Heavy-duty proton exchange membrane (PEM) fuel cell electric vehicles operating on hydrogen offer several advantages over incumbent technologies, including higher efficiency, reduced emissions, higher torque, and no noise pollution. Heavy-duty truck applications require a lifetime of up to one million miles, and therefore require fuel cells with innovative components with enhanced durability. Significantly longer vehicle lifetimes and range requirements also mean that hydrogen fuel costs comprise a greater proportion of vehicle lifecycle cost. As such, fuel cell efficiency, vehicle reliability, and upfront cost are all key parameters for economic viability.

Presently, commercial (and pre-commercial) heavy-duty fuel cell system architectures tend toward designs unique to each manufacturer, with few shared or standard components. It is reasonable to expect that each vehicle integrator will optimize their system to maximize the value of a particular platform, but substantial cost savings and reliability improvements will likely arise when standardized and interchangeable components are incorporated into the design. Power electronics that convert, condition, and manage the electrical output from the fuel cell stack to charge the onboard battery or provide power to the traction motor and balance of system have been identified as a target area for standardization and improvement by industry experts [H2PACE] [1]. These components broadly include DC/DC converters, DC/AC inverters, power conditioning, and high voltage bus(es). The benefits from standardization of power electronics modules include higher manufacturing volumes (and associated cost reductions), part interchange, greater part availability, and simplified system design.

Phase I of this effort is a modeling and design analysis to optimize and select the desired base modules for a heavy-duty fuel cell vehicle power electronics system, with Phase II building and testing a 'bread board' system comprised of the optimal base modules before final model validation. Base module design should emphasize heavy-duty vehicle lifetime (25,000 hours), conversion efficiency, and ease of manufacturing. At a minimum the effort must include DC/DC converter, power conditioning, and DC/AC inverter components. Applicants are not required to include traction motor control components as part of the research effort but are not restricted from including traction motor control or other balance of system control components in their proposed design.

Questions – Contact: Will Gibbons, William.Gibbons@ee.doe.gov

j. Fuel Cell Bipolar Plate Protective Coating Manufacturing and Refurbishment Development

This subtopic solicits applications for novel and innovative concepts that address challenges of scaling the manufacturing of high quality and durable protective coatings and treatments for metal bipolar plates for medium- and heavy-duty fuel cells and of refurbishing used coated or treated metal bipolar plates at end of life.

Bipolar plates play an important role in fuel cell performance through reactant distribution, water management, and the collection of the electric current produced. Bipolar plates are projected to be the second most expensive fuel cell stack component in scaled-up systems using state-of-the-art technology [1]. Metallic plates enable high power densities but are susceptible to corrosion. Corrosion can be mitigated through a corrosion-resistant coating or treatment applied to a low-cost base metal (e.g., gold-coated stainless steel). HFTO seeks to assist the hydrogen community in increasing manufacturing capacities so that near-term production targets of 20,000 stacks/year for medium- and heavy-duty fuel cells are enabled. This target is the first step toward the production volumes needed to meet ultimate system cost target of $80/kW (at 25,000-hour durability). As such, the challenges that must be overcome when scaling these processes to higher volumes are assuring high quality and uniformity of the coating while still maintaining the required electrical conductivity and durability.

In addition, as fuel cell deployment expands, the number of end-of-life systems will be growing. Development of methodologies to incorporate circularity concepts into the life cycle of cell components, including bipolar plates, are of the utmost importance [2]. Methods to refurbish used bipolar plates, with coatings or treatments that may be degraded or have lost integrity at end of life, are needed.

Phase I applications should provide details of the coating, treatment, or refurbishment technology concept, the approach to validating feasibility of the concept at a prototype scale, testing of the fabricated or refurbished plate to verify that relevant DOE fuel cell performance targets are met, and evidence of how the concept will facilitate increased manufacturing throughput toward the near-term 20,000 stacks/year target.

Questions – Contact: Michael Ulsh, Michael.Ulsh@ee.doe.gov

k. Non-PFSA Membranes for Electrolyzers and Fuel Cells

Proton exchange membrane (PEM) technology is used extensively in water electrolyzer and fuel cell applications. Interest in the use of clean hydrogen in decarbonization efforts and in reducing carbon emission has grown significantly. Deployment of PEM electrolyzers that can operate efficiently under dynamic conditions, such as with variable renewable energy sources or grid load shifting applications, is growing rapidly. At the same time, PEM fuel cells fueled by clean hydrogen are a leading candidate to power zero emission vehicles, with several major heavy/medium duty vehicle manufacturers already developing commercial vehicles powered by PEM fuel cells. PEM fuel cells are also of interest for stationary electric power generation, including primary power, backup power, and combined heat and power.

Commercial PEM technology for both electrolyzers and fuel cells is typically based on perfluorosulfonic acid ionomers (PFSA), but these ionomer materials are expensive, particularly at low production volumes. Recently, there has been growing concern that the use of PFSA in electrolyzers and fuel cells may face increased regulatory barriers due to detrimental environmental impacts. Therefore, non-PFSA PEMs, including those based on hydrocarbon membranes, could represent a lower-cost, environmentally friendly alternative; however, these membranes require improved performance and durability for electrolyzer and fuel cell applications.

This topic solicits applications to develop novel non-PFSA ionomers and membranes suitable for application in PEM electrolyzers and/or fuel cells. Novel PEMs developed through this subtopic should have properties and characteristics required for application in PEM electrolyzers and/or fuel cells, including:

- High proton conductivity in a range of temperature and humidity conditions
- Good film forming properties enabling formation of thin (<25 µm for fuel cells, <125 µm for electrolyzers) uniform membranes
- Low swelling and low solubility in liquid water
- Low creep under a range of stress, temperature, pressure, and humidity conditions
- Low permeability to gases including H_2, O_2, and N_2
- For fuel cell applications, meet DOE technical targets for membranes for transportation applications [1] and have sufficient chemical and mechanical durability to pass the accelerated stress tests in the Fuel Cell Tech Team Roadmap [2]
- For electrolyzer applications, capable of ~20 bar differential pressure operation and a gas crossover rate of <2% H_2 in O_2

PEM technology proposed for this subtopic should be based on proton-conducting non-perfluorinated ionomers but may include reinforcements or other additives. Membrane samples should be tested at an independent laboratory at the end of each phase. Phase I should include measurement of chemical and physical properties to demonstrate feasibility of meeting the properties and characteristics included above, while Phase II addresses long term durability and development of manufacturing processes to meet the cost targets.

Questions – Contact: Donna Ho, Donna.Ho@ee.doe.gov and McKenzie Hubert, mckenzie.hubert@ee.doe.gov

I. Electrolyzers for Impure Water Operation

This subtopic solicits applications that plan to develop low-temperature proton exchange membrane (PEM), alkaline exchange membrane (AEM), or liquid alkaline (LA) electrolyzers that can operate on impure water. Applicants may focus on materials development and/or cell/stack design developments to improve the efficiency and/or durability of electrolyzers that operate with impure water. Impure water feedstocks can be a range of sources including anything from tap water to seawater.

Impure water electrolyzers can enable direct coupling of electrolyzers with offshore wind and electrolyzer operation in water stressed areas. Using impure water has a significant effect on the durability and efficiency of traditional electrolyzers through fouling of the catalysts and membranes [1]. The effects of impure water

Back to Table of Contents

use can be mitigated through the development of novel catalysts and membranes that are resistant to fouling or through cell and/or stack designs that prevent fouling. Increasing the durability and efficiency of impure water electrolyzers will enable commercial use in additional applications. Applicants should address how they will achieve the relevant durability and efficiency targets by the end of a Phase II project. Phase I work should demonstrate promise for achieving these targets using an impure feedstock.

Electrolyzer Technology	Performance	Degradation Rate
PEM	2.0 A/cm^2 @ 1.8 V	4 mV/khr
AEM	2.0 A/cm^2 @ 1.9 V	4 mV/khr
LA	1.0 A/cm^2 @ 1.9 V	4 mV/khr

Phase I applications should provide details on the novel materials, components, cell, or stack designs proposed and how they will enable impure water operation. Applicants should also discuss the potential for their technology to reach the DOE 2026 \$2/kg H_2 goal. Applicants may consult the NREL H2A Production Models in discussions on the potential cost of their systems [2]. In Phase I, applicants should focus on demonstrating the capabilities of their materials to operate in impure water. In Phase II, applicants should work toward demonstrating cell-level operation of their systems.

Questions – Contact: Anne Marie Esposito, Annemarie.Esposito@ee.doe.gov or David Peterson, David.Peterson@ee.doe.gov

m. Alkaline Exchange Membranes for Water Electrolyzers

Alkaline exchange membrane (AEM) water electrolyzers have several advantages compared to other low temperature electrolyzer hydrogen production technologies. The AEM electrolyzer design aims to combine the advantages of both proton exchange membrane (PEM) and liquid alkaline (LA) electrolyzers: the alkaline environment enables the use of non-precious metal catalysts and less expensive metal interconnects, and the membrane enables differential pressure operation and operation at higher current densities than traditional LA electrolyzers [1]. Due to the local alkalinity in the membrane, pure water can be fed to the electrolyzer instead of liquid alkaline electrolyte to reduce balance of plant costs; although, current technology has better performance and durability with a low concentration supporting electrolyte feed (e.g., ~0.3M KOH). A critical limitation in the development of high-performance, long-lifetime AEMWEs is the fabrication of a stable membrane that can endure long-term operation while maintaining high hydroxide ion conductivity, which is a necessity for a durable water electrolyzer.

There are several reasons that the ion exchange polymer is currently the limiting factor in AEM electrolyzers. First, no commercial materials today are sufficiently stable at any temperature under the conditions of sustained electrolysis. Membranes which show good stability to liquid KOH may lack stability in pure water and can be oxidized at high cell potentials. AEM materials are not as thermally or chemically stable as PEM materials, leading to even higher degradation at temperatures above 60 ^{o}C, limiting achievable efficiency. Mechanical stability is also a pressing issue with swelling from water uptake and edge failures causing rapid performance decrease [2].

Novel membranes developed through this subtopic should have properties and characteristics required for application in AEM electrolyzers including:

- Operation ≥ 60 ^{o}C, preferably at least 80 ^{o}C
- Performance in a membrane electrode assembly (MEA) of >1 A/cm^2 @ 1.75 V
- MEA degradation rate of <4 mV/1000 hours with testing for a minimum of 500 hours
- High OH^{-} conductivity and high iconic capacity over relevant temperature and electrolyte conditions

- Low swelling and low solubility in liquid water
- Low creep under a range of stress, temperature, pressure, and humidity conditions
- Low permeability to gases including H_2 and O_2

Phase I should include measurement of chemical and physical properties to demonstrate feasibility of meeting the properties and characteristics included above, while Phase II should address long term durability and development of manufacturing processes with potential to meet DOE 2026 cost target of $2/kg H_2. Testing of novel AEM membranes in an MEA in Phase I is strongly encouraged. Operation on feedstocks consisting of both pure water and in the presence of a low concentration (<0.5 M) of supporting electrolyte are of interest. Membrane stability testing should be conducted in line with established best practices [3].

Questions – Contact: James Vickers, James.Vickers@ee.doe.gov

References:

1. Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," January 27, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/
2. Hydrogen Shot | Department of Energy, https://www.energy.gov/eere/fuelcells/hydrogen-shot
3. H2@Scale | Department of Energy, https://www.energy.gov/eere/fuelcells/h2scale
4. H2IQ webinar presentation "DOE Update on Hydrogen Shot, RFI Results, and Summary of Hydrogen Provisions in the Bipartisan Infrastructure Law," December 8, 2021, https://www.energy.gov/sites/default/files/2021-12/h2iq-12082021.pdf
5. See draft DOE National Clean Hydrogen Strategy and Roadmap, September 22, 2022, https://www.hydrogen.energy.gov/roadmaps_vision.html

References: Subtopic a:

1. DOE's Quadrennial Technology Review Cost and Performance targets for Electric Energy Storage Technologies, 2015. https://www.energy.gov/sites/prod/files/2015/09/f26/QTR2015-3C-Electric-Energy-Storage.pdf
2. Hydrogen and Fuel Cells Program Record, 2020. https://www.hydrogen.energy.gov/pdfs/20001-reversible-fuel-cell-targets.pdf

References: Subtopic b:

1. A. Burnham, D.Gohlke, L. Rush, et. al., "Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains Energy Systems Division." 2021 Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains (anl.gov)
2. J. Kopasz, T. Krause. "Mission Innovation Hudrogen Fuel Cells Off-Road Equipment and Vehicle Workshop Summary Report." 2021 H2@Offroad- Workshop Report-07-11-2022.pdf (anl.gov)
3. "Home | M2FCT." Millionmilefuelcelltruck.org, M2FCT (millionmilefuelcelltruck.org)

References: Subtopic c:

1. "Fast Flow Future for Heavy-Duty Hydrogen Trucks." www.nrel.gov/news/program/2022/fast-flow-future-heavy-duty-hydrogen-trucks.html. Accessed 2 Nov. 2022.
2. Innovating Hydrogen Station: Heavy-Duty Fueling https://www.hydrogen.energy.gov/pdfs/review22/h2061_onorato_2022_p.pdf

References: Subtopic d:

1. Arrigoni, A. and Bravo Diaz, L., Hydrogen emissions from a hydrogen economy and their potential global warming impact, EUR 31188 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-

92-76-55848-4, doi:10.2760/065589, JRC130362. https://publications.jrc.ec.europa.eu/repository/handle/JRC130362
2. Buttner, W., et al., Hydrogen Safety Sensor Performance and Use Gap Analysis. Presented at the 7th International Conference on Hydrogen Safety, September 2017. https://www.nrel.gov/docs/fy18osti/68773.pdf

References: Subtopic e:

1. See for example: Fast-Forwarding to a Future of On-Demand Urban Air Transportation – Uber Elevate. https://evtol.news/__media/PDFs/UberElevateWhitePaperOct2016.pdf
2. UAM Vision Concept of Operations (ConOps) https://ntrs.nasa.gov/citations/20205011091
3. "Air Taxi Market Size, Share | Growth Analysis | Industry Forecast - 2030." *Allied Market Research*, www.alliedmarketresearch.com/air-taxi-market
4. Ahluwalia, R. K., et al. "Performance and Cost of Fuel Cells for Urban Air Mobility." *International Journal of Hydrogen Energy*, vol. 46, no. 74, 26 Oct. 2021, pp. 36917–36929, https://www.sciencedirect.com/science/article/abs/pii/S0360319921034601
5. https://www.hydrogen.energy.gov/pdfs/review21/ta034_ahluwalia_2021_o.pdf Slides 10.11
6. "Technology Readiness Level." *Wikipedia*, 28 Aug. 2022, https://en.wikipedia.org/wiki/Technology_readiness_level#Current_TRL_definitions

References: Subtopic f:

1. Envision, from the Institute for Sustainable Infrastructure: https://sustainableinfrastructure.org/
2. CEEQUAL from BRE Group: https://bregroup.com/products/ceequal/
3. IS Ratings, from the Infrastructure Sustainability Council: http://www.iscouncil.org/is-ratings/
4. SOLVE from the Electric Power Research Institute (EPRI): https://www.epri.com/pages/sa/sustainability
5. Global Reporting Initiative (GRI): https://www.globalreporting.org/
6. The Capital Coalition's Natural Capital Protocol: https://capitalscoalition.org/
7. Argonne National Laboratory's GREET model: https://greet.es.anl.gov/
8. Argonne National Laboratory's AWARE model: https://greet.es.anl.gov/aware
9. EPA's EJScreen: https://www.epa.gov/ejscreen
10. The National Renewable Energy Laboratory's H2A model: https://www.nrel.gov/hydrogen/h2a-production-models.html
11. Argonne National Laboratory's Hydrogen Delivery Infrastructure Analysis models: https://hdsam.es.anl.gov/
12. The National Renewable Energy Laboratory's H2FAST model: https://www.nrel.gov/hydrogen/h2fast.html

References: Subtopic g:

1. A. Elgowainy and K. Reddi "Impacts of Hydrongen On-board Storage Options on the Refueling Cost of Fuel Cell Heavy Duty Vehicles." DOE Hydrogen and Fuel Cells Program Annual Merit Review, 2020 https://www.hydrogen.energy.gov/pdfs/review20/sa170_elgowainy_2020_o.pdf
2. Hensley, Mattie, and Jonathan Zimmerman. *H2@Rail*. 2019. H2@RailWorkshop_Report_SAND2019-10191R (sandia.gov)
3. J. Marcinkoski, R. Vijayagopal, J. Adams, et. al, "Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks." DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap. https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf
4. "H-Mat." *H-Mat.org*, h-mat.org/. Accessed 2 Nov. 2022. https://h-mat.org/

References: Subtopic h:

1. International Meeting on Fuel Cell and Electrolyzer Quality Control: Summary Report, Ulsh et al., December 2021. https://www.nrel.gov/docs/fy22osti/81354.pdf

2. Manufacturing Automation and Recycling for Clean Hydrogen Technologies Virtual Experts Meeting, May 2022. https://www.energy.gov/eere/fuelcells/manufacturing-automation-and-recycling-clean-hydrogen-technologies-experts-meeting

References: Subtopic i:

1. H2-PACE: Power and Control Electronics for Hydrogen Technologies 2021 Experts Panel Summary Report Hydrogen and Fuel Cell Technologies Office a Hydrogen Energy Earthshot Event. 2021. H2-PACE: Power and Control Electronics for Hydrogen Technologies (energy.gov)

References: Subtopic j:

1. Brian D. James, Jennie M. Huya-Kouadio, Cassidy Houchins, Daniel A. DeSantis, "Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2018 Update", Strategic Analysis Inc., December 2018. https://www.energy.gov/sites/prod/files/2020/02/f71/fcto-sa-2018-transportation-fuel-cell-cost-analysis-2.pdf
2. Manufacturing Automation and Recycling for Clean Hydrogen Technologies Virtual Experts Meeting, May 2022. https://www.energy.gov/sites/default/files/2022-07/h2-mach-workshop-agenda-final.pdf

References: Subtopic k:

1. 2012, Fuel Cell Technologies Office, Technical Plan- Fuel Cells, *Multi-Year Research, Development and Demonstration Plan*, Section 3.4. http://energy.gov/sites/prod/files/2014/12/f19/fcto_myrdd_fuel_cells.pdf
2. 2013, *Fuel Cell Technical Team Roadmap*, USDRIVE, Driving research and Innovation for Vehicle Efficiency and Energy Sustainability. http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf

References: Subtopic l:

1. Energy Environ. Sci., 2016,9, 1725-1733 https://pubs.rsc.org/en/content/articlelanding/2016/EE/C5EE03568F
2. "H2A: Hydrogen Analysis Production Models | Hydrogen and Fuel Cells | NREL." *Nrel.gov*, 2018, https://www.nrel.gov/hydrogen/h2a-production-models.html

References: Subtopic m:

1. Ayers, K., Danilovic, N., Ouimet, R., Carmo, M., Pivovar, B., and Bornstein, M. (2019). Perspectives on Low-Temperature Electrolysis and Potential for Renewable Hydrogen at Scale. Annu. Rev. Chem. Biomol. Eng. 10, 219–239. doi:10.1146/annurev-chembioeng-060718-030241 https://www.annualreviews.org/doi/abs/10.1146/annurev-chembioeng-060718-030241
2. Park, E. J., Arges, C. G., Xu, H., and Kim, Y.S. (2022). Membrane Strategies for Water Electrolysis ACS Energy Lett. 2022, 7, 3447−3457. doi.org/10.1021/acsenergylett.2c01609 https://pubs.acs.org/doi/abs/10.1021/acsenergylett.2c01609
3. Arges CG, Ramani V, Wang Z and Ouimet RJ (2022) Assessing the Oxidative Stability of Anion Exchange Membranes in Oxygen Saturated Aqueous Alkaline Solutions. Front. Energy Res. 10:871851. https://www.frontiersin.org/articles/10.3389/fenrg.2022.871851/full

C56-19. INDUSTRIAL EFFICIENCY AND DECARBONIZATION

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Industrial Efficiency and Decarbonization office (IEDO) is part of a larger EERE/DOE effort to research, develop, and demonstrate energy efficiency and GHG emissions reduction technologies to reach net zero carbon emissions nationwide by 2050 [1]. The IEDO focuses on emerging industrial technologies, pilot-demonstrations, and technology partnerships to drive U.S. industrial decarbonization, productivity, and economic competitiveness. This topic reflects DOE's support for activities that address decarbonization in energy- and emissions-intensive industries, cross-sector industrial emissions technologies, as well as technical assistance and partnerships.

All applications to this topic must:

- Clearly indicate the subtopic and area of interest;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions using appropriate metrics, key performance parameters, or properties -- Justify all performance claims with theoretical predictions and/or relevant experimental data.
- Propose a tightly structured program which includes clearly defined, relevant materials and manufacturing RD&D metrics (including energy savings where applicable). The program should include quantitative technical milestones, timelines, and expected deliverables that demonstrate aggressive but achievable progress towards meeting performance parameter targets.
- Provide evidence that the proposer has relevant materials and or manufacturing experience and capability;
- Explain applications of project output and potential for future commercialization including projections for cost and/or performance improvements that are tied to a clearly defined baseline.

The Phase I application should detail material, design and/or lab-scale systems that are scalable to a subsequent Phase II prototype development.

NOTE: IEDO is also considering funding applications in response to the following Joint Topics:

- JOINT TOPIC: DECARBONIZATION OF AGRICULTURE, BUILDINGS, TRANSPORT, INDUSTRY AND THEIR COMMUNITIES
- JOINT AMMTO/HFTO/IEDO TOPIC: FUEL CELL AND ELECTROLYZER RECYCLING

Applications must be responsive to the following subtopics:

a. Sustainable Chemistry: Mitigation of Hazardous Chemicals in Manufacturing Processes

DOE's Industrial Decarbonization Roadmap outlines pathways to decarbonize energy-intensive sectors [2]. As the industrial sector transforms to reduce carbon emissions and incorporate circular economy principles, there is an opportunity to incorporate equipment and modify processes to reduce adverse impacts of industrial chemicals used in manufacturing on human health and the environment. Over 96% of the world's manufactured goods include chemicals in the manufacturing processes or as building blocks in products [3]. Though chemicals are critical to the production of manufactured products, some chemicals have inherent hazardous properties that present a known or reasonably suspected risk to human health or the environment.

Within DOE's Industrial Decarbonization Roadmap, decarbonization strategies include opportunities for new processes that utilize the principles of sustainable chemistry including producing chemicals from feedstocks, reagents, and solvents that are less hazardous and designing synthesis pathways to reduce the production of chemical by-products and waste. In the report *Sustainable Chemistry in Manufacturing Processes* [4] industry stakeholders identify barriers and opportunities for incorporating these practices into the manufacturing of consumer and commercial products. The report highlights the need for scalable processes, favorable economics, and maximization of co-benefits to meet the goals of reducing energy and carbon emissions while also mitigating hazardous chemicals and toxicity.

In conjunction with decarbonizing the industrial sector, IEDO seeks to reduce hazardous chemicals in manufacturing processes by developing transformative processes that reduce or eliminate the use or generation of hazardous chemicals. This subtopic is seeking technologies and safer alternatives for hazardous chemicals used in manufacturing processes for the following needs:

- Reduce or eliminate hazardous by-products: Chemical processes that rely on harsh conditions including highly acidic or basic environments or rely on temporary modifications to block unwanted chemical reactions release excess by-products including toxic gases and hazardous waste. R&D on novel chemistries and processes to improve harsh conditions or streamline chemical steps yielding less hazardous by-products are of interest.
- Reduce or eliminate use of hazardous solvents: Chemical solvents are widely used in manufacturing as separation agents, oxidizers, cleaners, and degreasers. Solvent usage presents risks to the environment, communities, and workers due to evaporation, risk of accidental release, and management of waste. R&D to develop non-hazardous substitutes, reduce the magnitude of solvent used, or eliminate the need for a solvent are of interest.
- Reduce or eliminate use of toxic plasticizers or polyfluoroalkyl substances (PFAS) in consumer products: Substances including plasticizers and PFAS are commonly incorporated into manufactured products to improve the performance of the product. R&D to develop products with less hazardous materials while maintaining product performance standards are of interest.

Table 1. Requirements for technologies in for subtopic a

Objective/ Goal	Metric	Minimum	Baseline Performance
Reduce hazardous by-products	% reduction from current typical process	<95% reduction	Applicant Defined
Reduce toxic solvent, plasticizers or polyfluoroalkyl substances (PFAS)	Unit reagent/unit product (mass or volume)	Applicant Defined	Applicant Defined

Applicants must articulate how the proposed technology will minimize adverse impacts on the environment and human health and the role of the technology in industrial decarbonization.

Questions – Contact: Felicia Lucci, Felicia.Lucci@ee.doe.gov

b. Enhanced Waste Heat Recovery through Highly Efficient Heat Exchangers

The Industrial Decarbonization Roadmap published by DOE identifies waste heat as a significant industrial decarbonization opportunity, given the vast amounts generated thermal processes. [2] Process heating represents 7.2 Quads (23%) of the energy used in the industrial sector, with approximately 2.6 Quads lost as waste heat [5]. This subtopic seeks novel solutions to recovering residual heat with minimal downgrade in temperature or working pressure. This extracted waste heat can further be used as waste heat-to-power technologies, used as useful thermal energy in other processes, or stored until needed [6].

This subtopic is seeking enabling technologies to improve waste heat recovery for the following technology areas of interest (AOIs):

Back to Table of Contents

High Temperature Heat Exchangers for Thermal Storage

It has historically been challenging to recover waste heat from high-temperature (>400C) industrial processes due to the complexities and custom designs of most large-scale manufacturing equipment. Most heat exchangers face integration issues with real world systems that limit their optimal usage. This AOI seeks novel designs for heat exchanger design and manufacture that will facilitate uptake of waste heat recovery systems and enable systems integration with thermal storage technologies (without the need for capital and time-intensive customization). Prior R&D investment by DOE has looked at thermal energy storage for industrial waste heat recovery and waste heat to power (bottoming cycle combined heat and power). Applications should clearly describe the target manufacturing systems as well as the envisioned end uses of recovered heat. Applications specifically not of interest include materials discovery work without significant proposed progress toward novel design, designs that capture low temperature waste heat only, or thermal energy storage systems that rely on storing generated excess electric energy.

Non-metallic Heat Exchangers for Industrial Heat Pumps

This AOI seeks novel polymer or non-metal heat exchanger designs. Current state-of-the art air-to-refrigerant heat exchangers typically use copper-tube, aluminum-fin construction, with internal enhancement in the tubes and lances or louvers in the fins to promote heat transfer. However, non-metallic heat exchangers show distinct advantages due to their light weight, manufacturing potential, wide range of geometric design possibilities, corrosion resistance, and potential to be low cost. Prior R&D investment by DOE has looked at high performance compact heat exchangers, including low charge heat exchanger designs and rotating designs. Applications specifically not of interest include low-thermal conductivity polymer heat exchangers.

Thermoelectric/Heat Exchanger Systems

Currently thermoelectrics are employed only in niche markets where there is strong knowledge of their unique properties and how they might be integrated. This area of interest seeks to broaden thermoelectric (TE) technology deployment for waste heat recovery by seeking proof-of-concept systems involving thermoelectrics (including thermoelectric to thermoelectric) integrated with heat exchangers. These proposed technologies should have form-factors that fit in well within typical heat exchanger geometries.

