



U.S. Department of Energy

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

Topics FY 2022 Phase I Release 2

Version 4, November 30, 2021

- 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 Fossil Energy
- Office of Fusion Energy Sciences
- Office of High Energy Physics
- Office of Nuclear Energy

Schedule

Event	Dates
Topics Released:	Monday, November 8, 2021
Funding Opportunity Announcement Issued:	Monday, December 13, 2021
Letter of Intent Due Date:	Monday, January 3, 2022
Application Due Date:	Tuesday, February 22, 2022
Award Notification Date:	Monday, May 16, 2022*
Start of Grant Budget Period:	Monday, June 27, 2022

*** Date Subject to Change**

Table of Changes		
Version	Date	Change
Ver. 1	Nov. 08, 2021	Original
Ver. 2	Nov. 15, 2021	<ul style="list-style-type: none"> • Topic 19, subtopic e: Updated Subtopic Description • Topic 36, subtopic s: Added Subtopic • Topic 36, subtopic t: Added Subtopic
Ver. 3	Nov. 23, 2021	<ul style="list-style-type: none"> • Topic 2: Corrected Point-of-Contact Email • Topic 3: Corrected Point-of-Contact Email • Topic 7: Updated Topic Description • Topic 7, subtopic b: Updated Subtopic Description • Topic 9: Updated Table 1 Description • Topic 9, subtopic b: Updated Subtopic Description and Table 5 • Topic 19, subtopic e: Updated Subtopic Description • Topic 36, subtopic j: Updated Subtopic Description
Ver. 4	Nov. 30, 2021	<ul style="list-style-type: none"> • Topic 21: Updated Topic Description • Topic 22: Updated Topic Description • Topic 23: Updated Topic Description

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INTRODUCTION TO DOE SBIR/STTR TOPICS

This SBIR/STTR topics document is issued in advance of the FY 2022 DOE SBIR/STTR Phase I Release 2 Funding Opportunity Announcement scheduled to be issued on December 13, 2021. 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 and II awards, DOE provides small businesses with technical and business assistance (TABAs) 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 to 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. Cybersecurity for Energy Delivery Systems (CEDS) 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 CEDS 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 CEDS 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 CEDS' funding can be found [here](#).

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](#).

1. 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

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. Actionable Cyber Intelligence

This subtopic is for the development of tools, techniques, and/or methodologies that link information to action/comprehension for energy systems cybersecurity. This subtopic is for the development of capabilities that move past the diagnostic from system anomalies and towards actionable and implementable remediations to malicious intrusions or alterations or energy OT systems. In the interest of developing solutions that incorporate "security by design", the proposed solutions should add value to energy delivery systems operations through thoughtful approaches that aid in answering the question "what next?" when addressing a suspected or confirmed cyber concern. 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: Walter Yamben, Walter.Yamben@netl.doe.gov

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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:

2. 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

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 Industrial Radiography

Industrial radiography is widely used in the chemical, petrochemical, and building industries for radiographic inspection of pipes, boilers, and structures where the economic and safety consequences of failure can be severe. These gamma-ray-based instruments are most often used in domains where other measuring techniques may fail. However, the use of high-activity radioisotope sources (including Ir-192, Co-60, and Se-75) poses a radiological security risk since the sources have the potential to be lost or stolen and used in a radiological dispersal device or radiological exposure device.

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 nondestructive testing due to a lack of viable, comparable, or cost-effective replacements. High-energy x-ray generators have the potential to be used in place of radioisotope sources, thus eliminating the security risk posed by radioisotopic sources. However, several technical hurdles, including lack of portability, unique power requirements, and speed of use, have hampered the replacement of current radioisotopic devices across radiography applications. Therefore, further research and development is needed to overcome these deficiencies to address current and future security risks posed by industrial radiography sources.

The Office of Proliferation Detection is soliciting the development of novel devices capable of replacing the need for radioisotope source-based radiography cameras. Proposed designs must be reliable, robust challenging environmental conditions (e.g., cold weather, precipitation, dust), cost-competitive with gamma-ray radiography cameras, and should address noted deficiencies (e.g., size, weight, power, speed, etc.). Designs should aim to employ novel methods to identify material defects that have previously been challenging for ultrasonic testing, including narrow defects that are aligned with the sound wave, shallow surface defects, and porosity variations. Furthermore, designs that improve upon the mobility, flexibility in tight spaces or around pipes, and image quality of current devices should be prioritized.

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

b. Novel Non-Radioisotopic Technology for Well Logging

Well logging devices have been used worldwide for decades to explore the composition of geological formations, primarily to determine the locations of recoverable hydrocarbon reserves. These instruments often utilize small, sealed americium-beryllium (AmBe) sources in Category 2 or 3 quantities to produce neutrons and gamma-rays to evaluate geophysical conditions including composition, density, hydrogen content, and porosity. While in use in boreholes, these instruments are exposed to harsh operational conditions (e.g., high temperature, high pressure, shock, and vibration). The use of high-activity radioisotope sources (including Am-241 and Cs-137) poses a radiological security risk since these sources have the potential to be lost or stolen and used in a radiological dispersal device or radiological exposure device.

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 well logging due to a lack of viable, comparable, or cost-effective replacements. While there has been some development for alternatives to AmBe sources, including the use of deuterium-deuterium (D-D) or deuterium-tritium (D-T) neutron generators, radioisotope use throughout the industry remains the standard. Several technical challenges remain for transition to alternative technologies, including the robust nature of radioisotopes and power requirements for some forms of neutron or x-ray generators. Therefore, further research and development is needed to overcome these deficiencies to address current and future security risks posed by radioisotope source-based well logging devices.

The Office of Proliferation Detection is soliciting the development of novel devices capable of replacing the need for radioisotope source-based well logging devices utilized for analysis of formation density, shale content, formation composition, and hydrogen content. Proposed designs should provide improvements to inherent challenges of alternatives such as a form-factor and size conducive to drilling operations, ability to survive extreme environments, device portability and power requirements, etc. An example list of technical requirements can be found in the report from the Basic Research Needs Workshop on Compact Accelerators for Security and Medicine-Tools for the 21st Century. Additionally, any new technology must be technically comparable to current AmBe sources used for logging-while-drilling (LWD) and wireline logging used in the acquisition of geologic data and analysis of formation composition. Furthermore, anticipated procurement and operating costs of a replacement system should be on the same order or less than that of a typical radioisotope-based system. A key component of a successful application will include comparison studies and/or field testing between the developed device and conventional radioisotopic devices.

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 this topic are invited.

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

References: Subtopic a:

1. National Academies of Sciences, Engineering, and Medicine, 2021, Radioactive Sources: Applications and Alternative Technologies, Washington, DC: The National Academies Press, <https://doi.org/10.17226/26121>. (October 28, 2021)
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3. 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

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. Large Size, Low-Cost Scintillation Materials for Gamma-Ray Spectroscopy in Portal Monitors

Radiation portal monitors are deployed worldwide for the screening of individuals, vehicles, cargo, or other vectors for detection of illicit sources such as at borders or secure facilities. Most of these systems employ PVT-based plastic scintillator detectors for gamma-ray counting. While medium energy resolution detectors, such as thallium-doped sodium iodide (NaI(Tl)), have been evaluated to reduce nuisance alarms, the performance of such systems has arguably not justified the increased cost. Over the past decade, a wide range of alternative scintillator materials have been explored and several suitable materials have been developed at the proof-of-concept level, with reasonable performance, and at relatively low cost. However, these materials have not been scaled to the sizes and quantities required for use in fielded portal monitor systems.

The Office of Proliferation Detection is soliciting the development of techniques that produce high quality, large volume ($>1000 \text{ cm}^3$), low-cost ($\sim \$1/\text{cm}^3$ or less) plastic or composite scintillators with moderate spectroscopic performance ($<10\%$ @ 662 keV) that could be evaluated for use in radiation portal monitors.

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

References: Subtopic a:

1. Connolly, E.L.; Martin, P.G., 2021, Current and Prospective Radiation Detection Systems, Screening Infrastructure and Interpretive Algorithms for the Non-Intrusive Screening of Shipping Container Cargo: A Review, *J. Nucl. Eng.* 2021, 2, 246–280, <https://doi.org/10.3390/jne2030023> (October 28, 2021)
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4. ADDITIVE MANUFACTURING TECHNIQUES FOR SPACE APPLICATIONS

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

The Office of Nuclear Detonation Detection (NDD) is seeking to increase its options for manufacturing space systems in various radiation (RAD) environments for aerospace applications by simplifying the process of spot shielding components especially within complicated chassis shapes without adding appreciable mass. Grant applications are sought for research in the following areas:

a. Shielding of Electronic Circuits from Space Radiation via Additive Manufacturing

Bulk shielding has traditionally been used to protect electronic circuits from the effects of penetrating radiation in the space environment. Electron-dominated medium Earth orbits may require different shielding optimization than, for example, proton-dominated low Earth orbits. These optimizations may include differing thickness or gradations of high and low-Z materials for shielding, coupled with unique geometries that could be solved with Additive Manufacturing (AM). The development of AM to provide spot shielding, or even conformal shielding, to produce optimized radiation shielding for extending the life of electronic parts in aerospace applications is actively sought.[1, 2]

The Office of Nuclear Detonation Detections is soliciting applications to research, evaluate, and demonstrate via proof-of-concept the feasibility of additively manufacturing shielding that would meet the requirements of space launch and flight. AM parts must be able to withstand typical launch loads as specified in MIL-STD-1540 [3] or the NASA General Environmental Verification Standard (GEVS: GSFC-STD-7000 [4]).

Questions – Contact: Major Adam Rich, adam.rich@nnsa.doe.gov

b. Space Qualified Printed Circuit Boards Produced Via Additive Manufacturing

Production of printed circuit boards (PCBs) with additive manufacturing (AM) technologies is a developing technology with potential for a wide range of applications. Despite these advances, the applicability of the technology to the rigors of space launch and flight environments has not yet been proven. Future sensor development could benefit from using AM technologies for PCBs in the following ways: expedited development via rapid prototyping of new quick-turn design modifications, increased integration of constituent electronic components, and the ability to provide new capabilities not previously available in PCB manufacturing, such as the ability to print passive components (termination resistors and by-pass capacitors) directly into the PCB, thereby reducing board area and component assembly complexity. Additionally, AM may provide improved precision for minimizing conductor widths, conductor separation, and layer separation.

The Office of Nuclear Detonation Detections is soliciting applications to research, evaluate, and demonstrate via proof-of-concept the feasibility of additively manufacturing PCBs that would meet the requirements of space launch and flight. Constraining space application requirements include temperature cycles, shock, vibration, radiation, vacuum, contamination, electromagnetic interference and compatibility [1]. The thermal properties of AM PCBs need to provide conduction cooling of the electronic components similar to, or better than, conventional PCBs. The desired performance is IPC-6012 Class 3 [3]. A potential research goal is to demonstrate an AM-based technology via the production of a prototype(s) multi-layer PCB that meets the rigorous space flight qualification specifications of [1, 2].

Questions – Contact: Major Adam Rich, adam.rich@nnsa.doe.gov

c. Other

In addition to the specific subtopic listed above, NDD invites grant applications in other areas that fall within the scope of the topic descriptions above [1,2,3]. More specifically, topics utilizing advanced lightweight methods and/or materials for radiation shielding or support of space-based electronics by methods other than additive manufacturing.

Questions – Contact: Major Adam Rich, adam.rich@nnsa.doe.gov

References Subtopic a:

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References: Subtopic b:

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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 secure, resilient, and reliable. 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 has taken deliberate efforts to ensure the nation’s most critical energy infrastructure is secure and able to recover rapidly from disruptions.

OE recognizes that our Nation's sustained economic prosperity, quality of life, and global competitiveness depend on access to an abundance of secure, reliable, and affordable energy resources. The mission of OE is to drive electric grid modernization 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 Energy Review](#) and [Quadrennial Technology Review](#).

5. 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

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 energy resources (e.g., 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.

Grid modernization will require the adoption of advanced technologies, such as 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:

- a. Be consistent with and have performance metrics (whenever possible) linked to published, authoritative analyses in your technology space.
- b. Clearly define the merit of the proposed innovation compared to competing approaches and the anticipated outcome.
- c. Emphasize the commercialization potential of the overall effort and provide a path to scale up in potential Phase II follow-on work.
- d. 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.
- e. Fully justify all performance claims with thoughtful theoretical predictions and/or experimental data.

Grant applications are sought in the following subtopics:

a. Advanced Protective Relaying Technologies and Tools

The reliability of an electric transmission or distribution system in response to a fault is heavily dependent upon the underlying protection scheme(s) that would be utilized to identify and respond to that fault. The equipment that forms the basis of these schemes include:

- Protective relays which respond to electrical quantities,
- Communications systems necessary for correct operation of protective functions,
- Control circuitry associated with protective functions through the trip coil(s) of the circuit breakers or other interrupting devices.

Innovative advancements in protective relaying systems are almost limitless, which is why this topic area is focused more on reducing or eliminating those aspects that inhibit the performance and reliability of the elements in this field while improving the resiliency of such elements. Examples of such innovation include but are not limited to: Dynamic, adaptive or setting-less relays; Distinguishing between momentary and permanent faults; Misoperation reduction; and hidden failures. Collaboration with protection device manufacturers and utility protection engineers is strongly encouraged.

Questions – Contact: David Howard, david.howard@hq.doe.gov

b. Methods for Predicting Performance of Power Electronics Technologies

The grid of the future will require a flexible, reliable, resilient, and efficient transmission and distribution (T&D) system to support a smooth transition into accommodating increasing amounts of renewable energy. Power electronics technologies are critical components to the grid and can reduce T&D losses, optimize power delivery, protect critical assets, and enhance resilience. These technologies include solid-state transformers, fault current limiters, high-voltage direct current, and power flow controllers. As ambitious goals such as having 100 percent carbon pollution-free electricity by 2035 come to fruition, there is a need for research and development (R&D) activities that accelerate power electronics technologies from prototype to deployment.

For these technologies, there can be reliability challenges in which factors such as use case and operational conditions can lead to unpredictable behavior that may cause faults or require intervention. As ambitious

goals such as having 100 percent carbon pollution-free electricity by 2035 come to fruition, there is a need for research and development (R&D) activities that accelerate power electronics technologies from prototype to deployment. For these technologies, there can be reliability challenges in which factors such as use case and operational conditions can lead to unpredictable behavior that may cause faults or require intervention.

The objective of this topic is to develop technologies, methods, or processes that can validate the performance of a power electronics technology to ensure reliable and safe operation over its specified lifetime. Achieving these objectives will make progress towards allowing stakeholders such as energy storage developers, Engineering Procurement Construction (EPC), finance, and insurance entities to reduce their soft costs by taking advantage of validation methods that are highly accurate and time effective. There is a similar effort called the Rapid Operational Validation Index (ROVI), which aims to develop techniques to achieve similar objectives for energy storage technologies, this SBIR topic for power electronics is considered a complementary effort. Strong applications will successfully explain their approach to this challenge that can include the following activities:

- Developing new testing methods that can validate the performance of a power electronics technology under a grid related use case
- Utilizing Artificial Intelligence (AI) and Machine Learning (ML) techniques that can predict faults or failure based on operational data of a power electronics technology
- Development of methods that can reduce the time for existing testing and validation methods to be applied to a power electronics technology, includes novel approaches that utilize existing or newly developed sensing technologies

Other criteria that will be used to evaluate applications include:

- If the proposed solution can address multiple different power electronics use cases with an emphasis on applications in the T&D system or uses in energy storage systems
- If the proposed solution includes target metrics that outline an expected level of accuracy over a specific amount of operational time
- If the proposed solution can be applied to multiple types of power electronics technologies

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

References: Subtopic a:

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References: Subtopic b:

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6. ADVANCED ENERGY STORAGE AND POWER CONVERSION SYSTEM FOR ENERGY EQUITY

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

Energy access is a world-wide challenge and there are over a billion people that live their daily lives without electricity. In addition, 100s of millions of people live with expensive and unreliable power further hindering any type of economic development, especially in disadvantaged communities. These communities need clean, resilient, affordable, and dispatchable energy to meet their everyday needs. For example, and according to Energy Information Administration, about 37% Native Americans in the U.S. who live on reservations lack electricity and many lack access to safe, running water. Confronted by these challenges, Native Americans are

turning their attention to renewable energy and some cases renewable plus storage on tribal lands thus securing greater tribal and economic sovereignty through energy independence and economic development. Widespread adoption of grid storage continues to grow, especially due to increasing deployment of renewable energy such as photovoltaic and wind energy in grid-tied and off-grid systems. Grid storage will ultimately improve the reliability, flexibility, security, and quality of existing electricity grid. The enabling technology that is critical to these applications is the power conversion system (PCS). In off-grid renewable systems, the PCS controls the power supplied to and absorbed from the renewables while simultaneously optimizing the energy storage device performance and maintaining load stability.

All applications to this topic should:

- a. Be consistent with and have performance metrics (whenever possible) linked to published, authoritative analyses in your technology space.
- b. Clearly define the merit of the proposed innovation compared to competing approaches and the anticipated outcome.
- c. Emphasize the commercialization potential of the overall effort and provide a path to scale up in potential Phase II follow-on work.
- d. 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.
- e. Fully justify all performance claims with thoughtful theoretical predictions and/or experimental data.

Grant applications are sought in the following subtopic:

a. Adaptable, Deployable, and Robust Power Conversion System for Energy Storage Used by Disadvantaged Off-grid Communities

Remote renewable energy-based power systems deployment is growing in popularity around the world to address energy access challenges. They provide flexible and efficient supply of energy to off-grid communities. However, the lack of in-depth design considerations has resulted in some failures in some off-grid communities. Applications are being sought to develop advanced PCS that can seamlessly integrate various types of storage and renewable technologies and provide sustainable power solutions for disadvantage communities such as on Native Tribal lands. The advanced PCS must be affordable, flexible, and easily deployable for remote communities. The desired PCS rating is >1.5 kW (single user) to 30 kW (community systems) and 120V ac single-phase output. The final design should show a significant increase in performance, flexibility, adaptability (i.e., ability to sense and connect various types of storage and renewable technologies with ease), cost reduction, and decrease in footprint compared to a traditional off-grid power conversion design for remote communities. The PCS should also demonstrate flexible parallel operation to increase power level, as needed, and show advanced control capability that supplies the power to the load continuously while optimizing all power sources requirements.

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

References:

1. Aymen, C., Rashad, K., Ridha, A., Ken, N., 2012, Multiobjective Intelligent Energy Management for a Microgrid, *IEEE Transactions on Industrial Electronics*, Vo. 60, Issue 4, April 2013, <https://ieeexplore.ieee.org/document/6157610> (October 29, 2021)
2. Florin, I., Frede., B., Roger, B., Jon, C., Alfred, R., Stefano, S., Peter, B., Paul, T., Brigitte, S., 2007, Advanced Power Converter for Universal and Flexible Power Management in Future Electric Network, 19th *International Conference on Electricity Distribution*, Vienna, 21-24 May 2007, https://www.researchgate.net/publication/37450055_ADVANCED_POWER_CONVERTER_FOR_UNIVERSAL_AND_FLEXIBLE_POWER_MANAGEMENT_IN_FUTURE_ELECTRICITY_NETWORK (October 29, 2021)

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https://www.researchgate.net/publication/327516858_Versatile_Power_Electronic_Building_Block_for_Residential_DC_Microgrids (October 29, 2021)
4. Savitha, K.P., Kanakasabapathy, P., 2016, Multi-port DC-DC Converter for DC Microgrid Applications, *2016 IEEE 6th International Conference on Power Systems*, 2016, pp. 1-6,
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5. Haimin, T., et al., 2008, Multiport Converters for Hybrid Power Sources, *IEEE Annual Power Electronics Specialist Conference*,
https://www.researchgate.net/publication/224323987_Multiport_Converters_for_Hybrid_Power_Sources (October 29, 2021)

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 CO₂ 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 (TABAs) Program and the American-Made Network

Applicants are encouraged to take advantage of the Technical and Business Assistance (TABAs) 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.

7. EERE JOINT TOPIC: COMMUNITY-DRIVEN SOLUTIONS FOR A JUST AND EQUITABLE ENERGY TRANSITION

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

Achieving an equitable economic recovery powered by clean energy that is carbon pollution free by 2035 will require the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy to leverage the expertise and talents of small businesses. To meet this ambitious goal, the Office of Energy Efficiency and Renewable Energy is soliciting applications from small businesses to develop equitable and inclusive innovative technology solutions for current and future energy challenges and needs.

Technology faces significant cultural, economic, and societal hurdles that limit responsible and accelerated deployment that meets community priorities and equitable outcomes. Actualizing a national goal of net-zero carbon emissions hinges on communities exercising agency in the integration of innovative technologies. Integration into communities may happen through informed decision-making, community-centered research, and engagement at the local, state, and/or regional levels. 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.

This topic aims to support small businesses that advance technology by integrating opportunities for advancing equity. Specifically, this topic encourages small business technology developers from disadvantaged communities, and/or with extensive, substantive partnerships with disadvantaged communities. Please see each subtopic for more details and requirements.

Outcomes of funded projects may include (but are not limited to):

- Methods and processes for the incorporation of procedural justice in technology design and development (i.e., engaged, sustained, and meaningful engagement of community stakeholders in the design and development process);
- Integration of social science or multi-disciplinary approaches in the technological development and deployment;
- Maximized economic outcomes and/or wealth building for communities (Appendix 1) as a direct/indirect benefit of the technology deployment;
- Maximized other direct/indirect benefits for communities as an outcome of the technology development and deployment i.e., sustainable reuse of components or other models for replicable beneficial outcomes such as community agreements;
- Advancements for economic, planning, and/or standardized business models for justice-focused outcomes ranging from community benefits to workforce opportunities i.e. development of a tool or program that advances access to workforce opportunities in a specific clean energy sector for people from underrepresented groups in STEM and disadvantaged communities;
- Materials and components research or design applications that result in more sustainable opportunities for enabling communities to maximize economic benefits and revenue opportunities to inform and promote more sustainable outcomes in the development process.

Participating offices in this topic from EERE are as follows: Bioenergy Technologies, Water Power Technologies, Geothermal Technologies, Solar Energy Technologies, Advanced Manufacturing, Hydrogen & Fuel Cell Technologies, Wind Energy Technologies, and the Vehicle Technologies. Applicants should indicate

which sub-topic their project applies to (See Sub-topics A-H). Applications that do not apply to one specific sub-topic will not be considered.

All Phase I applications to this subtopic must:

- Identify the sub-topic their project applies to;
- Propose a tightly structured program which includes technical milestones/timeline that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Provide evidence that the team has sufficient experience, expertise, and/or capability in working in, or with disadvantaged communities;
- Identify the disadvantaged community organizations with they will work;
- Present a thorough plan that details the method and level of involvement from members of the disadvantaged community organization partner(s);
- Provide a letter of support/commitment from the partnering community organization(s) towards participation in the project;
- Include a design package of their proposed technology or deployment innovation;
- Clearly define metrics and expected deliverables;
- Explain applications of project output and potential for future commercialization;
- Include projections for cost and/or performance improvements that are tied to a clearly defined baseline 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 an energy savings impact and impact grid as well as a preliminary cost analysis
- Include a plan to report all relevant performance metrics; and
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

Applicants should 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 robust implementation and evaluation plan, and will therefore be reviewed based on the “Scientific/Technical Approach” review criteria.

During Phase I, most of the research emphasis is placed on end-user and community partnerships for the proposed concept; 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. Expected outcomes for Phase I will include a table of design specifications for the system and how each relates to a community need.

For Phase II, small businesses should plan to deploy the system design based on findings from Phase I and perform a pilot of the community-driven technological solution.

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. The small business should establish or build on their existing partnerships with members of an organization representing at least one disadvantaged community and/or non-federal government entity. Applicants may utilize the EERE Teaming Opportunity, see “Assistance with Teaming” section below. Applicants must make a case for their proposed application through an initial analysis of the solution’s value to the community partner.

Replicability of proposed technologies and processes in other communities must be examined (i.e., potential for replicability, applicability for other communities, barriers to replicability) in the research plan for this topic as well. The government's Justice40 initiative aims to deliver 40% of the overall benefits of relevant federal investments in climate and energy to persons in disadvantaged communities, and this SBIR topic supports those aims. Small business' processes must meet local regulatory needs (e.g., recycling rates or waste diversion goals) if any.

Assistance with Teaming

EERE seeks to encourage the participation of persons from underserved communities¹ and underrepresented groups in small business innovation. Applicants are highly encouraged to include individuals from groups historically underrepresented^{2,3} in STEM on their project teams.

To facilitate the widest possible national participation in the formation of teams for this topic, EERE is compiling a publicly available Partners List. The list allows organizations who may wish to participate in an application to express their interest to potential applicants and to explore potential partners. Including a partner from this list is not, however, a requirement to be eligible for this topic. Please visit [this website](#) for more information about the Teaming Opportunity.

Specific areas of interest include but are not limited to:

a. Bioenergy Technologies Office

- Emission-reducing technologies/strategies for biorefineries and agricultural operations.
- A conversion process transforming local sources of 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 community.
- Soil carbon sequestration technologies/strategies that can be implemented and/or monitored at the community scale

¹ The term "underserved communities" refers to populations sharing a particular characteristic, as well as geographic communities, that have been systematically denied a full opportunity to participate in aspects of economic, social, and civic life, as exemplified by the list of in the definition of "equity." E.O. 13985. For purposes of this FOA, as applicable to geographic communities, applicants can refer to economically distressed communities identified by the Internal Revenue Service as Qualified Opportunity Zones; communities identified as disadvantaged or underserved communities by their respective States; communities identified on the Index of Deep Disadvantage referenced at <https://news.umich.edu/new-index-ranks-americas-100-most-disadvantaged-communities/>, and communities that otherwise meet the definition of "underserved communities" stated above.

² According to the National Science Foundation's 2019 report titled, "Women, Minorities and Persons with Disabilities in Science and Engineering", women, persons with disabilities, and underrepresented minority groups—blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives—are vastly underrepresented in the STEM (science, technology, engineering and math) fields that drive the energy sector. That is, their representation in STEM education and STEM employment is smaller than their representation in the U.S. population. <https://nces.nsf.gov/pubs/nsf19304/digest/about-this-report> For example, in the U.S., Hispanics, African Americans and American Indians or Alaska Natives make up 24 percent of the overall workforce, yet only account for 9 percent of the country's science and engineering workforce. DOE seeks to inspire underrepresented Americans to pursue careers in energy and support their advancement into leadership positions. <https://www.energy.gov/articles/introducing-minorities-energy-initiative>

³ See also. Note that Congress recognized in section 305 of the American Innovation and Competitiveness Act of 2017, Public Law 114-329:

(1) [I]t is critical to our Nation's economic leadership and global competitiveness that the United States educate, train, and retain more scientists, engineers, and computer scientists; (2) there is currently a disconnect between the availability of and growing demand for STEM-skilled workers; (3) historically, underrepresented populations are the largest untapped STEM talent pools in the United States; and (4) given the shifting demographic landscape, the United States should encourage full participation of individuals from underrepresented populations in STEM fields.

- 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: Brianna Farber, brianna.farber@ee.doe.gov and Elizabeth Burrows, elizabeth.burrows@ee.doe.gov

b. Water Power Technologies Office

- Marine energy technologies, including tidal, current, and wave energy systems as well as ocean thermal energy conversion, suitable for microgrids and for remote, islanded, and isolated communities
- Hydropower technologies, including in small hydropower and low-impact hydropower growth, and new technology development for both existing water infrastructure and new stream-reach applications that incorporate ecological and social objectives

Questions – Contact: Rukmani Vijayaraghavan, rukmani.vijayaraghavan@ee.doe.gov

c. Geothermal Technologies Office

- Development of effective strategies and products for communicating the benefits of geothermal heating and cooling solutions to communities (Apps would need to clearly articulate the innovation in their proposed product and why it would reach communities specifically.)
- Innovative solutions for linking geothermal heating and cooling experts to rural and remote communities without a local workforce or the resources to bring in an expert from outside their region;
- Training materials and curricula for HVAC installers' professional development on geothermal heating/cooling installation and its benefits;
- Software to help communities apply to DOE opportunities; collect information and generate applications and submission packets.

Questions – Contact: Lauren Boyd, lauren.boyd@ee.doe.gov

d. Solar Energy Technologies Office

- Solutions that enable underserved communities to overcome systemic barriers to solar deployment. Applications must be topically distinct from Topics 9 and 10 with no apparent overlap.

Questions – Contact: Rukmani Vijayaraghavan, rukmani.vijayaraghavan@ee.doe.gov and Maggie Yancey, maggie.yancey@ee.doe.gov

e. Advanced Manufacturing Office

Appropriate projects would provide solutions that enable underserved communities to overcome systemic barriers to employment at new materials, clean energy or industrial decarbonization oriented manufacturing facilities with a particular focus on:

- Industrial Decarbonization for local food, chemicals, steel or cement manufacturers and/or
- Goals identified by DOE's Water Grand Challenge [1]

Questions – Contact: Brianna Farber, brianna.farber@ee.doe.gov and Elizabeth Burrows, elizabeth.burrows@ee.doe.gov

f. Hydrogen & Fuel Cell Technologies Office

- Hydrogen and fuel cell technologies that innovatively maximize participation of and/or benefit to communities directly

Questions – Contact: Donna Ho, donna.ho@ee.doe.gov

g. Wind Energy Technologies Office and Water Power Technologies Office – Technology Solutions for Advancing Ocean Co-Existence and Co-Use with Marine Energy and Communities

WETO and WPTO are jointly seeking applications for technology development that enhances understanding and improves co-location/multi-use management of ocean renewable energy development and other marine activities and end-user applications with a motivated purpose of serving disadvantaged communities. These may include communities co-located/or multi-use with potential marine energy sites. Co-location/multi-use is defined as an intentional joint use of space and resources by two or more users in close geographic proximity. Research topics should consider anthropogenic and environmental factors that influence multi-use potential.

Technology development motivations supporting coexistence may include, but are not limited to:

- Increasing and providing accessible and diverse participatory approaches for identifying coastal uses and needs, especially for disadvantaged communities;
- Enhancing access to knowledge and information of co-use activities and technology impacts (e.g., Tribal communities and subsistence fishing);
- Modeling and/or data tool development of marine energy technologies and co-use with other industrial interactions and associated socioeconomics (e.g., socioeconomic impacts on energy transitioning communities);
- Developing spatial analyses and methods that may support technology, data collection, and tool development and/or multi-use planning processes within ocean energy structures;
- Advancing siting, process, or engagement tools aimed at evaluating or minimizing impacts and maximizing benefits on coastal communities and co-users of ocean space;
- Synthesizing or leveraging existing tools into dashboards or data portals that enable improved user-experiences or access to existing data and capabilities (e.g., [Marine Cadastre](#)).

Technology development outcomes may include, but are not limited to:

- Develop non-duplicative tools or software that assess multi-use activities for economic, climate, safety, social, and/or environmental justice values through suitable analyses for ocean marine energy purposes;
- Develop methods and strategies for proposed tool or software uptake and usage that address known challenges, such as continued engagement;
- Encourage innovative methods or tool-use through strategies, such as gamification and virtual reality. User design and other interface design solutions are also encouraged;
- Target information gaps or data-deficient areas of ocean-use. This can be broadly interpreted but must have application to multiple ocean-uses, marine spatial planning processes, and/or local, regional or national ocean-use priorities;
- If access to data is needed for successful Phase I completion, confirmation of access to that data should be noted in the letter of intent, and a letter of commitment must be provided in the full application. Letters of support are also recommended by partners.

The applicants are strongly encouraged to work with State and Federal agencies such as NOAA, BOEM, or others to leverage data and better understand end-user needs. Applicants are also encouraged to engage with end users (e.g., government, manufacturers, and developers) to ensure uptake and adoption of the proposed solution.

Questions – Contact: Rukmani Vijayaraghavan, rukmani.vijayaraghavan@ee.doe.gov and Maggie Yancey, maggie.yancey@ee.doe.gov

h. Vehicle Technologies – Energy Efficiency in Emerging Mobility Systems (EEMS): Developing and Applying Novel Mobility Solutions for Underserved and Disadvantaged Communities

Disruptive transportation technologies and services, such as connected and automated vehicles, car-sharing, and ride-hailing services, provides new, low-cost mobility options for consumers. Additionally, the evolving retail sector, shaped by the convenience of online shopping, has resulted in not only a shift in how we transport and deliver goods, but it has also had ripple effects in personal transportation. This transforming mobility landscape presents a significant opportunity to improve economic and energy productivity and advance safety, affordability, and accessibility in the transportation sector. While these changes in the transportation system can provide benefits to the American public, they also present risks, challenges, and questions that must be addressed. DOE conducts research to understand how this transformation will affect transportation energy consumption and identifies opportunities to create more efficient, affordable, reliable, accessible, and secure transportation options that enhance mobility for individuals and businesses. Within DOE's Office of Energy Efficiency and Renewable Energy (EERE), the EEMS Program is responsible for this research portfolio.

The EEMS Program supports VTO's mission to improve transportation energy efficiency through low-cost, secure, and clean energy technologies. EEMS 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 previously funded EEMS research is included in the conclusion of this sup-topic[1, 2].

There have been previous and current federal RD&D initiatives on developing community-led mobility programs. For example, the Civic Innovation Challenge led by NSF [3] is a multi-agency, federal government research and action competition that aims to fund ready-to-implement, research-based pilot projects that have the potential for scalable, sustainable, and transferable impact on community-identified priorities. The Communities and Mobility track, which was co-funded by the Vehicle Technologies Office, sought to fund teams that could offer better mobility options to solve the spatial mismatch between housing affordability and jobs. Another example of VTO's efforts were in DE-FOA-0002197 [4], Area of Interest 14 on Electric Vehicle and Charging Community Partner Projects.

For this sub-topic, EEMS seeks to **continue and expand** these previous efforts to *more broadly address* the needs of *underserved and disadvantaged communities* [5] *by developing and applying novel mobility solutions*.

Successful applications should:

- Have evidence of strong stakeholder engagement for the underserved and disadvantaged communities they seek to apply their solutions to
- Clearly describe the mobility and transportation problems and challenges of the target community
- Clearly describe what *novel* mobility solution they seek to develop and apply
- discussion of how the proposed mobility solution addresses and reduces *at least 2* of the following:

- o transportation cost
 - o transportation energy
 - o transportation time
 - o transportation emissions
- for the relevant community
- Propose relevant metrics to be able to quantify the benefits of the proposed solutions.

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.

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.

Questions – Contact: eems@ee.doe.gov

References: Subtopic e:

1. U.S. Department of Energy, 2021, About the Water Security Grand Challenge, *U.S. Department of Energy*, <https://www.energy.gov/water-security-grand-challenge/water-security-grand-challenge> (November 1, 2021)

References: Subtopic h:

1. U.S. Department of Energy, 2020, Energy Efficient Mobility Systems, *2020 Annual Progress Report*, Office of Energy Efficiency & Renewable Energy, https://www.energy.gov/sites/default/files/2021-07/VTO_2020_APR_EEMS_06172021_compliant_.pdf (November 1, 2021)
2. U.S. Department of Energy, 2021, 2021 Vehicle Technologies Office AMR Presentations by Program, Office of Energy Efficiency & Renewable Energy <https://www.energy.gov/eere/vehicles/2021-vehicle-technologies-office-amr-presentations-program> (November 1, 2021)
3. Civic Innovation Challenge, 2021, Civic Innovation Challenge Powering Smart & Connected Communities, <https://nscivinnovation.org/> (November 1, 2021)
4. U.S. Department of Energy, 2020, EERE Archived Funding Opportunities, *EERE Funding Opportunity Exchange*, <https://eere-exchange.energy.gov/Default.aspx?foald=0479e8d2-3ad8-4964-ab4b-b665b77029d5> (November 1, 2021)
5. Executive Office of The President, 2021, Memorandum For The Heads of Departments and Agencies, *Office of Management and Budget*, <https://www.whitehouse.gov/wp-content/uploads/2021/07/M-21-28.pdf> (November 1, 2021)

8. JOINT AMO/FECM TOPIC: DIVERSIFYING SUSTAINABLE SOURCES OF CRITICAL MINERALS AND 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: YES

Clean energy technologies – such as wind, electric vehicles, solar, and energy storage – depend on critical minerals and materials (CMM). These CMMs serve essential functions in the technologies and have supply chains which are vulnerable to disruption. As the demand for clean energy technologies accelerates to meet climate goals, demand growth for CMMs is also projected to significantly increase [1]. However, the U.S. lacks

secure, resilient supply chains for many of these CMMs from mineral extraction to downstream manufacturing to end-of-life recycling. A recent report published in response to Executive Order 14017 on America's Supply Chains [3] recommended the expansion of sustainable domestic production and processing capacity – including recovery from secondary and unconventional sources and recycling [4].

This joint topic is a collaboration among the following Offices: DOE's Advanced Manufacturing Office within the Office of Energy Efficiency and Renewable Energy and DOE's Office of Fossil Energy and Carbon Management [5]. Please refer to each office's topics and websites for more information about each office.

For many of these CMMs, the U.S. has domestic resources that could be developed to provide diverse CMMs supply for manufacturing of clean energy technologies. To fully take advantage of these domestic resources, new technologies must be developed to responsibly extract the raw CMMs while minimizing negative environmental, social, and economic impacts. A key strategy to address this challenge is research and development. This SBIR joint topic provides the opportunity to develop resilient, diverse, and secure supply chains through (1) production of CMM by-products from domestic operating mines and oil, natural gas and carbon storage operations and (2) advanced mining techniques and increase environmental and material stewardship – all while minimizing negative environmental, social, and economic impacts.

To be responsive to this joint topic, applications must:

- Evaluate and quantify how the proposed innovation will contribute towards diversified, resilient, and secure sources of CMMs at a regional or national scale;
- Provide evidence that the proposed innovation is cost-competitive and scalable such that the material can be produced domestically in substantial quantities;
- Advance the state of the art and demonstrate improvement relative to a defined baseline;
- Provide evidence that the proposer has the relevant experience and capability for the manufacturing process and energy technology being addressed; and
- Complement and reinforce existing efforts at the Critical Materials Institute (CMI), a DOE Energy Innovation Hub led by Ames Laboratory and managed by the Advanced Manufacturing Office [6], the Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Initiative [7], the ARPA-E Biomining Program, or other projects currently funded by DOE.

To be responsive, proposed approaches should:

- Demonstrate reduction of greenhouse gas emissions¹ and energy, environmental footprint, water, and chemical intensity compared to a defined baseline, such as current production methods [8];
- Consider the full lifecycle of materials and processes;
- Minimize or eliminate waste generation while preserving human and environmental health and safety;
- Advance an approach that diversifies the supply of a CMM for clean energy technologies. For the purposes of this joint topic, clean energy technologies are inclusive of carbon capture and storage technologies and CMMs are defined as: rare earth elements, lithium, cobalt, nickel, graphite, titanium, platinum group metals, niobium, manganese, magnesium, vanadium, gallium, germanium, indium, and tantalum; and
- Engage local community stakeholders as part of their commercialization plan and address opportunities to support regional workforce development.

Applications must address one of the following subtopics:

¹ Compared to 2005 levels

a. Production of CMM By-Products and Other Value-Add Minerals from Domestic Operations

Waste generated from operating mines, oil and gas operations, and carbon storage activities often contains one or more CMM in low concentrations. Operating mines produce primary products as their main source of revenue. There is an opportunity to extract CMMs from these wastes in the form of by-products (Figure 1). By-products are produced along with primary products as described in Figure 1. Addition of new novel technologies to existing operations could extract additional CMMs as by-products. Responsive applications to this subtopic should seek to produce one or more CMM as a by-product from domestic:

- Operating mines (non-coal-based sources) [1]; or
- Produced waters from operating oil, gas and carbon storage operations [2-3].

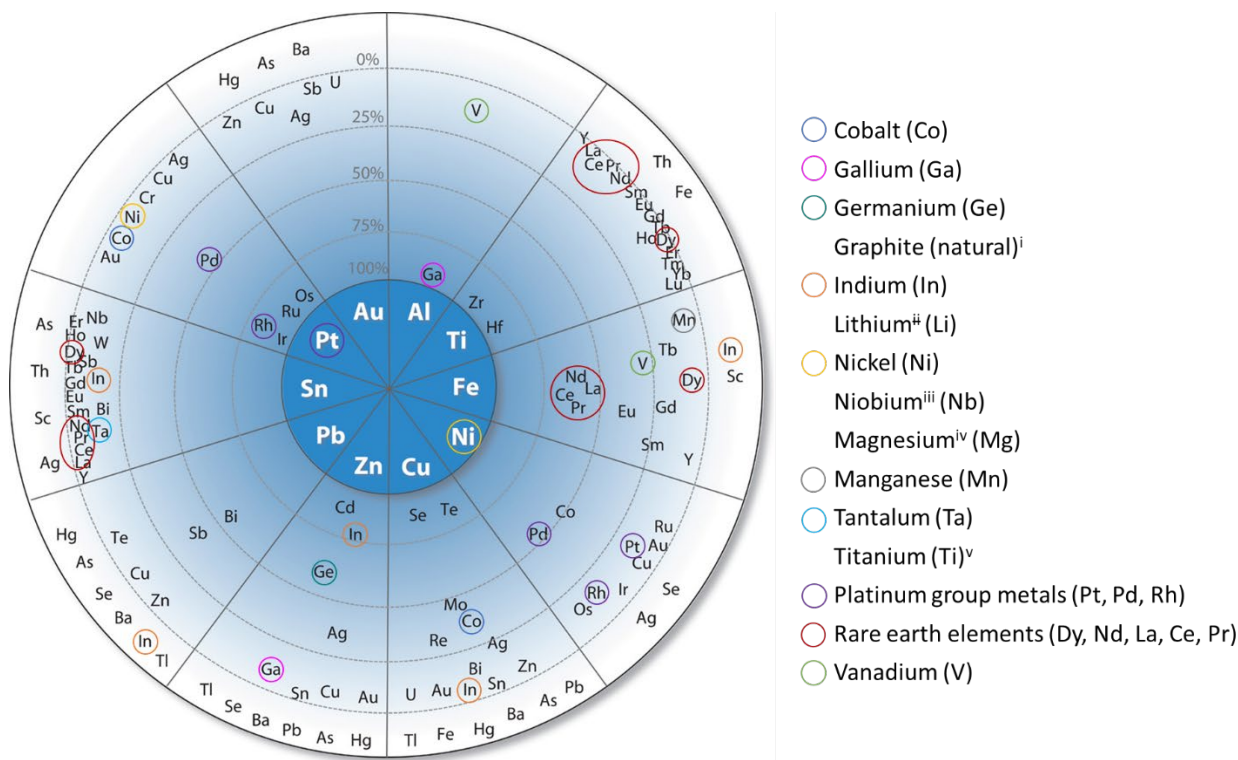


Figure 1. Primary products and by-products [4].

- Natural graphite is produced as a primary product outside the U.S.
- Lithium is produced as a primary product from hardrock and brines sources globally. Lithium can also be produced as by-product from various sources.
- Niobium is produced as a primary product outside the U.S.
- Magnesium is produced as a primary product in the U.S. in limited quantities.
- Titanium concentrates are produced as a primary product in the U.S. in limited quantities.

Production should be done in an environmentally responsible and cost-competitive way. Other value-add mineral(s)/material(s) may also be produced as a by-product to increase cost-competitiveness. The form of the CMM being produced should be specified and how the CMM supports domestic clean energy supply chains should be described. Applications should include a flow-sheet [5] that describes how the technology can be incorporated into an existing facility or operation. Applications should also include an Environmental Social and Governance (ESG) plan.

Applications will be considered non-responsive to this subtopic if they propose a method or technology to extract minerals/materials from:

- Geothermal brines;
- Coal-based sources; or

- Legacy mine waste.

Questions – Contact: Helena Khazdozian, Advanced Manufacturing Office, Helena.Khazdozian@ee.doe.gov or Grant Bromhal, Fossil Energy and Carbon Management Office, Grant.Bromhal@hq.doe.gov

b. Advanced Mining Techniques that Increase Environmental and Material Stewardship

Historic mining operations in the U.S. have resulted in legacy mine waste that have created environmental and health hazards [1]. There is an opportunity for new domestic mining operations to employ advanced mining techniques that both increase environmental and material stewardship, avoiding a new legacy of mining waste. Advanced mining techniques [2] that improve over current industry practices (open-pit mining), such as the use of highly selective extraction methods (e.g., horizontal drilling, in-situ mining), transformative mining techniques like bio-mining, and automation or sensor- and data-based approaches to streamline processes and improve traceability and understanding of the deposit [3], are needed to increase responsible stewardship of domestic sources. New mining operations should leverage all of the materials in a given deposit by including the production of by-products and co-products in the up-front design of the operation, rather than solely producing a primary product. This will develop diverse, resilient, and secure supplies of CMMs. By-products are produced along with primary products as described in Figure 1 above. Coproduction refers to cases where many materials are produced together, each bringing in similar revenues rather than one material accounting for an overwhelming majority of revenue. Responsive applications to this subtopic should seek to develop primary production of mineral(s)/material(s) from domestic onshore sources using advanced mining techniques that:

- Include the production of by-products or co-products in the upfront design of the mining operation;
- Demonstrate how the technique/technology is more environmentally responsible compared to state-of-the-art operations; and
- Produce mineral(s)/material(s) in an environmentally responsible and cost-competitive way.