Table 2. Requirements for Technologies in three areas of interest for subtopic b:

High Temperature HX for Thermal Storage	
Requirements	**Targets**
Waste Heat Collection Efficiency	80%
Physical size	Can be integrated into existing manufacturing systems
Cost	>40% reduction compared to current state of the art
Non-metallic Heat Exchangers for Industrial Heat Pumps	
Requirements	**Targets**
Performance, heat transfer rate (UA)	> 500% compared to state-of-the-art designs
Physical size	> 50% reduction compared to state-of-the-art designs
Fan, blower, or pump parasitic energy consumption	> 30% reduction compared to state-of-the-art designs
Required cleaning intervals, or difficulty of cleaning, to maintain as-new performance	Little to no increase as compared to state-of-the-art designs

Susceptibility to damage or corrosion or performance degradation during manufacture, assembly, transportation, installation, or use	Little to no increase as compared to state-of-the-art designs for relevant applications
Defrost requirements (for applications such as outdoor air-to-refrigerant heat exchangers)	Little to no increase as compared to state-of-the-art designs
Heat Exchanger-Thermoelectric Integrated Systems	
Requirements	**Targets**
Physical size	Can be integrated into existing manufacturing systems

Questions – Contact: Emmeline Kao, emmeline.kao@ee.doe.gov

c. Other Industrial Decarbonization

In addition, this topic seeks other applications related to industrial decarbonization, especially in alignment with the DOE priorities laid out in the Industrial Decarbonization Roadmap [2].

Questions – Contact: Emmeline Kao, emmeline.kao@ee.doe.gov

References:

1. Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," (Executive Office of the President. (2021). Executive Order 14008, https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad)
2. DOE Industrial Decarbonization Roadmap, 2022, https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap
3. American Chemistry Council, 2021, https://www.americanchemistry.com/chemistry-in-america/data-industry-statistics/the-business-of-chemistry-by-the-numbers
4. Advanced Manufacturing Office, Sustainable Chemistry in Manufacturing Processes Roundtable Report, https://www.energy.gov/sites/default/files/2021/03/f83/2020%20AMO%20Sustainable%20Chemistry%20Roundtable%20Report_Final_02_24_2021_compliant.pdf#:~:text=The%20Advanced%20Manufacturing%20Office%20%28AMO%29%20at%20the%20U.S.,into%20the%20manufacturing%20of%20consumer%20and%20commercial%20products.
5. U.S. Energy Information Administration (EIA), 2022, Annual Energy Review, https://www.eia.gov/totalenergy/data/annual/
6. U.S. Department of Energy, Quadrennial Technology Review 2015, Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing: Technology Assessment for Process Heating, September 2015, https://www.energy.gov/sites/prod/files/2016/06/f32/QTR2015-6I-Process-Heating.pdf.
7. Thermoelectric Energy Conversion Materials Roadmap, 2020. Henry Royce Institute. https://www.royce.ac.uk/content/uploads/2020/10/M4ET-Thermoelectric-Energy-Conversion-Materials-Roadmap.pdf

C56-20. ADVANCED MATERIALS AND MANUFACTURING TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

EERE's Advanced Materials and Manufacturing Technologies Office (AMMTO) supports research, development and demonstrations of next-generation materials and manufacturing technologies needed to improve Americans' quality of life, increase U.S. industrial competitiveness and drive economy-wide decarbonization. AMMTO supports the national plan to revitalize American manufacturing, secure critical supply chains, and develop diverse innovation ecosystems leading to new manufacturing jobs and increased economic strength of the nation. AMMTO provides planning, management, and direction necessary for a balanced program of research, development, demonstration, and workforce development to support domestic manufacturing that is critical to achieving a clean, decarbonized economy.

This Topic reflects DOE's support for activities that develop Next Generation Materials and Manufacturing Technologies, Secure and Sustainable Materials, Energy Technology and Manufacturing Workforce Development.

All applications to this topic must:

- Clearly indicate the subtopic and area of interest;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions using appropriate metrics, key performance parameters, or properties -- Justify all performance claims with theoretical predictions and/or relevant experimental data.
- Propose a tightly structured program which includes clearly defined, relevant materials and manufacturing RD&D metrics (including energy savings where applicable). The program should include quantitative technical milestones, timelines, and expected deliverables that demonstrate aggressive but achievable progress towards meeting performance parameter targets;
- Provide evidence that the proposer has relevant materials and or manufacturing experience and capability;
- Explain applications of project output and potential for future commercialization including projections for cost and/or performance improvements that are tied to a clearly defined baseline;

The Phase I application should detail material, design and/or bench scale systems that are scalable to a subsequent Phase II prototype.

NOTE: In addition to the subtopics below, AMMTO is considering funding applications in response to the following multi-office topics:

- JOINT TOPIC: DECARBONIZATION OF AGRICULTURE, BUILDINGS, TRANSPORT, INDUSTRY AND THEIR COMMUNITIES
- JOINT AMMTO/HFTO/IEDO TOPIC: FUEL CELL AND ELECTROLYZER RECYCLING

Applications must be responsive to the following subtopics.

a. Power Electronics for Energy Efficient Electrification

This subtopic aims for higher-power, lower loss, and higher efficiency electronic devices and materials to lower costs of interfacings electric vehicles, renewable energy, heat pumps and other technologies that benefit from higher-voltage and higher-current.

In 2020, the DOE, National Renewable Energy Laboratory (NREL), with support from its Advanced Research on Integrated Energy Systems (ARIES) facility, held a Power Electronic Grid Interface (PEGI) Workshop, focused on the research challenges of operating power systems with ever-increasing levels of power-electronic-based loads [1]. This was followed in 2022 by a Sandia National Laboratories Power Electronics & Energy Conversion Workshop to identify research directions and priorities for the next generation of power electronics and energy conversion systems for the electric grid, transportation, and national security [2]. To support these initiatives under this subtopic, AMMTO is seeking applications in the following two areas of interest:

1. Next Generation 1.2 kV Class GaN-on-GaN Vertical MOSFETs for Smart Grids
   In this area of interest, applications are sought for a gallium nitride (GaN) metal oxide semiconductor field effect transistor (MOSFET) device arranged in a Vertical Trench (aka UMOSFETs), which is easier and less costly to fabricate than the state-of-the-art a vertical fin field-effect transistor (FINFET). The next step up in power for this type of device is 1.2 kV. Wide bandgap (WBG)-based power electronics—especially Gallium Nitride (GaN) devices can meet smart Grid requirements for varying power levels, millisecond response times, asynchronous phases, programmability, modularity, and adaptability for industrial processes [3]. Industrial applications also require that the power electronics be cost-effective, noiseless, reliable, compact, and have a high efficiency (99% or higher). GaN has a higher switching frequency that the other WBG materials (e.g., SiC) leading to greater miniaturization/ reduced system volume/weight and thus higher power density. GaN devices also have low gate capacitance and low R_{ON}, which further increases their energy efficiency. Vertical device structures of GaN on native substrates (hence, GaN-on-GaN) are the focus of this area of interest because they facilitate an increase in the transistor breakdown strength of the transistor. Vertical devices also are almost insensitive to surface trapping effects, since current flow takes place in the bulk semiconductor [4]. Applications for UMOSFETs also are sought because they have higher current density, lower specific R_{ON}, lower current collapse, and simpler fabrication [5] than the most widely adopted GaN power device to date--the lateral high electron mobility transistor (HEMT). Furthermore, lattice matched GaN on GaN devices have lower defect densities, OFF state leakage, and higher breakdown voltage.

   In summary this area of interest in Phase I seeks proof-of-concepts for a high power (≥ 1.2 kV) vertical GaN-on-GaN UMOSFET with high switching frequencies and high current handling capabilities that meets the targets in Table 1 below.

   Table 1: Metrics for area of interest (1).

Suggested Targets for Proof of Concept	
Parameter	**Target**
Threshold Voltage	> 3.5 V
Specific R_{ON}	≤ 1.0 mW×cm^2
Breakdown voltage	> 1300 V
Current extraction	≥ 100 A
Baliga (unipolar) figure of merit	≥ 1.0 GW/cm^2
1.2 kV MOSFET cost (50% gross margin assumed)	< $0.10/Amp)

   In addition, AMMTO is interested in this area because there are manufacturing ecosystem advantages to using GaN substrates. Today's four-inch diameter GaN substrates are costly and mostly sourced from foreign suppliers. In Phase II applications submitted under this area of interest must show how the Phase I device design lays the groundwork for scaling up this technology to establish a U.S. domestic manufacturing capability with a cost structure that would allow the commercialization and global marketing of a competitively priced device. Scale up should be quantified according to manufacturing metrics such as wafter size, throughput, or other parameters deemed to be important by proposers. In Phase II as part of showing a viable path towards domestically manufacturing this GaN device, applications must also show how other domestic power electronics manufacturing that uses GaN substrates combined with this application at scale could provide enough domestic demand to justify a high-volume domestic supply of GaN substrates.

2. Advanced Manufacturing and Materials for Beyond-Next Generation Diamond Power Electronics in Grid Applications: Doping and Dielectrics
Diamond is one of the most promising ultrawide bandgap (UWBG) semiconductors proposed for future high voltage (e.g. 1.7kV) grid applications of power electronics because it has the highest thermal conductivity (> 2000 $Wm^{-1}K^{-1}$), high charge carrier mobilities (> 3000 $cm^2V^{-1}s^{-1}$), and high predicted breakdown field strength (> 10 MV cm^{-1}) related to its very large (ultra-wide) bandgap [6]. Impediments to scaled up manufacturing of diamond devices are related to 1) local, selective area impurity doping, 2) dopant activation/ionization, and 3) achieving low ON-state resistance, R_{ON}.

For 1) better control of surface transfer doping (i.e., formation of a two-dimensional hole gas, or 2DHG, near the interface) surface electron acceptor materials that induce surface transfer and enhance hole carrier concentration have been used. This area of interest seeks applications that optimize the use of such materials building on prototype diamond transistors that have been designed/modeled and devices that have been fabricated/demonstrated in recent years, including a vertical (trench) 2DHG metal oxide field effect transistor (MOSFET) with Al_2O_3 serving as the gate oxide and passivation layer [7]. For 2) further optimization is required for dielectric barriers on diamond. Dielectric materials on an H-diamond surface can act as electron acceptors that induce transfer doping and form a 2DHG within H-diamond. This area also seeks optimization of dielectric material choice by building on studies of metal oxides (e.g., Al_2O_3, Y_2O_3, V_2O_5) that have been reported as gate dielectric materials used in the manufacturing of hydrogen-terminated diamond-based FET devices. Such studies must also address how to overcome electron acceptor complications from by the field effect process induced by a gate voltage applied across dielectric materials on H-diamond in an actual FET device [8]. For 3) achieving high n-type (phosphorus) substitutional doping levels, could enable diamond power electronic devices with low R_{ON} for a wider range of applications.

In summary, this area of interest seeks applications that include experimental studies of the key issues related to the design of vertical and novel device structures and their manufacturing processes. Additional examples of interest include studies of:

- the hydrogen treatment duration (and other manufacturing parameters),
- factors that address some of the manufacturing challenges associated with lateral H-terminated diamond 2DHG Metal Insulator Semiconductor Field Effect Transistors, (MISFETs), (e.g., gate length, channel length, gate dielectric materials), and
- modeling or manufacturing other device architectures such as vertical MISFETs with 2DHG for the channel region and bulk transport in the drift region/substrate.

Table 2: Metrics* for area of interest (2).

1.7 kV diamond vertical MISFETs with a duty cycle of 0.5[6]	
Parameter	**Target**
Specific Current Density in ON-state	500 A/cm^2 (maximum junction temperature = 450 K)
Switched voltage	1200 V
Switching frequency	100 kHz
Current extraction	≥ 50 A
Power Loss Density	270 W/cm^2

*Metrics should be demonstrated in real devices produced in realistic manufacturing environments.

Questions – Contact: J. Nick Lalena, nick.lalena@ee.doe.gov

b. Chemistry-Level Electrode Quality Control (QC) for Battery Manufacturing

The objective of this subtopic is to advance US battery manufacturing by providing small businesses the opportunity to develop quality control (QC) technologies as cost-effective battery manufacturing solutions. These technologies will support DOE's goals in advancing battery manufacturing, in alignment with the Energy Storage Grand Challenge (ESGC) roadmap and Federal Consortium for Advanced Batteries (FCAB) National Blueprint for Lithium Batteries. [1-2] QC is pivotal for increasing battery manufacturing capacity at volume. Specifically, QC provides a way to ensure product specifications while maintaining manufacturing yield and can increase understanding of battery behavior and performance for further development. [3]

It is important to control the quality of all processed materials/components at every stage in the battery manufacturing line. Among them, fabricated electrodes with more consistent chemistries, which could be achieved by novel QC, are particularly crucial to enhancing battery performance. At present, the community must work with a limited capability to detect and measure the degree of chemistry heterogeneities — such as processing-related chemical/structural heterogeneities and charge/discharge-related heterogeneities — in active particles and electrodes. Electrode QC technologies are needed to measure these non-ideal variations to enable control of the chemical distribution of active and inactive materials.

Integrating QC technologies with battery manufacturing processing and data analytics is complicated and still underdeveloped. [4, 5] Currently, the battery manufacturing community currently relies on brute-force root cause analysis or data analytics to correlate processing conditions with battery performance. There is a critical need for operando investigation to analyze various battery behaviors, and it requires significant collaborative efforts between metrologists and process engineers. [4] In addition, there is no single characterization tool to probe different time and length scale; rather, multiple tools with unique spot sizes are combined to scan all relevant ranges. The data collected at different scales and by different instruments are heterogeneous, multi-scale, and voluminous. These factors cause QC tools to be difficult and expensive to for manufacturers to utilize effectively. [6]

Instead, this subtopic seeks to integrate QC technologies with battery manufacturing processing and data analytics to detect and mitigate battery heterogeneities. Examples of interest include inconsistent sedimentation and/or agglomeration of (coated) particles, Li homogeneity, transition-metal ion distribution, binder migration/diffusion, chemical impurities within the electrode, Si dispersion in Si anode, etc. Small businesses can be agile in developing and delivering such technologies.

Applications must address both of the following aspects to be considered responsive to this subtopic:

- Fast, yet precise, electrode QC technologies: The desired electrode QC should: 1) be fast; 2) be flexible for direct integration into process equipment (i.e., operando metrology); and 3) provide statistically significant chemical information throughout the depth of battery electrodes.
- Computational framework for real-time information integration to inform manufacturing control: The desired computational framework will be able to integrate information from a collection of measurements by QC tools to inform understanding material behaviors and battery performance based on quantitative chemistry heterogeneity-processing-performance relationships. As a result, the detection limits of any characterization will not be a hindrance, the ability to extract information from the proposed QC technologies will be maximized, and the speed of manufacturing technology development will be increased.

Measurement tools of interest include: 1) sensor technologies for high-precision measurement (e.g., thickness, temperature, etc.) and 2) characterization tools for morphology, chemical bonding, and elemental information. [4] Applications specifically not of interest include technologies that are incompatible with current battery manufacturing processes and QC that is not applicable to multiple chemistries.

The results from this Phase 1 funding opportunity will produce state-of-the-art capabilities in electrode QC as a value-added benefit to existing approaches that are commonly used in battery manufacturing.

Characteristic of QC system	Target Metric
Scanning speed	Applicant defined (e.g., scan rate/second)
Sensing/detecting capabilities	Elemental composition analysis, nano/microstructural characterization, chemical evolution, and so on, combined with surface analysis and/or depth profiling
Integration with system	Ex-situ or In-situ QC technologies are acceptable; operando measurement is ideal (integration into process)
Speed of computational framework	Capable of 1) real time feedback; and 2) elucidating process-performance relationships
Techno-Economic metrics	Applicant defined (e.g., cost, battery manufacturing energy consumption, material use, etc.)

Questions – Contact: Changwon Suh, changwon.suh@ee.doe.gov

c. Other Subtopic for Advanced Materials and Manufacturing Technologies

In addition to the specific subtopics listed above, AMMTO invites grant applications in other areas relevant to this Topic that enable Next Generation Materials and Manufacturing Processes as well as Secure and Sustainable Materials. For example, notional metrics for next generation materials and manufacturing technologies as well as for secure and sustainable materials are in the table below:

Example Metrics for Subtopic c

Parameter	Target*	Stretch Target
For Structural Materials mechanical properties such as yield strength, stiffness, ductility,	>20% improvement	>35% improvement
For Functional Materials their electric, electronic, magnetic, and/or optical Properties (e.g., conductivity) [1]	>7% improvement	>15% improvement
For Advanced manufacturing technologies such as one of the seven types of additive manufacturing, manufacturing parameters such as throughput, precision	>20% improvement	>35% improvement
For sustainable materials, lifecycle cost and emissions reductions	>20% improvement	>35% reductions
For secure materials, RDD&D leading to the U.S. producing more than this share of global materials.	>15%	>30%

*Over well-defined baseline for that material or manufacturing process

Back to Table of Contents

Questions – Contact: Tina Kaarsberg, tina.kaarsberg@ee.doe.gov

References: Subtopic a:

1. Power Electronic Grid Interface (PEGI) Platform Workshop. 2020. https://www.psma.com/sites/default/files/uploads/node/6851/is052-power-electronics-solar-grid-integration-doe-perspective.pdf
2. 2022 Power Electronics & Energy Conversion Workshop : Sandia Energy. https://energy.sandia.gov/programs/electric-grid/power-electronics-and-controls/2022-power-electronics-energy-conversion-workshop/
3. M. Meneghini, E. Fabris, M. Ruzzarin, C. De Santi, K. Nomoto, Z. Hu, W. Li, X. Gao, D. Jena, H. G. Xing, M. Sun, T. Palacios, G. Meneghesso, and E. Zanoni "Degradation mechanisms of GaN-based vertical devices: a review," https://onlinelibrary.wiley.com/doi/full/10.1002/pssa.201900750.
4. W. He, J. Li, Z. Liao, J. Wu, B. Wang, M. Wang, N. Liu, H-C. Chiu, H-C. Juo, X. Lin, J. Li, and X Liu "1.3 kV Vertical Gan-Based Trench MOSFETs on 4-inch Free Standing GaN Wafer," *Nanoscale Research Letters* 17:14 (2022): https://doi.org/10.1186/s11671-022-03653-z.
5. C. J. H. Wort and R. S. Balmar "Diamond as an Electronic Material," *Materials Today* Vol. 11, No 1-2, p. 22 (2008) https://www.sciencedirect.com/science/article/pii/S1369702107703498
6. N. Oi, N. Inaba, S. Okubu, I. Tsuyuzaki, T. Kageru, S. Onoda, A. hiraiwa, and H. Kawarada "Vertical-Type Two-Dimensional Hole Gas Diamond Metal Oxide Semiconductor Field-Effect Transistors," *Scientific Reports* **8**, 10660 (2018): https://doi.org/10.1038/s41598-018-28837-5
7. K. G. Crawford, I. Maini, D. A. Macdonald, and D. A. J. Moran "Surface Transfer Doping of Diamond: A Review," *Progress in Surface Science* **96**, 100613 (2021): https://doi.org/10.1016/j.progsurf.2021.100613

References: Subtopic b:

1. Department of Energy, Energy Storage Grand Challenge Roadmap, December 2020.
2. Federal Consortium for Advanced Batteries, National Blueprint for Lithium Batteries.
3. J. Renpenni, Challenges in Lithium-ion Battery Manufacturing and Quality Analysis – Part 1 & Part 2.
4. Committee on Revealing Chemistry through Advanced Chemical Imaging Board on Chemical Sciences and Technology, Division on Earth and Life Studies, National Research Council of the National Academies, Visualizing Chemistry: The Progress and Promise of Advanced Chemical Imaging, National Academies Press, Washington, DC, 2006: https://www.ncbi.nlm.nih.gov/books/NBK61764/pdf/Bookshelf_NBK61764.pdf
5. K. Liu *et al*., The Ways Ahead, in: Data Science-Based Full-Lifespan Management of Lithium-Ion Battery. Green Energy and Technology. Springer, Cham: https://link.springer.com/chapter/10.1007/978-3-031-01340-9_7
6. DOE Office of Science, Report of the Basic Research Needs Workshop on Next Generation Electrical Energy Storage, 2017: https://science.osti.gov/-/media/bes/pdf/brochures/2017/BRN-NGEES_rpt-low-res.pdf

C56-21. GEOTHERMAL TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Geothermal energy is secure, reliable, flexible, and constant. It continues to be one of America's best choices for low-cost renewable energy in power generation and in direct-use applications for heating and cooling of American homes and businesses. The Geothermal Technologies Office (GTO) focuses on applied research, development, and innovations that will improve the competitiveness of geothermal energy and support the continued expansion of the geothermal industry across the U.S. [1]. Specifically, GTO is focused on significantly increasing geothermal electricity generation and the use of geothermal heat pumps and district heating by 2050 [2].

A Phase I application should focus on proof of concept and/or bench scale testing that are scalable to a subsequent Phase II prototype development/deployment. Applications must be responsive to the subtopic below. Any application outside of this area will not be considered.

Applications must:

- Propose a tightly structured program which includes technical milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Include projections for price and/or performance improvements that are tied to a baseline (i.e. roadmap targets and/or state of the art products or practices);
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include a preliminary cost analysis;
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

Grant applications are sought in the following subtopic:

a. Long-Term Geothermal Reservoir Monitoring Strategies

GTO seeks applications that develop a single or multiple, integrated long-term reservoir monitoring tools/technologies coupled with data analysis techniques/modeling associated with monitoring an actively producing geothermal reservoir. Technologies should either (a) measure field parameters that have not been measured via current commercial technologies and/or (b) improve the accuracy, field-worthiness, and/or economic viability of such measurements. The technologies will need to address current technological gaps and uncertainties for long term deployment and/or permanent placement to acquire high quality data, will need to be cost-effective, and integrated into a long-term deployment system. Potential monitoring technologies include but are not limited to:

- Acquisition of real-time geochemical, geophysical, or biological data sets;
- Quantification of uncertainty of spatial and temporal movement of fluid in the reservoir;
- Definition of the lateral extent and boundaries of the reservoir;
- Tracking of other physical property changes (e.g., stress/strain) in the reservoir; and/or
- Demonstration of the long-term stability of the reservoir.

Applications must propose monitoring tools or technologies coupled with data analysis techniques or modeling. Applications proposing only monitoring tools/technologies or only data analysis/modeling will be deemed non-responsive.

Questions – Contact: William Vandermeer, william.vandermeer@ee.doe.gov

References:

1. Geothermal Technologies Office, U.S. Department of Energy. https://energy.gov/eere/geothermal
2. GeoVision: Harnessing the Heat Beneath our Feet, Geothermal Technologies Office, U.S. Department of Energy, https://www.energy.gov/eere/geothermal/geovision

Back to Table of Contents

PROGRAM AREA OVERVIEW: OFFICE OF ENVIRONMENTAL MANAGEMENT

With the end of the Cold War, the Department of Energy (DOE) is focusing on understanding and eliminating the enormous environmental problems created by the Department's historical mission of nuclear weapons production. The DOE's Office of Environmental Management (EM) seeks to eliminate these threats to human health and the environment, as well as to prevent pollution from on-going activities. The goals for waste management and environmental remediation include meeting regulatory compliance agreements, reducing the cost and risk associated with waste treatment and disposal, and expediently deploying technologies to accomplish these activities. While radioactive contaminants are the prime concern, hazardous metals and organics, as defined by the Resource Conservation and Recovery Act (RCRA), are also important.
DOE has approximately 91 million gallons of liquid waste stored in underground tanks and approximately 4,000 cubic meters of solid waste derived from the liquids stored in bins. The current DOE estimated cost for retrieval, treatment and disposal of this waste exceeds $50 billion to be spent over several decades. The highly radioactive portion of this waste, located at the Office of River Protection (Hanford Reservation), Idaho, and Savannah River sites, must be treated and immobilized, and prepared for shipment to a future waste repository.

DOE also manages some of the largest groundwater and soil contamination problems and subsequent cleanup in the world. This includes the remediation of 40 million cubic meters of contaminated soil and debris contaminated with radionuclides, metals, and organics [1]. Remediation of contaminated soil and groundwater has been ongoing at United States Department of Energy (DOE) Office of Environmental Management (EM) sites for over four decades, yet site closure remains elusive at many of DOE's complex groundwater sites, especially those complicated by challenging geologic, hydrologic, and chemical factors. DOE-EM is working to develop a consistent, complex-wide groundwater strategy. This strategy is being developed with two ultimate goals: (1) to provide actionable recommendations to shrink the remaining cleanup footprint over the coming decade, and (2) to identify overarching metrics that can be used to expedite and track cleanup progress.

For additional information regarding the Office of Environmental Management priorities, please visit us on the web at https://www.energy.gov/em/annual-priorities-strategic-vision-and-program-plan.

C56-22. *IN-SITU* CHARACTERIZATION METHODS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Reducing human effort and involvement in collection of analytical data has potential to greatly reduce the cost associated with treatment of residual waste streams, treatment of S&GW plumes, and long term monitoring at DOE sites.

a. Remote Characterization of HLW Tank Waste, Effluents from HLW Treatment, and Other Miscellaneous Slurry, Solid and Liquid Waste During Retrieval, Pretreatment, and Immobilization Processes

Sensors are needed for a variety of process streams with challenges that include high turbidity, chemical complexity, corrosive environments, and high radiation exposure.

- Measurements of interest:
    - Chemical Composition

Back to Table of Contents

        - Anions (Acetate, Carbonate, Chloride, fluoride, formate, glycolate, nitrate, nitrite, oxalate, phosphate, sulfate)
        - Metals (Al, B, Bi, Ca, Cr, Fe, K, Li, Mg, Mn, Na, Ni, S, Si, Ti, U, Zn, Zr)
        - RCRA metals (esp. Hg)
        - Organics (TOC, sugar, acetonitrile)
    - Physical Properties
        - pH
        - Density
        - Solid content (Total, Dissolved, Undissolved)
        - Rheologic Properties
            - Bingham plastic yield stress and consistency for slurries
            - Viscosity for supernatant streams
        - Particle size
    - Radionuclide Composition in high and low level waste streams
        - Gamma spectroscopy (Cs-137, Sr-90, all isotopes of Am, Cm, Np, Pu and U)
        - Beta emitters (I-129, Tc-99)

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

b. Development of New Technologies to Advance Autonomous Monitoring of Soil and Groundwater Contamination at Sites Undergoing Both Active and Passive Remediation

Sensors are needed for a variety of systems with challenges that include remote siting, long-distances between sensor and monitoring stations, outdoor sites, and low concentrations for contaminants of interest.

- Measurements of interest:
    - Geophysical
    - Geochemical
    - Water-quality data
        - pH
        - Conductivity

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

c. Deep Aquifer Characterization

Develop cost effective methods for accessing/characterizing contamination in deeper aquifers (with contamination in overlying aquifers likely).