Other value-added mineral(s)/material(s) can be included to increase cost-competitiveness and material stewardship. Approaches may consider CMMs as the primary product, but should also include the by-production or co-production of other CMMs or value-added minerals.

Teams should engage local community stakeholders as part of their commercialization plan. The form of the mineral(s)/material(s) being produced should be specified and how the mineral/material form supports domestic clean energy supply chains should be described. Applications should include a flow-sheet [4] that describes the approach proposed. Applications should also include an Environmental Social and Governance (ESG) plan.

Applications will be considered non-responsive to this subtopic if they propose mining of:

- Coal-based feedstocks;
- Legacy mine waste; or
- Offshore deposits.

Questions – Contact: Helena Khazdozian, Advanced Manufacturing Office, Helena.Khazdozian@ee.doe.gov or Grant Bromhal, Fossil Energy and Carbon Management Office, Grant.Bromhal@hq.doe.gov

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9. JOINT TOPIC: CABLE CHARACTERIZATION & MODELING FOR FABRICATION

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

The objectives of the Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and Thermal Applications (CABLE) Characterization and Modelling for Fabrication topic are 1) to scale up technology for the fabrication of breakthrough CABLE enhanced-conductivity materials for decarbonization [1] and 2) encourage small businesses to partner with research institutions on advanced characterization, computing, modelling and or theory to inform and optimize their fabrication so as to enhance and maintain enhanced conductivity. [2]

To meet the Administration goals for greenhouse gas reduction—50 percent reduction by 2030, net-zero grid by 2035 and net-zero economy by 2050—to address the climate crisis, the use of energy—both electric and thermal energy -- must undergo major paradigms shifts in how it is created, delivered, stored and consumed [4]. A major strategy for decarbonization of industry, the grid, buildings, transport, and agriculture is electrification [5,6]. The demand for CABLE materials will therefore be increasing rapidly as sectors become increasingly electrified and recover more thermal energy to aid decarbonization. In addition, there is an urgent need to upgrade electric systems for greater grid reliability because of increasing renewables and distributed energy resources (DERs). CABLE materials also can provide increased grid resilience in the face of evolving threats such as cyber-attacks and extreme weather and offer a once in a lifetime window of opportunity to upgrade the fundamental materials and applications that support it.

This joint topic is a collaboration among the following EERE Technology Offices: Advanced Manufacturing, Building Technologies, Geothermal Energy Technologies, Hydrogen and Fuel Cell Technologies, Vehicle Technologies, Wind Energy Technologies Office and Water Power Technologies Office as well as the DOE Office of Electricity and the Office of Science's Basic Energy Sciences Office [3]. Please refer to each office's specific topics for more information about each office.

Like FY 2021 CABLE subtopic 20a), this topic is focused on materials not applications, but unlike it, it encompasses all metal-based approaches [7,8,9,10,11] in the first subtopic and all non-metal-based approaches where the baseline or the enhanced conductivity material meets minimum standards for electrical and thermal conductivity respectively. For both subtopics, 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 a 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 the

connections, applicants must provide details of proposed research institute partners, tools, and techniques such as those in Tables 1, 2 and 3.

We strongly encourage all Applications to include one or more letters of support from a potential partnering research institute such as those in Table 1. While SBIR Applications without a formal agreement with a research institute are acceptable in Phase I, we encourage applicants to consider making the research institute a formal partner by Phase II. This can include switching to an STTR arrangement where the research institute can host the Principal Investigator.

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. [2]
- 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 [12]
- National Energy Technology Laboratory's Auburn campus' industrial scale metallurgy furnaces and covevics expertise and capability [13]
- Argonne National Laboratory's Advanced Photon Source and MERF [14] and
- Argonne National Laboratory's Chemical Deposition expertise, facilities, and capabilities [15]
- Oak Ridge National Laboratory's Manufacturing Demonstration Facility (MDF) expertise, facilities, and capabilities for both metals and non-metals (e.g., carbon fiber CFDF [16, 17]
- Ames National Laboratory metal powder production facilities, expertise, and capabilities [18]

Characterization – focused applications should describe the relevant expertise and facilities in this area of the partnering research institute. These may include ultra-small angle x-ray scattering (USAXS) beam lines at light sources as well as advanced microscopy techniques (e.g., SEM, TEM) such as those in Table 2 [19].

Applications focused on characterization should describe the relevant expertise and facilities in this area of the partnering research institute. Only materials exhibiting enhanced conductivity at bulk scale meeting are of particular interest for characterization. The following characterization data is of particular interest: sample microstructure including grain size, morphology, particle size, vacancies, and defects. These microscopy techniques should be combined with elemental mapping capabilities (e.g., APT, EELS, EDS, XRD, XPS) to confirm the proposed elemental composition and location/distribution of constituents. Multimodal characterization is necessary for identifying nanocarbon features, its morphology as well as topology with respect to the surrounding metallic and non-metallic matrices.

Since defects and contamination are known to reduce conductivity, a responsive application of this type might involve varying key process parameters such as wt. or vol.% of additives, or temperature, pressure or vacuum

results include characterization visualizing defects and contamination and processes that reduce them. If the associated modelling/simulation for the project includes extensive machine learning, then the application should demonstrate the ability to conduct high-throughput experiments to provide sufficient data to cover the space of key composition and processing variables.

All applications must use *[ASTM standards Update with CABLE Stage 2 standards if available by FOA]* for measuring sample performance in validation tests determining electrical properties such as conductivity and current density. If proposers choose to use their measurement set ups, then uncertainty in measurement of the setup has to be reported. Measurement repeatability must also be presented in relevant terms such as standard error, standard deviation, relative accuracy etc. Participants may choose to collaborate with National Laboratories with high accuracy measurement capabilities.

Table 2. Techniques and Tools Encouraged for Characterization include: [19]

- AFM (atomic force microscopy)
- APT (Atom-probe tomography)
- Corrosion Testing
- Density testing
- EDS (Energy Dispersive X-Ray Spectroscopy),
- EBSD (Electron backscatter diffraction)
- HR-STEM (High resolution scanning tunneling microscopy)
- EELS (Electron Energy Loss Spectroscopy)
- Electrochemical testing
- Light-based imaging (e.g., UV/VIS/NIR)
- Nanoindentation testing
- Product Reliability testing
- Raman Spectroscopy
- Rheology testing
- SAXS (small angle x-ray scattering)
- SEM (Scanning Electron Microscopy),
- STM (Scanning Tunnelling Microscopy)
- TEM (Transmission Electron Microscopy)
- Tensile testing
- X-ray based tools (e.g., XPS-ESCA XRD, XPS, USAXS)

Theory/Modelling/Simulation – focused applications are sought that involve scientific modeling, analytic and computation tools needed to successfully inform material and manufacturing research for accelerating materials design and scale-up for enhanced conductivity. Overall, an awareness of current materials design, material processing, and conductivity measurement practices will be important for the theory/modeling/simulation teams to be responsive to the requirements of this subtopic. Relevant areas of expertise include those in Table 3 [20, 21, 22, 23]. A key goal of physics-based theoretical predictions is to enable simulation over a much larger compositional phase space than is readily accessible by experiment including identification of metastable states, and their morphological and topological variations in the material architectures due to processing conditions. It is expected that breakthroughs in electrical and thermal conductivities relevant to CABLE will be made by understanding and controlling material structure and composition at atomic and nanoscale as well as meso-scale dimensions. While confirming enhanced properties at the nanoscale is important, in order to meet the manufacturability goals for CABLE materials,

improved abilities to predict how the enhancements at small length scales will translate into bulk properties is the ultimate goal. An example of an application of bulk materials would be wires for an electric power transmission cable.

Table 3. Theory/modelling/simulation general and specific approaches include:

Physics-based Atomistic Modelling including <i>ab initio</i> calculation [20]
Multiphysics Models [21]
Meso-scale Phenomenological Models
Integrated computational materials engineering (ICME) for conductivity enhancement
Physics-informed machine learning (PIML) for materials and microstructure design and process modeling

The ability to connect theoretical predictions with materials processing environments is often done via development of structure-property-processing-performance (SPPP) metrics for known and computationally designed materials. [24] Development of an integrated computational materials engineering framework (ICME) with connections to physics-based and atomistic understanding of enhanced conductivity will be important for developing capabilities for advancing the state-of-the-art. Use of physics-informed machine learning (PIML) models can include uncertainty quantification (UQ) based on data sets from both physics-based modelling or machine learning data sets, measurements, and/or available knowledgebase in related domains. In modeling and simulations, capabilities are sought to connect the materials chemistry and phase diagram insights to the microstructures obtained because of specific processing pathways and conditions which in turn are related to conductivity predictions. Structural models of chemicals, composites and alloys showing improved charge density and transport properties over metals in Table 3 may be considered. Literature suggests that far-from-equilibrium processing conditions typically develop conductivity enhancement in metals. Applications that extending the understanding of nonequilibrium conditions experienced during materials processing that may or may not lead to formation of a predicted phase or atomic arrangements will be considered responsive.

Preliminary evidence from metal composites [25, 26, 27] suggests that materials exhibiting enhanced conductivity most likely demonstrate metastable microstructures. Therefore, a responsive application of this type might involve modelling of metal microstructure where the additives exist in metastable states to understand the involved carrier transport mechanisms. Process models to exploring manufacturing parameters most likely to promote such metastable microstructures may also be of interest. Theoretical tools that can inform manufacturing processes need appropriate experimental information to validate model performance as there is a critical need to improve the accuracy of predicted materials properties.

All applications to this topic must:

- Propose a tightly structured program which includes clear, CABLE-relevant technical milestones/timeline that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Provide evidence that the proposer has relevant CABLE experience and capability;
 - Clearly define metrics and expected deliverables
 - Explain applications of project output and potential for future commercialization
- Include projections for cost and/or performance improvements that are tied to a clearly defined baseline 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 an energy savings impact and impact grid as well as a preliminary cost analysis;
- Report all relevant performance metrics; and
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

The types of materials that exhibit high and enhanced thermal or electrical conductivity fall into categories like those for the CABLE Conductor Manufacturing Prize Stage 1. Subtopic a. covers metals with and without nanocarbons and subtopic b. covers non-metals.

Applications must be responsive to the following subtopics. Applications providing both enhanced electrical and thermal conductivities are preferred and strongly encouraged. Applications outside of these subtopic areas will not be considered.

a. Enhanced Electrical Conductivity of Metals

This subtopic solicits innovative research and development (R&D) applications for characterization and/or theory, modelling and simulation to improve fabrication of enhanced conductivity materials that are primarily metal such as those in Table 4. The minimum electrical conductivity of metals of interest is 10 MS/m. The proposed metal conductivity enhancement must be more than 5 MS/m above the present baseline/minimum. Examples of eligible enhanced conductivity metals can be found in the recent announcement of the Stage 1 Winners of the CABLE Conductor Manufacturing Prize.

Applications focused on characterization should describe the relevant expertise and facilities in this area of the partnering research institute. The connection between the experimental data and the theoretical modeling should be described. Solely empirical theoretical models are not responsive to this subtopic.

Examples of potential theoretical approaches are described in [1]. An example of atomistic modeling used to develop macroscopic materials parameters to guide fabrication processes is shown in [3].

Table 4. Electrical Conductivity of Common Metal Elements and Alloys [4]

Source: Electrical Conductivity and Density for Common Materials @20C. Appendix A. CABLE Prize Stage 1 rules		
Metal	MS/m	kg/m ³
Silver	63	10,490
Copper (Electrical)	59	8,900
Copper (Annealed)	58	8,930
Gold	41	19,320
Aluminum	35	2,700
Calcium	30	1,550
Al 6061-T6	25	2,700

Magnesium	23	1,730
Tungsten	18	19,250
Zinc	17	7,130
Brass (Electrical)	15	8,500
Nickel	14	8,900
Iron	10	7,860

In this subtopic enhanced thermal conductivity (see Table 5) also is of interest.

Questions – Contact: Tina Kaarsberg, Advanced Manufacturing Office, Tina.Kaarsberg@ee.doe.gov

b. Enhanced Thermal Conductivity of Non-Metals

This subtopic solicits innovative research and development (R&D) applications for the characterization or theory, modelling and simulation to improve the fabrication of enhanced thermal conductivity of non-metallic materials, primarily non-bulk-metals. Improved thermal conductivity can target many applications, including unique anisotropic application (directional optimization). For inherently anisotropic materials such as CNTs, all conductivity values are as measured in plane or along the axis. No minimum baseline or enhanced thermal conductivity improvement (delta) is being required--it must be appropriate for the application being targeted and its unique material requirements. The enhanced thermal conductivity should be above the range of 10 W/mK (watts per meter-Kelvin). These non-metals can include but not limited to polymers and carbonaceous materials including bulk nanocarbons such as carbon nanotubes (CNTs). The connection between experimental data and the theoretical modeling should be clearly described by the applicant. Solely empirical theoretical models are not responsive to this subtopic, lacking the experimental data requirement. This subtopic is about bridging the gap between theory and the fabrication of these enhanced thermal non-metallic materials.

Table 5. Thermal Conductivity of Common Materials [1]

Element or alloy	W/M.k @25C
Diamond	2200 (3320 synthetic)
Individual Carbon Nanotube* or Graphene*	>3000
Doped Graphene*	1575
Doped Carbon Fiber	>1000
Doped CNT*	625
Doped Graphite	25-470
Silver	428
Graphite	168
Doped Silicon	130-148
Silicon carbide	3.8-120
Phosphor bronze	110
Alumina	36
Boron	25
Antimony	18.5
Bismuth	8.1

Tellurium	4.9
Silica Quartz mineral	1.4-3
Ice (0oC, 32oF)	2.18
Amorphous Carbon	1.7
Polyethylene low density, PEL	0.33
Polytetrafluoroethylene (PTFE)	0.25

Note that enhanced electrical conductivity also is of interest (see Table 4) but there is no minimum electrical conductivity requirement for materials under this subtopic.

*Measured in-plan or along axis.

Questions – Contact: Tony Bouza, Advanced Manufacturing Office, Antonio.Bouza@ee.doe.gov

Please refer to Topic 19 (Advanced Manufacturing) for other opportunities related to Advanced Manufacturing technologies.

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2. 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/>
3. For more information on the DOE offices supporting CABLE see the following websites: Office of Electricity (OE) (<https://www.energy.gov/oe/office-electricity>); Office of Basic Energy Sciences within the Office of Science (<https://www.energy.gov/science/bes/basic-energy-sciences>) and those for seven Offices within DOE's Office of Efficiency and Renewable Energy (EERE): Advanced Manufacturing Office (AMO) (<https://energy.gov/eere/amo>), Building Technologies Office (BTO) (<https://energy.gov/eere/buildings>), the Hydrogen and Fuel Cells Technology Office (<https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office>) Solar Energy Technologies Office (<https://www.energy.gov/eere/solar/solar-energy-technologies-office>), the Geothermal Technologies Office (GTO) (<https://www.energy.gov/eere/geothermal>) the Vehicle Technologies Office (VTO) (<https://www.energy.gov/eere/vehicles/vehicle-technologies-office>); the Wind Energy Technologies Office Wind Energy Technologies Office (WETO) (<https://energy.gov/eere/wind>) and the Water Power Technologies Office (WPTO) (<http://energy.gov/eere/water/water-power-program>). CABLE Team Members and Partners CABLE specific activities are described in presentations that can be found at: <https://blogs.anl.gov/cable-bigideas/wp-content/uploads/sites/93/2021/05/CABLE-Workshop-Recap-D1.pdf>. from the virtual CABLE Workshop Report April 7-9, 2021.
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10. JOINT BTO/AMO TOPIC: THERMAL ENERGY STORAGE (TES)

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

This joint topic between BTO[1] and AMO [2] solicits R&D applications for innovative solutions in advanced thermal energy storage technologies (TES) in buildings, including industrial buildings. There are four subtopics. Please note that awards may not be made in all subtopics, and the distribution will depend on the number and quality of applications received. In all cases, project benefits should be demonstrated and validated as part of the proposed project structure, and clear demonstration of product or technology capabilities is required for consideration for advancement to Phase II funding.

a. Simplified Sizing and Selection Tool for TES

Develop a simplified sizing and selection tool for HVAC installers and buildings owners. This tool should accurately model system performance of a TES integrated cooling/heating system, determine the most economical size of the TES and cooling/heating system, and show small to medium commercial and residential building owners the benefits of adding TES. The tool should be able to provide answers in seconds on a commonly used laptop, desktop computer, or tablet. Such a TES selector sizing tool can help installers choose the appropriate solution for each customer and make an informed decision without knowing the in-depth technical specifications of each technology.

Questions – Contact: Sven Mumme, Sven.Mumme@ee.doe.gov

b. Advanced Building Controls for Managing and Controlling TES

Develop intelligent and robust sensors for TES or controls with look ahead capability to properly schedule the TES charging/discharging. Advanced sensors are needed for TES, such as estimating the TES state of charge. Controls are needed to coordinate the TES operation with other equipment, such as HVAC system, to optimize or co-optimize energy efficiency, user comfort, tear and wear, utility bills, etc. Full control is needed over when/how TES charges and discharges, including considering the state of charge. Built-in robustness is required for ensuring guaranteed control performance by actively rejecting disturbance from the uncertainties associated with weather, occupancy, electricity price etc. The control algorithm should show meaningful improvement over simple schedule-based control algorithms. Additional functionality to control and co-optimize hybrid systems utilizing TES and battery storage is of interest.

Questions – Contact: Sven Mumme, Sven.Mumme@ee.doe.gov

c. Integrated TES in HVAC&R Systems

Design and develop turnkey packaged solutions with installation in mind and minimizing on-site customization needs. Systems that are market ready within 2 years are greatly preferred. This requires a thermal storage

that is integrated into a packaged system or is combined with central chillers more seamlessly without onsite custom engineering. This also requires maximizing the utility of the storage, by enabling the largest possible cost savings for the building owner or electric utility. Applications that seek to demonstrating the benefits of TES by developing use cases and field validation are also of interest.

The following targets are highly desirable:

- \$15/kWh incremental cost of adding TES to the system
- Mass fraction PCM for the whole HX system >90%
- For direct refrigerant evaporator/condenser operation, charge of refrigerant per unit thermal storage < 4 oz per kWh

Questions – Contact: Sven Mumme, Sven.Mumme@ee.doe.gov

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11. JOINT TOPIC: WATER AND WIND TECHNOLOGIES AND ADVANCED MANUFACTURING OFFICES: DEVELOPMENT OF COST EFFECTIVE SUBSEA WET-MATEABLE CONNECTOR 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

The Office of Energy Efficiency and Renewable Energy's Water Power Technologies Office (WPTO) (<http://energy.gov/eere/water>) conducts early-stage research and development to strengthen the body of scientific and engineering knowledge enabling industry to develop new technologies that increase US hydropower and marine energy (ME) generation. Hydropower and ME technologies generate renewable electricity that supports domestic economic prosperity and energy security while enhancing the reliability and resiliency of the US power grid.

The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's Wind Energy Technologies Office (WETO) (<https://energy.gov/eere/wind>) drives innovation through research, development, and testing

of advanced wind energy technologies. The portfolio focuses on land-based, offshore, and distributed wind, as well as integration with the grid.

EERE's Advanced Manufacturing Office (AMO) (<http://energy.gov/eere/amo>) collaborates with industry, small business, universities, national laboratories, state and local governments and other stakeholders on emerging manufacturing technologies to drive U.S. industrial decarbonization, energy productivity and economic competitiveness. AMO has a mission to develop technologies that 1) reduce manufacturing energy intensity and industrial carbon emissions 2) increase the competitiveness of the U.S. manufacturing sector with a focus on clean energy manufacturing and 3) reduce the life cycle energy and carbon impact of manufactured goods in industry, buildings, transport, power and agricultural sectors.

This Joint Topic is aimed at research and development of manufacturable, commercially-viable wet-mateable connectors for both Marine Energy (ME) and Offshore Wind Energy applications.

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 recent baseline (i.e. Roadmap targets and/or state of the art products or practices);
- Explicitly and thoroughly differentiate the proposed innovation with respect to state-of-the art existing commercially available products or solutions;
- Include a preliminary cost analysis;
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

Applications must be responsive to the following subtopic. Applications outside this subtopic will not be considered.

a. Development of Manufacturable, Cost Effective Wet-Mateable Connector Technologies

This subtopic seeks applications for research and development of manufacturable, commercially viable wet-mate connectors for both Marine Energy (ME) and Offshore Wind Energy applications. The goal is to research, design, fabricate and test wet-mate connectors that advance the current state of the art (see references 1, 2 and 3). In particular, we are interested in applications that meet one of these two objectives:

1. Research, design, fabricate, test and certify per reference 4 a 66kV wet mate subsea connector that is designed based on offshore wind applications.
2. Research, design, fabricate, test and certify per reference 4 a 11.4kV wet mate subsea connector and conduct operational testing in an open water environment by partnering with a ME developer that is developing plans for open water testing of their device through a separately funded project. The connector design specifications should be based on the ME developer's technical requirements, particularly with respect to typical operating depths of ME devices. The design should be based on 25-year service life with periodic maintenance intervals as required. The connector should also be designed for at least annual connection/disconnection during its service life. The application should include innovative methodologies for connection/disconnection that minimize operating costs over the service life of the connector.

To achieve either of these objectives the application should include manufacturing research to enable more cost-effective design and fabrication of either a 66kV or a 11.4kV wet-mateable subsea connector that reduces the connector's lifecycle cost by extending its service life with materials suitable for undersea harsh service conditions.

Where feasible, the application should include improved technologies for built in monitoring sensors that provide remote monitoring via fiber optics for maintenance planning. Modular designs that enable the connectors to be adapted for both offshore wind and marine energy (ME) renewable energy applications will have the greatest global market opportunity. In general, applications should advance the current state of the art with respect to system reliability and costs of wet-mate technologies. Applications should include initial design constraints for power and operating depth. It is anticipated that the wet mate connector design will enable the cable connection to be made with a remotely operated vehicle (ROV) operated from a support vessel to reduce Installation, Operation, and Maintenance (IO&M) costs.

Competitive applicants should demonstrate knowledge and experience in developing cost effective wet-mateable connector technologies and include the following in their application:

- Preliminary conceptual design of the proposed system with estimated physical dimensions and a clear description on how the system operates and drawings of the proposed system.
- State-of-the-art for incumbent technologies and how the proposed system advances the reliability and affordability of wet-mate connector technologies.
- Details of work to be performed in Phase I including resources required and intended performance targets.
- Preliminary description of Phase II work including plans for prototype fabrication and testing/certification.

Expected outcomes for Phase I work should include:

- Final design
- Final cost estimates for fabrication and testing
- Fabrication work plan
- Lifecycle durability estimates
- Testing and certification plan

Expected outcomes for Phase II work should include:

- Final test report
- Final certification in accordance with international technical specification/standards where feasible
- Project's final report should include discussion of lessons learned with respect to design, fabrication and testing challenges of subsea wet-mate connectors, and any suggestions for future R&D efforts to improve wet mate connector technologies. For the ME device connector, the final report should also include a discussion of the lessons learned with respect to connection/disconnection testing in the open water.
- The scope of the project also includes the development of associated IO&M documents.

Questions – Contact: Rajesh Dham, rajesh.dham@ee.doe.gov

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12. BIOENERGY 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

Bioenergy Technologies (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.

Note: BETO is also supporting Topic 7: Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition.

Applications are only being considered in the following subtopic:

a. Increasing the Algal Portion of Fuels and Products

Incorporating algae biomass derived materials into fuels and products (subsequently referred to as products) in initial or increasing amounts will help grow algae supply chains and contribute BETO's goals for sustainable aviation fuels (See Reference 1 for an overview of BETO). The biorefinery model, where multiple products are made from biomass feedstocks, can help increase both the value of algae biomass and the GHG impacts of algae products.² The inclusion of algae in products can add value to products, improve the performance of materials, and/or help differentiate branded consumer goods.^{3,4} However, there are challenges that limit incorporating algae and algae-derived materials at initial or increasing inclusion rates that include but are not limited to: composition and purity of the algae biomass; separation of algae biomass-derived materials; drying, stabilization and/or storage of algae and derived materials; mixing and rheology of algae and product formulations; and product performance. Overcoming these challenges will allow for greater amounts of algae to be included in products, increasing the demand for algae feedstocks, and accelerating the scale-up of the growing algae industry.

The purpose of this subtopic is to develop technologies, methods, and/or formulations for the greater inclusion of algae biomass or algae biomass-derived materials into products such as fuels or materials. Greater inclusion of algae must result in an improvement in life-cycle metrics such as lowered greenhouse gas emissions of the product to align with BETO's mission. While algae have promising applications for food and feed in addition to fuels and products, food and feed are not of interest for greater incorporation of algae under this topic.

Applications under this topic must have 1) a supply of algae identified and 2) a product or products that either have existing formulations that utilize algae in which the inclusion rate can be increased or a product formulation that could incorporate algae in novel or innovative ways. By the end of Phase I, projects should seek to understand and define the composition of the algae so as to be able to develop specifications for the acceptance of algae into their supply chains and should produce proof-of-concept products that contain the target inclusion rate of the algae. Phase II projects will further develop the supply chain and complete product acceptance testing. Projects must be guided by ongoing techno-economic and life-cycle analysis that seek to quantify the economic and environmental benefit of greater inclusion of algae in the target product(s) and deliver LCA analyses at the conclusion of the project.

For the purposes of this topic, algae biomass is defined as that derived from cyanobacteria, microalgae, and macro-algae (seaweed). The topic requires a scalable source of algae biomass that can be readily accessed for the Phase I and II projects as well as support further scale-up and commercialization. The topic requires specific product(s) to be identified and a discussion how greater amounts of algae can be included in their formulation if the specific challenges limiting the inclusion rate are overcome. By the end of Phase II, projects should target 50% increase in algae inclusion for products with existing algae inclusion and at least 10% algae by weight in products without prior algae inclusion.

Questions – Contact: Daniel Fishman, daniel.fishman@ee.doe.gov

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13. 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

The Hydrogen and Fuel Cell Technologies Office (HFTO) (<https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office>) 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. The overarching program goal, supporting the DOE H2@Scale initiative, is to facilitate widespread adoption of hydrogen and fuel cells across sectors by reducing the cost and improving the performance/durability of fuel cells, as well as developing affordable and efficient technologies for hydrogen production, delivery, and storage. The scope is technology-neutral and feedstock-flexible, emphasizing diverse end uses including energy storage, transportation (e.g., trucks, marine, rail, mining), chemicals (e.g., ammonia, synthetic fuels), backup power (e.g., emergency power, data centers), industry (e.g., iron and steel making), and others.

Applications sought will help to enable the H2@Scale vision by reducing the cost and increasing the durability of fuel cells and infrastructure components necessary to enable the wide-spread adoption of hydrogen across multiple end-uses.

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 cost and/or performance 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.

Note: HFTO is also supporting Topic 7: Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition.

HFTO seeks applications only in the following subtopics:

a. TECHNOLOGY TRANSFER OPPORTUNITY: In-line Hydrogen Contaminant Detector

This Technology Transfer Opportunity solicits interested companies to license a newly developed novel electrochemical hydrogen pumping cell for use as in-line hydrogen contaminant detector (HCD) at hydrogen refueling stations.

There is a compelling need to develop low-cost HCDs to warn hydrogen refueling station operators of any potential fuel quality problems. The current state-of-the-art analyzer uses a membrane that is humidified with water from a refillable reservoir. This HCD operates in an extractive/bypass mode where the hydrogen is sampled at a low flow rate and at atmospheric pressure and cannot be placed in the dry pressurized hydrogen stream. Moreover, the hydrogen once sampled cannot be returned to the fueling station and needs to be vented since it is humidified. Even in this extractive mode, the analyzer is an important improvement over expensive analytical equipment (e.g., non-dispersive infrared, spectroscopy, etc.) that is currently being utilized at stations to verify hydrogen fuel quality. The operators of refilling stations have expressed dissatisfaction with commercial analyzer technologies with concerns regarding the cost of ownership and operation as well as excessive drift.

Los Alamos National Laboratory (LANL) has developed an internal water wicking scheme where water is provided to the electrolyte and electrodes from an internal reservoir thus permitting the detection of any contaminants that poison the platinum catalyst in the working electrode and any contaminants that may interfere with hydrogen oxidation reaction or proton transport through the membrane. The HCD operates under a constant voltage mode (≈ 100 mV) where the hydrogen pumping current is continuously monitored. Periodically (\approx every 10-15 minutes) a high voltage pulse (up to 1.5 V for 30 seconds) is applied to reset the pumping current to its baseline. In this mode a current trigger level can be set to alert the HCD operator of fuel quality issues. Whenever the pumping current drops below this pre-set value, the HCD can be set to either trigger an alarm or to shut-down the system.

LANL researchers have installed and field tested an analyzer, based on this technology at the H2Frontier hydrogen filling station located in Burbank, CA. The performance of this analyzer was superior to that of a commercial analytical non-dispersive infrared CO analyzer installed at this station. The LANL HCD successfully operated for hundreds of hours with a stable baseline response (no false positives) and was sensitive to ≤ 200

ppb of CO without any need for repeated calibration over a period of one year. The response time of the HCD to 200 ppb CO has been demonstrated to be < 2 minutes during field testing at the filling station. The only maintenance required of the HCD is the periodic re-filling of water in the reservoir.

HFTO seeks applications to scale-up and commercialize deployable HCDs for use at hydrogen refueling stations. A culmination of over a decade of hydrogen fuel quality research at LANL, the in-line analyzer is versatile and can continuously monitor hydrogen fuel quality within the hydrogen refueling station dispenser and is sensitive to any contaminant that can adversely impact the performance of current fuel cell systems. This HCD can be used to quickly alert station operators of any fuel quality issues, that have the potential to damage expensive fuel cell systems.

Los Alamos National Laboratory Information:

Licensing Information: Los Alamos National Laboratory

Contact: Steven F. Stringer, stringer@lanl.gov

License type: Non-Exclusive Patent

Patent Status: Active – US Patent 10,490,833 -

<https://patents.google.com/patent/US10490833B1/en?q=10490833>

Publication Date: 11/26/2019

Filing Date: 11/07/2017

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

b. Innovative, Durable PEM Fuel Cell Cathode Catalysts for Medium- and Heavy-Duty Truck Applications

This subtopic solicits applications for novel and innovative concepts that advance the development and integration of oxygen reduction reaction (ORR) cathode electrocatalysts for use in heavy-duty direct hydrogen polymer electrolyte membrane (PEM) fuel cells, with a focus on high durability and high fuel efficiency.

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 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 is a key parameter for economic viability.

PEM fuel cell membrane electrode assemblies (MEAs) rely on expensive Platinum Group Metals (PGM) as catalysts within the electrodes. A critical path to reducing fuel cell cost is to reduce the amount of PGMs used in fuel cells and enhance ORR activity while maintaining fuel cell durability and efficiency. For state-of-the-art MEAs, durability and power output decrease with lower PGM loading. This makes it difficult to meet 2030 DOE target of 25,000 hours durability for medium- and heavy-duty transportation applications while simultaneously meeting targets for system cost (\$80/kW) and efficiency (68% peak). In the most demanding applications, the conditions include operation in the presence of fuel and air impurities, starting and stopping, freezing and thawing, and humidity and load cycling that result in mechanical and chemical stresses on fuel cell materials, components, and interfaces.

To expedite heavy-duty fuel cell competitiveness, the DOE established the Million Mile Fuel Cell Truck consortium (M2FCT), which includes national labs in partnership with universities and industry to accelerate R&D that would enable meeting a fuel cell durability of a million miles. M2FCT is a large-scale, comprehensive effort to enable widespread commercialization of fuel cells for heavy duty applications with a focus on achieving aggressive targets for fuel cell MEAs that meet efficiency, durability, and cost. Successful applicants

are expected to collaborate with M2FCT where possible, including testing and utilizing appropriate accelerated stress tests (ASTs). Proposed catalyst designs submitted in response to this subtopic should demonstrate significant progress, when integrated in an MEA, toward meeting the M2FCT 2025 MEA target of 2.5 kW/gPGM power output (1.07 A/cm² current density at 0.7 V) after running a heavy-duty AST equivalent to 25,000 hours. The target is for MEA-level performance with total PGM loading constrained to 0.3 mg/cm². MEA test conditions: 88°C, 2.5 atm, SR: 1.5 cathode/2 anode, 40% relative humidity, integral cell conditions.

Phase I applications should provide details of novel low-PGM (≤ 0.3 mgPGM/cm²) cathode oxygen reduction catalyst synthesis, MEA integration approach for enhanced performance, MEA testing, and substantial evidence of how the approach improves durability and efficiency of low-cost fuel cells under realistic conditions.

Questions – Contact: Gregory Kleen, Gregory.Kleen@ee.doe.gov

c. Flow Control and Metering Technologies for Heavy-Duty Hydrogen Fueling

This subtopic solicits applications to develop flow meters for use at hydrogen fueling stations for medium- and heavy-duty fuel cell vehicles (MHDFCVs). Stations selling retail fuel for MHDFCVs are expected to require high-accuracy meters to inform hydrogen sales. While high-accuracy (2% or better) performance has been achieved by meters for use at light-duty hydrogen stations, flow rates at MHD stations are expected to be significantly higher (up to 20 kg/min), and to challenge the performance of conventional designs. This topic seeks R&D to develop meters that can achieve 5% or better accuracy over the course of a 100-kg fill that occurs over 10 minutes, with a peak flow rate of 20 kg/min, peak pressure of 1,000 bar, and average temperature of -40C.

Phase I applications must describe the current status of the metering technology being developed, and innovations targeted to achieve at least 5% accuracy. Applications must also describe bench-scale testing that will be completed to assess the likelihood of the proposed concept achieving 5% or better accuracy.

Questions – Contact: Neha Rustagi, Neha.Rustagi@ee.doe.gov

References: Subtopic a:

1. Mukundan, R., et al, 2020, Development of an Electrochemical Hydrogen Contaminant Detector, *J. Electrochem. Soc.* 167 147507, <https://iopscience.iop.org/article/10.1149/1945-7111/abc43a/pdf> (November 3, 2021)
2. Los Alamos National Laboratory, 2020, R&D 100: Hydrogen Contaminant Detector, *Los Alamos National Laboratory Youtube*, https://www.youtube.com/watch?v=kz_1XAIDslw (November 3, 2021)
3. Rockwood, T., et al, 2021, Fuel Quality Assurance Research and Development and Impurity Testing in Support of Codes and Standards, *Los Alamos National Laboratory*, 2021 Annual Merit Review presentation, https://www.hydrogen.energy.gov/pdfs/review21/scs007_rockward_2021_o.pdf (November 3, 2021)

References: Subtopic b:

1. Marcinkoski, J., et al, 2019, Hydrogen Class 8 Long Haul Truck Targets, U.S. Department of Energy, https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf (November 3, 2021)

References: Subtopic c:

1. MacDonald, M., et al, 2021, Calibration of Hydrogen Coriolis Flow Meters Using Nitrogen and Air and Investigation of the Influence of Temperature on Measurement Accuracy, *Science Direct, Volume 79*, June 2021 101915, <https://www.sciencedirect.com/science/article/pii/S0955598621000303> (November 3, 2021)

2. Marcinkoski, J., et al, 2019, Hydrogen Class 8 Long Haul Truck Targets, U.S. Department of Energy, https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf (November 3, 2021)

14. 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

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.

Note: VTO is also supporting Topic 7: Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition.

Applications are sought in the following subtopics:

a. Electric Drive Vehicle Batteries

Applications are sought to develop electrochemical energy storage technologies that support commercialization of micro, mild, and full HEVs, PHEVs, and EVs. Some specific improvements of interest include the following: new low-cost materials; alternatives or recycling technologies of energy storage critical materials defined at: <https://www.energy.gov/policy/initiatives/department-energy-s-criticalmaterials-strategy> [1]; high voltage and high temperature non-carbonate electrolytes; solid electrolytes and lithium metal batteries; improvements in manufacturing processes – specifically the production of mixed metal oxide cathode materials through the elimination or optimization of the calcination step to reduce cost and improve throughput, speed, or yield; novel solid-electrolyte interphase stabilization techniques for silicon anodes; improved cell/pack design minimizing inactive material; significant improvement in specific energy (Wh/kg) or

energy density (Wh/L); and improved safety. Applications must clearly demonstrate how they advance the current state of the art and meet the relevant performance metrics listed at www.uscar.org/guest/article_view.php?articles_id=85 [2].

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 at www.uscar.org/guest/article_view.php?articles_id=86 [3]. Phase I feasibility studies must be evaluated in full cells (not half-cells) greater than 200 mAh in size while Phase II technologies should be demonstrated in full cells greater than 2 Ah.

Applications will be deemed non-responsive if the proposed technology is high cost; requires substantial infrastructure investments or industry standardization to be commercially viable; and/or cannot accept high power recharge pulses from regenerative braking or has other characteristics that prohibit market penetration. In addition, applications deemed to be duplicative of research that is already in progress or like applications already reviewed this year will not be funded; therefore, all submissions should clearly explain how the proposed work differs from other work in the field.

Questions – Contact: Simon Thompson, Simon.Thompson@ee.doe.gov

b. Planar Magnetic Solutions for High Frequency Power Conversion in Medium Voltage (MV) Grid-Tied EV Charging Systems

Continued advancements in wide-bandgap power semiconductors have introduced higher voltage rated power modules capable of withstanding voltages ≥ 3.3 kV with ≥ 100 A handling capability, increasing the viability of medium voltage (MV) grid-tied power electronics solutions for 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 MV grid voltage (~ 13 kVAC) to a LV (480 VAC) input for DCFCs while also providing the isolation critical for protecting the electrical grid. These solutions utilize a high frequency transformer to provide isolation, as well as to step-down the bus voltage to the voltage range necessary for EV charging.

Current state-of-the-art (SOA) soft magnetic core materials for high frequency transformers include amorphous, and nanocrystalline alloys, which are costly, constrained to a handful of suppliers, and have a limited operating temperature range. The most power dense high frequency transformer designs currently available utilize a planar structure with either EE or EI planar ferrite core structures with copper trace windings compared to conventional Litz wire windings [2]. Planar magnetics provide the benefits of reduced height, improved reliability, simplified manufacturing, and greater power density [3]. However, the high AC resistance, intrinsic parasitic capacitance, and limited voltage isolation of planar designs presents a current barrier for implementation in MV grid-tied DCFC systems. It is therefore critical to determine cost-effective, lightweight, and innovative solutions to advance high frequency planar transformer technology for suitable implementation in MV DCFCs and other applications.

This topic intends to find innovative, low-cost, efficient, and power dense solutions to improve planar transformer designs for utilization in MV grid-tied SSTs. Proposed innovations may include but are not limited to: novel soft magnetic core materials, superior isolation dielectric material, advanced copper trace winding interleaving, or innovative thermal solutions. The technology should meet standard requirements for dry type

transformers under IEEE Std. C57.12.01, such as applied voltage test, partial discharge test, and lightning impulse test [4].

Applications must clearly demonstrate how the proposed work will improve on the SOA performance and include possible cost-effective pathways for commercial adoption in DCFCs. Projects should aim to design and simulate/model a ≥ 160 -kVA prototype transformer implemented in a Dual Active Bridge (DAB) converter for a MV-to-LV EV DCFC with 150-kW output rating. Phase I should include in-depth analysis of the magnetic and thermal properties of the proposed innovation to demonstrate technology viability, with plans to prototype and test one unit in Phase II.

Questions – Contact: Steven Boyd, steven.boyd@ee.doe.gov

c. Innovative Green Composites for Future Vehicles

Electric Vehicles (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 composites design and manufacturing is urgently needed to enable lightweight composites in future vehicles with low embodied energy.

Green composites are an important class of composite materials with exceptional recyclability and low carbon footprint. Biodegradable or recyclable polymeric materials can be reinforced with natural or recyclable fibers to form composites that are eco-friendly and sustainable. Green composites have the potential to replace traditional nonbiodegradable or nonrecyclable petroleum-based composites and other heavier structural materials such as steels.

Areas of interest within this subtopic are as follow:

1. Novel matrix and/or reinforcement materials that significantly reduce the manufacturing energy of composite components as compared to carbon fiber reinforced polymers. Green composites should possess a specific strength and a specific stiffness equivalent to or superior over currently used materials while meeting vehicle lifetime durability requirements to be relevant for automotive structural use. Some of the green composites could absorb carbon emissions in their use. Technologies to process and employ natural fibers have the potential to replace traditional high energy manufacturing of composites. Exploring the manufacturing of natural fiber composites may open unprecedented opportunities for eco-friendly, green vehicles.
2. Recyclable dissimilar materials may be hybridized to simultaneously achieve lighter weight, lower cost, less carbon emissions, and more multifunctionalities for vehicle structures. Functionalities of interest may include structural health monitoring, thermal management, self-healing, etc. Novel matrix, reinforcement, or processing approaches should be explored in composites design and manufacturing to increase recyclability, decrease cost and decrease carbon footprint of composites. Recyclable dissimilar materials may be optimized via artificial intelligence/machine learning tools to realize unprecedented lightweighting, cost-reduction, and functionalities.

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

References: Subtopic a:

1. U.S. Department of Energy, 2010, Critical Materials Strategy, *U.S. Department of Energy*, <https://www.energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf> (November 3, 2021)
2. USCAR, 2021, Energy Storage System Goals, *United States Council for Automotive Research, LLC*. http://www.uscar.org/guest/article_view.php?articles_id=85 (November 3, 2021)

3. USCAR, 2021, USABC Manuals, *United States Council for Automotive Research, LLC*, www.uscar.org/guest/article_view.php?articles_id=86 (November 3, 2021)

References: Subtopic b:

1. USDRIVE, 2017, 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> (November 3, 2021)
2. Dixon, L., Designing Planar Magnetics, *Texas Instruments*, <https://www.ti.com/download/trng/docs/seminar/Topic4LD.pdf> (November 3, 2021)
3. Mukherjee, S., et al, 2021, A High-Frequency Planar Transformer with Medium-Voltage Isolation, *NREL*, June 2021, <https://www.nrel.gov/docs/fy21osti/79583.pdf> (November 3, 2021)
4. 2020, IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers, IEEE, Nov 2020, <https://ieeexplore.ieee.org/document/9269795> (November 3, 2021)

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

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. DOE recently 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 over 3%. In California, solar accounts for more than 20% of all electricity generated, with 10 other states generating 5%-10% from solar. [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 80 gigawatts alternating current (GW_{AC}) of solar capacity in the United States as of the end of 2020. [3] About 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]. Other programs include the American-Made Solar Prize [7], the Incubator topic area in SETO FOAs [8], and the Technology Commercialization Fund [9]. Please read the individual funding opportunities 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.

This topic is open to both SBIR and STTR applications. SETO also has an additional Topic (Topic 16) open only to STTR applications. SETO is also supporting Topic 7: Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition.

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 SBIR/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 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 federal assistance reporting checklist (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 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	$\leq \$50/\text{m}^2$	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	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.

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
				with capacity over 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 fabricate and test a large-scale prototype of this technology.	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.
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. Multiuse Integrated Photovoltaic Systems

This subtopic solicits applications for technology components and systems that integrate photovoltaic technologies with other energy, agricultural, and built environment systems. The goal of this subtopic is to support ideas and prototype development of technologies that can accelerate decarbonization of the agriculture and transportation systems and improve building efficiency while reducing carbon emissions associated with the electricity system.

As cumulative photovoltaic installations increase, the value of integrated, multi-technology, and multi-sector systems may grow significantly. This subtopic solicits improvements in three areas:

1. **Solar-enabled improvements in overall system performance.** Beyond simply avoiding negative impacts on other elements of an integrated system, adding solar technologies can directly increase value. For example, partial shading from photovoltaic arrays may increase crop yields through reduced plant stress, lower plant transpiration rates or water loss from the ground or decrease cooling loads in buildings. Integrating solar with water systems can decrease evaporative losses from irrigation canals and reservoirs, increasing water availability for other uses.
2. **Reductions in land-use competition.** Similarly, more solar installations may lead to competition with other land uses, particularly in areas of grid congestion where interconnection location is critical. Combining solar with other technologies and land uses in a manner that enables high performance of all elements of the combined system can increase siting flexibility and mitigate conflict with other sectors and communities, increasing value for all stakeholders.
3. **Improvements in system grid responsiveness.** Due to changes in electricity generation sources and end-use load profiles, grid responsiveness will be increasingly important. Photovoltaic systems alone have a limited capability to provide direct grid services and participate in all available markets. Combining solar with other generation, storage, building, transportation, and energy-efficiency technologies can increase overall system performance and responsiveness.

Specific areas of interest include but are not limited to:

- Photovoltaic building materials (PBM) and building integrated photovoltaics (BIPV). Specifically of interest are applications for roof-integrated and non-optical vertical façade-integrated technologies, such as walls and sound barriers.
- Agricultural photovoltaics (APV), including integration with greenhouses, high tunnels, and other controlled environment agricultural structures. Agricultural production at these sites should still rely primarily on natural light sources.
- Floating photovoltaic systems (FPV), including applications for innovative component and systems designs, manufacturing processes, and installation approaches.
- PV in transportation systems, including applications to displace auxiliary, internal combustion engines in refrigerated trailers.