- Measurements of interest:
    - Geophysical
    - Geochemical
    - Water-quality data
        - pH
        - Conductivity

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

d. Analytical Logistics

- Development of spool pieces or easily integrated sensor platforms

Back to Table of Contents

- Fusion of sensor technology (e.g., optical and flow) to gain more comprehensive system characterization (e.g. mass balance or tracking of species of concern in aquifers)

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

e. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

References:

1. Felmy, H.M., et al., 2022, Leveraging multiple Raman excitation wavelength systems for process monitoring of nuclear waste streams, *ACS ES&T Water*, 2022, 2, 3, 465-473. DOI: 10.1021/acsestwater.1c00408, https://pubs.acs.org/doi/abs/10.1021/acsestwater.1c00408 (November 2, 2022)
2. Lines, A.M., 2022, Combined Raman and Turbidity Probe for Real-Time analysis of Variable Turbidity Streams, *Anal Chem*., 2022, 94, 3652−3660, DOI: 10.1021/acs.analchem.1c05228, https://pubs.acs.org/doi/abs/10.1021/acs.analchem.1c05228 (November 2, 2022)
3. Lines, A.M., 2019, On-line, real-time analysis of highly complex processing streams: Quantification of analytes in Hanford tank sample, *Ind. Eng. Chem. Res*., 2019, 58, 47, 21194-21200, http://dx.doi.org/10.1021/acs.iecr.9b03636 (November 2, 2022)
4. Lackey H.E., et al., 2020, Reimagining pH Measurement: Utilizing Raman Spectroscopy for Enhanced Accuracy with Phosphoric Acid Systems, *Anal. Chem.* 2020, 92, 8, 5882-5889, https://doi.org/10.1021/acs.analchem.9b05708 (November 2, 2022)
5. Clifford, A.J., 2021, Raman Spectroscopy Coupled with Chemometric Analysis for Speciation and Quantitative Analysis of Aqueous Phosphoric Acid Systems, *Anal Chem,* 2021, 93, 14, 5890–5896, DOI: https://doi.org/10.1021/acs.analchem.1c00244 (November 2, 2022)
6. Singha K., 2015, Advances in interpretation of subsurface processes with time-lapse electrical imaging, *Hydrological Processes* 29, no. 6:1549-1576. PNNL-SA-110809. doi:10.1002/hyp.10280 https://onlinelibrary.wiley.com/doi/10.1002/hyp.10280 (November 2, 2022)
7. Johnson, T.C., 2022, Autonomous Time-Lapse Electrical Imaging for Real-Time Management of Subsurface Systems, *The Leading Edge* 41, no. 8:520-528. PNNL-SA-172662, doi:10.1190/tle41080520.1 https://pubs.geoscienceworld.org/tle/article-abstract/41/8/520/615912/Autonomous-time-lapse-electrical-imaging-for-real?redirectedFrom=fulltext (November 2, 2022)
8. Thomle J.N., 2020, A flux detection probe to quantify dynamic groundwater-surface water exchange in the hyporheic zone, *Groundwater* 58, no. 6:892–900. PNNL-SA-144934, doi:10.1111/gwat.13001, https://www.researchgate.net/publication/340257701_A_Flux_Detection_Probe_to_Quantify_Dynamic_Groundwater-Surface_Water_Exchange_in_the_Hyporheic_Zone (November 2, 2022)
9. Rockhold, M.L., 2020, Groundwater characterization and monitoring at a complex industrial waste site using electrical resistivity imaging, *Hydrogeology Journal* 28, no. 6:2115-2127. PNNL-SA-147892. doi:10.1007/s10040-020-02167-1, https://www.researchgate.net/publication/341271990_Groundwater_characterization_and_monitoring_at_a_complex_industrial_waste_site_using_electrical_resistivity_imaging (November 2, 2022)
10. Tso C., et al., 2020, Integrated hydrogeophysical modelling and data assimilation for geoelectrical leak detection, *Journal of Contaminant Hydrology* 234. PNNL-SA-152552. doi:10.1016/j.jconhyd.2020.103679, https://www.sciencedirect.com/science/article/abs/pii/S0169772220302680 (November 2, 2022)

11. Strickland C.E., et al., 2018, Deep Vadose Zone Monitoring Strategy for the Hanford Central Plateau, PNNL-28031. Richland, WA: Pacific Northwest National Laboratory, https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-28031.pdf (November 2, 2022)
12. McAliley, W. A., et al., 2022, Application of recursive estimation to heat tracing for groundwater/surface-water exchange, *Water Resources Research*, *58*, e2021WR030443, https://doi.org/10.1029/2021WR030443 (November 2, 2022)
13. Johnson, T., et al., 2022, Autonomous time-lapse electrical imaging for real-time management of subsurface systems, *The Leading Edge* 41 no. 8: 520-528, https://library.seg.org/doi/10.1190/tle41080520 (November 2, 2022)
14. Robinson, J., et al., 2022, Integration of Large-Scale Electrical Imaging into Geological Framework Development and Refinement, Environ, Process. 9, 21 (2022), https://doi.org/10.1007/s40710-022-00570-2 (November 2, 2022)
15. Robinson, J.L., et al., 2020, Geophysical methods for stratigraphic identification (No. PNNL-29182 Rev 1.0), Pacific Northwest National Lab. (PNNL), Richland, WA (United States), https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-29182Rev1.pdf (November 2, 2022)

C56-23. IMPROVED TREATMENT METHODS FOR LLW AND HLW

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Improved treatment methods for HLW and LLW could decrease the cost and schedule for immobilization of HLW tank waste and miscellaneous LLW streams. Examples of potential areas for study are:

a. Waste Retrieval

Advances methods for waste retrieval, particularly dry retrieval methods, offer the potential to decrease the risk of leaks during retrieval of tanks with known leak sites as well as to decrease the cost and schedule of the treatment of wastes stored in underground tanks including the HLW stored at Hanford and SRS. These methods could also be used for miscellaneous waste storage tanks.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

b. Separation of Contaminants from Waste Streams

Separation of radionuclides or other contaminants of concern from selected waste streams (particularly HLW supernatant waste) can allow the bulk of the waste stream to be disposed at a lower classification level resulting in cost savings or allow for a less expensive immobilization technique to be used. Separation processes of interest include:

- Filtration to remove TRU solids
- Remove of soluble analytes (Cs-137, Sr-90, Tc-99, I-129, soluble TRU)
- RCRA metals
- Nitrate

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

c. Waste Immobilization

Advanced techniques that improve the cost effectiveness and performance of waste immobilization processes could allow cost and schedule savings for treatment of a variety of waste streams. Examples are:

- ***Expanding the use of thermoset epoxy for waste immobilization***: Thermoset epoxy resins present a route for improved waste immobilization due to their handling of water, high strength and unique compositions. Providing expanded datasets on their performance as waste forms could open a new avenue for innovative and cost-effective waste immobilization.
- ***Improved phosphate bonded-ceramics for waste forms***: Magnesium-phosphate bonded ceramics have been considered as promising waste forms however have been limited in application due to their rapid setting and heat generation. Alternates to these phosphate bonded ceramics (e.g.; Al-bonded ceramics) have been developed recently and alleviate these challenges. Demonstrating these materials as waste forms could finally realize the potential held by this material class over the last 20 years.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

d. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

References:

1. Hatchell B.K., et al., 2019, *Advanced Retrieval Demonstrations of the Hanford Waste End Effector*, *In WM Symposium 2019*. PNNL-SA-139826, http://toc.proceedings.com/51905webtoc.pdf (November 2, 2022)
2. Berglin E.J., et al., 2018, *The Hanford Waste End Effector Phase II Test Report*, PNNL-27803., *Pacific Northwest National Laboratory*, Richland, WA, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26856Rev1.pdf (November 2, 2022)
3. Wooley T., et al., 2018, *Determining the Efficiency of the Hanford Waste End Effecter through Proof of Concept Testing-18165FP*, *PNNL-SA- WM2018 Conference*, March 18-22, 2018, Phoenix, Arizona USA, https://www.osti.gov/biblio/22975348 (November 2, 2022)
4. Berglin EJ, et al., 2017, *Hanford Waste End Effector Phase I Test Report*, *PNNL-26856 Rev 1*, Pacific Northwest National Laboratory, Richland, WA, https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26856Rev1.pdf (November 2, 2022)
5. Westesen, A.M., et al., 2022, Impact of feed variability on cesium removal with multiple actual waste samples from the Hanford Site, *Separation Science and Technology*, March 2022, https://doi.org/10.1080/01496395.2022.2059378 (November 2, 2022)
6. Westesen, A.M., et al., 2022, Impact of Load Behavior for Select Analytes in Hanford Tank Wase, *Industrial & Engineering Chemistry Research*, July 2022, https://doi.org/10.1021/acs.iecr.2c01656 (November 2, 2022)
7. Campbell, E.L., et al., 2020, Ion Exchange of Selected Group II Metals and Lead by Crystalline Silicotitanate and Competition for Cs Exchange Sites, *Solvent Extraction and Ion Exchange*, October 2020, https://doi.org/10.1080/07366299.2020.1830481 (November 2, 2022)
8. Sayenko, S., et al., 2022, Radioactive waste immobilization of Hanford sludge in magnesium potassium phosphate ceramic forms, *Progress in Nuclear Energy* 152 (2022): 104315, https://www.sciencedirect.com/science/article/abs/pii/S0149197022001901 (November 2, 2022)
9. Young, P.J., et al., 2021, Magnesium potassium phosphate cements to immobilize radioactive concrete wastes generated by decommissioning of nuclear power plants, *Nuclear Engineering and Technology* 53,

Back to Table of Contents

no. 7 (2021): 2261-2267, https://www.sciencedirect.com/science/article/pii/S1738573321000267 (November 2, 2022)
10. Singh, D., et al., 2006, Magnesium potassium phosphate ceramic for 99Tc immobilization, *Journal of Nuclear Materials* 348, no. 3 (2006): 272-282, https://www.sciencedirect.com/science/article/abs/pii/S0022311505004630 (November 2, 2022)
11. Rigali M.J., et al., Progress Toward the Development of Cement Fillers for Dual Purpose Canisters, SAND2019-723C, https://www.osti.gov/servlets/purl/1640973 (November 2, 2022)

C56-24. IMPROVEMENTS FOR DECONTAMINATION OF EQUIPMENT/STRUCTURES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: NO
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Disposal of contaminated equipment and dismantling of contaminated structures is a significant portion of the EM mission as sites eliminate facilities no longer needed or past their service life. Improvements in performing these processes would increase worker safety, reduce the environmental risk from these processes and enable cost and schedule savings. Areas of interest include:

a. Characterization

Focuses on identifying the nature, magnitude, and location of the contamination (nuclides, chemical constituents) in the facility. General mapping of dose rates and airborne contamination (rad and nonrad) supports conduct of hazard analysis and risk assessment. Characterization data and documents accumulated during deactivation, if applicable, serves as a starting point. The characterization data provides considerations in defining, organizing, and planning the technical components of decommissioning projects.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

b. Decontamination Methods

Decontamination processes reduce, remove, or neutralize radiological, chemical, or biological contamination and reduce the risk of exposure. Decontamination may be accomplished by cleaning or treating surfaces to reduce or remove the contamination; filtering contaminated air or water; subjecting contamination to evaporation and precipitation; or covering the contamination to shield or absorb the radiation. The use of natural decontamination process can also simply allow adequate time for natural radioactive decay to decrease the radioactivity.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

c. Fixatives

Fixatives can be used for Decommissioning and Maintenance of Radiological Facilities. Fixatives can deliver a process for reducing airborne radiological and/or chemical contamination and affixing loose contamination in place, thereby reducing contamination risk to employees and decreasing D&D cost and schedule. The developed process provides a reliable, unmanned method of introducing a coating that captures and fixes contamination in place within facilities.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

d. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited.

Questions – Contact: Latrincy Bates, Latrincy.Bates@em.doe.gov

References:

1. U.S. Department of Energy, 1999, Decommissioning Implementation Guide*, U.S. DOE, Office of Field Integration*, https://www.directives.doe.gov/directives-documents/400-series/0430.1-EGuide-4/@@images/file (November 2, 2022)

Back to Table of Contents

PROGRAM OFFICE OVERVIEW – OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT

The Office of Fossil Energy and Carbon Management (FECM) conducts research, development, demonstration, and deployment of technology to reduce carbon emissions and other environmental impacts of fossil fuel production and use, particularly the hardest-to-decarbonize applications in the electricity and industrial sectors. Furthermore, the program advances technologies that convert and durably store CO_2 into value-added products and technologies on carbon dioxide (CO_2) removal (CDR) to remove atmospheric and legacy emissions of CO_2.

To meet these challenges, FECM focuses on technology priority areas of point-source carbon capture, carbon transport and storage, carbon dioxide conversion, hydrogen with carbon management, methane emissions reduction, critical minerals (CM) production, and CDR. FECM recognizes that global decarbonization is essential to meeting climate goals—100% carbon pollution free electricity by 2035 and net-zero greenhouse gas (GHG) emissions economy-wide by 2050—and works to engage with international colleagues to leverage expertise in these areas. FECM is also committed to improving the conditions of communities impacted by the legacy of fossil fuel use and to supporting a healthy economic transition that accelerates the growth of good-paying jobs.

For additional information regarding the Office of Fossil Energy and Carbon Management priorities, visit Office of Fossil Energy and Carbon Management | Department of Energy

C56-25. CARBON CAPTURE, CONVERSION, AND STORAGE

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

To achieve net-zero carbon emissions economy-wide by 2050, technology development must address issues in the secure and cost-effective capture, conversion, transport, storage, and utilization of carbon dioxide. This topic brings together development needs identified in four programs in FECM's Office of Carbon Management Technologies: Carbon Transport and Storage (FE-222), CO_2 Removal and Conversion (FE-223), Integrated Carbon Management (FE-224), and Point Source Carbon Capture (FE-225). Subtopics include onsite carbon dioxide conversion to useful products from both point sources and direct air capture, use of CO_2 in treatment of produced waters with valuable products, and sensors for above-zone monitoring intervals and subsurface monitoring of storage sites.

For this topic, the National Energy Technology Laboratory is not eligible to act as a subawardee.

Grant applications are sought in the following subtopics:

a. Novel Reactive Capture Approaches that Convert Industrially Produced CO_2 to Useful Products On-Site

Among the objectives of the Point Source Capture Program is to support the deep decarbonization of the industrial sector. Facilities of interest for decarbonation are cement and lime plants, iron and steel manufacturing plants, hydrogen production plants, ethanol plants, and chemicals and petrochemicals plants. The conventional capture approach is to first separate/capture carbon dioxide (CO_2) from process emissions or pre/post-combustion flue gases and then, as applicable, to regenerate the capture medium and to compress, transport, and store or otherwise utilize the purified CO_2 in other applications. The act of capturing CO_2 in this method is often accompanied downstream by energy intensive and costly support infrastructure and processes to capture, purify, compress, transport and/or store the captured CO_2, and to regenerate the capture medium. It may therefore be highly advantageous in terms of energy efficiencies and costs to employ a “reactive capture” approach to carbon capture. 1 In the reactive capture approach, the act of capturing CO_2 and converting it into a higher value product is integrated into one continuous process onsite – thus eliminating the potential need to separately regenerate the capture medium and the need to purify, compress, transport, or store the captured CO_2. Removing the need for regeneration and compression steps from the carbon capture process could eliminate up to 90% of the energy loss associated with employing a typical amine capture process. 2 It is also possible that the integrated process could significantly reduce capital expenditures as well as provide distributed economic and employment opportunities.

Grant applications are desired for reactive capture approaches that integrate the CO_2 separation from diluted gas streams and the conversion of CO_2 to valuable product(s). The reactive capture process must achieve over 95% carbon capture rates and demonstrate significant progress towards a 30% reduction in the cost and 30% improvement in energy efficiency of carbon capture versus a reference conventional capture process where the acts of capture and conversion are separate. This topic area supports Infrastructure Investment and Jobs Act (IIJA) Title III: Fuels and Technology Infrastructure Investments; Subtitle A: Carbon Capture, Utilization, Storage and Infrastructure; and Carbon Utilization Program.

Applicants shall focus their applications on:

- Lab-scale R&D of the combined reactive capture process to prove initial feasibility of the concept,
- Identifying the end-use application for the product,
- Describing the conversion process material and energy flows in sufficient detail to allow for an evaluation of the proposed concept,
- Outlining a preliminary life cycle analysis (LCA), and
- Outlining a preliminary techno-economic analysis (TEA), characterizing the market value of the product relative to the current state of the art.

Questions – Contact: Andrew O’Palko, andrew.opalko@netl.doe.gov

b. Combined Direct Air Capture and Conversion of Carbon Dioxide to Chemical Products

The end-use of carbon-based chemical products results in widespread carbon dioxide (CO_2) emissions to the atmosphere, which are challenging to limit in comparison to point sources such as power plants. For this reason, the most effective approach to limiting the carbon footprint of the chemical industry sector is to develop carbon-neutral or carbon-negative methods of producing commodity chemicals. The feedstocks for these production processes and the energy provided must be considered in the overall carbon neutrality of the process. Grant applications are sought for the development of advancements in processes that combine a direct air capture (DAC) system with conversion to green commodity chemicals. The application must justify the end-products of the process by ensuring a sufficiently large and sustainable market to have a significant impact on carbon emissions. One-pot capture and conversion processes are of particular interest. Applications that combine existing DAC processes and chemical production methods with no novel advancement in technology will be considered non-responsive. Proposed methods should be subject to a preliminary life cycle analysis that demonstrates net neutral or negative carbon emissions accounting for all feedstocks and energy use, as well as a preliminary techno-economic analysis that shows cost-competitiveness with similar processes.

This topic area supports Infrastructure Investment and Jobs Act (IIJA) Title III: Fuels and Technology Infrastructure Investments; Subtitle A: Carbon Capture, Utilization, Storage, and Infrastructure; Carbon

Utilization Program; and Four Regional DAC Hubs. Technologies developed from this grant may be implemented in future DAC hubs that use CO_2 removed from the atmosphere for sustainable product markets.

Questions – Contact: Sai Gollakota sai.gollakota@netl.doe.gov

c. Mineralization of Produced Water Cations Using Anthropogenic CO_2

The Delaware and Midland Basins yield approximately four billion barrels of produced water annually, which represent only 16% of the total U.S. volume of produced water. The sodium concentration in the produced water of these basins is approximately 43,000 mg/l, which suggests up to 26 megatonnes of sodium could be available for mineralization with over 50 megatonnes of CO_2 annually. In addition to sodium, produced waters contain significant concentrations of magnesium, calcium, and other cations. These produced waters are typically reinjected for enhanced oil recovery (EOR) or disposal, while smaller amounts are disposed offsite, discharged to the surface, or evaporated (only a few percent are beneficially reused). If treated sufficiently, this water could have significant co-benefits for irrigation, municipal demands, mining, livestock, power, and manufacturing; thereby decreasing surface and groundwater demands.

Grant applications are sought for the research and development of technologies that utilize anthropogenic CO_2 to economically mineralize cations in produced water from any U.S. source. Proposed technologies should be capable of yielding products with a market value (including economic incentives such as 45Q) sufficient to offset conversion costs. Target products could include but are not limited to, building materials, clean fill, synthetic aggregates, soil amendments, and supplementary cementitious materials. Conversion approaches must be designed to utilize anthropogenic sources of CO_2 (including point source emissions and direct air capture), and a synthetic representative gas flow for the CO_2 source should be described. Proposed technologies should, to the greatest extent practicable, utilize commercial off-the-shelf technology, and should require no more than one scientific or technical breakthrough prior to commercialization. A specific end-use application must be identified for the mineralization product, and technical properties (performance) required for the end-use application must be quantified to an extent that would be expected by consumers of that product. Applicants should describe any water pre-treatment or post-treatment requirements, identify how the water effluent would be utilized or disposed, and describe a test campaign to determine whether the water effluent meets the specifications required for utilization or disposal.

Applications should focus on:

- Describing the conversion process mass and energy flows, material inputs and outputs, chemistry, CO_2 source, and process conditions in sufficient detail to allow for evaluation of the concept
- Outlining a preliminary life cycle analysis (LCA) on carbon emissions, including comparison to an incumbent (business as usual) product
- Identifying a specific end-use application for the mineralization product, including a preliminary techno-economic analysis (TEA) characterizing the required selling price of the product relative to the current state of the art
- Describing a test campaign that will determine whether the technology is ready to scale or requires additional research and development at the lab scale
- Describing a test campaign to determine whether the mineralization product and water meet the technical specifications (performance) required for their end-use applications
- Technologies that, to the greatest extent practicable, utilize commercial off the shelf technology and require no more than one scientific or technical breakthrough prior to commercialization
- Technologies that have achieved TRL 3

Questions – Contact: Isaac (Andy) Aurelio isaac.aurelio@netl.doe.gov

Back to Table of Contents

d. Development of Novel Sensors or System Components for Subsurface Electromagnetic (EM) Monitoring Applications

The Carbon Transport & Storage Program is focused on developing novel sensors that can accurately and affordably monitor carbon dioxide (CO_2) injected into the subsurface during a commercial-scale carbon capture and storage (CCS) operation (>1 million metric tons per year). Accurate monitoring at a carbon storage site is necessary to track the movement of CO_2 and assure permanence for geologic storage. Seismic and electrical geophysical methods are key methods for monitoring plume movement far from the injection wells. Electromagnetic (EM) techniques are of particular interest because they have the potential to provide a more precise measure of CO_2 saturation than seismic techniques. However, the spatial resolution of measurements using currently available EM systems is much lower than that of seismic systems. EM monitoring systems include frequency-dependent transmitters and receivers, which measure the elective and induced magnetic fields in the subsurface. EM system configurations can include surface, borehole, or surface-to-borehole configurations. It is not currently considered feasible to require that all wells in a storage project have non-metallic casings. Therefore, the ability to produce high resolution EM data in deep reservoirs using EM system configurations incorporating metallic well casing remains a significant research and development challenge.

Grant applications are sought for novel, reliable, rugged, high resolution, high precision EM sensors or system components for monitoring the subsurface. The system should be capable of monitoring plume movement at depths up to 15,000 feet for 20 years or more. System design should take into consideration the need for critical component redundancy or replacement due to failure. Deployment and operation should minimally interfere with other monitoring measurements and take into consideration the use of metallic casing versus non-metallic casings.

Questions – Contact: James Gardiner james.gardiner@netl.doe.gov

e. "Turn-key" System for High Resolution, Long Term AZMI Pressure Monitoring

The Carbon Transport & Storage Program is focused on developing novel technologies that can accurately and affordably monitor carbon dioxide (CO_2) injected into the subsurface during a commercial-scale carbon capture and storage (CCS) operation (>1 million metric tons per year). Accurate monitoring at a carbon storage site is necessary to track the movement of CO_2 and assure permanence for geologic storage. Work to date shows that monitoring fluid pressures in permeable rock layers above the main reservoir caprock or seal layer can be effective for detecting significant leakage through the caprock or seal layer. Such monitoring has sometimes been referred to as “Above Zone Monitoring Interval (AZMI) pressure monitoring” and can provide detection of unintended fluid flow long before underground sources of drinking water or the ground surface are affected, providing an opportunity to mitigate the problem before environmental impacts occur. The method involves placement of fluid pressure sensors at strategic locations in a porous and permeable rock formation above the reservoir seal, monitoring the fluid pressure changes over long periods of time (perhaps 30 to 80 years), and recording the data. It is highly desirable for the monitoring system to be co-deployable in monitoring wells along with other monitoring systems for things such as fluid sampling, periodic wireline logging, temperature monitoring, and geophysical (e.g., seismic or electromagnetic) measurements. Detection of a small leak can require high resolution and precise pressure measurements. System robustness and/or easy component replacement and calibration along with minimal sensor “drift” are highly desirable since commercial geologic storage projects may require that these measurements be made continuously for decades under the extremely harsh environmental conditions (high pressure, high temperature, high salinity) found deep in the subsurface.

Grant applications are sought for a reliable, rugged, high resolution turnkey AZMI pressure monitoring system. The system includes the sensors, components needed for deployment, power, data acquisition, data analysis, and reporting. “Turnkey” refers to full service in terms of site-specific system design, installation, initialization and debugging, and, if desired by the storage site operator, monitoring services. The system should be expandable in the future as more monitoring wells may become available. Data analysis needs to differentiate leakage pressure signals from other pressure signals such as those caused by earth tides or geomechanical effects of injection. The system should be capable of continuous operation at depths up to 15,000 feet for 20 years or more. System design should take into consideration the potential re-use of existing wells, in addition to the need for critical component redundancy or replacement due to failure. Ideally, AZMI pressure monitoring system wells can also serve other monitoring or measurement systems.

Questions – Contact: James Gardiner james.gardiner@netl.doe.gov

f. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited.

Questions – Contact: Isaac (Andy) Aurelio isaac.aurelio@netl.doe.gov

References: Subtopic a:

1. T. Deutsch, S. Baker, P. Agbo, D. R. Kauffman, J. Vickers, J. Schaidle, 2020, Summary Report of the Reactive CO2 Capture: Process Integration for the New Carbon Economy Workshop, Feb 18-19, 2020, https://netl.doe.gov/projects/files/SummaryReportoftheReactiveCO2CaptureProcessIntegrationfortheNewCarbonEconomyWorkshop_08242021.pdf (October 31, 2022)
2. Oexmann, J., Kather, A., Linnenberg, S., Liebenthal, U., 2012, Post-combustion CO2 capture: chemical absorption processes in coal-fired steam power plants, Greenhouse Gas Sci Technol. 2 (2012) 80-98, https://onlinelibrary.wiley.com/doi/abs/10.1002/ghg.1273 (October 31, 2022)

References: Subtopic b:

1. IRENA and METHANOL INSTITUTE, 2021, Innovations Outlook: Renewable Methanol, *International Renewable Energy Agency*, Abu Dhabi, https://www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol (October 31, 2022)

References: Subtopic c:

1. Xu, P., Hightower, M., 2022, Characterization of Produced Water and Surrounding Surface Water in the Permian Basin in the United States, In Produced Water Society Seminar 2022, Houston TX, 2022, https://www.sciencedirect.com/science/article/abs/pii/S0304389422001972 (October 31, 2022)
2. Veil, J., 2020, Produced Water Volumes and Management Practices in 2017, *GWPC UIC Conference*, San Antonio TX, February 16-18, 2020, https://www.gwpc.org/sites/gwpc/uploads/documents/2020_UIC_Conference/Veil___Produced_Water.pdf (October 31, 2022)

References: Subtopic d:

1. Barajas-Olalde, C., Davydycheva, S., Hanstein, T., Laudal, D., Martinez, Y., MacLennan, K., Mikula, S., Adams, D.C., Klapperich, R.J., Peck, W.D. and Strack, K., 2021, Using controlled-source electromagnetic (CSEM) for CO2 storage monitoring in the North Dakota CarbonSAFE project, *In First International Meeting for Applied Geoscience & Energy* (pp. 503-507), Society of Exploration Geophysicists, https://kmstechnologies.com/Files/publications/segam2021-3585379.1.pdf (October 31, 2022)
2. Zhdanov, M.S., Endo, M., Black, N., Spangler, L., Fairweather, S., Hibbs, A., Eiskamp, G.A. and Will, R., 2013, Electromagnetic monitoring of CO2 sequestration in deep reservoirs, *First Break*, vol. 31(2), http://www.cemi.utah.edu/PDF_70_10/2013a.pdf (October 31, 2022)

3. Gasperikova, E., Appriou, D., Bonneville, A., Feng, Z., et al., 2022, Sensitivity of geophysical techniques for monitoring secondary CO2 storage plumes, International Journal of Greenhouse Gas Control, vol. 114, https://www.sciencedirect.com/science/article/abs/pii/S175058362200007X (October 31, 2022)
4. Gasperikova, E., and Li, Y., 2021, Time-lapse Electromagnetic and Gravity Methods in Carbon Storage Monitoring, SEG Library, The Leading Edge 2021 40:6, 442-446, https://library.seg.org/doi/full/10.1190/tle40060442.1 (October 31, 2022)

References: Subtopic e:

1. Meckel, T.A. and Hovorka, S.D., 2010, Above-Zone Pressure Monitoring as a Surveillance Tool for Carbon Sequestration Projects, *SPE International Conference on CO2 Capture, Storage, and Utilization, OnePetro*, https://onepetro.org/SPECO2/proceedings-abstract/10CO2/All-10CO2/SPE-139720-MS/104700 (October 31, 2022)
2. Kim, S., & Hosseini, S. A., 2014, Above-Zone Pressure Monitoring and Geomechanical Analyses for a Field-Scale CO2 Injection Project in Cranfield, MS, Greenhouse Gases: Science and Technology, 4(1), 81-98, https://onlinelibrary.wiley.com/doi/abs/10.1002/ghg.1388 (October 31, 2022)

C56-26. HYDROGEN TECHNOLOGIES

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Hydrogen is a versatile fuel that can be produced using diverse clean domestic energy resources, including wind, solar, and nuclear energy. Feedstocks include methane, biomass, coal, and carbonaceous waste (e.g., plastics, coal wastes, municipal solid waste) with carbon capture, or water with no capture needed. Hydrogen can fuel electricity generation by combustion in a gas turbine or conversion in a fuel cell, with water as the sole effluent. As the lightest gas, hydrogen has extremely high gravimetric energy density, making it an efficient and lightweight energy carrier. However, hydrogen's volumetric energy density at atmospheric pressure is lower than that of natural gas or gasoline. Hydrogen is generally compressed or liquified for transport and storage to increase its volumetric energy density.

These characteristics make hydrogen a strong option to decarbonize energy-intensive heavy industry and support heavy-duty transportation. Hydrogen's flexibility makes it an important component of President Biden's strategy to achieve a carbon-free grid by 2035 and net-zero emissions by 2050.

Hydrogen Technologies research explores a diverse set of technologies required to implement a transition to clean hydrogen energy systems. These range from efficient hydrogen production with carbon capture if needed, through secure hydrogen transport and storage, to hydrogen fueled electricity generation. This solicitation's subtopics include technologies needed for producing hydrogen cleanly from waste materials and biomass and manufacturing advances to enable efficient use of hydrogen as fuel in gas turbines and new approaches for transport and storage technology.

For this topic, the National Energy Technology Laboratory is not eligible to act as a subawardee.

Grant applications are sought in the following subtopics:

a. Smart Manufacture of Ceramic Matrix Composite (CMC) Substrates

CMC coatings are applied to surfaces operating at elevated temperatures, such as gas turbine or aero-engine parts, as a form of exhaust heat management. CMCs allow for higher operating temperatures and extending hydrogen turbine part life by reducing excessive metallic oxidation and thermal fatigue. Ceramic matrix composites reinforced with long fibers are commonly fabricated by infiltration. In this fabrication techniques the ceramic matrix is formed from a fluid (gaseous or liquid) infiltrated into the fiber structure (either woven or non-woven). In this regard, chemical vapor deposition (CVD) is well suited for this purpose but is known to be time-consuming. In the presence of a fiber preform, CVD takes place in between the fibers and their individual filaments and therefore is called chemical vapor infiltration (CVI). One example is the manufacture of C/C composites: a C-fiber preform is exposed to a mixture of argon and a hydrocarbon gas (methane, propane, etc.) at a pressure of around or below 100 kPa and a temperature above 1000 °C. The gas decomposes depositing carbon on and between the fibers. Such fabrication and manufacture of CMC substrates for use in Hydrogen Turbine applications may be currently slow and labor intensive. DOE is interested in reducing their manufacturing cost through smart manufacturing fabrication and robotic automation. Applications are sought for research and development that develops improved, automated, and innovative low-cost CMC manufacturing processes.

Questions – Contact: Andrew Downs, andrew.downs@netl.doe.gov

b. Advanced Thermal Barrier Coatings (TBC) and Environmental Barrier Coatings (EBC) for Ceramic Matrix Composites (CMC)

Higher operating temperature materials are clearly tied to advancing hydrogen turbines technology. DOE is interested in advancing the Hydrogen Turbine technology through increased operating temperatures and efficiencies. Of particular interest is in advancing EBC and TBC to protect Ceramic Matrix Composites (CMC) for use at elevated operating temperatures which would be applicable to Hydrogen Turbines operating on 100% hydrogen. These 2 -100 µm thick coatings of environmentally isolating and thermally insulating materials serve to protect CMCs from high water and hydrogen content gases and large and prolonged heat loads and can sustain an appreciable environmental and temperature differences between the load-bearing alloys and the coating surface. In doing so, these coatings can allow for higher operating temperatures while limiting the environmental and thermal exposure of CMC's, extending hydrogen turbine part life by reducing excessive oxidation and thermal fatigue. Due to increasing demand for more efficient engines running at higher temperatures with better durability/lifetime and thinner coatings to reduce parasitic mass for rotating/moving components, there is significant motivation to develop new and advanced EBC's and TBCs especially suitable for CMC's. Applications are sought for research and development that develops improved, innovative, and low-cost EBC's and TBCs for CMC's.

Questions – Contact: Adam Payne adam.payne@netl.doe.gov

c. Advanced Manufacturing Concepts for Hydrogen Transportation and Storage

Technical challenges associated with transporting and storing hydrogen include metal component degradation and increased energy requirements for transportation and storage as compared to natural gas due to hydrogen's relative smaller molecule size. With only 1,600 miles of dedicated hydrogen pipelines and a handful of long-term hydrogen storage locations in the United States, research is necessary to advance technologies to provide a reliable, flexible, and robust hydrogen transportation and storage supply chain. One such area of research that could assist in the development of novel materials and technologies includes advanced manufacturing.

Advanced manufacturing typically refers to the use of 3D printing technology. Technical advances have shown that hydrogen can be stored through physisorption onto the surfaces of metal hydrides and carbon nanostructures which reduces the energy requirements for storage of gaseous hydrogen. In general, there are seven categories of advanced manufacturing that are used to describe methods of 3D printing. Specifically, metal hydrides have shown the ability to absorb and desorb hydrogen more efficiently than other liquid or solid phase storage techniques. Carbon nanostructures have demonstrated the ability to provide a cheaper physisorption storage option by storing between 3.0-7.0 weight percent hydrogen depending on the carbon structure at ambient temperatures. It appears to be possible that the use of advanced manufacturing could be applied to hydrogen transportation and storage by developing improved components that will reduce hydrogen embrittlement and increase storage potential.3

Grant applications are sought for technologies that will improve advanced manufacturing technologies for transportation and storage of hydrogen in gaseous, liquid, or solid states. Components of interest that are expected to have the potential to be improved by advanced manufacturing technologies include:

- Pipeline Materials
    - These materials are expected to include metals, fittings, or any other components that are affected by hydrogen embrittlement.
- Compressor or Gathering Station Components
    - These components are expected to include all facets of compressor or engine designs such as mechanical parts, O-rings, and gaskets.
- Storage Tanks
    - These components are expected to include novel methods to reduce energy requirements for storage (and removal) of hydrogen by incorporating the use of physisorption technologies.
- Wellbore or Injection Well Components
    - These components are expected to improve reliability and operational integrity of wellbores and injection wells that are used to assist in the storage of hydrogen in the subsurface. These components would be required to withstand the differing chemical and physical interactions at both the surface and subsurface.

Questions – Contact: Stephen Henry stephen.henry@netl.doe.gov

d. Feedstock Dechlorination Technologies of Mixed-Plastics and MSW for Downstream Gasifier Use to Produce Clean Hydrogen

Applications are sought for the development of novel technologies for removal of chlorine from solid feedstocks intended for gasification for production of clean decarbonized hydrogen. Since clean hydrogen would likely require the use of pre-combustion carbon capture technology, it would be beneficial to develop methods to reduce the chlorine loading of incoming solid fuel feedstocks when sourcing them from waste streams. The desired fuel pre-treatment technologies would provide cost, efficiency, and/or performance benefits over the alternate approaches of post-gasification capture of chlorine or chlorine species from syngas. Likewise, the desired pre-treatment technology would also offer benefits over in situ capture of chlorine in the gasifier.

Technology development to reduce chlorine loading in solid feedstocks intended for gasification input should focus on mixed plastics containing a representative amount of high chlorine-content plastic types (e.g. PVC) as is often found in residential and commercial waste. As DOE continues to develop clean hydrogen producing technologies from MSW and other wastes, the proper handling of chlorine-containing fractions is essential. Development of raw syngas dechlorination and other post-gasification, including in situ capture technologies, are not of interest in this funding mechanism.

Questions – Contact: Evelyn Lopez evelyn.lopez@netl.doe.gov

e. Contaminant Filter for Clean Hydrogen Production and Separation from Coal Waste, Biomass, MSW and Plastics

Back to Table of Contents

Applications are sought for the development of a contaminant capture device that is integrated into a hydrogen separation device for syngas produced by the gasification of mixtures containing two or more of the following: (1) coal, (2) biomass, (3) waste plastics as a portion of MSW, and/or (4) industrial waste. The desired catalyst product would address the removal of mercury (Hg), ammonia (NH3), selenium (Se), cadmium (Cd), metal hydrides (e.g. AsH3, H2Se, SbH3…) particulates, arsenic (As), phosphorous (P), antimony (Sb), chlorine (Cl) and/or other impurities from the syngas. The resulting product should have the potential of being integrated into an existing syngas process, such as water gas shift. Improvements in such catalysts are expected to reduce the cost of producing hydrogen from gasification of such mixtures. Development of sulfur and mercury removal technologies is not of interest under this funding mechanism because of the department's prior investment in those technologies. Development of integrated water gas shift (WGS) technologies are also not of interest for the same reason.

Questions – Contact: Sarah Michalik sarah.michalik@netl.doe.gov

f. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited.

Questions – Contact: Adam Payne adam.payne@netl.doe.gov

References: Subtopic a:

1. Bansal, N. P. & Lamon, J., 2015, Ceramic Matrix Composites: Materials, Modeling and Technology, *Hoboken: Wiley, ISBN 978-1-118-23116-6*, https://www.wiley.com/en-us/Ceramic+Matrix+Composites:+Materials,+Modeling+and+Technology-p-9781118231166 (October 31, 2022)
2. Krenkel, W., 2008, Ceramic Matrix Composites, *Weinheim: Wiley-VCH, ISBN 978-3-527-31361-7*, https://www.wiley.com/en-us/Ceramic+Matrix+Composites:+Fiber+Reinforced+Ceramics+and+their+Applications-p-9783527622405 (October 31, 2022)
3. Zoli, L., Vinci, A., Silvestroni, L., Sciti, D., Reece, M., Grasso, S., 2017, Rapid spark plasma sintering to produce dense UHTCs reinforced with undamaged carbon fibres, *Materials & Design*, 130: 1–7, https://www.sciencedirect.com/science/article/abs/pii/S0264127517305087 (October 31, 2022)
4. Vinci, A., Zoli, L., Landi, E., Sciti, D., 2017, Oxidation behavior of a continuous carbon fiber reinforced ZrB2–SiC composite, *Corrosion Science*, 123: 129–138, https://www.sciencedirect.com/science/article/pii/S0010938X16311490 (October 31, 2022)

References: Subtopic b:

1. Zhang, H., Liu, Z., Yang, X., Xie, H., 2019, Interface failure behavior of YSZ thermal barrier coatings during thermal shock, Journal of Alloys and Compounds, 779: 686-697, https://www.sciencedirect.com/science/article/abs/pii/S092583881834444X (October 31, 2022)
2. Wei, Z.Y., Cai, H.N., Tahir, A., Zhang, W.W., Li, X.F., Zhang, Y., Huang, Y.P., Liu, Y., 2019, Stress states in plasma-sprayed thermal barrier coatings upon temperature cycling: Combined effects of creep, plastic deformation, and TGO growth, *Ceramics International*, 45: 19829-19844. doi:10.1016/j.ceramint.2019.06.238, https://www.sciencedirect.com/science/article/pii/S0272884219317390 (October 31, 2022)
3. Tejero-Martin, D., Bennett, C., and Hussain, T., 2021, A review on environmental barrier coatings: History, current state of the art and future developments, *Journal of the European Ceramic Society*, Volume 41, Issue 3, March 2021, Pages 1747-1768, https://www.sciencedirect.com/science/article/pii/S0955221920308700 (October 31, 2022)

References: Subtopic c:

1. Andrews, R.M., Gallon, N., Huisin, O.J., Lam-Thanh, L., 2021m Hydrogen Transport Pipelines - Design Challenges and Mitigations, 01 Apr 2021, 18TH PIPELINE Technology Conference, https://www.pipeline-conference.com/abstracts/hydrogen-transport-pipelines-design-challenges-and-mitigations (November 1, 2022)
2. Andersson, J., Grönkvist, S., 2019, Large-scale storage of hydrogen, International Journal of Hydrogen Energy, vol. 44, Issue 23, 3, May 2019, https://www.sciencedirect.com/science/article/pii/S0360319919310195 (November 1, 2022)
3. Free, Z., Hernandez, M., Mashal, M., Mondal, K., 2021, A Review on Advanced Manufacturing for Hydrogen Storage Applications, Energies 2021, 14, 8513. https://doi.org/10.3390/en14248513 (November 1, 2022)
4. U.S. Department of Energy, 2022, Hydrogen Pipelines, Hydrogen and Fuel Cell Technologies Office, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, https://www.energy.gov/eere/fuelcells/hydrogen-pipelines (November 1, 2022)

References: Subtopic d:

1. Lewandowski, K., and Skórczewska, K., 2022, A Brief Review of Poly (Vinyl Chloride)(PVC) Recycling, *Polymers* 14(15): 3035, https://www.mdpi.com/2073-4360/14/15/3035 (November 1, 2022)
2. Wang, G., Liu, S., Zhang, H., Wang, J., and Xue, Q., 2022, Pulverization of Waste Polyvinyl Chloride (PVC) Film by Low Temperature Heat Treatment and Properties of Pulverized Product for Blast Furnace Injection as Alternative Fuel, *Polymers* 14(9): 1689, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9104656/ (November 1, 2022)

References: Subtopic e:

1. Yao, Z., et al., 2018, Particulate emission from the gasification and pyrolysis of biomass: Concentration, size distributions, respiratory deposition-based control measure evaluation, *Environmental Pollution*, vol. 242, Part B, https://www.sciencedirect.com/science/article/abs/pii/S0269749117349072 (November 1, 2022)
2. Gallucci, F., et al., 2022, Fluidized bed gasification of biomass from plant-assisted bioremediation: Fate of contaminants, *ScienceDirect, Sustainable Energy Technologies and Assessments,* vol 53, https://www.sciencedirect.com/science/article/pii/S2213138822005100 (November 1, 2022)
3. Nzihou, A., et al., 2013, The fate of heavy metals during combustion and gasification of contaminated biomass—A brief review, *ScienceDirect, Journal of Hazardous Materials*, vol 256-257, https://www.sciencedirect.com/science/article/abs/pii/S0304389413001660?pes=vor (November 1, 2022)
4. Brereton, C., 1996, Municipal solid waste — incineration, air pollution control and ash management, *ScienceDirect, Resources, Conservation and Recycling*, vol. 16, Issues 1-4, https://www.sciencedirect.com/science/article/abs/pii/0921344995000593 (November 1, 2022)

C56-27. METHANE MITIGATION

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

According to the International Energy Agency, methane is responsible for around 30% of the rise in global temperatures since the Industrial Revolution, and rapid and sustained reductions in methane emissions are key to limiting near-term global warming and improving air quality. The oil and natural gas industry is the largest source of methane emissions in the United States, responsible for about 30% of total emissions. Approximately 211 million metric tonnes of methane are emitted across the oil and natural gas value chain, which consists of more than two million miles of pipelines; more than two million actively producing, abandoned, or repurposed oil and natural gas wells; and more than 100,000 unit operations consisting of natural gas processing plants, compressor stations, and gathering stations.

FECM's Methane Mitigation Technologies program aims to eliminate non-trivial methane emissions from the oil and gas supply chain by 2030. The program is focused on developing accurate, cost-effective, and efficient technology solutions and best practices to identify, measure, monitor, and eliminate methane emissions from these sources. Methane mitigation research and development (R&D) efforts include advanced materials of pipeline construction, monitoring sensors, data management systems, and more efficient and flexible compressor stations. Research efforts for methane emissions quantification focus on developing technologies to detect, locate, and measure emissions. This includes the development and validation of measurement sensor technologies for the collection, dissemination, and analysis of emissions data, which will inform efforts such as the Greenhouse Gas Inventory and orphan well remediation programs of the U.S. Environmental Protection Agency (EPA) and Department of the Interior (DOI), respectively.

The Office is also working on creating innovative solutions to reduce associated gas flaring and venting, including alternative uses for the "stranded" natural gas, through modular technologies designed to convert the gas to higher-value solid and liquid products that can be transported efficiently. In addition, modular conversion technologies designed to generate hydrogen as a clean, distributed energy carrier is also being pursued.

For this topic, the National Energy Technology Laboratory is not eligible to act as a subawardee.

Grant applications are sought for the following subtopic:

a. Mitigation of Emissions of Methane and Other Gases Through the Monitoring and Maintaining Combustion and Destruction Efficiency in Gas Flares

One of the objectives of the DOE Methane Mitigation Technologies Program includes a focus on the measurement, estimation, and tracking of gaseous emissions (methane, hydrogen sulfide, volatile organic compounds, and other gases) to support Administration goals for a "net-zero" carbon economy by 2050. The gases noted above are released when natural gas associated with oil production is flared but the combustion efficiency in the flare is not maintained. The decision to flare natural gas rather than monetize it may be related to safety, economics, a lack of takeaway capacity, operational expediency, or a combination of all three. , Individual state regulations are meant to control the volume of associated gas flaring that is permitted, while the U.S. Environmental Protection Agency (EPA) sets parameters for flaring system elements that affect combustion to ensure proper operation.

However, flameouts, intermittent periods of non-safety related venting, and incomplete combustion in the flare can still occur, as there no monitoring requirements to ensure flare stability and efficiency. This results in undesired emissions such as non-combusted methane, carbon monoxide, and other gases such as sulfur dioxide and nitrous oxides (SOx and NOx) being emitted to the atmosphere. Incomplete combustion in the flare also means that chemicals that are intended to be destroyed may instead be released, such as polycyclic aromatic hydrocarbons (PAH) like naphthalene and volatile organic compounds (VOCs) like formaldehyde. Inefficient combustion in the flare can also produce a sooty flame resulting in solid particulate matter (black carbon) settling out of the air and depositing on surrounding lands, which further impacts the environment. Grant applications could be sought for technologies that will support:

- Development of sensors, feedback systems, and algorithms related to maintaining a high flare combustion efficiency over variable conditions and changing gas composition and flow rates,
- Development and integration of advanced supervisory control and data acquisition (SCADA)-supported systems for continual monitoring and operation of flares,
- Simulation and additive manufacturing concepts to be developed related to burner design and flame stability concepts,
- Development of supplemental utilization technologies that fully leverage the energy from the flare,
- Low-cost catalysts and catalytic systems suitable for flares

Questions – Contact: Stephen Henry stephen.henry@netl.doe.gov

b. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited.

Questions – Contact: Stephen Henry stephen.henry@netl.doe.gov

References:

1. U.S. Department of Energy, 2019, Natural Gas Flaring and Venting: State and Federal Regulatory Overview, Trends, and Impacts, *U.S. Department of Energy, Office of Oil and Natural Gas, Office of Fossil Energy*, https://www.energy.gov/sites/prod/files/2019/08/f65/Natural%20Gas%20Flaring%20and%20Venting%20Report.pdf (November 1, 2022)
2. IHS Markit, 2018, The Permian: $308 billion, 41,000 wells, and other key ingredients in the IHS Markit outlook to 2023, *Crude Oil Markets Strategic Report*, https://news.ihsmarkit.com/prviewer/release_only/slug/energy-new-ihs-markit-outlook-%E2%80%93-stunning-permian-basin-oil-production-more-double-2017 (November 1, 2022)
3. U.S. Department of Energy, 2022, State-Level Natural Gas Flaring and Venting Regulations, *U.S. Department of Energy, Office of Fossil Energy and Carbon Management*, https://www.energy.gov/fecm/state-level-natural-gas-flaring-and-venting-regulations (November 1, 2022)
4. U.S. EPA Office of Air Quality Planning and Standards (OAQPS), 2012, Parameters for Properly Designed and Operated Flares, *Report for Flare Review Panel*, April 2012, https://www3.epa.gov/ttn/atw/flare/2012flaretechreport.pdf (November 1, 2022)

C56-28. ADVANCED REMEDIATION

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Advanced Remediation Technologies Program develops technologies to be applied to the remediation and prevention of environmental impacts from the recovery of fossil energy resources. The program conducts research, development, demonstration, and deployment of technologies to address wellbore integrity, induced seismicity, water use, produced water treatment, and offshore safety and spill prevention. Research efforts lead to solutions that address the environmental impacts of oil and natural gas development.

The advanced remediation technologies program focuses on:

- Produced Water treatment and reuse technologies and water management research and development.
- Addressing Environmental Impacts of Unconventional Oil and Gas Resources
- Gas Hydrate R&D

For this topic, the National Energy Technology Laboratory is not eligible to act as a subawardee.

Grant applications are sought for the following subtopics:

a. Produced Water Management

Produced water is by far the largest volume byproduct stream associated with oil and gas exploration and production. Approximately 21 billion bbl or 57.4 million bbl/day (barrels; 1 bbl = 42 U.S. gallons) of produced water are generated each year in the United States onshore and offshore from the nearly 1 million wells in the United States. The cost of efficiently and effectively managing such a large volume of water is a key consideration to oil and gas producers and could be a beneficial source of water. (https://doi.org/10.2172/1007397).

The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geological formation from which it comes, and the type of hydrocarbon product being produced. Produced water properties and volume can even vary throughout the lifetime of a reservoir.

Two general water management themes have been followed by most U.S. operators. More than 98% of produced water from onshore wells is injected underground. Approximately 59% is injected into producing formations to maintain formation pressure and increase the output of production wells. Another ~40% of produced water from onshore wells is injected into nonproducing formations for disposal. This has caused other problems such as seismic events. The remaining 2% of onshore produced water volume is managed through evaporation ponds, offsite commercial disposal, beneficial reuse, and other management methods. More than 91% of offshore produced water, including the water from inshore platforms in Cook Inlet, Alaska, is discharged to the ocean.

Currently onshore produced water treatment facilities and disposal sites take grab samples from tanks or trucks at irregular intervals for lab diagnosis or simple IR type color analysis. Chemicals are adjusted based on analysis hours if not days old. This creates slow and inaccurate response to changing operation conditions.

The major constituents of interest in produced water are:

- Salt content can be expressed as salinity, total dissolved solids, or electrical conductivity. The salt content in produced water varies widely, from nearly freshwater to salt levels up to ten times higher than seawater.
- Oil and grease though not an individual chemical but rather, the term "oil and grease" refers to a common test method that measures many types of organic chemicals that collectively lend an "oily" property to the water.
- Various inorganic and organic chemicals are found naturally in the formation, are transferred to the water through long-term contact with the hydrocarbon, or are chemical additives used during drilling and operation of the well. The presence of specific chemicals and the concentrations of those chemicals vary widely among different produced water samples.
- Naturally occurring radioactive material (NORM) from some oil and gas formations. Low levels of the radioactivity can be transferred into produced water. Generally, the radiation levels in produced water

are very low and pose no risk. However, scale from pipes and sludge from tanks holding produced water can concentrate NORM.

Grant applications are sought for digital twin type concepts that provide real time monitoring and control of chemical feed and treatment of produced water systems. The intent would be to create an internet of things to optimize produced water management operations integrating digital solutions with sensors. Concepts should combine sensors with artificial intelligence (AI) and/or machine learning (ML) computing software to monitor and, analyze water characteristics and predict optimal operating conditions of produced water system treatment facilities.

1. Sensors: Physical to digital advanced real time sensors for water quality and composition that can provide real time data on water quality and composition (salinity, TDS etc.)
2. AI and ML computing Software: Cognitive and high-performance computing that can analyze large volumes of data in real time from sophisticated water chemistry sensors and accurately diagnose issues and make recommendations to operator and/or an automated decision-making system, i.e., real-time, AI-assisted autonomous operation and maintenance monitoring and control.

Proposed concepts must describe their potential to promote the environmental sustainability of produced water treatment by: reducing costs of water treatment, improving or enabling predictive maintenance for treatment and disposal sites, reducing asset failure, maintaining optimal operating conditions, minimizing chemical use, reducing energy use, reduce impacts to environment and ecology, and reduce risks of seismic events or other adverse impacts to the environment or ecology, and/or increasing possible beneficial use of produced water. Techniques optimizing waterflooding or EOR techniques are not part of this request.

Questions – Contact: Stephen Henry stephen.henry@netl.doe.gov

b. Other

In addition to the specific subtopics listed above, grant applications in other areas relevant to this topic are invited. Applications regarding Environmental Impacts of Unconventional Oil and Gas Resources or Gas Hydrates are not of interest for this subtopic.

Questions – Contact: Stephen Henry stephen.henry@netl.doe.gov

References:

1. Wenbin, J., et al., 2021, Analysis and prediction of produced water quantity and quality in the Permian Basin using machine learning techniques, *Science of The Total Environment*, Volume 801, 2021, https://www.sciencedirect.com/science/article/abs/pii/S0048969721047689 (November 1, 2022)
2. Wang, D., et al., 2021, A machine learning framework to improve effluent quality control in wastewater treatment plants, Science of The Total Environment, Volume 784, 2021, https://www.sciencedirect.com/science/article/pii/S0048969721022087 (November 1, 2022)
3. Bernardelli, A., et al., 2020, Real-time model predictive control of a wastewater
4. treatment plant based on machine learning, *Water Science and Technology*, 81.11, https://pubmed.ncbi.nlm.nih.gov/32784282/ (November 1, 2022)
5. Doorn, N., 2021, Artificial intelligence in the water domain: Opportunities for responsible use, *Science of the Total Environment*, 755, 2021, https://www.sciencedirect.com/science/article/pii/S0048969720360903 (November 1, 2022)

Back to Table of Contents

PROGRAM AREA OVERVIEW: OFFICE OF FUSION ENERGY SCIENCES

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. This is accomplished through the study of plasma, the fourth state of matter, and how it interacts with its surroundings. FES has four strategic goals:

- Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source;
- Support of enabling technologies in plasma heating, fueling, and operations and maintenance for future fusion reactors, which enhances economic competitiveness, energy diversity, and climate change resilience.
- Pursue scientific opportunities and grand challenges in high energy density plasma science to better understand our universe, and to enhance national security and economic competitiveness, and;
- Increase the fundamental understanding of basic plasma science, including both burning plasma and low temperature plasma science and engineering, to enhance economic competitiveness and to create opportunities for a broader range of science-based applications.