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 achieving a commercially viable value proposition. Proposed technologies must balance any installed cost increases with clear, substantiated value propositions from the non-photovoltaic system components and site utilization. For APV applications, applications must include a clear plan to validate any claimed production increases, including replication, site diversity, and partnerships with entities with established expertise in agricultural research. For BIPV/PBM applications, applications should consider partnerships and engagement with the architectural, construction, and other building industries.

Applications will be considered nonresponsive and declined without external merit review if they:

- Exclusively address solar window technologies

- Target fully controlled-environment agricultural applications driven by artificial lighting
- Address only off-grid applications of floating photovoltaic systems (water pumping, aeration, etc.) without substantive changes to system design

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.

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.

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

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c. Next-Generation Power Electronics based on Silicon Carbide and/or Planar Magnetics

This subtopic solicits applications for the development of the next generation of power-electronic components and systems that integrate and leverage the greater efficiencies, lower costs, and lower weight of devices based on silicon carbide (SiC) and gallium nitride (GaN). The goal of this subtopic is to support ideas and prototype development of technologies that can accelerate decarbonization of the electricity system.

Driven by the expanding electric vehicle industry, SiC chips of certain power ratings are dropping in price quickly. This creates an opportunity to use them 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 topologies, which facilitate pick-and-place manufacturing—make a compelling case for domestic manufacturing. This subtopic solicits applications for new power-electronics 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.

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 reliability or performance.

Applications focused on power conversion without including or incorporating SiC- or GaN-based chips into the power conversion topology will be considered nonresponsive and declined without external merit review.

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

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d. Technologies to Integrate Solar Generation with Energy Storage Systems and/or Electric Vehicle Charging

This subtopic solicits applications for the development of technologies to integrate and optimize distributed energy resources – in particular, photovoltaic (PV) 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.

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

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

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e. Concentrating Solar-Thermal Power System Construction, Manufacturing, and Reliability

This subtopic solicits applications for the development of innovative technologies to engineer and build reliable concentrating solar-thermal power (CSP) plants. The goal of this subtopic is to support ideas and prototype development of technologies that can accelerate decarbonization of the electricity system and of the industrial system.

Nearly 7 GW of CSP has been deployed worldwide, with the total capacity of installed plants increasing by almost six times from 2010 to 2019. To document this progress, and to take advantage of opportunities to iteratively improve technology through multiple commercial deployment cycles, SETO supported a consortium of researchers, led by the National Renewable Energy Laboratory, to publish the *Concentrating Solar Power Best Practices Study* [1] in 2020. The study resulted in the identification of best practices and lessons learned from the engineering, construction, commissioning, operations and maintenance of existing CSP systems. Significant opportunities to improve the performance and reliability of specific components were identified in several areas. Additionally, SETO is seeking applications that apply new innovations in systems, materials, equipment, and manufacturing directly to CSP plants that use existing nitrate salts as heat transfer fluids (HTF) and/or steam Rankine-based power cycles.

Suggested areas of interest include but are not limited to:

- Innovations in low-cost thermal energy storage for molten nitrate salts or solid particles, below 600°C, including, as appropriate, design of pumps or particle transport
- Design of low-cost (<30 \$/kW_{th}) solid-particle transport systems capable of at least 6,000 metric tons per hour, at elevated particle temperatures from 200°C to 600°C

- Innovations in steam-generating systems for molten nitrate salts or solid particle heat transfer media, leading to costs below 100 \$/kW_e
- Innovations in low-cost design and construction of CSP towers, for either molten salt or solid particle receivers

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

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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 [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 (CSP) 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 enabling advanced photovoltaic module manufacturing supporting domestic supply chain;
- Advanced metrology for scaled PV manufacturing;
- Optical annealing technologies for photovoltaic module manufacturing (including thin films and emerging materials such as perovskites);
- Heliostat collectors remain a large cost contributor to the levelized cost of energy (LCOE) of CSP power tower plants. SETO is especially interested in opportunities to improve 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;
- To advance next-generation CSP systems that can achieve higher efficiency than existing systems, SETO is supporting a MW-scale integrated test facility to prototype and de-risk key components of a thermal transport system based on solid particle based system heat transfer media. [3] Opportunities for further development of particle CSP systems includes: innovations for mass flow rate and other property measurement at high temperature during operation; novel designs and manufacturing technologies for particle-based solar receivers, particle horizontal and vertical conveyance, and particle to power cycle heat exchangers; lower-cost particles (\leq \$100 per metric ton) that are able to achieve key physical properties, including high density and specific heat capacity, high optical absorptivity in the solar spectrum, low optical emissivity in the infrared range, and sufficient durability.
- 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.

Applications will be considered nonresponsive and declined without external merit review if they:

- 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.

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

g. TECHNOLOGY TRANSFER OPPORTUNITY: Hierarchical Distributed Voltage Regulation in Networked Autonomous Grids

This is a technology-transfer opportunity (TTO) for a non-exclusive license to develop and commercialize a product that optimizes real-time dispatch of distributed energy resources (DER).

This patent application describes a highly efficient method to optimally dispatch a huge amount of DER in large-scale distribution networks in real time, based on a hierarchical distributed implementation of the optimal power flow (OPF). By jointly exploring the tree/subtree structure of a large radial distribution network and the structure of the linearized distribution power flow model, this method provides unprecedented computational speed improvement for real-time OPF in large systems without compromising solution quality.

From the perspective of theoretic algorithm development, the effectiveness and efficiency of the proposed methods have been mathematically proved and experimentally validated by large-scale hardware-in-the-loop tests. However, in real-world implementation, a series of fundamental infrastructures, including system state

measurement devices and telecommunications devices—which are generally required for most smart grid algorithms—are needed to facilitate the system monitoring and algorithm implementation.

[US20210013720A1 - Hierarchical distributed voltage regulation](#)

National Renewable Energy Laboratory Information:

Licensing Information: National Renewable Energy Laboratory

Contact: Erin Beaumont; erin.beaumont@nrel.gov; (303) 275 4353

License type: Non-Exclusive

Patent Status: Pending

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

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h. TECHNOLOGY TRANSFER OPPORTUNITY: Novel Solar Collector Tracking Error Direction; “NIO-Heliostat”

This is a technology-transfer opportunity (TTO) for a non-exclusive license to develop and commercialize a technology to track solar collector error direction on a commercial-scale heliostat field. Supporting the Biden-Harris Administration’s goal of a clean energy economy, the success of this project will ensure concentrating solar-thermal power (CSP) power plants are more efficient and cost-effective.

Innovative research, development, demonstration, and deployment (RDD&D) strategies are crucial to reducing U.S. emissions by more than 50% by 2030. Related to CSP, NREL researchers have advanced a patent pending non-intrusive optical (NIO) technology to the demonstration stage, validating the optical characterization tool on a subset of a commercial-scale heliostat field. Continued RDD&D is necessary to enhance the NIO technology. Future efforts include:

- Automating data collection, data discretization, ID labelling, image processing, and results mapping
- Converting the NIO data processing algorithm to run efficiently on a GPU cluster or a parallel computer cluster
- Developing and executing a full-field test campaign at a commercial-scale CSP power plant
- Testing the NIO technology with commercially available drones.

[US20210110571A1 - Heliostat error detection](#)

National Renewable Energy Laboratory Information:

Licensing Information: National Renewable Energy Laboratory

Contact: Erin Beaumont; erin.beaumont@nrel.gov; (303) 275 4353

License type: Non-Exclusive

Patent Status: Pending

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.

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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 3, 2021)
3. Feldman, D., Margolis, R., 2021, H2 2020 Solar Industry Update, *NREL/PR-7A40-79758*, <https://www.nrel.gov/docs/fy21osti/79758.pdf> (November 2, 2021)
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8. 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 3, 2021)
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11. U.S. Department of Energy, 2021, Funding Opportunities, *US DOE, Office of Science*, <https://science.osti.gov/sbir/Funding-Opportunities> (November 3, 2021)
12. NERL, 2021, The American-Made Challenges, <https://network.americanmadechallenges.org/> (November 3, 2021)

References: Subtopic b:

1. U.S. Department of Energy, 2021, End-of-Life Management for Solar Photovoltaics, *US DOE, Solar Energy Technologies Office*, <https://www.energy.gov/eere/solar/end-life-management-solar-photovoltaics> (November 3, 2021)

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1. Mehos, M., et al, 2020, Concentrating Solar Power Best Practices Study, *NREL*, *NREL/TP-5500-75763*, 2020, <https://www.nrel.gov/docs/fy20osti/75763.pdf> (November 3, 2021)

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1. U.S. Department of Energy, 2021, 2030 Solar Cost Targets, *US DOE, Solar Energy*, <https://www.energy.gov/eere/solar/articles/2030-solar-cost-targets> (November 3, 2021)
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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

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. DOE recently 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 over 3%. In California, solar accounts for more than 20% of all electricity generated, with 10 other states generating 5%-10% from solar. [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 80 gigawatts alternating current (GW_{AC}) of solar capacity in the United States as of the end of 2020. [3] About 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]. Other programs include the American-Made Solar Prize [7], the Incubator topic area in SETO FOAs [8], and the Technology Commercialization Fund [9]. Please read the individual funding opportunities 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.

This topic is open only to STTR applications. SETO also has an additional Topic (Topic 15) open to both SBIR and STTR applications. SETO is also supporting Topic 7: Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition.

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.

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 federal assistance reporting checklist (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.

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
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.
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.

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
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 large-scale prototype of this technology.	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.
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 only 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.

b. Concentrating Solar Power Technologies for Industrial Decarbonization

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 essential commodities, refined products, and other goods. The goal of this subtopic is to support technology transfer from research institutions to small businesses in the area of industrial thermal and thermochemical processes.

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. Concentrating solar-thermal (CST) energy has the potential to be a renewable resource for industrial thermal and thermochemical processes that require substantial external heat inputs. To develop these technologies, SETO seeks to advance the modeling and development of promising methods and system designs to enable efficient delivery of solar heat, either by direct on-sun heating or from thermal energy storage (TES) systems. There are a number of promising chemical processes requiring temperatures up to 650°C that warrant consideration for heating with CST, which include paraffin dehydrogenation to olefins, Haber-Bosch nitrogen fixation, thermal cracking of hydrocarbons, and some mineral processing steps, like calcination. Reactions in this temperature range may be driven with existing or near-term CST thermal transport systems based on thermal oils or molten nitrate salts. Next-generation systems based on solid particles, or other heat transfer media (like supercritical carbon dioxide or molten chloride salts), may also be able to achieve significantly higher temperatures relevant to industrial processes like iron ore reduction or calcium carbonate decarbonation and calcination.

Specifically, SETO is seeking collaboration between small businesses and academics or national laboratories who can help optimize and prototype componentry, sensors, and processes to provide guidance on the needs of the end-use application. A key challenge of these systems is the design of carefully controlled and understood reaction zones, using reactors designed for CST-relevant heat transfer media, or direct solar irradiation. While the basic physics is understood, engineering principles are not well developed, or validated, on how to design the process, reactors, and catalysts (if needed) to integrate heat from CST with these industrial processes, and how to control the reaction. Innovations are needed to assess system designs under non-isothermal and potentially non-steady-state solar heating conditions, in contrast to incumbent industrial process schemes. Opportunities exist for novel approaches to catalyst distribution, TES, and reactor design.

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.

c. Next Generation Solar Forecasting

This subtopic solicits applications for the development and commercialization of the next-generation tools and capabilities to increase accuracy and reliability of solar forecasting. The goal of this subtopic is to support ideas and prototype development of technologies that can accelerate decarbonization of the electricity system.

An electric grid with large amounts of solar power requires operators to know in advance how much energy may be generated by solar power plants over the next couple of days. This knowledge is provided by solar forecasting, a process that uses weather models and data, which can predict solar power generation at various time scales. While utilities and other grid operators recognize solar forecasting as an important part of system operations, the accuracy of the forecasting methods is uneven and their results are not yet well integrated into the operation and planning processes.

A better way to deal with the uncertainty behind weather forecasts, including solar radiation and solar power forecasts, is to assign a likelihood to events such as rain, cloud cover, amount of solar power generation, etc. The result is a so-called probabilistic forecast, which can assist the decision-making of energy planners by providing them information regarding the uncertainty of future power generation. A recent SETO funding program – Solar Forecasting II (SF2) [1] – helped develop probabilistic forecasts, which can be helpful in grid operations, such as the calculation of when and how much reserve power is necessary to support the system if, for example, an unexpected bank of clouds reduces the available solar power. Probabilistic forecasts are new in the grid operations world. To build confidence in the use of these forecasts by system operators, SETO has funded under SF2 an open platform, the Solar Forecast Arbiter (SFA) [2], which utilities and other system operators can use to create rigorous and transparent analyses of solar forecasts.

SETO hopes that the innovations gained from the SF2 program, and other SETO-funded solar forecasting initiatives, will lead to a larger offering of probabilistic forecasting tools and a wider adoption of probabilistic power forecasts by end-users in the solar forecasting industry. This topic seeks to support the development and/or commercialization of such tools that can add concrete value to the operation of a low-carbon grid.

A successful STTR award is expected to:

- Generate probabilistic forecasts of solar and potentially other power sources, such as wind, or net load with a skill better than that of the persistence ensemble forecast over the requisite horizon, as shown on the SFA (or a similar platform);
- Be used by potential customers—i.e., the computation efficiency, delivery times, and the delivery formats are compatible with established energy management use cases (unit commitment, economic dispatch, real time dispatch, etc.); and
- Have proof of commercial interest from other forecast vendors or from forecast end-users.

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.

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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

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 research and development to advance technologies for offshore, land-based, and distributed wind energy, as well as its integration with the electric grid. WETO also supports research to understand wind-related siting and environmental challenges. WETO's R&D program pursues three overarching objectives: (a) reduce the cost of wind energy for all wind applications (land-based, offshore, and distributed); (b) enable the integration of substantial amounts of wind energy reliably and resiliently into the dynamic and rapidly evolving national energy system, including integrated systems with other renewable energy and energy storage; and (c) create siting and environmental solutions to reduce environmental impacts and facilitate responsible wind energy development. WETO focuses on novel research not being undertaken by the U.S. wind industry due to perceived cost, risk, or focus on near-term investment returns.

Wind power grew at record pace in 2020 and is an important part of the U.S. energy mix with over 122 gigawatts installed at utility scale across 41 states [1]. Wind power represented the largest source of U.S.

electric-generating capacity additions in 2020, constituting 42% of all capacity additions, surpassing solar for the first time since 2015 [1]. Five states added more than 1,000 MW of wind in 2020, and wind energy provided over 30% of electricity in 5 states, and over 10% of electricity in 16 states. Texas, Iowa, Oklahoma, Kansas, and Illinois currently have the most installed wind power by capacity [1]. A nascent offshore wind industry is beginning to grow in the United States. The project development pipeline grew 24% over the previous year, with 35,324 Megawatts (MW) in development—driven by federal offshore wind lease auctions, complementary state policies, technology innovation, and falling wind turbine prices—but challenged by unique characteristics of U.S. waters [2, 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 [3]. WETO aims to advance scientific knowledge 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.

Note: WETO is also supporting the following Joint Topics:

1. Topic 7: Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition and
2. Topic 11: Joint Topic: Water and Wind Technologies Offices: Development of Cost Effective Wet-Mate Connector Technologies.

Applications may submit to any one of the subtopics listed below, but 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.

Applicants are encouraged, but not required, to describe how the award will foster participation by underrepresented group members including, but not limited to, women or socially or economically disadvantaged persons within the applicant's technology development team, including recruiting, hiring, and training staff to help lead the SBIR research effort.

a. Offshore Wind Operations & Maintenance Topic

Offshore wind deployment has a unique set of challenges when compared to land-based energy plants. DOE supports advanced work to improve system health while minimizing labor in the open sea, including incorporation of new sensors and artificial intelligence into defect detection, diagnosis, and maintenance planning. This subtopic has three areas of interest:

Ruggedized Sensing Technologies to Support Cost-Effective O&M and Offshore Turbine Design Validation

This subtopic area seeks applications for research and development of commercially viable sensor packages that are easily installed, minimally intrusive in physical form or system requirements, and rugged enough to perform in an offshore environment for the design life of an offshore wind turbine (20-30 years). As wind farms move offshore, the cost and risk of hands-on maintenance increase, as does the opportunity cost of downtime. Therefore, a low and predictable maintenance burden is essential [5]. Condition monitoring using SCADA data has shown promise, but it is constrained by the low time resolution (often 10-min statistics) and the limited spatial extent of data: most sensors are concentrated near or within the nacelle [6]. Enhanced monitoring of the environment, system dynamics, and aerodynamic performance of offshore assets throughout their life could lead to improved turbine reliability, predictable performance, and lower cost of energy.

The proposed innovation should demonstrate confidence in performance for future wind turbine prototype testing and certification. Modern wind turbine prototypes include a vast suite of sensors installed to monitor the turbine and ensure that it performs as expected. Prototype tests for offshore wind often take place on land, with ready access to lift equipment and technicians to help ensure these sensors remain functional over the course of the prototype testing period. Easier and faster installation and reduced maintenance requirements of wind turbine sensing technologies could enable thorough prototype testing in the most relevant offshore environments.

The research should aim to deliver low-powered or self-powered sensor technologies capable of on-blade, undersea, or atmospheric data collection and transmission to a central data acquisition system. Specific quantities of interest for these sensing technologies are the time-varying distributions of aerodynamic surface pressure and shear stress, wind velocity and temperature, and turbine component position and/or acceleration. Successful applications will demonstrate awareness of the challenges experienced in wind turbine design validation and instrumentation, and describe how their application advances the state of the art through one or both of the following objectives:

- Develop the ability to measure, transmit, and store for retrieval the quantities of interest where access and maintenance is challenging and/or costly, or where current commercial offerings fail to provide data of sufficient resolution or accuracy.
- Improve the lifespan, performance, or practical usefulness of sensors that already exist such that they can be used beyond short, heavily monitored field campaigns and can provide operators with useful data throughout the turbine design life.

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

Quick Connects for Floating Offshore Wind Hulls

This subtopic area seeks applications for development of commercially viable connectors on floating offshore wind platform power cables and mooring lines. Some floating offshore wind designs allow the hull, support structure, and turbine to be towed back to port for maintenance. These operations require safe and quick ways to disconnect the hull from all mooring lines and electrical cables. This subtopic seeks design of reliable mooring or electrical easy-connect designs to be used at the hull of floating offshore wind platforms. New connectors should reduce time, improve safety, and reduce vessel requirements for disconnecting and reconnecting floating platforms from their offshore wind energy plant array. Reliable connections that can be

repeatedly released and engaged will enable tow-to-port maintenance for some floating offshore wind hull designs. Additionally, temporary cable joints are needed to connect adjacent array cables to continue energy production of wind turbines installed upstream and downstream along the on the array string of the floating offshore wind turbine that is removed from service and towed away for maintenance.

New connection designs for power cables should reduce time, improve safety, and reduce vessel requirements for temporary cable joints to be installed within one day, compared to current estimates of about 100 hours using existing methods [7]. Connectors should be appropriately sized for 10–15 MW offshore wind turbine systems. Applications should describe how the new connector designs are used in overall connection and disconnection operations and the impact of new connectors on operation time, safety, and requirements of vessels or specialty equipment. Applications should describe how connectors will be resilient to the marine environment including corrosion protection and biofouling management.

Successful applications will demonstrate awareness of the challenges experienced in connecting and disconnecting floating offshore wind platforms to mooring and electrical cables at offshore wind plant sites. Applications may consider semisubmersible or spar type offshore wind substructures. Applications may consider catenary, taut, or semi-taut mooring configurations. Applications should describe how their application advances the state of the art through one of the following objectives:

- Improve the feasibility of both disconnecting and reconnecting heavy marine mooring lines to a floating offshore wind substructure to enable tow-to-port maintenance and re-deployment of the floating offshore wind turbine. Connections should be sized to fit chain sizes of 150mm or greater.
- Improve the feasibility of both disconnecting and reconnecting 66kV dynamic power cables to a floating offshore wind substructure to enable tow-to-port maintenance and re-deployment of the floating offshore wind turbine.

Questions – Contact: Nate McKenzie, nathan.mckenzie@ee.doe.gov

Autonomous Repair Technologies for Offshore Wind Turbine Blades

Operational expenditures (OpEx) for offshore wind energy can be more than twice as costly per kilowatt of capacity than OpEx for land-based wind, and this is due in large part to the higher difficulty in accessing turbines and performing O&M procedures [2]. Remote maintenance capabilities can contribute to reducing accessibility barriers, safety risks, and downtime, thereby reducing the overall OpEx costs for a wind farm. This subtopic seeks to support the development of autonomous O&M technologies that can perform maintenance and repair tasks and reduce hands-on labor requirements for maintenance workers [8]. Once mature, this technology should be able to achieve the following:

- Autonomous performance of a routine maintenance or repair task on wind turbine blades.
- Be deployable and operable without a human needing to go up-tower

This technology will need to operate in far offshore environments that would be found in United States coastal waters. Although the autonomous system may support other capabilities, applications will be reviewed based on potential to advance the state of the art for wind turbine blade repair. The resulting product should reduce maintenance costs and asset downtime while increasing worker safety. Please refer to the AWEA Operations & Maintenance Recommended Practices [9] or similar standards and/or appropriate sources when identifying maintenance and repair procedures to be automated.

Competitive applicants should demonstrate knowledge and experience in developing cost-effective autonomous maintenance and repair technologies and include the following in their application:

- Preliminary conceptual design of the proposed system with estimated physical dimensions a clear description of how the system operates, and drawings of the proposed system.
- If an existing commercial or near-commercial platform will be included in the system, provide a description of the platform.
- State-of-the-art for incumbent technologies and how the proposed system reduces costs and safety risks for wind blade repairs.
- A plan to engage with offshore wind energy asset operators, original equipment manufacturers, and/or third-party wind turbine blade service providers to identify needs and ensure accurate reproduction of maintenance procedures.
- Details of work to be performed in Phase I including resources required and intended performance targets.
- Preliminary description of Phase II work including plans for prototype fabrication and testing/certification.

Questions – Contact: Nate McKenzie, nathan.mckenzie@ee.doe.gov

b. Innovative Solutions to Wind Transmission Interconnection and Wind Cybersecurity Challenges

The goal of WETO's systems integration R&D is to ensure the cost effective, cybersecure, reliable, and resilient integration of substantial amounts of wind energy into the dynamic and rapidly evolving national energy system, including integrated systems with other renewable energy and energy storage. This topic directly addresses the transmission interconnection and cybersecurity challenges. It aims to support innovative solutions that reduce the cost of transmission interconnection for offshore and land-based wind, streamline the interconnection process [8] for rapid wind deployment at scale, and ensure interconnected wind plants are designed to be cyber secure and protected from cyber threats and disruption. Technological improvement funded under this topic should be focused on advancements to software solutions. If access to wind farm data or transmission data are needed for successful Phase I completion, confirmation of access to those data should be noted in the application. Specific areas of interest are:

- Technological solutions that can estimate cost of transmission interconnection [10] for potential wind sites. The solutions should be able to conduct grid analyses that identify available capacity of potential points of interconnection [11] considering reliability [12] constraints. Applications are highly encouraged to compare transmission technology options, such as high-voltage alternating current or high-voltage direct current; apply grid-enhancing technologies [13]; and consider environmental and community impacts of transmission routing.
- Cost-effective cyber protection [14] solutions that can harden wind plants from cyberattacks. The solution should be in, but not limited to, one or multiple areas of boundary protection, access control, asset management, and network monitoring for wind industrial control systems. Solutions that are retrofittable to legacy wind plants are highly encouraged.

Applicants should clearly articulate the state-of-art, how the proposed solutions address the specific challenges, and evaluate the cost and benefit of the proposed solutions.

Questions – Contact: Jian Fu, jian.fu@ee.doe.gov

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18. 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

EERE's Water Power Technologies Office (WPTO) (<http://energy.gov/eere/water/water-power-program>) works with national laboratories, industry, universities, and other federal agencies to conduct research and development activities through competitively selected, directly funded, and cost-shared projects. WPTO pioneers research and development efforts in both Marine Energy and Hydropower technologies to improve performance, lower cost and ultimately support the United States' ability to sustainably meet its growing energy demand. Marine Energy technologies capture energy from waves, tides, ocean, and river currents, as

well as from ocean thermal gradients. Hydropower and Marine Energy technologies generate renewable electricity that supports domestic economic prosperity and energy security while enhancing the reliability and resiliency of the US power grid. WPTO is seeking applications for both Hydropower and Marine Energy technologies.

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;
- 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.

Note: WPTO is also supporting the following Joint Topics:

1. Topic 7 – EERE Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition
2. Topic 11 – Joint Topic: Water and Wind Technologies Offices: Development of Cost Effective Wet-Mate Connector Technologies

Grant applications are sought in the following subtopics:

a. Cost Saving Innovations for Water Conveyance Systems for Powering Non-Powered Dams

Resource assessments have shown a potential opportunity for development of up to 12 GW of clean energy from hydropower at the more than 90,000 non-powered dams (NPDs) in the US. Because of this, new hydropower development over the past 10 years has strongly concentrated on the addition of hydropower generation to NPDs and conduits. As of December 2019, of the 217 projects in the U.S. hydropower development pipeline, 88 are NPD projects and 109 are conduit projects.

However, recent work at Oak Ridge National Laboratory has indicated that the water conveyance system can be a major cost prohibitive factor for powering NPDs. The study reviewed approximately 3,100 NPDs, breaking them into representative clusters including lake and lock dams. Cost studies show that for lake dams, the water conveyance system accounts for the largest percentage of costs, with between 40% and 60% in most cases.

To enable further development of NPDs to produce clean energy, cost saving opportunities should be explored for water conveyances systems. These include, but are not limited to the intake, penstock (including bypass and bifurcation), and tail races as well as siphon and tunnel water conveyance components. WPTO is seeking technological innovations in water conveyance systems to power NPD to help reduce the capital and maintenance costs. Applications may address cost savings through innovative designs and constructions methods for pressurized tunnels, conduits, and/or syphons, through or around the dam. In addition, innovations associated with cost-effective tunnel and pipeline/penstock construction including thrust restraints, backfill, and alignment methods, and friction loss reduction will be considered. While the focus is on powering NPDs, such innovations may have broad applicability.

Successful applicants are required to demonstrate one or more of the following and provide the necessary justification including baseline assumptions and anticipated benefits of novel approaches:

- Reduced cost with respect to typical industry practice of routing water to power generation components, including, but not limited to:
 - Methods of excavation, reduced excavation, or elimination of excavation.

- Methods of hydrodynamic force resistance, including thrust restraint, water hammer, etc.
- Alternative materials, advance manufacturing methods, and/or improvements to onsite fabrication.
- Innovative technologies that improve operational performance relative to current penstock or water conveyance structures, including:
 - Reduced inlet and/or discharge losses
 - Innovative flow isolation technologies
 - Reduced frictional losses over the length of the penstock or water conveyance system
 - Incorporation of methods for debris and/or sediment removal/passage
- Improvements to current water conveyance systems, construction methods, or installation methods are highly encouraged. Reductions of cost, time, materials etc. are the desired outcomes.
- Combinations of cost reduction and operational performance improvements for existing component refurbishments, such as slip-lining are also encouraged.

During Phase I the applicants will:

- Research, design, and develop innovative systems for a particular location and demonstrate understanding of the specific requirements for deployment at that site.
- Illustrate the integration of the innovative water conveyance system and/or improvement within a project (i.e. how the innovation will interface with a whole hydropower project).
- Provide a description of how the innovation relates to various types of dams (i.e. concrete arch, concrete gravity, earth fill, or combinations)
- Select a suitable location for demonstration of the technology and obtain necessary permits if needed.
- Perform a customer discovery and analysis to understand the potential for commercialization and scaling-up of the solution to multiple locations globally.

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.

Phase II work will include but not limited to the following:

- 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.
- A detailed plan for commercialization of the proposed technology.

In addition to the above requirements for Phase I, competitive applicants should demonstrate knowledge, experience, and/or capabilities in developing hydropower technologies and include the following in their application:

- 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 how the proposed design is an improvement in performance or reduction in cost;
- 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 if possible, end-user partners.

Questions – Contact: Rajesh Dham, rajesh.dham@ee.doe.gov

b. Innovative Hydropower Technologies for Low Head (Less Than 30-ft.)

To achieve the Biden administration's clean energy goals, there is demand for development and improvement of renewable generation technologies. DOE's *Hydropower Vision* identified that hydropower has significant near-term potential to increase its contribution to the nation's clean energy generation portfolio. This can be achieved through existing infrastructure, including existing facility upgrades and adding generation capabilities to non-powered dams (NPDs) and water conveyances, such as irrigation canals and conduits. However, longer-term hydropower growth potential, particularly at NPDs, undeveloped sites (new stream-reaches), relies on the development of innovative, environmentally sustainable, and economically competitive technologies.

Opportunities for hydropower applications for NPDs and conduits in the United States typically have lower head potential. In addition, approximately 75% of identified potential new stream-reaches for hydropower development have a head of less than 30-ft. These same sites often also have smaller power densities and higher normalized costs.

To address the challenges, applications are sought for innovative water power turbine-generator (unit) technologies that are suitable for NPDs with a gross head of about 30-ft or less. Such technologies should be scalable to generate no less than 50kW power per unit at low heads of less than 30-feet and help to reduce disturbances to existing structures. The aim is to develop a cost-effective stand-alone system including necessary controls and storage as needed for a fully functional hydropower turbine-generator unit that can be used independently and/or for small, isolated grids. Innovative technologies that can be integrated in larger grids will also be considered. These technologies may also be useful for development at new stream-reaches and conduits.

Please note that instream current, ocean current or tidal current technologies are not of interest under this subtopic.

Given the typical sizing of these systems, solutions should be tightly coupled to end-user needs and clearly show how the power generated will be utilized. Upfront engagement with end-users is essential for successful technology integration to achieve design and commercialization goals.

For Phase I applications, competitive applicants should demonstrate knowledge, experience, and/or capabilities in developing hydropower and/or hydrokinetic technologies and include a detailed description of their technology including the following parameters:

- Type of resource targeted for the technology including a description of the intended deployment location(s) including identification of any key environmental, social, and regulatory challenges
- Minimum and maximum head or the water level difference between the entrance and exit to be used for hydropower power generation
- Minimum and Maximum discharge through the units for power generation
- Device rating in terms of kilowatts (kW). This is typically the maximum sustainable power output of a device on a continuous basis without failure. Normally, the peak power rating of a device is greater than the rated capacity
- Projected unit or device dimensions including weight
- Type of materials proposed to be used
- Targeted Levelized Cost of Energy (LCOE) including Annual Energy Production (AEP) and associated resource intensity; assumed useful life; Installation and Operation & Maintenance (IO&M) costs; and unit cost with a justification
- Modularity and scalable aspects of the technology

- The method or methods by which end-user needs will be converted into design requirements or specifications, for example: Quality Function Deployment, Design Structure Matrix, Kano Method, or Axiomatic Design
- The state-of-the-art for incumbent technologies and how the proposed design is an improvement in performance or reduction in cost
- Initial description of Phase II work including the scale of the demonstration prototype, the intended test location or facility, and potential end-user partner
- The commercialization potential of the technology. SBIR/STTR Phase I applicants must 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 along with a plan to commercialize the technology will be required as during the period of performance.

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. A detailed plan for commercialization of the proposed technology.

Phase II work will include but not limited to the following:

- Further research as needed to develop a fully functional unit for testing
- Building and testing a functioning prototype in the lab or at a suitable location determined by the applicant in Phase I.
- Concerted efforts to commercialize the innovative technology.

Questions – Contact: Rajesh Dham, rajesh.dham@ee.doe.gov

c. Innovations Accelerating Pumped Storage Hydropower Deployment

Pumped storage hydropower (PSH) provides over 90% of utility-scale electricity storage in the US, and it is the primary source of long-duration energy storage currently available. Increasing penetrations of variable resources such as wind and solar have made this storage increasingly important (1), and modeling results suggest that the need for long-duration storage will continue to increase (2). However, PSH expansion has slowed, with only one new facility, San Vicente in San Diego, coming online in the past 20 years. Several factors contribute to diminishing PSH growth in the US, including market uncertainty, development costs and financing, long payback times, permitting challenges, construction risks, competition from other storage technologies, and technical challenges related to energy storage valuation. (3)

Efforts under DOE's HydroWIREs Initiative focus on increasing the flexibility of existing hydropower and overcoming PSH deployment barriers to support power system decarbonization (4). Unconventional PSH configurations like underground and modular systems could solve some of the PSH deployment challenges, but none have reached commercial viability in the US. The time, cost, and risk of PSH development in today's markets have resulted in limited PSH growth, despite the rising energy storage demand.

Conventionally, PSH is a configuration of two water reservoirs at different elevations where gravity drives water from the upper reservoir to the lower. As the water moves to the lower-elevation reservoir, it passes through a turbine-generator (discharge). The same system is uses power as a pump-motor to move the water back into the upper reservoir (recharge). (5) Thus, the system stores energy by pumping water to the upper reservoir at times of low demand and uses the stored water to generate during high demand.

This topic seeks applications for innovative technologies to accelerate the deployment of PSH through improved PSH components or alternative PSH configurations that reduce cost and/or improve value.

Innovative technologies will address one or more of the following characteristics of PSH:

- Reduce initial capital costs and/or operation & maintenance (O&M) costs
- Increase operational revenue and value to the grid
- Increase development and deployment speed
- Reduce negative environmental and community impacts

While applicants may address multiple improvements mentioned above, applications will be judged on the technology's cumulative impact irrespective of the number of characteristics addressed. Applications should seek to commercialize technologies that address one or more of the above improvements to PSH.

In addition to addressing conventional PSH configurations, proposed innovations may also address unconventional PSH configurations. In addition to gravitational potential energy between two reservoirs at various elevations as described above, a pressure gradient between the two pressurized reservoirs can also facilitate potential energy difference. For applications regarding unconventional configurations, applicants must provide a description of how their technology is an improvement to existing energy storage technologies.

Examples of unconventional PSH configurations currently in development are elaborated in the “Innovative Pumped Storage Hydropower Configurations and Uses” report, published by the International Forum on Pumped Storage Hydropower (6). In addition, a technoeconomic assessment from Oak Ridge National Lab examines modular PSH configurations that can achieve lower costs through standardized manufacturing and excavation (7).

WPTO is *not* interested in configurations that:

- Do not use water to drive a turbine-generator for producing electricity.
- Have unique constraints (e.g., siting) limiting the number of possible deployments to fewer than 5.

Competitive applicants should demonstrate knowledge, experience, and capabilities in developing hydropower and PSH technologies. Applications should show:

- How the proposed concept is an improvement in performance and/or reduction in cost compared to the state-of-the-art for incumbent technologies; and
- How the system would operate, using conceptual designs, drawings, or schematics of the proposed system with estimated physical dimensions.

The application should also clearly demonstrate how the team will accomplish the following during Phase I:

- Develop a comprehensive analysis of the commercial potential of the proposed PSH technology innovation (component or configuration) due to improved PSH installation and/or operation;
- Provide detailed metrics to quantify the state-of-the-art baseline and the improvement due to the proposed innovation in terms of cost/kW, cost/kWh, and performance metrics corresponding to categories in the Energy Storage Grand Challenge Cost and Performance Database (8);
- Define clear constraints on where and how the PSH innovation can be deployed, including specific locations and sites as examples;
- Produce detailed schematics and/or simulations illustrating the innovation's features and operating states and;
- Prepare for Phase II with a plan for testing the component or configuration under a range of representative conditions, including the following details:

- intended performance targets and the metrics for measuring them;
- budget for testing equipment, facilities, and other resources required; and
- potential end-use partners and how the technology will benefit them.

During Phase II, awardees will:

- Conduct laboratory and/or field tests designed during Phase I, and
- Identify and develop detailed plans for possible demonstration in the future, including:
 - target site,
 - specific partners and capacity of partnerships,
 - budget, and
 - policy and community considerations regarding target site and partners.

Questions – Contact: Rajesh Dham, rajesh.dham@ee.doe.gov

d. Co-Development of Marine Energy Technologies with End User Partners (CMET)

This 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 eight non-grid applications where marine energy could provide consistent, reliable power. This report serves as the foundation for the Powering the Blue Economy Initiative that supports R&D for non-grid applications of marine energy. 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 new 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.

In addition to open-ended blue economy applications for marine energy systems, particular areas of interest for FY 2022 include:

1. Applications that incorporate combined with marine energy systems. Although the ocean is an abundant source of raw energy (ocean waves, tides, currents, ocean thermal energy conversion, salinity gradient, etc.), useable energy on the shore or in the water is scarce. People in the ocean or on the shore bring their stored energy with them from land, mainly in the form of batteries and marine

fuels. Projects will involve research, development, and deployment of systems where useful stored energy can come from the ocean for use in the ocean or right on shore. This shift in where the energy is coming from, along with the potential collocation of short duration storage in the ocean or on the coast, may make new businesses viable. Additionally, marine related short duration energy customers may not be as cost sensitive as other terrestrial energy consumers.

2. Innovative technologies to harvest energy from instream/tidal current and water conveyances, such as irrigation canals and conduits that can be rapidly deployed and retrieved with a useable life of around 20 years at a site. Such technologies should be scalable to generate no less than 50kW power per unit. Projects should be aimed at developing a stand-alone system including necessary controls and storage as needed for a fully functional turbine-generator unit that can be used independently and/or for small, isolated grids and may include storage device(s) as needed for smooth operation. Solutions should be tightly coupled to end-user needs.
3. Applications for promising early marine energy markets in coastal tourism and recreation. These opportunities may be short duration and not as technically demanding as other market segments that require high reliability and availability. Marine related recreation and tourism markets may not be as cost sensitive as other terrestrial energy consumers. Additionally, tourism and recreation opportunities could build awareness and acceptance of marine energy technologies with the public, potential suppliers, and future investors. Potential marine related tourism and recreation market opportunities include ecotourism, recreation, ocean observatories, and ocean STEM opportunities.

Successful applications will identify and demonstrate at least one end-user whom they will work with during the project. WPTO strongly encourages engaging with end users to understand their power requirements and the functional requirements required. 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 the published “Enabling Power at Sea: Opportunities for Expanded Ocean Observations through Marine Renewable Energy Integration”.

An assessment of the proposed marine energy resource necessary for energy harvesting for the technology should be provided in the Phase I application and refined during the period of performance. While the system should be designed for a particular end-user for the purpose of this solicitation, the solution should demonstrate potential for applicability for other applications or purposes. It is expected that Phase I work would be centered on end-user and customer discovery for the proposed concept; collecting end-user or customer requirements; converting collected customer 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. One of the expected outcomes for Phase I will include a table of design specifications for the system and how each relates to a customer need.

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 sustainable business plan including target markets;
- Plan to incorporate customer needs based on interviews, workshops, expert panels, literature searches, and other methods;
- A preliminary design of the proposed system with estimated physical dimensions;
- A clear description on how the system would function;
- The end-user or customers that will be engaged during the project;
- Identification of the marine energy resource that would be utilized;

- The method or methods by which customer needs will be converted into design requirements or specifications;
- 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;
- 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 support DOE’s climate and energy justice goals;
- Description of this project will incorporate the needs and considerations of, and/or benefit of disadvantaged communities;
- 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.

In Phase II, the awardee(s) will refine system designs based on the findings from Phase I and proceed to build a functioning prototype to be tested and/or deployed. Phase II awardees must also present a detailed plan for technology commercialization including a detailed market analysis.

Questions – Contact: Rajesh Dham, rajesh.dham@ee.doe.gov

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2. U.S. Department of Energy, 2021, U.S. Hydropower Market Report, US DOE, Office of EERE, <https://www.energy.gov/sites/prod/files/2021/01/f82/us-hydropower-market-report-full-2021.pdf> (November 4, 2021)
3. Oladosu, G.A., et al., 2021, 2020 Cost Analysis of Hydropower Options at Non-Powered Dams, *ORNL/TM-2020/1656* <https://www.osti.gov/biblio/1770649-cost-analysis-hydropower-options-non-powered-dams> (November 4, 2021)

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1. U.S. Department of Energy, 2016, Hydropower Vision Report: Full Report, *US DOE, Office of EERE*, <https://www.energy.gov/eere/water/downloads/hydropower-vision-report-full-report> (November 4, 2021)
2. DeNeale, S., et al., 2020, Hydropower Geotechnical Foundations: Current Practice and Innovation Opportunities for Low-Head Applications, *US DOE, ORNL/TM-2020/1553*, <https://info.ornl.gov/sites/publications/Files/Pub140772.pdf> (November 4, 2021)

References: Subtopic c:

1. Hadjerioua, B., et al., 2020, Pumped Storage Hydropower FAST Commissioning Technical Analysis, US DOE, Office of EERE, https://www.energy.gov/sites/prod/files/2020/07/f76/PSH_FAST_Commissioning_Technical_Report_ORN_L.pdf#:~:text=The%20Pumped%20Storage%20Hydropower%20FAST%20Commissioning%20Project%20aims,and%20excludes%20factors%20related%20to%20permitting%20or%20licensing (November 4, 2021)
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4. International Hydropower Association, 2020, Innovative Pumped Storage Hydropower Configurations and Uses, <https://www.hydropower.org/publications/innovative-pumped-storage-hydropower-configurations-and-uses> (November 4, 2021)
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6. Pacific Northwest National Laboratory, 2021, Energy Storage Cost and Performance Database, *PNNL*, <https://www.pnnl.gov/ESGC-cost-performance> (November 4, 2021)

References: Subtopic d:

1. U.S. Department of Energy, 2019, Powering the Blue Economy Report, *US DOE, Office of EERE*, <https://www.energy.gov/eere/water/articles/powering-blue-economy-report> (November 4, 2021)
2. U.S. Department of Energy, 2019, Powering the Blue Economy Report, *US DOE, Office of EERE*, <https://www.energy.gov/eere/water/articles/powering-blue-economy-report> (November 4, 2021)
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4. Water Power Technologies Office (WPTO), Existing Ocean Energy Performance Metrics, <https://eere-exchange.energy.gov/FileContent.aspx?FileID=89a224a1-6062-4567-a52d-66ddca0aa158> (November 4, 2021)
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19. ADVANCED MANUFACTURING

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

EERE's Advanced Manufacturing Office (AMO) (<http://energy.gov/eere/amo>) collaborates with industry, small business, universities, national laboratories, state and local governments and other stakeholders on emerging manufacturing technologies to drive U.S. industrial decarbonization, productivity and economic competitiveness. AMO has a mission to develop technologies that 1) reduce manufacturing energy intensity and industrial carbon emissions, 2) increase the competitiveness of the U.S. manufacturing sector with a focus on clean energy manufacturing and 3) reduce the life cycle energy and carbon impact of manufactured goods in industry, buildings, transport, power, and agricultural sectors.

This Topic reflects DOE's support for activities that develop new Foundational Materials and Manufacturing Technologies, and advance Industrial Decarbonization, Manufacturing for Clean Energy as well as Manufacturing Workforce Development, Technical Assistance, and Partnerships.

All applications to this topic must:

- Propose a tightly structured program which includes clear, manufacturing-relevant technical milestones/timeline that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Provide evidence that the proposer has relevant manufacturing experience and capability;
- Clearly define metrics and expected deliverables;
- Explain applications of project output and potential for future commercialization;
- Include projections for cost and/or performance improvements that are tied to a clearly defined baseline 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 an energy savings impact and impact grid as well as a preliminary cost analysis;
- Report all relevant performance metrics; and
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

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

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

- Topic 7: EERE Joint Topic: Community-Driven Solutions for a Just and Equitable Energy Transition
- Topic 8: Joint AMO/FECM Topic: Diversifying Sustainable Sources of Critical Minerals and Materials
- Topic 9: Joint Topic: CABLE Characterization & Modelling for Fabrication
- Topic 10: Joint BTO/AMO Topic: Thermal Energy Storage (TES)

Applications must be responsive to the following subtopics:

a. Decarbonizing Industrial Heat with Heat Pumps: Industrial Heat Pumps Research

This subtopic 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). By replacing fossil fuel combustion that is conventionally used to reach these manufacturing temperatures and capturing industrial waste heat streams, this topic supports industrial decarbonization. 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 subtopic 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 also 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:

Industrial Heat Pumps R&D	
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)	
COP @ Highest Supply Temperature	≥ 45% Carnot COP

Questions – Contact: Antonio Bouza, antonio.bouza@ee.doe.gov

b. High Operating Temperature Storage (HOTS) for Manufacturing

This subtopic solicits applications to develop and demonstrate an integrated High Operating Temperature Storage (HOTS) (>400°C) system that can extract and store the high-temperature waste heat from industrial processes, such as steel, glass, and cement manufacturing and later extract and provide that stored thermal

energy as needed for additional lower temperature applications such process heating, district heating, or electrical power generation. In addition, HOTS systems also can store direct solar heat. HOTS builds upon the experience of the Advanced Manufacturing Office (AMO) (<http://energy.gov/eere/amo>) with thermal energy recovery and advanced materials manufacturing. While thermal energy storage systems have been demonstrated at medium- and large-scales (hundreds of MW) in concentrating solar-thermal energy plants, there has been little demonstration of such systems to harvest, store, and dispatch the high-temperature waste heat from material manufacturing processes. This subtopic supports the priorities of the Assistant Secretary for EERE for inter-office cooperation to address (1) De-Carbonization; and (2) Energy Storage Grand Challenge.