The next frontier for fusion research is the study of the burning plasma state, in which the fusion process itself provides the dominant heat source for sustaining the plasma temperature (i.e., self-heating). Production of strongly self-heated fusion plasmas will allow the discovery and study of new scientific phenomena relevant to fusion energy, including the properties of materials in the presence of high heat and particle fluxes and neutron irradiation.

To achieve its research goals, FES invests in flexible U.S. experimental facilities of various scales, international partnerships leveraging U.S. expertise, large-scale numerical simulations based on experimentally validated theoretical models, development of advanced fusion-relevant materials, and invention of new measurement techniques.

FES also supports discovery plasma science, including research in laboratory plasma astrophysics, low- temperature plasmas, small-scale magnetized plasma experimental platforms, and high-energy-density laboratory plasmas.

Research supported by FES has led to many spinoff applications and enabling technologies with considerable economic and societal impact.

The following topics are restricted to advanced technologies and materials for fusion energy systems, fusion science, technology relevant to magnetically confined plasma, and high energy density laboratory plasmas.

For additional information regarding the Office of Fusion Energy Sciences priorities, click here.

Back to Table of Contents

C56-29. ENABLING TECHNOLOGIES IN PLASMA HEATING, FUELING, AND DISTRUPTION MITIGATION

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The Enabling Research and Development program supports R&D required to produce, support, and maintain a burning plasma environment within a fusion reactor. Specifically, this program is looking to support research that enables advanced plasma heating, vacuum pumping systems, fusion component system design, and remote maintenance systems. The goal of this program is to support the future fueling, operation, and maintenance of a fusion reactor.

a. Advanced Plasma Heating and Current Drive

Such techniques are open to any plasma heating and current drive technology, but should include at least one of the following:

- Develop a novel physics design to enable stable operation in a higher order operating mode
- Design and implementation of a current drive technologies that improve energy recovery
- Use advanced Additive Manufacturing techniques using high-strength materials to reduce the cost and fabrication time while increasing reliability and lifetime

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

b. Advanced Vacuum Pumping Systems

Fusion plants require specific technologies that account for the specific challenges of tritium operation. Even the pumps in a tritium facility are specialized for use with tritium, to prevent exchange with hydrogen into materials such as oils and polymers, which creates tritiated waste and increases permeation losses. Areas of interest are on vacuum pumping system technologies specific to fusion reactor operation.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

c. Fusion Engineering Component Modeling or Tool Development

Fusion components such as the blanket, fuel cycle, or other fusion components require engineering system analysis, modeling, and simulation to inform design and development but also as a way reduce risk of future fusion reactors. This program is interested in the following research areas:

- Multiphysics modeling of fusion materials
- Fusion neutronic analysis
- Multiphysics modeling of fusion blanket systems
- Tritium process modeling of the fusion fuel cycle

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

d. Remote Maintenance

A fusion reactor will need efficient methods for periodic maintenance and inspection of neutron irradiated components. The importance of Reliability, Availability, Maintainability and Inspectability (RAMI) was recognized in the reports to be able to construct and operate a fusion nuclear facility like the

Fusion Pilot Plant. Such areas of interest are the following: Remote Materials and Measurements Development, Tritium Contamination Control, and Advanced Maintenance Development.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

e. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

C56-30. SUPERCONDUCTING MAGNETS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

New or advanced superconducting magnet concepts are needed for plasma fusion confinement systems. Fusion specific magnetic confinement devices operate at higher magnetic fields (14T-20T), in higher nuclear irradiation environments, and require provide access/maintenance or allow for wider operating ranges in temperature or pulsed magnetic fields. Of particular interest are the following:

a. Superconducting Magnetic Technology

Innovative and advanced superconducting materials manufacturing processes that have a high potential for improved conductor performance and low fabrication costs. Specifically addressing manufacturing capacity (>500 km/yr) while maintaining quality assurance and quality control.

Innovative and advanced superconducting materials manufacturing processes focusing on increasing deposition area (>0.5 m^2)

Radiation-resistant electrical insulators, e.g., wrap able inorganic insulators and low viscosity organic insulators that exhibit low gas generation under irradiation, less expensive resins and higher pot life; and insulation systems with high bond and higher strength and flexibility in shear.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

b. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

C56-31. LOW TEMPERATURE PLASMAS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Low-temperature plasmas (LTPs) have continued to play a major role in breathtaking technological advances, ranging from the development of cost-effective lighting to advanced microelectronics, that have improved the quality of our lives in many ways. LTPs are continuing to enable technological advances in new fields, such as deactivation of antibiotic resistant bacteria, disinfection of viruses, water treatment, and cancer therapy in plasma medicine. All of these advances are enabled by the unique properties of low-temperature, non-equilibrium plasma and the chemistry they drive. Building upon fundamental plasma science, further developments are sought in plasma sources, plasma-surface interactions, and plasma control science that can enable new plasma technologies, marketable product, or impact in other areas or disciplines leading to even greater societal benefit. The focus of this topic is utilizing fundamental plasma science knowledge and turning it into new applications.

LTP science and engineering addresses research and development in partially ionized gases with electron temperatures typically below 10 eV. This is a field that accounts for an enormous range of practical applications, from light sources and lasers to surgery and making computer chips, among many others. The commercial and technical value of LTP is well established where much of this benefit has resulted from empirical development. As the technology becomes more complex and addresses new fields, such as advanced microelectronics and biotechnology, empiricism rapidly becomes inadequate to advance the state of the art. Predictive capability and improved understanding of the plasma state becomes crucial to address many of the intellectually exciting scientific challenges of this field.

All low-temperature plasma applications must have a strong commercialization potential. Grant applications are sought in the specific areas listed under the following subtopics:

a. LTP Science and Technology for Biomedical Applications

This subtopic is focused on improving our current understanding and scientific knowledge in the area of plasma chemistry, plasma-liquid and plasma-biomatter interactions related to plasma medicine. Current challenges include: development of efficient plasma sources, discharges, and/or jets for biomedical applications; improving the control of plasma produced reactive species, charged particles, photons, and fields and understanding of how these agents impact or destroy cancer cells, antibiotic resistant bacteria, COVID-19 viruses, and/or wound healing.

Note: The two subtopics: (i) LTP Science and Technology for Biomedical Applications and (ii) LTP Science and Engineering for Microelectronics and Nanotechnology are planned to be rotated subsequently.

Questions – Contact: Nirmol Podder, Nirmol.Podder@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications that can enhance the understanding of other emerging areas of plasma applications, including plasma-based water treatment, sterilization, food sanitation, and/or agriculture.

Questions – Contact: Nirmol Podder, Nirmol.Podder@science.doe.gov

References:

1. U.S. Department of Energy Office of Science, Basic Research Needs Workshop for Microelectronics, October 23-24, 2018, https://science.osti.gov/-/media/bes/pdf/reports/2018/Microelectronics_Brochure.pdf?la=en&hash=5FEFD0131FA3DA1CC8C3196452D1AFB5558DE720 (October 26, 2022)

2. U.S. Department of Energy Office of Fusion Energy Science, 2016, Plasma: At The Frontier of Scientific Discovery, Report of the Panel on Frontiers of Plasma Science, chapter 5, pp. 85-96, https://science.osti.gov/-/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf?la=en&hash=85B22EBF1CF773FFC969622524D603D755881999 (October 26, 2022)
3. National Academies of Sciences, Engineering, and Medicine, 2020, Plasma Science: Enabling Technology, Sustainability, Security, and Exploration, *Washington, DC: The National Academies Press*, https://doi.org/10.17226/25802 (October 26, 2022)
4. 2020, Powering the Future Fusion & Plasmas, *A Report of the Fusion Energy Sciences Advisory Committee*, https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf (October 26, 2022)

C56-32. INERTIAL FUSION ENERGY (IFE)

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Substantial scientific and technical progress in inertial confinement fusion has been made during the past decade. Recently, the National Ignition Facility achieved a record yield of more than 1.3 megajoules (MJ) from fusion reactions. However, many of the technologies required for an integrated inertial fusion energy system are still at an early stage of technological maturity. For example, optical components such as high-reflection (HR) and anti-reflection (AR) coatings for optics in high-energy, high-power lasers consistent with Inertial Confinement Fusion drivers must withstand fluences beyond typical industrial operation limits.

a. High Damage Threshold Optics for Inertial Fusion Energy Laser Drivers

Laser-initiated defects accumulate and grow during prolonged operation and ultimately lead to laser performance reduction, coating and optic component failure. Developing commercially viable laser drivers for an IFE powerplant will require engineered beam transport and focusing optics systems capable of operating robustly 24/7 at high energy, high average power, and MTTFs in the multi-Gigashot Regime. While comprehensive economic models will determine the requirements, optic components for a laser driven IFE plant will likely have the following nominal performance:

- Transmissive UV optics on Fused Silica or other appropriate materials: operating wavelength ≤355 nm; nominal pulse duration <10 nsec; Fluence >10 J/cm^2, average power >200 W/cm^2, T~99.7%, operating environment vacuum, Number of shots >10^9 shots where these parameters are maintained at a level for commercial viability.
- Transmissive UV optics on nonlinear crystals such as LBO or DKDP: operating tri-wavelength ≤355 nm (>10 J/cm^2), 525nm (>15 J/cm^2), 1053nm (>30 J/cm^2); nominal pulse duration <10 nsec, average power >200 W/cm^2, T~99.7%, Number of shots >10^9 shots where these parameters are maintained at a level for commercial viability.
- Reflective UV optics on Fused Silica, Ultra-low-expansion glass or other appropriate materials, and nonlinear crystals such as LBO or DKDP: operating wavelength ≤355 nm; pulse duration <10 nsec; Fluence >10 J/cm^2 (fluence in beam normal), average power >200 W/cm^2, R~99.5%, Number of shots >10^9 shots where these parameters are maintained at a level for commercial viability.

Therefore, we invite applications in development of high-damage threshold optics with a focus on:

1. Investigation of new coating materials and/or design.
2. Investigation of damage mechanisms and environment effects on coating performance.
3. Development of more sophisticated models that will quantitatively predict the laser induced damage threshold (LIDT) to realistically guide experimental efforts.
4. Identifying and parameterizing coating degradation in different environmental conditions and in the presence of neutron, ion, and x-ray flux and debris deposition.

Questions – Contact: Kramer Akli, kramer.akli@science.doe.gov

b. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas of optics that fall within the scope of the topic description above.

Questions – Contact: Kramer Akli, kramer.akli@science.doe.gov

References:

1. National Research Council, 2013, An Assessment of the Prospects for Inertial Fusion Energy, Washington DC: The National Academies Press, https://nap.nationalacademies.org/catalog/18289/an-assessment-of-the-prospects-for-inertial-fusion-energy

PROGRAM AREA OVERVIEW: OFFICE OF HIGH ENERGY PHYSICS

The goal of the Department of Energy's (DOE or the Department) Office of High Energy Physics (HEP) is to provide mankind with new insights into the fundamental nature of energy and matter and the forces that control them. This program is a major component of the Department's basic research mission. Such foundational research enables the nation to advance its scientific knowledge and technological capabilities, to advance its industrial competitiveness, and to discover new and innovative approaches to its energy future.

The DOE HEP program supports research in three discovery frontiers, namely, the energy frontier, the intensity frontier, and the cosmic frontier. Experimental research in HEP is largely performed by university and national laboratory scientists, using particle accelerators as well as telescopes and underground detectors located at major facilities in the U.S. and abroad. Under the HEP program, the Department operates the Fermi National Accelerator Laboratory (Fermilab) near Chicago, IL. The Department also has a significant role in the Large Hadron Collider (LHC) at the CERN laboratory in Switzerland. The Fermilab complex includes the Main Injector (which formerly fed the now dormant Tevatron ring), which is used to create high-energy particle beams for physics experiments, including the world's most intense neutrino beam. The Main Injector is undergoing upgrades to support the operation of Fermilab's present and planned suite of neutrino and muon experiments at the intensity frontier. Another Fermilab upgrade project called PIP-II (Proton Improvement Plan II) will greatly increase the intensity of proton beams sent to the Main Injector. The SLAC National Accelerator Laboratory and the Lawrence Berkeley National Laboratory are involved in the design of state-of-the-art accelerators and related facilities for use in high-energy physics, condensed matter research, and related fields. SLAC facilities include the two-kilometer-long Stanford Linear Accelerator capable of generating high energy, high intensity electron beams. The first kilometer of the linear accelerator are used for the Facility for Advanced Accelerator Experimental Tests (FACET-II). At Argonne National Laboratory resides the Argonne Wakefield Accelerator (AWA) facility, which houses two test electron accelerators, one for 15 MeV electrons, and the other for 70 MeV electrons. Experiments focus on two-beam and collinear wakefield acceleration as well as tests of novel accelerator structures and beam-line components. Brookhaven National Laboratory operates the Accelerator Test Facility, which supports accelerator science and technology demonstrations with electron and laser beams. While much progress has been made during the past five decades in our understanding of particle physics, future progress depends on the availability of new state-of-the-art technology for accelerators and detectors.

As stewards of accelerator technology for the nation, HEP also supports development of new concepts and capabilities that further scientific and commercial needs beyond the discovery science mission. Quantum information science is another rapidly-developing area that both benefits from expertise in the HEP community and offers novel approaches for extending HEP science. The DOE SBIR program provides a focused opportunity and mechanism for small businesses to contribute new ideas and new technologies to the pool of knowledge and technical capabilities required for continued progress in HEP research, and to turn these novel ideas and technologies into new business ventures.

Grant applications must be informed by the state of the art in High Energy Physics applications, commercially available products, and emerging technologies. An application based on merely incremental improvements or little innovation will be considered non-responsive unless context is supplied that convincingly shows its potential for significant impact or value to the DOE High Energy Physics program. DOE also expects all applicants to address commercialization opportunities for their product or service in adjacent markets such as medicine, homeland security, the environment and industry.

For additional information regarding the Office of High Energy Physics priorities, click here.

Back to Table of Contents

C56-33. ADVANCED CONCEPTS AND TECHNOLOGY FOR PARTICLE ACCELERATORS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The DOE HEP program supports a broad research and development (R&D) effort in the science, engineering, and technology of charged particle accelerators, storage rings, and associated apparatus. The strategic plan for HEP includes initiatives in the energy and intensity frontiers that rely on accelerators capable of delivering beams with the required energy and intensity. As high energy physics facilities get bigger and more costly, the DOE HEP program seeks to develop advanced technologies that can be used to reduce the overall machine size and cost, and also to develop new concepts and capabilities that further scientific and commercial needs beyond HEP's discovery science mission.

In many cases the technology sought is closely tied to a specific machine concept which sets the specifications (and tolerances) for the technology. Applicants are strongly encouraged to review the references provided. Applications to subtopics specifically associated with a machine concept that do not closely adhere to the specifications of the machine will be considered non- responsive. For subtopics that are not machine-specific, applicants are strongly advised to understand the state-of- the-art and to clearly describe in the application what quantitative advances in the technology will result.

Grant applications are sought only in the following subtopics:

a. Non-Destructive Electron Beam Position Monitors
Advancements in RF-driven and plasma-driven accelerators have resulted in the production of femtosecond-duration electron beams in an environment potentially subject to strong background EMP radiation. In order to integrate active stabilization, machine learning and artificial intelligence, as well as shot-tagged correlation studies, it is desirable to develop shot-correlated non-perturbative diagnostics for the electron beam position and pointing angle. Challenges related to the shortness of the electron beam and noisy chamber environment have frustrated conventional BPMs (beam position monitors). Applications are sought for either improvements to BPMs or for novel technologies such as fiber-integrated electro-optic sampling components and/or near-field imaging of aperture-based coherent diffraction radiation. These diagnostics should provide a path for robust, reliable, and operation-friendly passive centroid and pointing monitors for high-current ultra-short electron beams in noisy environments.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

b. Beam Control Systems for Future HEP Advanced Accelerator Facilities
Advanced accelerator applications (e.g. SWFA) call for precise control over the beam distribution [2], such as requiring specific shapes of the beams projected along one coordinate – i.e. bunch shaping. Applications are sought to develop novel systems for controlling the beam phase space that are capable of efficiently and precisely shaping the bunch at a variety of charge levels and bunch lengths including, but not limited to (i) high-charge bunches (>10 nC) with (<1 ps) resolution, (ii) multiple bunches (i.e. bunch trains) with accurate time separation (<100 fs) with minimal charge losses (<10%). Beam control methods include, but are not limited to, emittance exchange, flat beam generation with low-emittance dilution, longitudinal beam shaping using deflecting cavities or 3D laser bunch shaping for photocathode guns, control of microbunching instabilities for ultrabright electron beams, and improved understanding of CSR. Contributions can include

experiments, computational studies, and algorithmic developments. Applications that emphasize combined approaches are encouraged.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

c. High Fidelity Modeling of Advanced Accelerator Structures

Technologies leveraging structured plasmas are increasingly central to next generation particle accelerators. The application of controlled plasma channels shows promise for improving electron and positron beam energy and quality from plasma-based accelerator concepts, while plasma lens and dechirper systems can enhance beam control and diagnostics for a diverse set of high-brightness accelerator applications. The design, modeling, and optimization of structured plasma systems remain obstacles to their adoption [2,3]. Applications are sought for the development of modeling tools in support of plasma shaping technologies. Solutions capable of integrating across related systems and accelerator components are of particular interest.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

References:

1. Ha, G., Kim, K.J., et al., 2022, Bunch Shaping in Electron Linear Accelerators, *Reviews of Modern Physics 94*, 025006 – Published 31 May 2022, https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.94.025006 (November 1, 2022)
2. Biedron, S., et al., 2022, Snowmass21 Accelerator Modeling Community White Paper, *Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)*, arXiv:2203.08335v3, https://arxiv.org/pdf/2203.08335.pdf (November 1, 2022)
3. Vay, J.L., et al., 2021, Modeling of advanced accelerator concepts*, JINST 16 T10003* (2021), DOI: 10.1088/1748-0221/16/10/T10003, https://iopscience.iop.org/article/10.1088/1748-0221/16/10/T10003 (November 1, 2022)

C56-34. RADIO FREQUENCY ACCELERATOR TECHNOLOGY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Radio frequency (RF) technology is a key technology common to all high energy accelerators. RF sources with improved efficiency and accelerating structures with increased accelerating gradient are important for keeping the cost down for future machines. DOE-HEP seeks advances directly relevant to HEP applications and new concepts and capabilities that further scientific and commercial needs beyond HEP's discovery science mission.

In many cases the technology sought is closely tied to a specific machine concept which sets the specifications (and tolerances) for the technology. Applicants are strongly encouraged to review the references provided. Applications to subtopics specifically associated with a machine concept that do not closely adhere to the specifications of the machine will be considered non- responsive.

For subtopics that are not machine-specific, applicants are strongly advised to understand the state-of- the-art and to clearly describe in the application what quantitative advances in the technology will result.

a. Low-Cost Radio Frequency Power Sources for Accelerator Application

Low cost, highly efficient RF power sources are needed to power accelerators. Achieving power efficiencies of 70% or better and decreasing capital costs below $2/Watt of average power output is essential. Sources must phase lock stably (<1 degree RMS phase noise) to an external reference and have excellent output power stability (<1% RMS output power variation). Device lifetime must exceed 10,000 operating hours. Priority will be given to applications that develop RF power sources operating at frequencies that are in widespread use at the large Office of Science accelerators.

Sources may be either vacuum tube or solid state, however: (1) if the proposed source is a vacuum tube, priority will be given to applications for tubes with operating voltages below 100kV, and (2) if the proposed source is a solid-state power amplifier, strong evidence and arguments must be presented as to how the R&D will enable the cost metric above to be met. Innovative cost-reduction engineering and the application of advanced manufacturing techniques, where appropriate, are encouraged.

	Warm Accelerators	**Cold Accelerators**
Capital cost metric	$2/watt of average power	$2/watt of average power
Wall-plug-to-RF-power efficiency	70% minimum	70% minimum
Phase jitter	<1 degree RMS	<1 degree RMS
Power jitter	<1% RMS	<1% RMS
Device lifetime	>10,000 hours	>10,000 hours
RF Frequency	L-band or higher	UHF or L-band
Size	Consistent with delivering 100 MW peak every meter of the accelerator	Consistent with delivering 100 kW average every meter of the accelerator
Duty Factor	>0.1%	>5%, CW preferred
Other Requirements	If source is a tube, beam voltage <100 kV preferred If source is an SSPA, application must discuss development path to meeting $2/W metric	

Applications must clearly articulate how the proposed technology will meet **all** metrics listed in this section.

Questions – Contact: Eric Colby, Eric.Colby@science.doe.gov

b. Automation of SRF Cavity String Assembly

SRF cavities and other highly reflective metallic components are assembled together in a cleanroom environment. At present the largest impact on the quality of the assembly is the human factor. In order to minimize this impact and also to decrease touch labor and cost, vision-assisted assembly technology is of great interest. Full digitalization of the assembly area, contactless measurement of the component positions, assisted positioning and alignment are some of the steps that could be implemented. The ultimate goal is to develop a contactless technology to reconstruct the pose of highly reflective metallic components to enable a machine assisted assembly of SRF components in a cleanroom environment.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

Back to Table of Contents

c. New Superconducting RF Cavity Design

Grant applications are sought to develop:

- New SRF cavity designs with reduced RF frequency sensitivity to Lorentz-force detuning (<0.5 $Hz/(MV/m)^2$ for elliptical cavities and (<0.5 $Hz/(MV/m)^2$ for QWR, HWR and SSR) and helium bath pressure fluctuations (<10 Hz/mbar) for use in future accelerators requiring narrow-bandwidth systems, e.g., upgrade of PIP-II linac at FNAL or energy recovery linacs.
- New tunable SRF cavity designs for operation with high current beams (up to 1 A) The tuning range is to be up to 10^{-2}. The cavity should provide efficient high-order mode extraction while not sacrificing good SRF performance.
- New fabrication and processing techniques for niobium cavities to reduce the cost and improve quality factor and accelerating gradient (e.g., improved welding technique, hydroforming, doping, Nb_3Sn coating, etc.) along with new materials for SRF cavity manufacturing.
- Improved SRF low-beta cavity designs with mitigated multipacting compared to existing QWR, HWR, and SSR cavities, reduced field emission, and reduced losses.
- Development of the universal data interface for data exchange between the different commercial codes used for SRF cavity design. For example, the data interface between EM codes – CST, HFSS, COMSOL, and mechanical – ANSYS. For example, an interface between EM codes – CST and beam dynamics code MICHELLE.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

References:

1. Hartill, D., 2015, Accelerating Discovery: A Strategic Plan for Accelerator R&D in the U.S., *U.S. Department of Energy Office of Science*, April 2015, https://science.osti.gov/-/media/hep/hepap/pdf/Reports/Accelerator_RD_Subpanel_Report.pdf (see especially section 7) (November 1, 2022)
2. Blazey, G., Radiofrequency Accelerator R&D Strategy Report, *DOE HEP General Accelerator R&D RF Research Roadmap Workshop*, March 8-9, 2017, https://science.osti.gov/-/media/hep/pdf/Reports/DOE_HEP_GARD_RF_Research_Roadmap_Report.pdf (see especially section 5) (November 1, 2022)
3. Henderson, S., Waite, T., 2015, Workshop on Energy and Environmental Applications of Accelerators, *U.S. Department of Energy Office of Science*, see especially section 2.11, 2015, http://science.osti.gov/~/media/hep/pdf/accelerator-rd-stewardship/Energy_Environment_Report_Final.pdf (November 1, 2022)
4. Zorzetti, S., 2020, Computer Vision solutions for Robot-assisted technology in SRF assembly at Fermilab, *CERN*, February 4-7, 2020, https://indico.cern.ch/event/817780/contributions/3716530/ (November 1, 2022)

C56-35. LASER TECHNOLOGY R&D FOR ACCELERATORS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES

Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Lasers are used or proposed for use in many areas of accelerator applications: as drivers for novel accelerator concepts for future colliders; in the generation, manipulation, and x-ray seeding of electron beams; in the generation of electromagnetic radiation ranging from THz to gamma rays; and in the generation of neutron, proton, and light ion beams. In many cases ultrafast lasers with pulse lengths well below a picosecond are required, with excellent stability, reliability, and beam quality. With applications demanding ever higher fluxes of particles and radiation, the driving laser technology must also increase in repetition rate—and hence average power—to meet the demand. Please note that applications submitted in this topic should clearly articulate the relevance of the proposed R&D to HEP's mission.

This topic area is aimed at developing technologies for (1) ultrafast lasers capable of high average power (kilowatt-class) operating at the high electrical-to-optical efficiency (>20%) needed for advanced accelerator applications, and (2) high average power custom-pulse-structure lasers for proton and ion beam manipulation and diagnosis.

Accelerator applications of ultrafast lasers call for one of the following four basic specifications:

	Type I	Type II	Type III	Type IV
Wavelength (micron)	1.5-2.0	0.8-2.0	2.0-5.0	2.0-10.0
Pulse Energy	3 microJ	3 J	0.03–1 J	300 J
Pulse Length	300 fs	30–100 fs	50 fs	100–500 fs
Repetition Rate	1–1300 MHz	1 kHz	1 MHz	100 Hz
Average Power	Up to 3 kW	3 kW	3 kW and up	30 kW
Energy Stability	<1 %	<0.1%	<1%	<1%
Beam Quality	M^2<1.1	Strehl>0.95	M^2<1.1	M^2<1.1
Wall-plug Efficiency	>30%	>20%	>20%	>20%
Pre-Pulse Contrast	N/A	>10^{-9}	N/A	>10^{-9}
CEP-capable	Required	N/A	Required	N/A
Optical Phase Noise	<5°	N/A	<5°	N/A
Wavelength Tunability Range	0.1%	0.1%	10%	0.1%

In category (2), longer-pulse lasers are finding increasing application in the control and diagnosis of proton and H-minus beams. Near IR lasers are used in a variety of applications ranging from partial neutralization of H-minus beams (0.75 eV binding energy) for diagnostics to total neutralization (for notching and phase space sculpting). UV lasers are used for stripping neutral hydrogen beams (13.6 eV binding energy) by resonantly exciting the atom, then Lorentz stripping the more loosely bound electron in a strong magnetic field. As proton machines move steadily into the megawatt beam power range, the need for non-intercepting techniques to control and diagnose such beams will motivate increased use of lasers, and the increased duty factor of such machines will motivate increases in the average power of lasers used for this purpose.

Grant applications are sought to develop lasers and laser technologies for accelerator applications only in the following specific areas:

a. High Energy and Broadband Components for Fiber Lasers and Arrays

Back to Table of Contents

Due to their high average power capability and high wall-plug efficiency, ultrafast fiber lasers are promising for driving high rep-rate laser-plasma accelerators, generating radiation from THz to gamma rays, and as important tools for material processing. Realizing this requires pulse energies and durations not now achievable from fiber lasers. Coherent combination of ultrafast fiber lasers, in spatial and temporal domains, potentially provides a path to pulse energies up to Joules, with high average powers and efficiencies well beyond the current generation of lasers. Pulse duration limitation of fiber lasers can be overcome using spectral combining of multi-band fiber lasers, which has the potential to achieve tens of femtosecond durations.

The practicality of aggregating a large number of fiber amplifiers requires that each is implemented as a compact and robust module. However, current state-of-the-art specialty fibers with 50–100 micron core diameters, which produce the highest pulse energies in diffraction-limited beams, lack fiber-optic components which can be fusion-spliced into monolithically-integrated subsystems.

Spectral combining of ultrafast fiber lasers (Yb-doped) will need fiber components optimized at different bands within the Yb gain spectrum. However, most fiber components in the current market are optimized with a central wavelength only in the range of 1040-1065 nm, and a bandwidth up to ~30 nm.

Grant applications are sought to demonstrate and develop fiber laser components for module integration (monolithic pump combiners, mode adapters, optical interconnects, residual-pump-power strippers, etc.), as well as complete integrated amplifier subsystems using 50–100 micron core specialty fibers with diffraction-limited output. These components and subsystems should sustain multi-mJ pulse energies and average powers in the 100 W – 1 kW range, when operating within the ~1 micron gain spectrum of Yb-doped fibers. In addition, applications are sought to develop and demonstrate fiber components for spectral combination (WDMs, isolators, etc.), both single-mode and large-mode-area, with spectral boundaries extended to <1010 nm OR >1090 nm and covering a broad band (>30-40 nm bandwidth). Cost-effective solutions are particularly encouraged.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

b. High Damage Threshold Large Area Spatial Light Modulators

The size and damage tolerance of active laser optics are a key limit in the compactness, performance, and durability of lasers. Realizing compact, high efficiency lasers combining high peak and average powers strongly motivates improved damage threshold for active optics.

Active shaping of the laser mode is key to many applications, and active elements such as spatial light modulators currently suffer from low intensity and fluence tolerance which limits their application.

Applications are sought to develop larger area SLMs (30mm width up to 100mm) to allow for (chirped) Joule-class lasers to be spatially manipulated. Increasing the active aperture, power density tolerance, and damage fluence by applying high reflectance dielectric coatings, active cooling, and stabilization mechanisms is needed. SLMs may be optimized for 0.8- or 1-micron lasers and must be designed with minimal GVD to support ultrafast pulses (>10% bandwidth). A finished large-area SLM that can tolerate incident average power densities of >300 W/cm^2 and incident fluences of >0.25 J/cm^2 per pulse in 30 fsec (stretched) pulses is the goal.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

c. Feedback Systems for Control of High Intensity Laser Mode and Delivery

Back to Table of Contents

Reduction of shot-to-shot variations in high-power lasers is a key driver to allowing increased control of the physics mechanisms at play, and hence dramatically reducing the variations in applications such as accelerators and machining. The environmental factors (resulting from environmental factors such as fluctuations in temperature, sound, vibration, and humidity) are typically dominated by <100Hz spectral components (for example, a specific mirror mount might have a vibration resonance at 40.6Hz) and are thus well suited to be compensated with fast feedback systems. Of interest is stabilization wavefront, amplitude, and phase of the laser, and potentially pointing of high peak power (10's TW) systems which use approximately 4"-12" optics. Such systems in the long term are envisioned at kHz rates, and at present when only Hz-class rates are available could use high-rate pilot lasers for correction.

Applications are sought on the development of fast feedback systems to correct laser parameters such as a spectral-phase, wavefront, amplitude, and transverse mode content. For large optics only (i.e., ≥100mm diameter), correction of transverse position of the final focus, pointing angle of the focused beam are also of interest (Commercial systems exist for pointing control of 50mm diameter optics and are not covered here). Systems should be capable of mitigation of frequencies up to ~100Hz. Such systems would include diagnostics (preferably non-perturbative), correcting hardware, and a fast feedback control system. Ability to correct systems requiring large optics ≥100mm in size (piezo mirrors, deformable mirrors, etc.) is of particular interest.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

References:

1. U.S Department of Energy Office of Science, 2013, Workshop on Laser Technology for Accelerators: Summary Report, *U.S. Department of Energy,* p. 47, January 23-25, 2013, https://projects-web.engr.colostate.edu/accelerator/reports/Lasers_for_Accelerators_Report_Final.pdf (November 1, 2022)
2. Hogan, M.J., 2016, Advanced Accelerator Concepts 2014: 16th Advanced Accelerator Concepts Workshop, *AIP Conference Proceedings*, San Jose, C.A., Vol. 1777, 010001, ISBN: 978-0-7354-1439-6, 2016, https://aip.scitation.org/toc/apc/1777/1?expanded=1777 (November 1, 2022)
3. Simakov, E., et al., 2018, Preface: 18th Advanced Accelerator Concepts Workshop (AAC 2018), *2018 IEEE Advanced Accelerator Concepts Workshop (AAC)*, 2018, pp. 1-1, https://ieeexplore.ieee.org/document/8659389 (November 1, 2022)
4. Fazio, M., et al., 2019, Basic Research Needs Workshop on Compact Accelerators for Security and Medicine: Tools for the 21st Century, May 6-8, 2019, United States: N. p., https://www.osti.gov/servlets/purl/1631121 (November 2, 2022)

C56-36. HIGH FIELD SUPERCONDUCTING MAGNET TECHNOLOGY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

Superconducting magnets are widely used in particle accelerators for beam steering and focusing. Advanced R&D is needed in support of this research in high-field superconductor and superconducting magnet technologies. This topic addresses only those superconducting magnet development technologies that support accelerators, storage rings, and charged particle beam transport systems and only those superconducting wire technologies that support long strand lengths suitable for winding magnets without splices. For referral to lab and university scientists in your area of interest contact: Ken Marken, ken.marken@science.doe.gov.

Grant applications are sought only in the following subtopics:

a. High-Field HTS Wire and Cable Technologies for Magnets

Grant applications are sought to develop improved High Temperature Superconducting (HTS) wire for magnets that operate above 18 Tesla (T). Applications should address demonstration scale (>1 km lengths) and/or production scale (> 3 km continuous lengths) wire technologies. Current densities should be at least 400 amperes per square millimeter of strand cross-section (often called the engineering current density) at 20 T and 4.2 K temperature. Tooling and handling requirements restrict wire cross-sectional area to the range 0.4 to 2.0 square millimeters, with transverse dimension not less than 0.25 mm. Of specific interest are the HTS materials Bi2Sr2CaCu2O8 (Bi-2212) and (RE) Ba2Cu3O7 (ReBCO) that are engineered for high field magnet applications. All grant applications must result in wire technology that will be acceptable for accelerator magnets, including not only the operating conditions mentioned above, but also production of a sufficient amount of material (1 km minimum continuous length) for winding and testing cables and subscale coils.

New or improved wire or cable technologies must demonstrate at least one of the following criteria in comparison to present art:

- property improvement, such as higher current density at fields above 18 T;
- improved tolerance to property degradation as a function of applied strain;
- reduced transverse dimensions of the superconducting filaments (sometimes called the effective filament diameter), in particular to less than 30 micrometers at 1 mm wire diameter, with minimal concurrent reduction of the thermal conductivity of the stabilizer or strand critical current density;
- HTS cables supporting 10 to 30 kA currents with engineering current density above 600 A/mm^2, lower losses under changing transverse magnetic fields, and/or improved tolerance to transverse stress;
- significant cost reduction for equal performance in all regards, especially current density and length.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

b. Cryogenic Power Electronics for Distributed Powering and Quench Protection of HTS and Hybrid Magnets

Powering and protection of high-field superconducting magnets are traditionally accomplished with current control and energy extraction systems operating at ambient temperature. These systems are costly, have low energy efficiency and put significant limitations on the powering and depowering profiles that can be executed. Recent advances in power electronics have enabled a new class of MOSFET devices that exhibit extremely low resistance in the “closed” state and allow for cryogenic operation. Implementation of these devices with superconducting magnets would significantly reduce cost and complexity of magnet powering infrastructure and enable novel capabilities such as independent current control for hybrid HTS/LTS magnet coils from a single power supply and generation of special AC current waveforms for clearing remnant magnetization or boosting protection through ac loss mechanisms.

Applications for practical implementation of a viable cryogenic power control system for superconducting magnets are sought.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

References

1. Larbalestier, D., Jiang, J., Trociewitz, U.P., et al., 2014, Isotropic Round-Wire Multifilament Cuprate Superconductor for Generation of Magnetic Fields Above 30 T, *Nature Materials,* vol.13, p. 375, 2014, https://www.nature.com/articles/nmat3887 (November 2, 2022)
2. Maeda, H., Yanagisawa, Y., Recent Developments in High-Temperature Superconducting Magnet Technology (Review), *IEEE Transactions on Applied Superconductivity*, vol. 24, no. 3, 4602412, 2014, https://ieeexplore.ieee.org/document/6649987 (November 2, 2022)
3. Todesco, E., Bottura, L., Rijk, G., et al., 2014, Dipoles for High-Energy LHC*, IEEE Transactions on Applied Superconductivity*, vol. 24, no. 3, 4004306, 2014, https://ieeexplore.ieee.org/document/6656892 (November 2, 2022)
4. IOP Science, 2021, Advances in Cryogenic Engineering – Materials: Proceedings of the International Cryogenic Materials Conference (ICMC) 2021, *2021 IOP Conference Series: Materials Science and Engineering*, https://iopscience.iop.org/issue/1757-899X/1241/1 (November 1, 2022)
5. IOP Science, 2021, Advances in Cryogenic Engineering: Proceedings of the Cryogenic Engineering Conference (CEC) 2021*, IOP Conference Series: Materials Science and Engineering*, https://iopscience.iop.org/issue/1757-899X/1240/1 (November 2, 2022)
6. Scanlan, R., Malozemoff, A.P., Larbalestier, D.C., 2004, Superconducting Materials for Large Scale Applications, *Proceedings of the IEEE,* vol. 92, issue 10, pp. 1639-1654, 2004, https://www.researchgate.net/publication/2986363_Superconducting_materials_for_large_scale_applications (November 2, 2022)
7. Proceedings of the 2020 Applied Superconductivity Conference, IEEE Transactions on Applied Superconductivity, *A Publication of the IEEE Council on Superconductivity*, vol. 31 no. 5, 2021, https://ieeexplore-ieee-org.proxy.scejournals.org/xpl/tocresult.jsp?isnumber=9351575&punumber=77 (November 2, 2022)
8. The 26th International Conference on Magnet Technology, IEEE Transactions on Applied Superconductivity, vol. 30 no. 4, 2020, https://ieeexplore-ieee-org.proxy.scejournals.org/xpl/tocresult.jsp?isnumber=8952829 (November 2, 2022)

C56-37. HIGH ENERGY PHYSICS ELECTRONICS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

High Energy Physics experiments require advanced electronics and systems for the acquisition and processing of experimental data. As an example, high-priority future experiments in the DOE Office of High Energy Physics (HEP) portfolio need advances that can benefit from small business contributions. These experiments include potential upgrades to the High Luminosity Large Hadron Collider (HL-LHC) detectors currently under construction (see https://home.cern/science/accelerators/large-hadron-collider) or other potential future High Energy Colliders, neutrino experiments including those sited deep underground (e.g., https://www.dunescience.org), next-generation direct searches for dark matter, and astrophysical surveys to understand dark energy, including cosmic microwave background experiments.

We seek small business industrial partners to advance the state of the art and/or increase cost effectiveness of electronics needed for the above experiments and for the wider HEP community. Specific technical areas are given in the subtopics below. These are areas where experimental needs have been defined and shortcomings of existing technology identified. R&D seeking new technology will typically be in progress at DOE national laboratories and/or DOE-funded universities. While the subtopics offer initial guidance about specific technology areas, the scientists involved are the best source of detailed information about requirements and relevance to the experimental programs listed above. Applicants are therefore urged to make early contact with lab and university scientists in order to develop germane applications. Clear and specific relevance to HEP programmatic needs is required and supporting letters from lab and university scientists are an excellent way to show such relevance. Direct collaboration between small businesses and national labs and universities is strongly encouraged. For referral to lab and university scientists in your area of interest contact:
Helmut Marsiske, helmut.marsiske@science.doe.gov.

Grant applications are sought in the following subtopics:

a. Radiation-Hard Sensors and Engineered Substrates for Detectors at High Energy Colliders

Silicon detectors for high energy particle physics are currently based on hybrid technology, with separately fabricated diode strip or pixel sensors and bump-bonded Complementary Metal Oxide Semiconductor (CMOS) readout chips. As larger area detectors are required for tracking, and for new applications such as high-granularity calorimetry, new sensor concepts and lower manufacturing cost are needed. Sensors must withstand both ionizing and displacement damage radiation, and they must have fast signal collection and fast readout, as well as radiation tolerance in the range 100 to 1000 Mrad and 1E14 to 2E16 neutron-equivalent fluence.

Of interest are applications in the following focus areas:

- We seek monolithic CMOS-based sensors with moderate depth (5–20 micron) high resistivity substrates that can be fully depleted and can achieve charge collection times of 20 ns or less. Technologies of interest include deep n- and p-wells to avoid parasitic charge collection in CMOS circuitry and geometries with low-capacitance charge collection nodes. We aim for stitched, large-area arrays of sensors with sensor thickness less than 50 microns and pixel pitch of less than 25 microns.
- We also seek low to moderate gain (×10–50) reach-through silicon avalanche diodes (LGADs) as a proposed sensor type to achieve ~10 ps time resolution for collider experiments. The current generation of reach-through diodes suffers from large fractional dead area at the edges of the pixel and only moderate radiation hardness. A moderately doped thin buried (~5 micron) layer replacing a reach-through implant can address some of these problems. We seek substrate fabrication technologies to improve the radiation hardness and stability of these devices by using graded epitaxy or wafer bonding to produce a buried and moderately doped (1E16) thin buried gain layer on a high resistivity substrate. We also seek techniques to arrange internal doping of detectors by multiple thick epitaxial layers or other methods to allow engineering of the internal fields and resulting pulse shape.
- Development of sensors fabricated in materials other than silicon and with enhanced performance was identified as a priority research direction in [1]. A promising development is with ultrafast sensors using Silicon Carbide (SiC), a large bandgap material for which industry is currently focused mainly on power electronics applications. We seek development of thick epitaxially grown SiC with low n-type doping as a new substrate material for the development of ultrafast, radiation-hard, high-temperature SiC-based sensors.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

b. High-Density Chip Interconnect Technology

With the large channel counts and fine granularity of HEP detectors, there is an ever-increasing need for new technologies for higher-density interconnects. Applications are sought for the development of new technologies for reducing cost while increasing the density of interconnection of pixelated sensors to readout electronics by enhancing or replacing solder bump-based technologies. Development of cost-effective technologies to connect arrays of thinned integrated circuits (<50 microns with areas of ~2×2 cm^2) to high-resistivity silicon sensors with interconnect pitch of 50 microns or less are of interest. Technologies are sought that can minimize dead regions at device edges and/or enable wafer-to-wafer interconnection, by utilizing 3D integration with through-Si vias or other methods. Present commercial chip packaging and mounting technologies can, at cryogenic temperatures, put mechanical stress on the silicon die which distorts the operation of the circuit. Low-cost and robust packaging and/or interconnect solutions that do not introduce such stresses would be of advantage—especially in the case of large-area circuit boards (>0.5 m on each edge).

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

c. Electronics Systems for Ultra-Low-Temperature Experiments

Many HEP experiments are operated in the deep cryogenic regime (10–100 mK) with large numbers of readout channels required. Data acquisition and control signals from the mK stage out to room temperature require high-fidelity RF signals, extremely low noise, and low thermal load on the cryogenic systems. Applications range from future CMB experiments that will have large focal plane arrays with ~500,000 superconducting detector elements, to axion dark matter searches with similar channel counts to reach to high axion masses, to large-scale phonon-based particle-like dark matter searches.

Specific areas of interest include: low-noise cryogenic amplifiers (HEMT, SQUID, parametric, etc.); high-density cryogenic interconnects for mK to LHe to room temperature stages; low-power (<100 mW per channel), high-resolution (14 bits or more), high-sampling rate (200 kHz or more) ADCs operating at 4 K or below; scalable high-density superconducting interconnects for micro-fabricated superconducting devices; high-frequency superconducting flex circuits; specialized electronics for processing large numbers of frequency-domain multiplexed RF signals; wafer processing combining niobium metal and MEMS; fabrication of miniature, ultra-low loss, superconducting resonator arrays; and electronic frequency tuning mechanisms for microwave resonators.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

References:

1. 2020, DOE Basic Research Needs Study on High Energy Physics Detector Research and Development, Aug 2020 *BRN Report*, https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf (November 2, 2022)

2. TWEPP 2022 Topical Workshop on Electronics for Particle Physics, *Indico, CERN*, Bergen, Norway, Sep 19–23, 2022, https://indico.cern.ch/event/1127562/ (November 2, 2022)
3. 25th International Conference on Computing in High Energy and Nuclear Physics (vCHEP), *Indico, CERN*, Online, May 17–21, 2021, https://indico.cern.ch/event/948465/ (November 2, 2022)
4. PM2021 – 15th Pisa Meeting on Advanced Detectors, *Indico*, La Biodola, Isola d'Elba, Italy, May 22–28, 2022, https://agenda.infn.it/event/22092/ (November 2, 2022)
5. International Conference on Technology and Instrumentation in Particle Physics (TIPP2021), *Indico, CERN*, Online, May 24–28, 2021; https://indico.cern.ch/event/981823/ (November 2, 2022)
6. 23rd IEEE Real-Time Conference, *Indico, CERN*, Online, Aug 1–5, 2022, https://indico.cern.ch/event/1109460/ (November 2, 2022)
7. VCI2022 – The 16th Vienna Conference on Instrumentation, *Indico, CERN*, Online, Feb 21–25, 2022, https://indico.cern.ch/event/1044975/ (November 2, 2022)
8. Braga, D., Li, S., and Fahim, F., 2021, Cryogenic Electronics Development for High-Energy Physics: An Overview of Design Considerations, Benefits, and Unique Challenges, *IEEE Solid-State Circuits Magazine* 13 (2021) 36–45, https:/doi.org/10.1109/mssc.2021.3072804 (November 2, 2022)

C56-38. HIGH ENERGY PHYSICS DETECTORS AND INSTRUMENTATION

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

High Energy Physics experiments require specialized detectors for particle and radiation detection. As an example, high-priority future experiments in the DOE Office of High Energy Physics (HEP) portfolio need advances that can benefit from small business contributions. These experiments include potential upgrades to the High Luminosity Large Hadron Collider (HL-LHC) detectors currently under construction (see https://home.cern/science/accelerators/large-hadron-collider) or other potential future High Energy Colliders, neutrino experiments including those sited deep underground (e.g., https://www.dunescience.org), next-generation direct searches for dark matter, and astrophysical surveys to understand dark energy, including cosmic microwave background experiments.

We seek small businesses to advance the state of the art and/or increase cost effectiveness of detectors needed for the above experiments and for the wider HEP community. Specific technical areas are given in the subtopics below. These are areas where experimental needs have been defined and shortcomings of existing technology identified. Improvements in the sensitivity, robustness, and cost effectiveness are sought. R&D towards these ends will typically be in progress at DOE national laboratories and/or DOE-funded universities. While the subtopics offer initial guidance about specific detector areas, the scientists involved are the best source of detailed information about requirements and relevance to the experimental programs listed above. Applicants are therefore urged to make early contact with lab and university scientists in order to develop germane applications. Clear and specific relevance to HEP programmatic needs is required and supporting letters from lab and university scientists are an excellent way to show such relevance. Direct collaboration between small businesses and national labs and universities is strongly encouraged. For referral to lab and university scientists in your area of interest contact: Helmut Marsiske, helmut.marsiske@science.doe.gov.

Grant applications are sought in the following subtopics:

a. Low-Cost, High-Performance (V)UV/Visible/Near-IR Photon Detection

Particle physics detectors need to cover large areas with high-sensitivity photodetectors. Requirements include combinations of the following: 1) Wavelength sensitivity in the range 100–1100 nm over large photosensitive areas; 2) Fast response, radiation hardness, magnetic field compatibility, and high quantum efficiency for collider and intensity frontier experiments; 3) Compatibility with cryogenic operation and built with low-radioactivity materials for neutrino and dark matter experiments; and 4) Low cost and high reliability. Technologies using modern manufacturing processes and low-cost materials are of interest. These include use of semiconductor-based avalanche photodiodes (APD) and Geiger mode APD arrays, SiPM arrays, large-area microchannel plate-based systems (highly pixilated, fast readback with position resolution of less than 0.3 mm and time resolution of less than 100 ps), new alkali and non-alkali photocathode materials, and high-volume manufacturing of large-area, ultra-clean, sealed vacuum assemblies.

For collider and intensity frontier experiments, grant applications are sought to develop and advance wide-bandgap solid-state photodetector technology with internal gain that has low dark current, good radiation hardness, and reduced gain sensitivity to temperature.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

b. Scintillating Detector Materials and Wavelength Shifters

HEP utilizes scintillating materials for large calorimeters in colliding beam and intensity frontier experiments as well as for the active medium in some neutrino and dark matter detectors. Development of radiation-hard (tens of Mrad), fast (tens of ns) scintillators and wavelength shifting materials is of particular interest for colliding beam experiments. Development of fast (tens of ns), wavelength-matched shifting materials is of interest for liquid-argon and liquid-xenon detectors for neutrinos and dark matter. Large (>100 cm^3), bright (>10,000 ph/MeV), fast (tens of ns), radiation-hard (tens to hundreds of Mrad) ceramics or glasses with high density (>6 g/cm^3) are of interest for intensity frontier experiments as well as colliding beam experiments if high-volume (multi-m^3), cost-effective (few $\$/cm^3$) production methods can be developed.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

c. Low Radioactivity Integration Solutions for Cryogenic Detectors

Cryogenic detectors used to search for rare dark matter and neutrino interactions, as well as some quantum devices, are sensitive to radioactive backgrounds (see, e.g., [13–16]). As future experiments aim to achieve unprecedented sensitivities, material radiopurity requirements are becoming ever more stringent. The most concerning contaminants are the primordial radionuclides ^{40}K, ^{232}Th, ^{238}U, and their decay progeny. Radioactive impurities in materials located close to active detector components have a disproportionately large impact, resulting in the need for new integration solutions for the packaging and wiring of cryogenic detectors.

Applications are sought in the following areas:

- An important challenge is the electronic packaging of several thousand silicon sensors (e.g., CCDs, CMOS) for cryogenic operation at 140 K (as in [17]). This packaging connects the sensors to their front-end electronics. Current solutions typically include hand assembly of ceramic based packages, which are expensive ($100/sensor) and have a radiation background 100× larger than the requirements. We seek development of alternative packaging techniques for a large volume of sensors in low-radioactive-background cryogenic experiments, with the goal of producing systems capable packaging ten thousand silicon sensors with a radiation-background rate below 1 event/kg/day/keV and sub-electron readout noise.
- A common element in the packaging of superconducting devices (e.g., qubits or advanced sensors) for operation at mK temperatures is an interconnect board: a printed circuit board (PCB) laminate to which active elements are wire bonded and to which RF coax connectors are attached. The laminate must have low dielectric loss to avoid negatively impacting device performance and often has a

thermal expansion coefficient close to that of copper to avoid delamination of traces. Common materials (e.g., alumina, and advanced laminates such as Rogers TMM and RO4000) typically include ceramics, which are often high in natural radioactivity that can negatively impact device performance or sensitivity. We seek identification of a new material or process improvement to reduce the laminate radioactivity to less than ~100 mBq/kg, while maintaining the desired electrical and physical properties.

- Radiopure superconducting cables are needed for next-generation dark matter detectors and possibly quantum sensors. The cables must achieve ppt levels of U and Th and a ppb level of K. Non-superconducting radiopure flexible cables have been developed [18], but additional R&D is required for superconducting materials. Cables must satisfy thermal and electrical requirements for HEP instrumentation; general considerations include operation at mK temperatures, traces with an appropriate superconducting transition temperature (T_c > 2 K with > 4 K preferred), low thermal conductivity (example heat loads are available in the literature; see, e.g., [19] and Table 2 in [20]), low parasitic resistance (~mOhm/trace), and possibly low inductance (~100 nH/trace).

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

References:

1. 2020, DOE Basic Research Needs Study on High Energy Physics Detector Research and Development, Aug 2020 *BRN Report*, https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf (November 2, 2022)
2. Demarteau, M., Lipton, R., Nicholson, H., et al., 2014, Chapter 8: Instrumentation Frontier Report, Planning the Future of U.S. Particle Physics, *arXiv:1401.6116*, p. 44, 2013, https://arxiv.org/pdf/1401.6116v1.pdf (November 2, 2022)
3. 2018, Demarteau, M., and Shipsey, I., 2018, New Technologies for Discovery, *A report of the 2018 DPF Coordinating Panel for Advanced Detectors (CPAD) Community Workshop,* 2019, https://cds.cern.ch/record/2688980/?ln=en (November 2, 2022)
4. 2015, International Conference on New Photo-Detectors, *PhotoDet 2015*, Moscow, Troitsk, Russia, Jul 6–9, 2015, https://pos.sissa.it/252/ (November 2, 2022)
5. 2017, 8th International Conference on New Developments in Photodetection (NDIP17), Tours, France, Jul 3–7, 2017, *Conference Proceedings*, https://inspirehep.net/conferences/1633680 (November 2, 2022)
6. 2022, 17th Trento Workshop on Advanced Silicon Radiation Detectors, *TREDI 2022*, Online, Mar 2–4, 2022, https://indico.cern.ch/event/1096847/ (November 2, 2022)
7. Casse, G., Moll, M., et al., 2021, Radiation Hard Semiconductor Devices for Very High Luminosity Colliders, *RD50 Status Report at 147th LHCC Meeting,* Sep 1–2, 2021, https://indico.cern.ch/event/1062348/ (November 2, 2022)
8. 2022, RD50-Radiation Hard Semiconductor Devices for Very High Luminosity Colliders, RD50 Workshop, Freiburg, Germany, Juny 2009, http://rd50.web.cern.ch/ (November 2, 2022)
9. Brau, J.E., Jaros, J.A., and Ma, H., 2010, Advances in Calorimetry, *Annual Review of Nuclear and Particle Science*, Vol. 60 (2010) p. 615–644, http://www.annualreviews.org/doi/abs/10.1146/annurev.nucl.012809.104449 (November 2, 2022)

10. Snowmass, 2022, Report of the Topical Group on Calorimetry, *arXiv:2208.12861*, 2022, https://arxiv.org/abs/2208.12861 (November 2, 2022)
11. 2021, The 19th International Workshop on Low Temperature Detectors (LTD19), *NIST*, Online, Jul 19–29, 2021, https://www.nist.gov/news-events/events/2021/07/19th-international-workshop-low-temperature-detectors-ltd19 (November 2, 2022)
12. Forti, F., and Paoletti, R., 2022, PM2021 – 15th Pisa Meeting on Advanced Detectors, *Indico*, La Biodola, Isola d'Elba, Italy, May 22–28, 2022, https://agenda.infn.it/event/22092/ (November 2, 2022)
13. International Conference on Technology and Instrumentation in Particle Physics (TIPP2021), *Indico, CERN*, Online, May 24–28, 2021, https://indico.cern.ch/event/981823/ (November 2, 2022)
14. 2021 IEEE Symposium on Radiation Measurements and Applications, *IEEE SORMA West*, Online, May 19–28, 2021, http://sormawest.org/ (November 2, 2022)
15. VCI2022 – The 16th Vienna Conference on Instrumentation, *Indico, CERN*, Online, Feb 21–25, 2022, https://indico.cern.ch/event/1044975/ (November 2, 2022)
16. Akerib, D.S., et al., 2020, The LUX-ZEPELIN (LZ) radioactivity and cleanliness control programs, *Eur. Phys. J. C* 80 (2020) 1044, https://doi.org/10.1140/epjc/s10052-020-8420-x (November 2, 2022)
17. Agnese, R., et al., 2017, Projected sensitivity of the SuperCDMS SNOLAB experiment, *Phys. Rev. D* 95 (2017) 082002, https://doi.org/10.1103/PhysRevD.95.082002 (November 2, 2022)
18. Vepsäläinen, A.P., et al., Impact of ionizing radiation on superconducting qubit coherence. *Nature* 584 (2020) 551–556, https://doi.org/10.1038/s41586-020-2619-8 (November 2, 2022)
19. McEwen, M., et al., 2022, Resolving catastrophic error bursts from cosmic rays in large arrays of superconducting qubits, *Nature Phys.* 18 (2022) 107–111, https://doi.org/10.1038/s41567-021-01432-8 (November 2, 2022)
20. Aguilar-Arevalo, A., et al., The Oscura Experiment, 2022 *Preprint*, https://doi.org/10.48550/arXiv.2202.10518 (November 2, 2022)
21. Arnquist, I.J., et al., 2020, Ultralow radioactivity Kapton and copper-Kapton laminates, *NIMA* 959 (2020) 163573, https://doi.org/10.1016/j.nima.2020.163573 (November 2, 2022)
22. Krinner, S., et al., 2019, Engineering cryogenic setups for 100-qubit scale superconducting circuit systems, *EPJ Quantum Technol.* 6 (2019) 2, https://doi.org/10.1140/epjqt/s40507-019-0072-0 (November 2, 2022)
23. Hollister, M.I., et al., 2017, The cryogenics design of the SuperCDMS SNOLAB experiment, *IOP Conf. Ser. Mater. Sci. Eng.* 278 (2017) 012118, https://doi.org/10.1088/1757-899X/278/1/012118 (November 2, 2022)

C56-39. ARTIFICIAL INTELLIGENCE/MACHINE LEARNING FOR ACCELERATORS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

High Energy Physics accelerators provide access to the some of the world's most advanced research instruments and produce increasingly larger quantities of data. Reaching the full potential of the rapidly growing data streams requires new innovations to solve a variety of technical challenges in data acquisition, control, modeling, and analysis. Artificial intelligence and machine learning (AI/ML) have opened corresponding new avenues in optimization, efficient surrogate models, data analytics, and inverse problems. These intriguing capabilities suggest that AI/ML can greatly accelerate the quest to probe and understand fundamental phenomena across a vast range of lengths and timescales, potentially leading to transformative advances across scientific disciplines.