This subtopic enables decarbonization by recovery and storage of waste heat for re-use as well as direct solar heat for use in manufacturing. In prior decades, the recoverable heat loss from producing steel or for manufacturing glass with both waste streams at the ultra-high temperature range ($>900^{\circ}\text{C}$) was estimated to total nearly 50 TBtu/year [1-4]^[1]. While industry has currently evolved to utilize a somewhat lower temperature profile, there is still much available recoverable waste heat from high-temperature manufacturing. The HOTS system is a way to decarbonize formerly fossil fuel-based industrial processes and provide lower temperature process and/or space heating and possibly electricity generation for local or district regions [5] directly and indirectly.

Applications must:

- Propose a tightly structured program which includes high-temperature thermal energy storage, relevant technical milestones that demonstrate clear progress, are aggressive but achievable, and are quantitative.
- Provide evidence that the proposer has relevant high-temperature thermal energy storage experience and capability.
- Include projections for cost and/or performance improvements that are tied to a clearly defined baseline and/or state of the art products or practices.
- Describe and report all relevant performance metrics clearly and describe the expected heat transfer design and the expected cost and efficiency, for both heat input and output to the TES system.

In Phase I, AMO is seeking proof of concepts and in Phase II we are seeking relatively small-scale prototypes of HOTS systems. Additional Phase IIs may be needed for larger scale prototypes. The Phase I application should detail material, design and/or bench scale systems that are scalable to a subsequent Phase II prototype development. For Phase I, the following on Table 1 shows example metrics.

Table 1. Example Metrics for Phase II prototype HOTS system

Input Process (Temperature):	Large-scale high-temperature processes, such as Electric Arc Furnace (1500°C), Glass Kiln (1200°C)
Output Processes (Temperature):	Process Heating (as needed for desired process-most industrial thermal energy requirements are below 300°C [7]), See Table 2. District Heating (95°C), Steam Rankine ($340\text{--}370^{\circ}\text{C}$), Stirling (600°C)
Required Thermal Charge:	$>300\text{ kW}\cdot\text{h}$
Required Charge Thermal Power (Time):	25 kW (12 hr)
Required Discharge Thermal Power (Time):	25 kW (12 hr)

Table 2. U.S. Industrial Process Heat. (Source: McMillan 2019)

Process Heating Operation	Description	Temperature Range (°C)
Fluid heating, boiling, and distillation	Distillation, reforming, cracking, hydrotreating; chemicals production, food preparation	65-540
Drying	Water and organic compound removal	90-370
Metal smelting and melting	Ore smelting, steelmaking, and other metals production	425-1650
Calcining	Lime calcining	815-1095
Metal heat treating and reheating	Hardening, annealing, tempering	90-1370
Non-metal melting	Glass, ceramics, inorganics manufacturing	815-1650
Curing and forming	Polymer production, molding, extrusion	150-1370
Other	Preheating; catalysis, thermal oxidation, incineration, softening, and warming	90-1650

We are seeking applications specifically for systems that incorporate and demonstrate state-of-the-art technologies and advancements in the following areas:

- Advanced and efficient heat exchanger materials, geometry, and manufacturing
- High performance thermal insulations (low heat loss for long-duration storage)
- Thermal storage media (high thermal energy density)
- Corrosion protection for harsh conditions (high-temperature chemical resistance)

The proposed systems should also consider and demonstrate the potential for successful market entry and a commercialization plan to deploy the HOTS systems in manufacturing industries.

Questions – Contact: Chris Oshman, Christopher.Oshman@ee.doe.gov

^[1] The heat loss studies of Refs [1-4] were conducted decades ago when most steel manufacturing was basic oxygen furnace (BOF) and BOF waste energy totaled 27.2 TBtu/yr and the container glass waste energy totaled 19.3 TBtu/yr. Today there are far fewer BOFs (1700°C) in operation in the U.S. and the ratio of BOF to electric arc steel production is now 30:70 BOF:EAF. Hence in what follows we use EAF operating parameters. Other equipment in steel is reheat furnaces, annealing furnaces. Other options might be aluminum reverberatory furnaces.

c. High Voltage (≥ 3.3 kV, ≥ 100 A) Half-Bridge SiC Powers Module for High Voltage EV Charging Stations, and DC-AC Inverters for Grid-Tied Renewables

The Administration has launched several initiatives signaling the importance of lowering greenhouse gas emissions from the transportation, energy, and industrial sectors in the United States. For example, an executive order was recently signed that sets an ambitious new target to make half of all new vehicles sold in 2030 zero-emissions vehicles, including battery electric, plug-in hybrid electric, or fuel cell electric vehicles. This will help meet major decarbonization goals by saving about 200 billion gallons of gasoline and reducing approximately two billion metric tons of carbon pollution over the life of standards set by the Environmental Protection Agency (EPA) and U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) [1]. To achieve these goals, it is necessary to install the first-ever national network of electric vehicle charging stations. Likewise, the administration's rapid embrace of renewable energy would swiftly cut emissions from the energy sector. Solar panels, however, need DC-AC inverters to interface with the electric grid. The silicon carbide (SiC) power modules described below can be used in each

of these transportation and energy applications. The administration also wishes to bolster American industrial and technological strength to ensure future products are made in America by America's workers. For that reason, this topic addresses the aspect of domestic manufacturing in the U.S., as well.

It is common in power electronics / power conversion systems (PCS) to boost system voltages to reduce system currents for the same or greater power handling capability. Lowering system currents enables a reduction in conductive power losses, thermal management volume, weight, and cost [2]. For example, multi-level converters using conventional silicon (Si)-based power semiconductor devices have been employed since 1975 to interface electrical sources and loads to a medium voltage electric grid [3]. However, the necessary series connection of multiple low voltage power semiconductor devices also introduces added complexity, cost, and size/volume/weight to the PCS. Therefore, power electronics based on SiC, specifically 4H-SiC, allow for improved high-power conversion, in terms of efficiency and power density, when compared to Si counterparts. The individual high voltage rating of SiC power devices enables a direct interface between electric grid transmission and distribution networks, and direct motor drive connections, resulting in fewer numbers of voltage conversions that further contribute to system losses.

The rise of individual high voltage (3.3 kV) -rated SiC power devices offer power electronics circuit designers a simpler means of processing and conditioning power [4].

Yet, the use of these 3.3 kV SiC power semiconductor devices will be most effective when they are housed and interconnected using appropriately SiC-tailored packaging solutions from bare die to power converters [5].

Drop-in solutions, where Si power devices are simply replaced with SiC power devices within commercial-off-the-shelf (COTS) discrete packages and power modules, will throttle the performance improvements these SiC power devices offer in terms of voltage, temperature, and switching frequency. Currently, ≥ 3.3 kV SiC power modules are produced by U.S. companies and foreign companies, but they are built and used in a proprietary manner, expensive, and are only of limited availability to select customers. This topic seeks to lay the groundwork for developing U.S. domestic manufacturing capability for a competitively priced product based on innovative packaging solutions (in the form of ≥ 100 A power module lab bench prototype) supporting ≥ 3.3 kV capability of SiC MOSFETs commercially available in the U.S. [4]. Power density likeness to COTS XHP3, nHPD2, and LinPAK –class power modules is encouraged. Applicants should show a viable path towards domestically manufacturing a high voltage packaging solution that takes a holistic, multi-physics design approach; optimizing for trade-offs between minimizing electrical packaging parasitics (capacitance and inductance) that are the natural result of necessary clearance and creep-age spacing needed for high voltage operation.

Packaging material systems in the form of substrates, attachments, interconnects, terminations, encapsulates, potting compounds, housing, etc. must enable high voltage withstand capability via electric-field mitigation (i.e., triple points and partial-discharge control). For example, electric-field grading techniques are an innovation that have shown promise in research but have yet to be employed in commercial power modules [6]. Methods to reduce electric-field concentrations in the proposed module should complement other packaging techniques, where further power density improvements can be made. Applications should aim towards a manufacturable electro-physical packaging solution suitable for high volume production within the U.S. within the capabilities of industry standard packaging equipment. Material systems and structures that are also high-temperature capable and can provide high voltage withstand capability across a wide range of temperatures (up to 200 °C), are encouraged. Greater adoption of ≥ 3.3 kV SiC power devices in the U.S. market is expected if proposed packaging solutions meet pollution level-2 reinforced insulation system requirements of IEC 61950-1. Lastly, with the adoption of ≥ 3.3 kV SiC power modules into PCS of critical U.S. infrastructure, the incorporation of prognostic monitoring and control capabilities into the module is of

increased interest from a security and resiliency standpoint. The ability to extend the overall operational lifetime of the module and PCS, as well as to achieve microsecond tracking of power flow, is desired to not only enable real-time response against detrimental cyber events, but also to achieve compatibility with future IIOT, prosumers, NFTs, and virtual digital twins of smart infrastructure and systems [7]. Proposers should also ensure that their proposed solutions incorporate manufacturing cybersecurity best practices [8].

The following specifications are suggested:

- Configuration
 - Half-bridge
- Current rating
 - ≥ 100 A
- Voltage rating
 - 3.3 kV – 6.5 kV
- Insulation requirements (based on IEC 61800-5-1)
 - Required impulse withstand voltage: 8,692 V for overvoltage category 2
 - Assuming nominal system supply voltage of 2,400 V DC / 1,700 V AC rms
 - Required minimum clearance distance for functional and basic insulation: 9.1 mm for pollution degree 3
 - Assuming impulse voltage of 8,692 V and application altitude ≤ 2 km
 - Required minimum creep-age distance for functional and basic insulation: 21.3 mm for pollution degree 3
 - Assuming system rms voltage of 1,700 Vrms, application altitude ≤ 2 km, and insulating CTI material group 1
- Packaging parasitics (impedance calculated at 100 kHz)
 - Stray inductance in the power loop: ≤ 10 nH
 - Stray capacitance between substrate and case: ≤ 100 pF
- Total switching losses at 175 °C
 - 3.3 kV Module: $E_{on} + E_{off} < 500$ mJ
 - 6.5 kV Module: $E_{on} + E_{off} < 1$ J
- Operating temperature
 - ≥ 200 °C
- Junction-to-case thermal resistance:
 - $0.065 \leq R_{th,JC} \leq 0.125$ °C /W

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

d. Analog Semiconductor Devices for Sensing and Communications in Manufacturing

Sensor systems that communicate wirelessly can improve manufacturers' abilities to decarbonize through more efficient operations and better monitoring of greenhouse gas emissions. In addition, by providing small business opportunities to develop semiconductor technologies that will be applied in next-generation manufacturing, [1] this application can help the U.S. regain its semiconductor manufacturing leadership. A recent series of AMO workshops, held throughout 2021, focused on areas of semiconductor manufacturing R&D [2]. One of the problems identified in the first workshop was that in 2016, the amount of data produced by sensors already surpassed total human data consumption (1017 Bits/s) and due to its continuing exponential growth, this sensor "data deluge" is expected to increase by three orders of magnitude (1020 Bits/s) by 2032 due to the expected output from 45 trillion sensors.

Two important classes of analog electronics emerged as pivotal to achieving widespread benefits from use of sensors and controls in manufacturing: 1) Analog electronics connected directly to the sensor, in front of the analog-to-digital conversion, are needed to reduce the ‘data deluge’ dramatically, as appropriate for most industrial automation and 2) analog electronics for robust wireless communication (fifth generation (5G) or ultimately sixth generation (6G)) for fast, efficient control and/or data collection systems [3]. Therefore, AMO seeks applications from small businesses for analog semiconductor devices, or systems that utilize such components, to improve sensor systems and/or wireless communication systems in manufacturing.

Areas of interest include:

I. Analog Electronics for Sensors in Manufacturing

In this area of interest, analog electronics to address the ‘data deluge’ are sought [6]. Sensors have many manufacturing related applications -- from tracking process parameters such as temperature [7], pressure [8], and ultraviolet radiation [9], to spatio-temporal control, to defect detection and quality control. Sensors integrated with silicon circuits detect crucial parameters and offer the user the opportunity to optimize local environmental control for energy efficiency. The diverse sensor field is the subject of several scientific journals [6] and numerous commercial efforts [10] to explore and productize these devices. A recent AMO workshop focused on integrated sensor systems prioritized several research areas, including sensing in harsh environments, wireless technology, and edge computing, which has the potential to significantly reduce energy consumption of data transmission [2]. To illustrate an example of state-of-the-art existing commercial offering, the first workshop provided a detailed case study of a 209 Watt self-powered (with solar) multi sensor (acoustic, vibration, cutting force) coupled with a cutting tool for a UPM machine [2] Other examples from other workshops included [5]. The SIA-SRC Decadal Plan for Semiconductors promotes a data compression goal of 100,000/1 with a focus on sensor-to-information transmission enabled through local computing [6].

Table 1. Key Metrics for Analog Electronics in Sensing

Sensor capability and power usage vs. existing commercial offerings
Sensor capability in harsh environment vs. existing commercial offerings
Sensor node data acquisition & process capability vs. existing commercial offerings
Sensor data transmission energy reduction capability (i.e., information vs. data)

As a result of the wide diversity in sensors and integrated systems, even the smallest companies can make significant contributions. Areas of interest include development of energy-efficient sensors (specifically those sensors that can function in harsh environments – temperature, radiation, chemical, etc.), methods for efficient, co-integrated sensor node data acquisition and processing (i.e., mixed-signal integrated circuits), and methods for efficient local computing and/or data transmission to realize >10x reduction in energy consumption of sensor data transmission. Technologies of interest include energy efficient devices with low noise and low latency. They are expected to be 5G compatible and be of direct use in analog approaches such as in-memory computing.

II. Analog Electronics for Wireless Communication in Manufacturing

In this area of interest, fast, analog RF electronics for robust, energy efficient cybersecure [4] communication are sought. 5G wireless communication will enable manufacturers to access the full process’ wireless sensor networks. 5G uses 3.4-3.8GHz carrier frequencies with potential future expansion to 21GHz, 40GHz, and 66GHz [3]. By 2035, 6G is expected to reach commercialization with carrier frequencies in the range from 95GHz to 3THz [3]. In order to interface with these high-speed networks, sensors’ analog electronics for communication will need to support high-speed (THz) operation and interface with high-speed digital circuitry in an effective manner. Applications are

sought to improve the bandwidth, dynamic range, and operational frequencies of RF analog electronics to enable wireless sensor networks in manufacturing facilities.

Table 2. Examples of Key Metrics for Analog Electronics in Communication

Cutoff frequency (F_t)	> 350 GHz
Unity power gain frequencies (F_{max})	> 450 GHz

Proposers are encouraged to explore both CMOS-compatible and compound semiconductor approaches to create high-speed devices. These may include (a) use of SiGe-based high-speed bipolar junction transistors integrated with CMOS [14]. To date, the fastest SiGe devices have cutoff frequencies (F_t) in the range of 350GHz and unity power gain frequencies (F_{max}) in the range of 450GHz [15]. Proposed methods to increase the speed and power gain capability of these CMOS-compatible approaches are of interest. (b) Use of III-V based heterojunction bipolar transistors. This approach has enabled F_t and F_{max} in the range of 500GHz and 1THz, respectively [8]. Proposed methods to increase the speed and power of these compound semiconductor devices and to integrate them with effectively with high-speed digital circuits are of interest. Applications may complement and support but not duplicate other agencies’ efforts in this area including DOD DARPA’s program in mixed-mode RF electronics – those that integrate RF, analog, and digital circuits onto a single chip [16]

Questions – Contact: Paul Syers, Paul.Syers@ee.doe.gov

e. Affordable Technologies for Controlled Environment Agriculture

AMO seeks to improve the energy efficiency, water efficiency, and overall resilience of facilities not only for manufacturing plants but also other industrial applications such as in agriculture. One such application is in indoor agriculture, which can refer to greenhouses, warehouses, converted shipping containers, or other indoor facilities that grow plants using electric lighting, HVAC, building controls and automation [1, 2]. Specifically, controlled environment agriculture (CEA) can produce high-quality fruits and vegetables year-round with greater productivity on less land using potentially less water and less (or no) pesticides compared to traditional on-field farming [1]. CEA implementation and scaling can furthermore support local communities including underserved populations by increasing food security, and also creating local technically skilled jobs [3]. While CEA requires intensive energy use due to the need to maintain growing conditions year round, it is more energy efficient (and productive) in terms of crop yield per area of land use, and is nearly entirely electrified, leading to its ability also to be powered by renewable sources. Additionally, CEA coupled with fuel-flexible combined heat and power (CHP) has also been demonstrated to potentially add decarbonization benefits by reducing the wasted energy by recycling that heat to power the CEA’s HVAC system, increasing the facility’s overall energy efficiency. With greenhouses, there is also an added ability to use cleaned exhaust gas to add CO₂ to increase crop yield. CHP-equipped CEA also may provide voltage support and the export of electricity to stabilize the grid, when needed [1, 4]. If connected to a microgrid, the CHP system increases its resiliency, allowing operation in an island mode and allowing for the utilization of a diversity of energy sources, including carbon neutral biogas or hydrogen as well as other renewable energy [1, 5]. CEA is not a new technology, although its adoption rate in the U.S. is lower than that of Europe and even Canada. Applicants with proposals that emphasize team partnerships, particularly with underserved communities located in food deserts, are highly encouraged to apply.

A key challenge is showing the sustainability of CEA as compared to an open-field farming baseline in a technoeconomic or life cycle analysis. This requires extensive modelling of all the variables associated with controlling the multiple factors that affect plant productivity, health, quality (and consequently taste). AMO encourages applicants to address all such factors in their proposed CEA technology during Phase I. Applicants

should perform life cycle and technoeconomic analysis of their technologies by the end of Phase I. AMO encourages applicants to improve upon current state-of-the-art CEA technoeconomic analysis with user-defined metrics (e.g. % energy improvement, cost per acre, ability to use non-traditional water sources, etc.). For example, current CO₂ recovery for a facility with 3.3 MW net electric power can cost about \$200/kW, whereas emerging carbon neutral technology (using biogas) with both CO₂ recovery and heat integration might cost \$600/kW over the baseline. In Phase I, proposals that can show how to reduce CO₂ recovery costs are desired.

Another key challenge is addressing the high capital costs for infrastructure as well as operational costs to keep the lights on and HVAC systems going. For Phase II applicants should explain how their technical solutions might be integrated into an existing greenhouse or indoor farm facility. If such an existing facility cannot be found, Phase II applicants may instead model to scale an optimized CEA engineering design. Phase II applicants also should develop a preliminary business plan. In Phase II, teams are encouraged to document any existing relationships with a consultant or commercial partner with a letter of support. Phase II applications should also address possible process intensification steps that can lead to lower-cost solutions.

Areas of interest include:

I. Modular, packaged solutions for CO₂ capture, utilization, and polishing to food-grade quality

Decarbonization is maximized when CEA integrated with CHP with the added requirement of recovery of the CO₂ in the CHP unit's exhaust gas, and its conversion into food-grade quality CO₂ for crop uptake in greenhouses. Currently most CO₂ is vented to the atmosphere due to lack of incentives or requirements [6]. Post-combustion separation of CO₂ from the CHP exhaust would be best for use in greenhouses. Separation is typically achieved through solid sorbents, solvents (absorption), membranes, or cryogenic separation and represent a mature technology, although its added cost for the infrastructure and treatment materials make it a barrier for widescale implementation. Low-cost CO₂ storage solutions are also needed to permit its safe and optimal annual use, on-demand by crops in greenhouses. Advances in emerging materials and improved process design are responsive to this area of interest. The key here is to achieve lower cost systems to deliver food grade CO₂ and then economically store it to enable metering of CO₂ dosing year-round.

II. Modular systems for water and nutrient management and recycling

There is a need to better utilize unconventional sources of water, such as from brackish, brine, by-product or reclaimed sources. Due to the presence and variety of contaminants and relatively complex and expensive filtration requirements, these resources are underutilized for CEA as uptake of contaminants and ensuring food safety remain critical barriers [7]. Some emerging techniques in this space include oxidation processes and ultraviolet disinfection. Water treatment needs include the removal of polyfluoroalkyl substances, metals, and other contaminants of emerging concern while mitigating the prevalence of membrane fouling—a major issue with available filtration solutions today. Similarly, nutrient recycling poses challenges with controlling the concentration, pH, dissolved oxygen, temperature, and electrical conductivity of the nutrient solution ideal for a particular plant but would theoretically have similar technical solutions as with the water treatment space [8]. R&D innovations are sought in 1) low-cost membrane materials for filtration, 2) modular water/nutrient treatment and recycling processes that can be piloted for integration with hydroponic or aquaponic systems common to CEA, and 3) automated high-sensitivity sensors with Internet of Things integration (and the software/platform to manage them therein).

Questions – Contact: Felicia Lucci, Felicia.Lucci@ee.doe.gov or John Winkel, John.Winkel@ee.doe.gov or Antonio Bouza, antonio.bouza@ee.doe.gov

f. Other for Industrial Decarbonization

In addition to the specific subtopics listed above, AMO invites grant applications in other areas relevant to this Advanced Manufacturing Topic that enable Industrial Decarbonization.

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

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20. BUILDING 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

DOE's Building Technologies Office (BTO) (<http://energy.gov/eere/buildings>) is working in partnership with industry, academia, national laboratories, and other stakeholders to develop innovative, cost-effective, energy saving technologies that could lead to a significant reduction in building energy consumption and enable interactions between buildings and the power grid. The rapid development of next-generation building technologies are vital to advance building systems and components that are cost-competitive in the market, to enable deep energy use reduction and lead to the creation of new business and industries.

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 cost and/or performance improvements that are tied to clearly defined baseline 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 an estimate of energy savings and/or demand flexibility impact as well as a preliminary cost analysis.
- Justify all performance claims with theoretical predictions and/or experimental data.

All successful applications must demonstrate that the enabling research completed under this effort will succeed in producing the predicted performance advancement and reduction of technical risk required to move to successive stages of research. The proposed Phase I effort should be designed to retire significant technical risk and to establish the technical merit, feasibility, proof of principle, and commercial potential of the proposed approach. The objective of Phase II is to continue the efforts initiated in Phase I. Funding is based on the results achieved in Phase I. The fundamental question of penultimate price and performance of the proposed innovation should be well documented and clear in the Phase II application. Only Phase I awardees are eligible for a Phase II award.