AI/ML approaches can have a significant impact on increasing the operational efficiencies of large, complex scientific facilities and instrumentation. AI/ML approaches, for example, can be used to predict detector and accelerator component performance which can result in improved performance and higher beam availability for research.

We seek small business industrial partners to advance the state of the art and/or increase cost effectiveness of implementation of data science techniques such as AI/ML to improve operations of large accelerator complexes, including development of tools and techniques that enable guided optimization, semi-autonomous operations, de-noising and data mining, digital twins (e.g., virtual laboratories), and failure anticipation.

Grant applications are sought in the following subtopics:

a. Machine Learning, Diagnostics, Controls and Digital Twins for Particle Accelerators

Machine learning (ML) promises significant enhancements for particle accelerator operations, including applications in diagnostics, controls, and modeling. However, it is essential that as these promising ML methods are experimentally demonstrated before being deployed at user facilities. The ability to generalize the training and deployment of ML algorithms to different operating configurations for the same beamline, or between facilities, remains a challenge. Applications are sought to develop novel algorithms and associated software to support the training and deployment of ML tools at accelerator facilities. Developments, which facilitate domain transfer between facilities and diagnostic types, are highly encouraged. Applications for ML based high fidelity surrogate models, or digital twins, that improve the accuracy of accelerator simulation or reduce the computing time needed to simulate accelerators are sought. Successful applications must include plans for experimental demonstration and validation.

Questions – Contact: Jeremy Love, Jeremy.Love@science.doe.gov

b. Adaptive Online Machine Learning for Dynamic Beam Diagnostics

Particle accelerators are large complex systems composed of hundreds to thousands of interconnected electro-magnetic components including radio frequency (RF) resonant accelerating structures for beam acceleration and longitudinal focusing and various magnets for beam steering and transverse focusing. Charged particle beams are themselves complex objects living in a six-dimensional phase space. They undergo complex collective effects such as coherent synchrotron radiation and vary with time in unpredictable ways. Sources of variation include accelerator RF phase and amplitude jitter, and magnet current jitter, and time-varying laser intensities and photoemission at the beam source. As bunches become shorter and more intense, the effects of intra-bunch collective interactions such as space charge forces and bunch-to-bunch influences such as wakefields also increase. Short, intense bunches are extremely difficult to accurately image because their dimensions are beyond the resolution of existing diagnostics and they may be destructive to intercepting diagnostics.

Applications are sought for the design and implementation of adaptive machine learning methods as applied to time-varying systems since they have the potential to aid in the diagnostics and control of high-intensity, ultrashort beams by interfacing online models with real time non-invasive beam data, and thereby provide a detailed virtual view of intense bunch dynamics. The goal is to enable beam prediction and control, and to develop new diagnostics in order to increase beam phase-space density by at least an order of magnitude than currently achievable.

(See References 1 through 7 for further information.)

Questions – Contact: Jeremy Love, Jeremy.Love@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Jeremy Love, Jeremy.Love@science.doe.gov

References:

1. U.S. Department of Energy, Basic Research Needs Workshop on Compact Accelerators for Security and Medicine, Tools for the 21st Century, May 6-8, 2019, https://science.osti.gov/-/media/hep/pdf/Reports/2020/CASM_WorkshopReport.pdf?la=en&hash=AEB0B318ED0436B1C5FF4EE0FDD6DEB84C2F15B2 (See sections 2.2 and 5.2.1-5.2.3) (November 2, 2022)
2. Litos, M., Adli, E., An, W., Clarke, C., Clayton, C., Corde, S., Delahaye, J., England, R., Fisher, A., Frederico, J., et al., 2014, High-efficiency acceleration of an electron beam in a plasma wakefield accelerator, *Nature 515*, 92, 2014, https://www.nature.com/articles/nature13882 (November 2, 2022)
3. Corde, S., Adli, E., Allen, J., An, W., Clarke, C., Clayton, C., Delahaye, J., Frederico, J., Gessner, S., Green, S., et al., 2015, Multi-gigaelectronvolt acceleration of positrons in a self-loaded plasma wakefield, *Nature 524*, 442 (2015), https://www.nature.com/articles/nature14890 (November 2, 2022)
4. Adli, E., Ahuja, A., Apsimon, O., Apsimon, R., Bachmann, A. M., Barrientos, D., Batsch, F., Bauche, J., Olsen, V.B., Bernardini, M., et al., 2018, Acceleration of electrons in the plasma wakefield of a proton bunch, *Nature 561*, 363–367, 2018, https://www.nature.com/articles/s41586-018-0485-4 (November 2, 2022)
5. Joshi, C., Adli, E., An, W., Clayton, C.E., Corde, S., Gessner, S., Hogan, M.J., Litos, M., Lu, W., Marsh, K.A., et al., 2018, Plasma wakefield acceleration experiments at FACET II, *Plasma Physics and Controlled Fusion 60*, 034001, 2018, https://iopscience.iop.org/article/10.1088/1361-6587/aaa2e3/meta (November 2, 2022)
6. Scheinker, A., and Gessner, S., 2015, Adaptive method for electron bunch profile prediction, *Physical Review Special*, Topics-Accelerators and Beams 18, 102801, 2015, https://doi.org/10.1103/PhysRevSTAB.18.102801 (November 2, 2022)
7. Scheinker, A., Edelen, A., Bohler, D., Emma, C., and Lutman, A., 2018, Demonstration of model-independent control of the longitudinal phase space of electron beams in the linac-coherent light source with femtosecond resolution, *Physical review letters 121*, 044801, 2018, https://doi.org/10.1103/PhysRevLett.121.044801 (November 2, 2022)

Back to Table of Contents

PROGRAM AREA OVERVIEW: OFFICE OF NUCLEAR ENERGY

The primary mission of the Office of Nuclear Energy (NE) is to advance science and technology to meet U.S. energy, environmental, and economic needs.

NE has identified the following four goals to address challenges in the nuclear energy sector, help realize the potential of advanced technology, and leverage the unique role of the government in spurring innovation:

(1) Enable continued operation of existing U.S. nuclear reactors;
(2) Enable deployment of advanced nuclear reactors;
(3) Develop advanced nuclear fuel cycles; and
(4) Maintain U.S. leadership in nuclear energy technology.

Each goal includes supporting objectives to ensure progress and performance indicators to measure success.

Collectively, all NE-sponsored activities support the Department's priorities to combat the climate crisis, create clean energy jobs with the free and fair chance to join a union and bargain collectively, and promote equity and environmental justice by delivering innovative clean energy technologies for nuclear energy systems.

All applications submitted under this Small Business Innovative Research (SBIR)/Small Business Technology Transfer (STTR) Funding Opportunity Announcement (FOA) must demonstrate a strong tie to at least one of the four NE goals and highlight how it supports the Department of Energy (DOE) priorities.

NE's SBIR/STTR work scopes also support the DOE Gateway for Accelerated Innovation in Nuclear (GAIN) initiative (see https://gain.inl.gov), which provides the nuclear energy community with access to the technical, regulatory, and financial support necessary to move new or advanced nuclear reactor designs toward commercialization while ensuring the continued safe, reliable, and economic operation of the existing nuclear fleet.

For additional information regarding the Office of Nuclear Energy goals and priorities, click here.

C56-40. ADVANCED TECHNOLOGIES FOR NUCLEAR ENERGY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

New methods and technologies are needed to address key challenges affecting the future deployment of nuclear energy and to preserve U.S. leadership in nuclear science and engineering, while reducing the risk of nuclear proliferation. This topic addresses several key areas that support the development of crosscutting and specific reactor and fuel cycle technologies.

Grant applications are sought in the following subtopics:

a. Advanced Modeling and Simulation

Computational modeling of nuclear reactors for design and operation is becoming increasingly predictive and able to leverage high-performance computing architectures. While these tools perform similarly to legacy tools for simple problems, utilizing the advanced features of these tools requires more in-depth training, skills, and knowledge. Furthermore, to integrate robust multi-physics capabilities and current production tools for ease-of-use and deployment to end users, and for enabling the use of high-fidelity simulations to inform lower-order models for the design, analysis, and licensing of advanced nuclear systems and experiments, it is worthwhile to invest in technologies that ease the adoption of these modern computational tools.

Applications are sought that apply Office of Nuclear Energy's (NE) advanced modeling and simulation tools (https://neams.inl.gov/code-descriptions/) to industry problems for increased use by industry, either light-water reactor (LWR) or non-LWR reactor industry.

This can include:

- Facilitate access to Office of Nuclear Energy's (NE) advanced modeling and simulation tools for inexperienced users;
- Apply the results of high-fidelity simulations to inform the improved use of lower-order models for improved use of fast-running design tools;
- Provide capabilities for automated verification of numerical solutions, including mesh refinement studies; or
- Use of the tools with existing plant operational data to demonstrate the value for real-world industry applications.

Questions – Contact: David Henderson, David.Henderson@nuclear.energy.gov

b. Component Development to Support Liquid Metal Reactors – Electromagnetic Pumps

Liquid metal reactors have been demonstrated in a number of countries. Advanced versions of these first-generation reactors attempt to simplify the large pumps by utilization of electromagnetic pumps that have the ability to operate submerged at high temperature, and under irradiation.

DOE is seeking applications for collaborative small business partnerships from a U.S. company or companies to advance liquid metal reactors and foster growth for U.S. industry.

Potential areas of collaboration include but are not limited to:

- Development of insulation technology for electromagnetic pumps that can withstand high temperatures and gamma and neutron radiation during liquid metal reactor operations
- Development of a small electromagnetic pump that could be tested in a high temperature prototypic sodium environment.

Questions – Contact: Kat Abbott, Kaatrin.Abbott@nuclear.energy.gov

c. Roller Bearings for High Temperature Sodium Applications

Liquid metal reactors have been demonstrated in a number of countries. Advanced versions of these first-generation reactors attempt to reduce the cost of the primary heat transport system by utilization of advanced robotic refueling systems. Advanced robotic refueling systems allow for the reduction in the reactor vessel size and thus a reduction in overall costs of the reactor plant. A number of these advanced refueling systems use mechanisms such as gears, roller bearings, ball screws, universal joints and other mechanical components in liquid metals at high temperatures.

DOE is seeking applications for collaborative small business partnerships from a U.S. company or companies to advance liquid metal reactors and foster growth for U.S. industry.

Potential areas of collaboration include but are not limited to:

- Development of roller bearings for use in high temperature sodium applications – both radial, thrust, and combined radial and thrust bearings are of interest.

Questions – Contact: Kat Abbott, Kaatrin.Abbott@nuclear.energy.gov

d. Rapid, Inexpensive Molten Salt Property Measurement

Developing adequate understanding of the behavior of molten salt reactors under both normal and accident conditions is dependent on adequate understanding of molten salt properties. DOE-NE is in the process of populating a molten salt thermophysical and thermochemical property database. Measuring molten salt properties is currently expensive and time-consuming. Molten salts are hot, can be corrosive, may include volatile components, are frequently hydroscopic, and can be both toxic and intensively radioactive, substantially increasing the difficulty of each of the steps in performing adequate quality measurements. Moreover, the measurements can be significantly impacted by sample purity at levels resulting from environmental contamination.

DOE is seeking applications for collaborative small business partnerships from a U.S. company or companies to advance molten salt property measurement technology and foster growth for U.S. industry.

Development of innovative property measurement tools and techniques that decrease the time and expense of conventional measurement methods are encouraged. Potential areas for sensor development and candidates for collaboration include but are not limited to:

- Oxygen concentration
- Moisture content
- Viscosity
- Thermal diffusivity
- Phase development and precipitation
- Heat capacity
- Density
- Vapor pressure
- Surface tension

Questions – Contact: Janelle Eddins, Janelle.Eddins@nuclear.energy.gov

e. National Reactor Innovation Center (NRIC)

The National Reactor Innovation Center (NRIC) is charged with accelerating the demonstration and commercialization of new reactor concepts and technologies, effectively advancing U.S. nuclear energy leadership. In support of successful demonstration and economic deployment of advanced nuclear energy, grant applications are sought in the following areas:

1. Advanced Construction Technology (ACT) Initiative

Various studies of nuclear energy economics have identified the major role of construction costs and schedule risks in driving up the costs of nuclear power plants. (e.g. *The Future of Nuclear Energy in a Carbon-Constrained World*, Massachusetts Institute of Technology 2018; *The ETI Nuclear Cost Drivers Project: Summary Report*, Energy Technologies Institute (ETI), 2018; *Advanced Nuclear Technology: Economic-Based Research and Development Roadmap for Nuclear Power Plant Construction*, Electric Power Research Institute (EPRI), 2019.) Through its ACT Initiative, NRIC seeks to develop and demonstrate technologies, processes, and approaches that would mitigate construction risks and improve construction outcomes through improved project management, advanced technologies, manufacturing approaches, and/or supply chain improvements.

Applications are sought that identify, evaluate and/or develop methods, processes, or technologies that can significantly improve advanced nuclear construction cost and schedule outcomes by addressing key challenges identified in literature or projects. These could include approaches to project management, digital engineering, open architecture design, construction technologies, manufacturing approaches, etc. Proposed activities should not be duplicative of activities currently being pursued through the NRIC ACT Initiative. For more information on the ACT Initiative please visit: https://nric.inl.gov/advanced-construction-technologies-initiative/

2. Robotics for Advanced Nuclear Facilities

NRIC seeks to develop and demonstrate mobile robotic technologies that will provide for more economical and safer advanced reactor plants including fuel handling systems. Robotic systems have the potential to reduce human exposure to radiological and industrial hazards, improve quality, improve efficiency and aid in emergency response.

Grant applications are requested for modifying existing robotic platforms or developing and demonstrating robotic systems that can:

- Support operations and inspections by automating daily plant rounds, performing inspections in confined space or other hazardous areas, performing general inspections, etc.
- Support fuel management such as providing fueling and defueling capability for advanced reactors
- Assist in emergency response to avoid endangering humans
- Perform maintenance tasks such as filter replacements or liquid metal valve replacements

In addition, grant applications are requested for modifying existing or developing new robotics that can withstand:

- Radiation levels in and around advanced nuclear reactors
- Temperature and pressure conditions present in nuclear plants including the conditions found in helium cooled and liquid metal cooled reactors.

The application should clearly outline the benefits of the proposed system such as new capability not currently done by humans, improved safety, reduced costs, improved quality, etc.

3. Supporting Technologies for Microreactor Operations

The Office of Nuclear Energy supports activities to enable the development, demonstration and commercialization of a variety of microreactor concepts. Key to demonstrating and commercializing these concepts, is development of supporting capabilities such as transportation, defueling, and shielding technologies.

To help support advanced reactor demonstration and commercialization, NRIC is establishing the Demonstration and Operation of Microreactor Experiments (DOME) test bed which will be capable of hosting critical reactor experiments that operate at less than 20MWt using High Assay Low Enriched Uranium (HALEU) fuel. These tests and experiments will require many support systems. Transporting fueled reactors, shielding reactors during shipping and testing, and fueling/defueling reactors pose unique problems during demonstration of these systems.

Applications are requested for developing and demonstrating fueling/defueling systems, modular shielding, and transport options for microreactors that are fueled by HALEU fuel.

Questions – Contact: Janelle Eddins, Janelle.Eddins@nuclear.energy.gov

f. Advanced Methods and Manufacturing Technologies (AMMT) Program

Advances in nuclear energy technologies critically depend on high-performance materials that can withstand harsh environmental conditions in nuclear reactors. The advances of new manufacturing technologies open up new opportunities for the design of innovative materials with improved properties beyond what are achievable with traditional manufacturing techniques. Applications are sought to develop new, high-performance materials enabled by advanced manufacturing for nuclear energy applications. Of particular interest is the design of new materials that exploit the unusual characteristics of additive manufacturing processes to create materials with enhanced performance. A broad range of materials for nuclear energy systems will be considered, including iron-based alloys, nickel-based alloys, high entropy alloys, refractory alloys, composites, or functionally graded materials. The new materials must demonstrate one or more of high-temperature properties, radiation, and corrosion resistance relative to existing reactor materials, in a way that is significantly improved. The stability of microstructure and properties during long service life should also be demonstrated through accelerated testing and/or model predictions. The goal is to strengthen the pipeline of new materials that can make advanced nuclear reactors and the current fleet more resilient and economically competitive.

Questions – Contact: Dirk Cairns-Gallimore, Dirk.Cairns-Gallimore@nuclear.energy.gov

g. Nuclear Science User Facilities (NSUF) Program

The NSUF program has strong interest in the development of new and advanced techniques that will enable cutting edge and more cost-effective studies related to irradiation effects in nuclear fuels and materials. Irradiation embrittlement due to long-term and high-energy neutrons is a major concern for reactor pressure vessel (RPV) materials degradation in light water reactors (LWRs), causing mechanical property changes such as increase of hardness, yield stress, and tensile strength, and decrease of toughness. Consequently, many reactors include capsules containing representative steels that are located on the inside of the RPV for several years before their fracture toughness is determined by destructive Charpy impact testing. Alternative, non-destructive methods for directly assessing material embrittlement of in-situ RPV material under operating service conditions due to irradiation are desirable. Applications are sought focused on developing in-situ sensors and detectors and diagnostic equipment for embrittlement testing under extreme reactor environments of high temperature, radiation, and pressure.

Questions – Contact: Christopher Barr, christopher.barr@nuclear.energy.gov For more information on the NSUF program visit https://nsuf.inl.gov/

h. Cybersecurity Technologies for Protection of Nuclear Critical Systems

The Office of Nuclear Energy is seeking science and engineering solutions to prevent, detect, and mitigate cyber threats to nuclear energy systems with specific emphasis on digital instrumentation, control, and communication systems. Applications of interest will develop technologies and tools that will enable nuclear energy system designers, operators, and researchers to characterize cybersecurity of instrumentation and control (I&C) components and systems specific to the nuclear energy sector and identify and mitigate cybersecurity vulnerabilities in such components and systems. Technologies of most relevance will: 1) Identify and model the characteristics of a nuclear power plant I&C system under cyber-attack; 2) identify the cyber

Back to Table of Contents

risk impacts of upgrades and maintenance on such systems; and/or 3) facilitate the secure design of future control systems for the existing fleet and advanced reactors.

Proposers' product(s) of interest may provide designers, operators, and researchers with capability to:

- Develop and demonstrate technologies that enable cyber secure digital I&C system architectures for use in nuclear facilities across a broad range of current reactors and future reactors, including small modular reactors and microreactors.
- Prevent, detect, and respond to cyber-attacks in complex and interdependent I&C systems relevant to nuclear facilities. Of particular interest are methods and tools that address supply chain vulnerabilities, common cause and common access cyber-attacks, and response and recovery to cyber-attack.
- Develop and demonstrate cyber secure wireless technology architectures that enable the use of advanced sensors, actuators, controllers, etc. – architectures that are resilient to cyber-attacks, jamming, and other man-made failure mechanisms.

Applications not of interest include general cybersecurity solutions for information technology, I&C components and systems or wireless architectures, not specific to the nuclear power sector.

Questions – Contact: Rebecca Onuschak, rebecca.onuschak@nuclear.energy.gov

i. Envisioning Distributed Nuclear Generation and Reactor Siting Considerations for Integrated Energy Systems

DOE is seeking applicants to develop concepts for integrating advanced nuclear reactors into both existing sites and new construction or developments. Concepts will be developed taking into account generic design requirements that require established regulations or make a case for updating regulations. The applicant should develop design requirements, with consultation or review of available data from a variety of reactor vendors, that account for physical space for equipment, installation, maintenance, control and operating concepts, refueling (or core replacement), and safety; physical security; required setbacks; shielding; thermal distribution and storage systems; electrical distribution components; and cooling components for normal operation and loss of load. The applicant will select an application and assess the thermal and electrical requirements, including thermal and electrical load operating schedule and dynamics. The applicant will determine an appropriately sized/type of reactor and thermal distribution system if applicable. Utilizing publicly available or calculated specifications for the reactor, the applicant will develop generic design requirements for installing a reactor addressing installation, regulatory or suggested modified regulatory requirements, safety, operations, control, and maintenance. The applicant will use existing plans and drawings for an integrated industrial plant, neighborhood, and/or large building or campus to demonstrate the feasibility of integrating an advanced reactor into these locations while meeting design requirements. Three dimensional renderings will be used to demonstrate the final design concept, with views that highlight the design aspects that address requirements. The final product will include rationale for any modifications needed to regulatory requirements.

Potential applications include:

- residential / commercial cogeneration (new developments with district heating/cooling)
- scenarios accounting for great adoption of plug-in hybrid and electric vehicles.
- large building / campus cogeneration (with existing thermal distribution systems)
- data centers
- industrial parks and industrial applications including refining, minerals, paper/wood/biomass, synfuel production

Back to Table of Contents

- large-scale energy users such as automobile manufacturing, steel, aluminum, ammonia, chlor-alkali plants

Questions – Contact: Jason Marcinkoski, Jason.Marcinkoski@nuclear.energy.gov

j. Small Modular Reactor Capabilities, Components, and Systems

Improvements and advancements are needed to address capabilities, components, and systems that might be deployed in small modular reactor (SMR) designs. The economics of SMRs depend on fewer and smaller components, smaller site footprints, and reduced operations and maintenance requirements as compared to the existing fleet. Concepts that can potentially improve SMR plant capability and performance while reducing capital, construction, operations, and maintenance costs are sought through this work scope. The proposed technology or capability should demonstrate and support improved functionality and efficiencies in SMR-specific plant operation and maintenance processes. Proposed technology improvements can be applicable to any SMR design types (e.g., light water, liquid metal, gas, and molten salt cooled) and to both electrical or non-electrical uses but should be available on a timeframe to support SMR deployments in the early 2030's and compatible with an SMR design currently under development. A wide range of technology areas may be considered, but the associated improvement(s) should specifically support or enhance the benefits offered by either a specific SMR or SMR type, or by SMRs as a class.

Applications that address the following technology development areas are NOT of interest for this subtopic and will be declined: new small modular reactor design concepts, instrumentation and control capabilities (unless the proposed technology is convincingly unique to SMRs), sensors, remote operations concepts, fuel design & development, and spent fuel storage & handling.

Questions – Contact: Melissa Bates, Melissa.Bates@nuclear.energy.gov

k. Microreactor Applications, Unattended Operations, and Cost-Reduction Technologies

Improvements and advances are needed in support of novel applications, unattended operations, and cost reduction technologies that support wide-spread deployment of microreactors. Microreactors are a crosscutting class of very small reactors that are factory fabricated, transportable, and self-regulating. Microreactors are not defined by power output, but in most cases produce on the order of ones to tens of megawatts-electric. Given their size, they are ideal for novel applications that are "off-grid by circumstance": those which require substantial local power to areas where either there is no grid access or where fuel transportation is challenging/ undesirable, such as remote communities, resource extraction sites, Electric Vehicle charging stations, and disaster relief sites. Microreactors are ideal as well for applications which are "off-grid by design": those which require highly reliable power or local ownership/control of the power source, such as hospitals, data centers, airports, shipping ports, desalination plants, manufacturing facilities, industrial and district heating, and other critical infrastructure which may be vulnerable to natural or intentional disruption.

There is a strong desire to improve integration with applications, reduce costs, and enable wider use of microreactor technology. Therefore, this topic seeks new and innovative technologies that support microreactor deployment or application integration in the following areas:

- Civilian applications requiring 100's of kW to MW-scale power in the form of heat or electricity to support remote or non-remote uses. These applications should specifically highlight the need and value of having a reliable source of energy provided by microreactors and have significant potential market opportunities. These applications should represent the utilization of the energy, not generation.

- Technologies that support unattended and remote operations of microreactors and minimize on- site highly trained personnel, operators, and maintenance staff. The technologies should not be microreactor design-specific but may need to consider the operational characteristics of microreactors. Ultimately, the staffing targets for microreactors are 0.5-1.5 FTE/MW.
- Technologies that can result in significant reductions in microreactor costs that can expand their applications by increasing their competitiveness with other energy sources. The technologies should not be microreactor design-specific but should provide microreactor hardware, system, and operation cost reductions.

Applications that address the following technology development areas are NOT of interest for this subtopic and will be declined: new microreactor concepts, non-civilian applications of microreactors, radioisotope power source applications.

Questions – Contact: Diani Li, Diana.Li@nuclear.energy.gov

l. Advanced and Small Reactor Physical Security Cost Reduction

Advanced and small nuclear reactors will not be competitive with other electrical generation sources unless they are able to drastically reduce physical protection costs. Both intrinsic and extrinsic design features should be considered that can significantly reduce either the up-front capital costs or the operational costs. For example, advanced reactors may be able to rely more on local law enforcement than on-site security personnel. Applications are sought for new ideas or revitalization of past work that has evaluated physical security cost reductions, including new physical protection approaches and the use of new technologies. Preparation of commercial modeling and simulation tools used for security performance assessments to evaluate those approaches will help nuclear vendors with licensing efforts.

Questions – Contact: Savannah Fitzwater, savannah.fitzwater@nuclear.energy.gov

m. Materials Protection Accounting and Control for Domestic Fuel Cycles

The Materials Protection, Accounting, and Control Technologies (MPACT) program supports the U.S. advanced nuclear fuel cycles technology developers to effectively and economically address nuclear materials control and accounting (MC&A) requirements. MPACT is seeking grant applications that develop MC&A technologies with application to the front and back-ends of the nuclear fuel cycle. Examples include technologies that can quantitatively or qualitatively measure Special Nuclear Material (SNM) during fuel fabrication, reprocessing, storage, and in waste forms. Applications for both discrete and continuous measurement capabilities are sought.

Grant applications that address border security, nuclear forensics, nuclear medicine, personnel dose monitoring, nuclear weapons related R&D, or remote monitoring are not sought.

Questions – Contact: Tansel Selekler, tansel.selekler@nuclear.energy.gov

n. Advanced and Small Reactor Material Control and Accounting Modernization

Material Control and Accounting will be a critical aspect of operations in future advanced and small nuclear reactors, particularly given the variety of future types and forms under consideration. Applications are sought for improved and modernized mass and material tracking software to reduce costs, improve usability, and increase effectiveness associated with mass and material tracking systems to support material control and accountability (MC&A) requirements for future advanced and small nuclear reactors. Additional information on MC&A work already completed through the Office of Nuclear Energy's Advanced Reactor Safeguards Program can be found at energy.sandia.gov/ars.

Back to Table of Contents

Questions – Contact: Savannah Fitzwater, savannah.fitzwater@nuclear.energy.gov

o. Risk Informed Licensing

The existing fleet of light water reactors (LWRs) were licensed for operation based on deterministic rules and analyses which were intentionally conservative to overcome multiple uncertainties associated with phenomenology of processes that nuclear systems would experience under accident conditions. Later, risk considerations were introduced into the reactor oversight process, an important aspect that allowed better understanding of nuclear safety risks and prioritization of risk-important aspects. However, metrics adopted to measure LWR risks, such as core damage frequency (CDF) and large early release frequency (LERF), allow only a partial understanding of potential consequences that could emerge from a nuclear incident. The actual consequence is the potential harm to the surrounding population and environment which is expressed as a radiation dose. Determination of radiation doses from a variety of potential nuclear accidents is a very complex and lengthy process since it involves many deterministic and probabilistic analyses. Given such complexity, the LWR fleet has not adopted "radiation dose" as the risk measure and continues to rely on surrogate metrics, CDF and LERF, instead. Surrogates like LERF contain underlying conservatisms and gross simplifications imbedded in the calculations because (1) it is derived indirectly from actual population safety goals and (2) it was considered using models and computers from ~30 years ago. These conservatisms are necessary because of the practice of "bounding assessments" where instead of evaluating the full spectrum of scenarios, only a subset of scenarios is considered, and these selected scenarios are made intentionally conservative to cover the rest of the spectrum.

While this approach served the commercial nuclear industry well over the past decades, advancements in scientific understanding of phenomena and significant improvements in modeling and simulation capabilities make it possible to progress from the simplified bounding phenomenology modeling to explicit analyses. It is now possible to analyze the impact of consequences in a less conservative, more direct fashion using modern computational approaches. This strategy is already embraced by the advanced nuclear reactor community as part of the Licensing Modernization Project endorsed by the Nuclear Regulatory Commission (NRC) in RG-1.233. The vision of the full spectrum risk assessment can be achieved with the support of novel methodologies and approaches for modeling and simulation (M&S). These advanced M&S tools will allow for the simplification of accident scenario modeling and evaluation by combining numerous assessments into an integrated framework.

Applications are sought for M&S tools that will be capable of supporting one or multiple evaluations in the following areas:

- Dynamic risk modeling with physics-based assessments integrated into the scenario progression simulation
- Evaluation of a release of radiological constituents from nuclear fuel damaged during simulated accidents (source terms analysis)
- Evaluation of phenomena of radiological material distribution from a nuclear facility to the environment

Questions – Contact: William Walsh, william.walsh@nuclear.energy.gov

p. Software Development for Digital I&C System Risk Assessment and Design Optimization

Digital instrumentation and control (DI&C) systems at nuclear power plants (NPPs) have been proven to be more reliable, cheaper, and easier to maintain given obsolescence of analog components. However, they also pose new engineering and technical challenges including the potential common cause failures (CCFs) unique to safety-critical DI&C systems. Adding diversity within a system or components is the main means to eliminate and mitigate CCFs, but diversity also increases plant complexity and errors and may not address all sources of systematic failures. How to optimize the diversity and redundancy for safety-critical DI&C systems remains a challenge.

The DI&C Assessment project within the Risk-Informed Systems Analysis (RISA) pathway of the Light Water Reactor Sustainability (LWRS) program has developed an integrated risk assessment framework to support vendors and utilities with optimization of design solutions from economical perspectives while still achieving risk-informed safety requirements. This integrated risk assessment framework includes both qualitative hazard analysis and quantitative reliability and consequence analysis for addressing software CCF in the safety-critical DI&C system. It offers a capability of design architecture evaluation of various DI&C systems to support system design decisions and diversity and redundancy applications.

Applications are sought for the development of a common and a modularized software platform for DI&C designers, software developers, cybersecurity analysts, and plant engineers to efficiently predict risk and reduce cost in the early design stage of DI&C systems. This software platform should be able to process and transfer quantitative and qualitative data to realize the comprehensive capabilities of the integrated framework including (1) identifying software failures in the unit-level interactions inside of a digital system, (2) quantifying software failure probabilities based on suitable software reliability methods, and (3) integrating with probabilistic risk assessment and cost analysis models. A user-friendly interface should be designed to reduce the difficulty and complexity in the application of the comprehensive framework. Sufficient and concise information should be provided to users to support DI&C system risk assessment and design optimization.

Questions – Contact: William Walsh, william.walsh@nuclear.energy.gov

q. Plant Modernization

Improvements and advancements are needed to address nuclear power plant economic viability in current and future energy markets through innovation, efficiency gains, and business model transformation. This includes transformative digital technologies that results in broad innovation and business process improvement in the nuclear light water reactor fleet's operating model. The modernization of plant systems and processes will enable a technology-centric business model platform that supports improved performance at lower cost, contributing to the long-term sustainability of the Light Water Reactor (LWR) fleet, which is vital to the nation's energy and environmental security. Technology should demonstrate and support improved functionality and efficiencies in plant operation and maintenance processes. This will include improvements for both core operations and maintenance work activities, as well as support functions, such as security, management, administration, procurement, and radiation protection. Effective modernization requires improved process automation, machine intelligence and computer aided decision making.

To achieve this mission in the nuclear power industry, applications are sought in one of the following plant modernization areas:

- Artificial intelligence/machine learning technologies are sought for troubleshooting and diagnosing nuclear plant operational problems to improve the timeliness and effectiveness of response to emergent degraded conditions. These technologies should enable significant savings in engineering and technical support costs while addressing model explainability concerns. These technologies should be able to integrate into plant processes for automated assessment and correction, including corrective action program, risk management, and work management functions. Further, the technologies should enable third party outsourcing of trouble shooting and diagnosis through data sharing and remote collaboration capabilities.

- Digital twin technologies for operating nuclear plants are sought to reduce costs in plant monitoring and performance deviation detection. These technologies are intended to enhance operational monitoring by detecting anomalies much lower than instrument setpoints, validating them as real plant phenomena verses sensor malfunctions, determining the deviation trend rate, and identifying the degraded component. The technologies will differentiate cascade effects in connected plant systems from the system with the degraded component. The logic of the digital twin will be transparent and immediately available for rapid verification by plant operators and support staff.
- Self-diagnosis and health monitoring technologies for nuclear plant components are sought for elimination of plant surveillances and other forms of periodic testing, enabling exclusive use of condition-based monitoring for applicable classes of plant components. For these components, all credible failure modes will be addressed, with condition status transmitted on a user-specified frequency. The condition information will support real-time risk monitoring and operational determination. These technologies should be able to integrate into plant processes for automated assessment and correction, including corrective action program, risk management, and work management functions.

Questions – Contact: William Walsh, william.walsh@nuclear.energy.gov

r. Light Water Reactor Central Alarm Station Simulator Based Human Factors Studies

Simulators provide a platform to train and evaluate responses to a variety of scenarios to better prepare for real world responses. The simulators created by Central Alarm System (CAS)/Secondary Alarm System (SAS) vendors provide the opportunity for a new research area in human factors studies. Applications are sought for CAS operators, in possible partnership with a company or university with a strong human factors' component, to integrate their CAS/SAS simulators with security modeling visualizations to engage in full-scope human factor studies with the ultimate goal of moving force-on-force exercises to an augmented reality/simulated environment.

Questions – Contact: Savannah Fitzwater, savannah.fitzwater@nuclear.energy.gov

s. Develop or Improve Small Scale Mechanical Testing Techniques to Provide Size-independent Material Properties of Alloys in a Nuclear Power Plant Environment

Reactor metallic materials are subjected to a challenging core environment with complex mechanical loads, corrosive coolant, and intensive neutron irradiation during operation. As a result, the mechanical properties and service performance of reactor metals can degrade considerably over time. To assure the long-term sustainability and reliability of light water reactors, the extent of materials degradation must be evaluated quantitatively with well-designed tests and relevant materials. Currently, most mechanical tests require full-scale, engineering-size samples to assure the adequate constraints and statistical significance. This imposes a significant challenge for testing neutron-irradiated materials which are highly radioactive and difficult to handle experimentally. Heavily shielded facilities with strict controls are often required for testing such samples. Thus, mechanical test methods with small-scale samples are highly desirable from both economic and technical stand points. With the rapid development of digital and sensor technologies in recent decades, new opportunities have become available to minimize the test samples. Applications are sought to develop or improve the mechanical testing techniques to provide tensile, creep, fatigue, impact toughness, fracture toughness, and stress corrosion cracking properties with miniature specimens to provide size-independent material properties. Coordinated effort with continuum models and simulations are encouraged.

Questions – Contact: Sue Lesica, Sue.Lesica@nuclear.energy.gov

Back to Table of Contents

t. Cost of Construction and Installation of Advanced Reactor Technologies for Industrial Purposes

Nuclear reactors are an attractive technology to power multiple applications, particularly hydrogen, synthetic fuels, polymers, chemicals, minerals production, refineries, and district heating, where clean, reliable energy, or high-quality heat is needed with very high availability. Nuclear reactors offer the ability to provide heat and electricity at the location where it is needed, greatly reducing the cost to transmit/distribute energy. For commercial deployment in these areas, it is critical for nuclear reactors to provide a competitive cost of heat and electricity with incumbent and advanced technologies with no compromise in durability and robustness of designs. Cost is one of the fundamental drivers for enabling commercialization of technologies.

Proposed projects should define the current state-of-the-art in key areas, develop and refine system configurations and designs over time, and identify technology gaps. Cost analysis should identify manufacturing and construction efficiencies and economies of scale based on production rates ranging from 5 GW/year to 30 GW/year.

DOE recognizes that third party cost analysis will have limited access to proprietary information and cannot be leading experts in all aspects of the work, thus applications should include opportunities and mechanisms to obtain up to date information from commercial industry as a whole and subject matter experts in industry and research communities.

Applications are sought for the development of cost analysis focusing on either reactor and fuel manufacturing cost, or reactor installation cost:

- Reactor and Auxiliary Component Costs—Proposed projects will develop a detailed reference design that focuses on a single reactor type, based on an understanding of the design requirements, and an engineering approach to meeting those requirements derived from open literature, patents, and engineering analysis. Once a cost-representative design is established, the methods for manufacturing the reactor and auxiliary components will be developed in detail to establish the basis for a manufacturing cost estimate. Proposed projects should define the current state-of-the-art in key areas, develop and refine system configurations and designs, provide guidance on R&D gaps, and provide results that help direct future R&D priorities in the implementation of nuclear technologies. The cost of the reference design will be based on thorough understanding of manufacturing processes likely to be used in various production rates. Manufacturing cost will include, but is not limited to: Equipment costs, Labor, Materials (including reactor fuel), and Energy**.**
- Reactor Installation Costs—Proposed projects will develop a reference cost-representative plan for the on-site construction and installation of advanced reactor technologies with connections necessary for industrial applications. It is expected that proposed projects will develop a detailed reference design that focuses on an industrial process heat application and installation based on development of application requirement definitions addressing anticipated safety, physical security, thermal and electrical demands, and operational and regulatory needs. Once the reference design is established, the methods for construction and installation will be developed in detail to establish the cost to install an integrated nuclear system for the chosen application. The cost of the reference design will be based on thorough understanding the installation process and parameters (e.g., to determine excavation time, equipment, labor, energy) through the use of references, experience, and engineering judgement justifying the underlying assumptions made. Cost of construction and installation of the coupled system will include but is not limited to:

Site specific Architecture / Engineering, Equipment costs, Labor, Materials, Fuel, Licensing, Management, Construction bonds / Insurance, and Financing.

Questions – Contact: Jason Marcinkoski, Jason.Marcinkoski@nuclear.energy.gov

u. Process Models and Economics for Nuclear Power-Integrated Industrial Applications

A key strategy for economy-wide decarbonization is expanding the use of nuclear energy beyond the electric grid. Several candidate industrial processes, such as refineries, polymers, minerals processing, ammonia, pulp and paper, and industrial/district heating/combined heat and power, have been identified as having high concentrated energy demand where nuclear plants could provide a direct, clean, reliable source of carbon-free heat and/or electricity. Applications are being sought for the detailed analyses that are needed to model the through-put of unit operations for these candidate processes and assess the capital equipment cost for thermal and electrical distribution infrastructure and industrial plant integration. The desired outcome of this work is at least one reference process models for integrating nuclear heat and electricity into industrial applications.

Completion of this work will require a thorough understanding of the existing processes to determine which combustion processes can be replaced with heat from nuclear reactors and/or nuclear generated electricity (for upgrading heat), which electrical processes can use nuclear generated electricity, and which mechanical processes can be electrified or otherwise driven with nuclear heat. Applications should identify the reactor type that is best suited to supply energy for the application chosen, based on the size of the reactor, the quality of heat required, ability to upgrade the heat, and the maturity of reactor technologies.

Questions – Contact: Jason Marcinkoski, Jason.Marcinkoski@nuclear.energy.gov

v. Advanced Technologies for the Fabrication, Characterization of Nuclear Reactor Fuel

Improvements and advances are wanted for the fabrication, characterization, and examination of nuclear reactor fuel. Advanced technologies are sought for light water reactor fuels and for Advanced Reactor fuels for sodium cooled fast reactors.

- Provide new innovative accident tolerant LWR fuel cladding/assembly concepts that have the potential to support achieving very-high fuel burnups (viz. greater than 100,000 MWD/MTU peak pin average burnup). Improvements to LWR fuel and cladding may include but not be limited to fuel constituents or fabrication techniques to improve the overall performance or characterization techniques to improve understanding of performance of the nuclear fuel system. Cooperation is strongly encouraged with a national lab or other entity with fuel fabrication capabilities, as production of a prototypic samples for irradiation would be required for any follow-on phase.
- Develop and/or demonstrate improved fabrication methods for sodium fast reactor fuels and cladding materials, especially for uranium and plutonium based metallic fuels. Manufacturing features of interest include methods to eliminate sodium bonding, produce advanced cladding compositions, methods to apply liners, and fuel slug production processes taking into account retention of volatile constituents associated with reuse as well as special additives or "getters."
- Provide improved fabrication techniques or characterization techniques for silicon carbide accident tolerant LWR fuel cladding and fuel structures to improve the overall fuel performance. Cooperation is encouraged with a national lab or other companies with fuel fabrication capabilities, since the production of a prototypic sample for irradiation would be required for any follow-on phase.

Grant applications may use non-fueled surrogate materials to simulate uranium, plutonium, and minor actinide bearing fuel pellets.

Back to Table of Contents

Questions – Contact: Frank Goldner, Frank.Goldner@nuclear.energy.gov

w. Advanced Sensors and Instrumentation (Crosscutting Research)

Applications are sought for the Advanced Sensors and Instrumentation (ASI) program regarding the development of innovative technologies that support: the existing fleet of nuclear reactors, including materials test reactors; the development of advanced reactor concepts and the acceleration of advanced fuel cycle technology commercialization. The proposed sensors and instrumentation should demonstrate greater accuracy, reliability, resilience, higher resolution, and ease of replacement/upgrade capability for applications in the nuclear environment, while striving to reduce operations and maintenance (O&M) costs. The proposed technology should be applicable to multiple reactor concepts or fuel cycle applications, i.e., crosscutting.

Applicants should focus on the following areas:

- Develop and demonstrate innovative sensors and instrumentation that can reliably operate in the nuclear reactor core, primary and secondary coolant loop or other relevant plant systems. All sensors/instrument technologies should be developed to be operable with consideration for harsh environmental conditions (i.e., temperature, pressure, corrosion, radiation). Irradiation experiments in Material Test Reactors should be considered as the preferred method for the technology demonstration and the definition of design requirements for near term deployment. The following are some examples of technical areas of interest: distributed or multi-point measurement of operational conditions (neutron and gamma-ray flux, temperature, pressure, fission gas products, fluid flow rate) or material behavior (stress/strain, deformation, thermal conductivity).
- Advanced control systems that increase nuclear plant system reliability, availability, and resilience including the ability to detect and manage faults in instrumentation and control (I&C) systems and plant components; state of the art control rooms, control systems, and plant control technologies. The project outcomes must enable semi-autonomous and remote operation, and advanced automation.

Applications that address the following areas are NOT of interest for this subtopic and will be declined unless crosscutting capabilities are demonstrated as part of the submission: nuclear power plant security (e.g., cyber, physical, etc.); homeland defense or security; reactor building/containment enhancements; radiation health physics dosimeters (e.g., neutron or gamma detectors); radiation/contamination monitoring devices; U. S. Nuclear Regulatory Commission (NRC) probabilistic risk assessments or reactor safety experiments, testing, licensing, and site permit issues; special nuclear materials (SNM) monitoring and non-proliferation; technologies that support nuclear weapons research & development.

Questions – Contact: Daniel Nichols, daniel.nichols@nuclear.energy.gov

For more information on the ASI program visit https://www.energy.gov/ne/nuclear-energy-enabling-technologies & https://www.ASI.inl.gov

x. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall outside the scope of the topic descriptions above.

Questions – Contact: JoAnne Hanners, joanne.hanners@nuclear.energy.gov

C56-41. ADVANCED TECHNOLOGIES FOR NUCLEAR WASTE

Back to Table of Contents

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES
Accepting SBIR Fast-Track Applications: NO	Accepting STTR Fast-Track Applications: NO

The US DOE-NE, Office of Spent Fuel and Waste Science and Technology, is conducting research in long-term storage, transportation, and eventual disposal of spent nuclear fuel (SNF). Storage of SNF is occurring for longer periods than initially intended; therefore, it is desirable to assess technical performance issues of the SNF storage systems and transportation systems after extended durations. In the area of SNF disposal, research is directed toward generic repository disposal systems in argillite, salt, and crystalline rock.

Grant applications are sought only in the following subtopics:

a. Disposal Research

Assessments of nuclear waste disposal options start with waste package failure and waste form degradation and consequent mobilization of radionuclides, reactive transport through the near field environment (waste package and engineered barriers), and transport into and through the geosphere. Science, engineering, and technology improvements may advance our understanding of waste isolation in generic deep geologic environments and will facilitate the characterization of the natural system and the design of an effective engineered barrier system for a demonstrable safe total system performance of a disposal system. DOE is required to provide reasonable assurance that the disposal system isolates the waste over long timescales, such that engineered and natural systems work together to prevent or delay migration of waste components to the accessible environment.

Mined geologic repository projects and ongoing generic disposal system investigations generate business and R&D opportunities that focus on current technologies. DOE invites applications:

- Involving novel material development, testing methods, and modeling concept and capability enhancements that support the program efforts to design, develop, and characterize the barrier systems and performance (i.e., to assess the safety of a nuclear waste repository).
- Addressing applications of state-of-the-art uncertainty quantification and sensitivity analysis approaches to coupled-process modeling and performance assessment which contribute to a better assurance of barrier system performance and the optimization of repository performance.
- Reducing uncertainties in data and in models currently used in geologic repository performance assessment programs.

Research applications are sought to support the development of materials, modeling tools, and data relevant to permanent disposal of spent nuclear fuel and high-level radioactive waste for a variety of generic mined disposal concepts in clay/shale, salt, crystalline rock, and tuff. Key research contributions for the disposal portion of this activity may include one or more of the following:

- Improved understanding of waste package failure modes and material degradation processes (i.e., corrosion) for heat generating waste containers/packages considering direct interactions with canister and buffer materials in a repository environment leading to the development of improved models (including uncertainties) to represent the waste container/package long term performance.

- New concepts or approaches for alleviating potential post-closure criticality concerns related to the disposal of high-capacity waste packages. Development of models and experimental approaches for including burn-up credit in the assessment of the potential for criticality assessment for spent nuclear fuel permanently disposed in dual- purpose canisters that are designed and licensed for storage and transportation only.

- Development of pertinent data and relevant understanding of aqueous speciation, multiphase barrier interactions, and surface sorption at elevated temperatures and geochemical conditions (e.g., high ionic strength) relevant to deep geologic disposal environments.

- Identification and assessment of innovative and novel buffer materials, new methods and tools for multi- scale integration of relevant repository characterization data (including hydrological, thermal, transport, mechanical, and chemical properties), new approaches for imaging and characterization of low permeability materials, state-of-the-art tools and methods for passive and active characterization and monitoring of engineered/natural system component properties and failure modes and their capability to isolate and contain waste.

Questions – Contact: Prasad Nair, Prasad.Nair@nuclear.energy.gov

b. Storage & Transportation R&D

Spent nuclear fuel (SNF) will continue to be stored, typically in dry cask storage systems, until a determination on final disposition is made. Over 90% of dry cask storage systems in the United States are welded dry storage canisters (DSC), typically on the order of 5/8-inch thick (Type 304 or 316) stainless steel, emplaced in either concrete or metal overpacks. The U.S. Nuclear Regulatory Commission has identified key safety functional areas for storage, including retrievability, thermal performance, confinement, radiation protection, and subcriticality. It is important to demonstrate that these safety functions are met during extended storage and after transportation.

Accordingly, the Storage and Transportation division is tasked with developing the technical bases to demonstrate spent fuel integrity for extended storage periods, to ensure fuel retrievability and transportation after extended storage, and to transport high burnup fuel. The areas of highest priority for the mission are described in the following document: Teague et al. 2019, 'Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment', SAND2019- 15479R, which can be found at https://www.osti.gov/servlets/purl/1592862. Applications are sought for developing novel technologies that support our endeavors in the areas described therein, including i) Chlorine Induced Stress Corrosion Cracking in the Canister Wall, ii) Canister Internal Environment Monitoring, iii) Fuel Cladding Degradation, iv) Stresses and Strains on Fuel Bundle Components due to Transportation or Seismic Loads, or v) other areas.

Questions – Contact: John Orchard, John.Orchard@nuclear.energy.gov

c. Salt Vapor Trap + Reversible Chlorine Gas Absorber Technology for Recovery and Recycle of Chlorine

Several molten chloride pyrochemical processes for recycling solid and molten chloride reactor fuels involve the generation of chlorine gas such as electrolytic separations processes and conversion of fission product metal chlorides to metal phosphates. When the evolved chlorine gas has been enriched in ^{37}Cl or contains ^{36}Cl (formed from ^{35}Cl) it is essential to recover and recycle the chlorine to the molten chloride process salt or to new molten chloride reactor fuel. Therefore, there is a need for a remotely handled turnkey chlorine gas absorber system that can remove chlorine gas from an Ar/Cl_2 gas mixture that may also contain metal chloride vapor such as LiCl, KCl, or NaCl. For gas streams that contain chloride salt vapor, a two-stage cartridge system that traps salt vapor in the first stage and absorbs chlorine gas in the second stage. The chlorine gas absorber cartridge must be able to store and later release the absorbed chlorine as chlorine gas into a gas stream and regenerate the absorber material. One possible chlorine absorber is CuCl which reacts with Cl_2 at ambient temperature to form $CuCl_2$. At higher temperatures, the $CuCl_2$ decomposes to give Cl_2 and CuCl. This project includes both the design of the cartridge-based system as well as development of the reversible chlorine absorber material.

Questions – Contact James Wilit, james.willit@nuclear.energy.gov

d. High Durability, Low-Cost Sorbents and Waste Form for Iodine Capture and Immobilization

To ensure the safe disposal of radioiodine nuclear wastes, a durable iodine wase form is required. The development and performance of many different types of sorbents to capture iodine have been researched for decades. Optimally, the path from the trap to the waste form should be simple and straight forward. This application is seeking a highly durable, low-cost iodine waste form for iodine loaded materials. The desired waste form should be environmentally stable with a disposition pathway for iodine-loaded materials. Emphasis on maximizing iodine loading while minimizing the overall waste form volume should be considered. Emphasis for materials concepts that provide options for recycling high-expense metals from sorbents should also be considered. Specific scope items include:

- Develop metal-exchanged sorbents for iodine capture under prototypical off-gas conditions
- Develop and demonstrate chemical processes for recycle of iodine-loaded sorbents ((i.e., to remove iodine and recycle the base sorbent)
- Characterize materials for both chemical durability and environmental stability

Questions – Contact: Kimberly Gray, Kimberly.Gray@nuclear.energy.gov

e. Crucible Materials for Phosphate Waste Glass Melts

The properties of phosphate glasses and melts vary with concentrations of chemical additives. Some advantages of phosphate glasses over other nuclear waste glasses are the relatively high solubility of chemical components that tend to be sparsely soluble in silicate melts and relatively low melting temperatures. However, phosphate glasses tend to be less chemically durable, more susceptible to devitrification and more corrosive to process materials. This corrosive nature of phosphate melts leads to significant interactions with the crucible during the final processes of phosphate waste form development. Unwanted crystal formation can occur and lead to a reduction in the waste form performance and processing issues. Evaluation of crucible materials is needed to provide information for potential process equipment. Specific scope items include:

- Determine how the various crucible materials react with phosphate melts
- Evaluate corrosion resistance of various metal crucibles as well as high silica crucibles in phosphate melts at high temperature
- Determine thermal properties and thermal limits for the phosphate glass

Questions – Contact: Kimberly Gray, Kimberly.Gray@nuclear.energy.gov

f. Optimize the Kr/Xe Capture Process to Reduce Cost for the Overall Process

The adsorption separation cycle for noble gases (Xe and Kr) requires a semi-batch process and relatively large equipment. A continuous separation process could reduce equipment size substantially and simplify operations. Ideas for maximizing noble gas capture, Xe/Kr separations efficiencies, and minimizing costs are the goal of this call. Specific scope items include:

- Develop a process capable of Kr/Xe separation/concentration from air and complete proof of concept testing.
- Develop and test bench scale continuous process to include simulation of stagewise concentration.

Back to Table of Contents

- Demonstrate small pilot-scale with stable Kr gas mixtures, emulating expected used nuclear fuel reprocessing conditions.

Questions – Contact: Kimberly Gray, Kimberly.Gray@nuclear.energy.gov