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

- Topic 9 – Joint Topic: CABLE Characterization & Modeling for Fabrication.
- Topic 10 – Joint BTO/AMO Topic: Thermal Energy Storage (TES)

BTO seeks grant applications in the following subtopics:

a. High Performance Insulated Cladding for Residential Field Applied Applications

Today, approximately 2 million homes are resided each year with minimal insulation such as “fan fold” foam board offering R1 performance. Insulated vinyl siding improves this performance to roughly R2.5-R3 but installed cost tends to have a high price premium and performance falls short of at least R5 continuous insulation that is routinely installed in new construction per building code requirements. BTO seeks innovative solutions that offer at least R5 insulating cladding solutions for one or all of the typical siding products including vinyl, wood, fiber cement, engineered wood, etc. The additional R-value added by the cladding system should be equivalent to adding a layer of continuous insulation of identical R-value, i.e., a cladding system adding R5 should increase the overall wall assembly R-value by R5. The designs should focus on at least R5 performance with effective rain screen performance and be easy to install with consideration of interfaces including fenestration, roof to wall, wall to foundation, and typical construction penetrations. Overall details

for R5 performance should be applicable to R10 performance with minor modifications. The overall system should ensure that proper moisture control and air sealing can be applied, potentially even as part of the insulated cladding system itself, while ensuring the building will have long term performance without degradation. Long-term predicted performance through modeling programs such as WUFI are highly encouraged. Finally, cladding selection is driven by aesthetic considerations which need to be considered during the development process. The total installed re-cladding system price premium over existing cladding systems should be affordable based on life-cycle-cost basis with preferred simple pay back of less than 15 years when installed on homes in cold climates that have R11 cavity insulation.

In Phase 1, awardees are expected to develop representative proof of concept prototypes at sufficient scale that demonstrate installation details and airtightness and watertightness of the proposed technology. Simulation results that indicate long-term predicted performance of the retrofit solution are highly encouraged.

Parameters	Minimum Performance	Preferred Performance
Thermal performance	R5 CI	R10 CI
Max combined thickness of insulation and cladding (in)	2 (ideally ≤ 1.5)	3 (ideally ≤ 2.5)
Detailing	Uses readily available materials or components that can be easily manufactured to meet quick demand	
Cladding types	Fiber cement, vinyl, wood, engineered wood	

Questions – Contact: Sven Mumme, Sven.Mumme@ee.doe.gov

b. Low-Cost Exterior Window Attachments for Disadvantaged Communities

Exterior window attachments (e.g. shades, awnings, solar screens, etc.) can have a dramatic impact on reducing the heat that enters homes and are especially effective in dense urban neighborhoods and cooling-dominated climate zones in the south which have some of the highest energy burdens in the country. The Attachment Energy Rating Council established with DOE support rates the energy performance of window attachments, and research has shown that the performance is highly dependent upon a few key factors 1) the base window, 2) reflective materials, 3) being outside of the glazing, and 4) how the attachments are controlled. Very low-cost exterior attachments that use inexpensive white PVC hollow tubes, vinyl sheeting, or fabric can be effective, but they are controlled manually and may be hard to operate thus their general application is low and operation is far from optimized. DOE is seeking to innovate ways to offer very low-cost exterior attachments that can be automatically controlled (e.g. low-cost motors, spring mechanisms, or other clever devices), can be controlled from inside the home (e.g. magnetic wand), or devices that may deploy based on sun intensity or temperature. Desired performance and cost considerations for the solution are as follows:

- **Price:** The mature retail price should be no more than \$50 per attachment for a typical sized 3' x 4' double hung window, and less than \$25 per attachment is desirable. This would hopefully allow for solutions that would cost around \$250 to \$500 per home and be cost effective for low-income homes. The low price point should encourage innovation but discourage elaborate expensive solutions which are beyond the intent of this subtopic.
- **Material:** The material should reflect all or most of the near infrared energy and a large fraction of the visible light. Having some visible light illumination is desirable since it will prevent the use of electric lighting and may result in greater consumer acceptance even if it does not have the greater solar

energy rejection. For more information, please see [AERC Home - Attachments Energy Rating Council \(aercnet.org\)](#) or [Outreach | Windows and Daylighting \(lbl.gov\)](#).

- Installation: The design should also be easy to install. The attachment materials should be measured in accordance with Lawrence Berkeley National Laboratory/Attachments Energy Ratings Council established procedures, and the effort can include AERC product certification.

While applicants can propose a novel material not typically used in this application, any solution will be evaluated to ensure cost effectiveness, commercial viability, and conformity with these standards.

Questions – Contact: Marc LaFrance, Marc.Lafrance@ee.doe.gov

c. Home Energy Score

The US Department of Energy is interested in expanding the use of Home Energy Score™ in utility programs, real estate transactions, and efficiency financing to increase use of aggregable home energy asset data. Some localities and efficiency programs have expressed interest in leveraging the Home Energy Scoring Tool and Home Energy Score data, but specific technological barriers may prevent their current participation. Two particular use cases of Home Energy Score have been identified:

- Use of Home Energy Score in programs that support specific recommended energy measures beyond the methodology employed by the Home Energy Scoring Tool, including different payback timeframes, decarbonization measures, smart technology measures, and measures of specific fuel sources.
- Use of Home Energy Score in programs that require utility-specific energy cost rates, including customer-specific cost rates and adoption of time-of-use (TOU) rates, particularly in programs that require projects to be cashflow positive for recipient consumers.

The use cases named above have been identified by the Home Energy Score team as of interest based on limited applicability to national scale implementation and yet necessary for implementation within local jurisdictions. Applicants should propose software development use-cases that connect to Home Energy Score via the application programming interface (API). Those that demonstrate partnership with utilities or jurisdictions on their software development will be preferred. Other applications that support innovative use of Home Energy Score in residential efficiency programs, real estate transactions, and financing programs may also be deemed responsive.

Questions – Contact: Maddy Salzman, Madeline.Salzman@ee.doe.gov

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PROGRAM OFFICE OVERVIEW – OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT

The U.S. Department of Energy’s Office of Fossil Energy and Carbon Management (FECM) is dedicated to enabling fossil fuels to provide clean, affordable energy—essential for global prosperity and security—while minimizing their environmental impacts and working toward a national economy with net-zero carbon emissions. FECM’s programs use research, development, demonstration, and deployment (RDD&D) approaches to advance technologies to reduce carbon emissions and other environmental impacts of fossil fuel production and use. The Office is committed to improving the conditions of communities impacted by the legacy of fossil fuel use and 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](#)

21. INNOVATIVE ENERGY SYSTEMS

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

NETL’s Innovative Energy Systems (IES) research focuses on transformational technologies that improve power generation through efficient, low-cost, dynamic innovations. Four technology areas—advanced turbines, advanced materials, gasification, and solid oxide fuel cells—are represented in this Topic. Under the Advanced Turbines subtopics, the targeted use of hydrogen and ammonia as fuel induces a range of technology development from sensors and instrumentation for analysis of diverse gas streams feeding turbines through ammonia reforming for improved efficiency in gas turbine applications, and even extends beyond turbine applications to industrial hydrogen burners. Advanced Materials subtopics are focused on manufacture of silicon carbide fibers and development of lifing models for ceramic matrix composites generally, both of critical value to the durability of power systems operating under extreme conditions. Gasification takes up component aspects of extracting hydrogen from low-quality coal wastes and biomass. Solid oxide fuel cells, which produce electricity from hydrogen, and the complementary solid oxide electrolysis cells which electrolyze water to produce hydrogen, both suffer electrode degradation as a limiting economic factor. Development of hardier nickel-based cermet electrodes by the promising atomic layer deposition technique may provide a solution.

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. Advanced Sensors and Instrumentation for Online Measurement of Hydrogen and Natural Gas Fuels for Gas Turbines

Gas turbines have been a focus of power generation worldwide because of their advantages in producing a low cost of electricity, meeting or exceeding regulations for criteria pollutants, dispatchability, and load following capabilities. Gas turbines are also fuel flexible and can be modified to use carbon free fuels like hydrogen.

To mitigate carbon emissions from the power sector gas turbine manufacturers are developing combustion systems for fuel blends that range from mixtures of hydrogen and natural gas to pure hydrogen. Operating these machines on hydrogen fuel blends while maintaining state-of-the-art performance for efficiency and

emissions of pollutants (i.e., NO_x, CO, and VOCs) will be challenging. It will be important to understand real time fuel composition upstream of the combustor to optimize the combustion process and limit the effects of fuel variation. Grant applications are sought for the research, development, and implementation of fuel sensors and instrumentation that will allow gas turbine operators to measure hydrogen and hydrogen-natural gas blends comprising fuel composition in real time.

Proposed advanced sensors, electronics, and instrumentation that will be developed must be closely coupled to process control systems in order to provide actionable information to gas turbine operators. Applications should specify and justify the useful range of the sensor for measuring mixtures. It is believed that initial ranges for hydrogen and natural gas blends will be less than 30% by volume hydrogen and will ramp up to 100% hydrogen. Applications should specify anticipated perturbations (including magnitude and temporal variability) in the nominal fuel mixture and how the sensor will respond to these perturbations in real time so that there are opportunities to control and optimize the gas turbine combustion process. The sensor and instrumentation must be designed to operate at conditions (temperature and pressure) similar to existing fuel control systems for natural gas fueled gas turbines. Developers should specify appropriate blend range capabilities, suitable applications, and general sensor location within the gas turbine power plant. The proposed advanced sensor technologies must achieve relevant laboratory-scale demonstration and should also have the potential to eventually be integrated into actual gas turbine power plants.

Typical natural gas pipelines that supply fuel to gas turbine power plants operate at a range of pressures. Gas turbines can also operate across a wide range of pressures. At the same time, for operational purposes, the fuel entering the gas turbine combustor needs to be at a pressure significantly higher than the combustor operating pressure. For practical purposes applicants should plan to locate the proposed sensor technology downstream of the fuel processing skid and at operating pressures nominally as high as 600 psig.

Only those applications that propose the development of a sensor-based system to monitor blends of hydrogen and natural gas in real time that could allow gas turbine combustor operating systems or operators to control the combustion process in real time will be considered responsive. Collaboration with gas turbine original equipment manufacturers is encouraged.

Questions – Contact: Richard Dalton, richard.dalton@netl.doe.gov

b. Ammonia Reforming for Gas Turbine Applications

Ammonia is a potentially attractive carbon-free fuel source (or hydrogen carrier) that possesses significant advantages compared to pure hydrogen. Ammonia can be easily liquefied by refrigeration or compression, making it simpler to store and transport than hydrogen. Liquid ammonia's energy density (15.6 MJ/L) is 70% greater than liquid hydrogen (9.1 MJ/L at cryogenic temperature) and almost three times greater than compressed hydrogen (5.6 MJ/L at 70 MPa). Additionally, ammonia is already utilized commercially as a commodity chemical and fertilizer and, consequently, has established infrastructure for its production and transportation. However, ammonia's combustion properties are significantly different than those of hydrogen or natural gas. Ammonia exhibits narrower flammability limits and slower flame speeds which leads to issues with lean blow out, flame holding, and flame stability. One strategy for resolving the challenges with combustion of ammonia is to partially or completely reform (or "crack") the pure ammonia fuel into a mixture of hydrogen, nitrogen, and, potentially, residual ammonia prior to combustion. However, ammonia reformation is an endothermic process that requires significant energy input.

Applications are being sought for the research, development, and implementation of efficient and reliable strategies for reforming pure ammonia into a fuel mixture that improves combustion performance for gas turbine applications. Small, cost-effective systems with the potential for rapid small-scale deployment are of

significant interest. The fuel of interest is high-purity ammonia, including, but not limited to, high-purity ammonia produced from the industrial Haber-Bosch process. Thermal, catalytic, and hybrid reformation processes are all of interest, and the degree of reformation that is being targeted should be discussed and technically justified. The applicant should include an initial estimate of the expected ammonia conversion efficiency, relative to the theoretical minimum. The applicant must clearly describe how the technology will improve combustion performance of the fuel and justify why the proposed approach is beneficial for gas turbine applications. Applications may focus on the development of either a stand-alone reforming process, or a heat integrated reforming process. Integration of the reformer with an actual gas turbine is not required at this stage, but the impacts on the overall power plant system (i.e., combustor performance, turbine performance, emissions, etc.) should still be considered. Applicants are encouraged to provide a letter of support from a gas turbine original equipment manufacturer that indicates support for the proposed technology.

Questions – Contact: Matt Adams, matthew.f.adams@netl.doe.gov

c. Hydrogen Burners for Industrial Application

Hydrogen is being adopted as a carbon-free fuel to address near term decarbonization goals. To this end, large-scale hydrogen production can occur by renewable or nuclear generated electricity through electrolysis and fossil energy by reforming with carbon capture and storage. Gas turbines and fuel cell platforms can effectively use hydrogen across several scales to produce clean electric power. Hydrogen also provides options for energy storage and is adoptable in our existing infrastructure and assets. With wide scale availability, hydrogen can be used to decarbonize sources unmitigated by the electric grid. These difficult-to-mitigate sources include a wide array of industrial emitters that generate heat through the combustion of fossil fuels. Developing industrial-scale hydrogen-fueled burner technology will provide options for difficult to decarbonize processes. Grant applications are sought for the research, development, and implementation of hydrogen and hydrogen and natural gas blended fuel burners for industrial applications.

In 2019, the U.S. emitted 6,558 million metric tons of CO_{2eq}. Twenty-three percent of these emissions, approximately 1,500 million metric tons of CO_{2eq}, are from industrial sources (1). Combustion of fossil fuels accounts for 52%, or 780 million metric tons, of this industry derived CO_{2eq} (80 % of that is likely CO₂) (2). Addressing this greenhouse gas source by fuel switching to hydrogen will eliminate the most significant source of CO₂ in the industrial sector.

Grant applications are sought that develop industrial scale burners for hydrogen and hydrogen and natural gas blended fuels. Burner technology often incorporates additional air as a diluent, above the stoichiometric combustion requirements, to control emissions. Applications should develop technology that does not use additional diluents (e.g., steam, nitrogen, etc.), besides air, to control oxides of nitrogen (NO_x). (Some industrial process may require additional diluents as an integral part of the industrial process; in these cases, applications may propose, and need to justify, the use of additional diluents in their burner technology development). The burner technology should be able to demonstrate corrected (3% oxygen) low-single-digit NO_x emissions. Industrial burners have many applications and scale across orders of magnitude in heat delivery. Applicants should show how the new burner technology will function and scale across a range of industrial applications using a range of fuels from natural gas and hydrogen blends to 100 % hydrogen. The goal is to develop stable, low-single-digit NO_x burners that can operate on 100 % hydrogen fuel across a range of scales. Successful applications will show burner technology that can demonstrate the flexibility and modularity to accommodate discrete ranges of fuel blends and 100% hydrogen.

Industrial combustion burner development, application, and use has occurred in regions and cities that are now, in some cases, under environmental stress from the use of fossil fuels in industrial applications. These

same communities can be underserved and burdened by limited employment opportunities. Grant applications that show a synergistic ability to address local air emissions (criteria pollutants and carbon dioxide) and employment in underserved communities are desired.

Only those applications that propose the development of industrial scale burners for hydrogen and hydrogen and natural gas blended fuels for a broad range of sizes and industrial applications that are stable and have low-single-digit NO_x emissions will be considered responsive. Demonstrated collaboration with appropriate industries is encouraged.

Questions – Contact: Richard Dalton, richard.dalton@netl.doe.gov

d. Processing Methods to Manufacture High-Quality, Low-Cost Silicon Carbide (SiC) Fibers

In supporting widespread implementation of ceramic matrix composites (CMCs) for hot gas path applications within hydrogen turbines, research is needed to optimize CMC manufacturing processes, process modeling, and improve understanding to effectively increase production rates. Widespread utilization of components that incorporate very high-temperature CMCs (that are suitable for surface temperatures up to and exceeding 1,500°C/2,700°F) is hindered by the very high cost of fibers and the high cost of current composite manufacturing processes. CMC components are manufactured using ceramic fibers in a ceramic matrix. The composite requires a high-strength, refractory fiber that can sustain thermal excursions. High-strength, creep-resistant, oxygen-free SiC fibers provide these properties. SiC fiber is manufactured by a limited number of suppliers, each with unique processing and chemistry. This drives the need to optimize and balance chemical compositions, material properties, and cost.

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

e. Improved Lifing Models for CMC.

This research topic would develop models of environmental degradation of CMC materials in the hot section of the main gas path of a hydrogen turbine. These models will be particularly useful to guide the development of long-term retention of CMC mechanical properties at extreme turbine operating temperatures. The challenges associated with developing advanced lifing models for conventional materials are especially difficult to overcome for materials such as CMCs. Operation of CMCs and their associated environmental barrier coatings within high temperature hydrogen environments almost certainly will aggravate hot corrosion. Additional degradation modes will very likely arise as CMC components accumulate more time in service, creating currently unforeseen durability challenges.

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

f. Component Technology Advancement in Coal Waste and Biomass Gasification Systems

Long-term historical coal use in the United States has resulted in a significant amount of waste from coal preparation (e.g., coal fines and coal gob), which represents an environmental liability. With current moves toward a net-zero carbon economy, in addition to mandates to reduce burdens of past practices of fossil fuel use, there is an opportunity to consider, specifically, coal waste and biomass as inexpensive carbonaceous materials for use as combined feedstocks for value-added processes, such as hydrogen production.

Gasification technology has robust potential for converting coal waste and biomass to hydrogen, which will increasingly figure in the future decarbonized industry/economy of the United States. Research and development (R&D) to enable more efficient, economical, and environmentally friendly gasification-based technologies to create hydrogen from coal waste and biomass may be needed. Combined use of these feedstocks, plus deployment of carbon capture and storage technologies in gasification-based processes,

should enable a net-zero or net-negative carbon footprint. However, challenges exist in relatively low heating values and varying forms of both coal waste and biomass, and in realizing efficient systems at the smaller scales appropriate to current market opportunities.

Under this subtopic, scope of possible R&D can consider technical improvements in major components of gasification systems and processes (e.g., mixed feed gasifier systems, gas clean-up, hydrogen separation, and effluent treatment to produce only benign waste materials), which will enable effective gasification of low-quality coal waste and biomass for hydrogen production. Proposed work should consider life cycle carbon footprint concerns and help lead toward ultimate commercialization of these systems or processes.

Proposed technologies and systems should be able to accommodate utilization of actual types of co-located biomass and coal waste, thereby reducing the need for transportation and minimizing carbon emissions from a life cycle analysis (LCA) perspective in target plant locations. Plants should be sited to address economic revitalization and environmental justice initiatives. Significant quantities of these feedstocks exist; however, applicants should address specific feedstock availability and suitability questions. When scoping out R&D projects/investigations, applicants must clearly identify certain key technology and process assumptions that will be important in establishing how the proposed R&D will advance components or process technology relative to the state-of-the-art. At a minimum, the following R&D conditions and technology targets must be specified:

- Which technology is utilized?
- What is the research scale of investigation (i.e., feedstock throughput or amount of hydrogen production)?
- What is the end scale or targeted commercial scale of the technology envisioned to be?

Specific investigation topics to consider include (but are not limited to):

- Gasification characteristics of specific feedstock streams and combinations.
- Feed pre-treatment/separations, briquetting, or other methods that may be required for gasification feasibility for low-quality coal waste and biomass feedstocks.
- Combinations of feedstocks' behavior in feed systems for gasifiers (e.g., grinding, milling, conveying, burners, etc.).
- Slag or ash characteristics when gasifying biomass and coal waste.
- Approaches to immobilize toxics of concern to assure waste products are environmentally benign as related to liquid and solid effluents management.
- Syngas reactivity produced as it impacts downstream water-gas shift, including characterization of byproducts, trace species, etc.
- Hydrogen separation at modular scales and efficient integration in coal waste and biomass gasification systems.
- Development of validated models that can be used for device and system modeling and optimization based on fundamental chemistry, data, and machine learning/artificial intelligence. These models will help with design and scale-up of new gasification systems.

Proposed work should not involve use of newly produced fossil fuels in the feedstock mix. Portions of early analytical research should make efforts to demonstrate feasibility of these processes and find ways to reduce overall capital and operating costs in ways to result in cost-competitive hydrogen production.

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

g. High Performance Hydrogen Electrodes in Solid Oxide Electrolysis Cells using Atomic Layer Deposition (ALD) Technique

Ni-based cermet electrodes such as Ni-YSZ are the most commonly applied hydrogen electrodes for solid oxide cells (SOC) both when targeting solid oxide fuel cell (SOFC) applications and when used in a solid oxide electrolysis cell (SOEC); however, the hydrogen electrodes are the primary source of degradation for most long-term SOEC tests in which the cell is subjected to high steam concentrations, and the degradation of SOECs is a significant barrier to commercial viability.

High-performance hydrogen electrodes require high porosity, high surface area, high-density triple phase boundaries (TPBs), sufficient electrical and ionic conductivity, and high catalytic activity. Ni agglomeration is a common degradation phenomenon in Ni-YSZ electrodes operating at high fuel gas humidity, which leads to a reduction in TPB length which can be correlated to a high Ni mobility due to Ni(OH)_x formation. Therefore, there is an urgent need to develop a stable Ni-YSZ electrode under SOEC operating conditions.

Atomic Layer Deposition (ALD), an ultra-thin film deposition technique with its distinct abilities, has gained attention as a method for modifying SOFC and SOEC electrodes. ALD provides uniform deposition of conformal films with controllable thicknesses, even on complex three-dimensional surfaces, allowing the surface composition to be modified or tailored for multifunction. ALD has been shown to be one of the most promising techniques in lowering area specific resistance (ASR) and increasing the performance and longevity of electrode materials. Although ALD has been identified as a potentially attractive option for the manufacture of hydrogen electrodes used in SOFC and SOEC technology, one of the challenges of ALD is related to the integration and scaling up processes in SOFC/SOEC manufacturing, where cost and throughput are critical to determine the economic viability of a technology.

Grant applications are sought for research and development that uses ALD techniques to make a better hydrogen electrode (Ni-YSZ) that is stable in high steam concentrations usually observed in SOEC mode. Applicants must clearly outline what can cause the hydrogen electrodes (Ni-YSZ) to degrade during SOEC operation and how ALD techniques can be used to minimize the degradation. Applicants must clearly state how entire hydrogen electrode architectures would be fabricated and implemented, and why it would minimize the degradation under SOEC testing. A complete description of the ALD manufacturing process required to achieve the proposed architectures should be provided to facilitate analysis of potential cost issues and implementation complexity, and Applicants must clearly state how they can overcome challenges related to the integration and scaling up of the ALD processes in SOFC/SOEC manufacturing where cost and throughput are critical to determine the economic viability of a technology.

Applications that focus on cathode electrodes or other deposition techniques other than ALD will be considered non-responsive. Applications that do not clearly state how to overcome the challenges of integration and scaling up of the ALD process will be considered non-responsive.

Questions – Contact: Patcharin Burke, Patcharin.Burke@netl.doe.gov

h. Other

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

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

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1. York, W., et al., 2015, Advanced IGCC/Hydrogen Gas Turbine Development, US DOE, <https://www.osti.gov/servlets/purl/1261809> (November 5, 2021)
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3. Chen, K., 2015, Development of Metal Oxide Nanostructure-Based Optical Sensors for Fossil Fuel Derived Gases Measurement at High Temperature, United States: N. p.,2014, <https://www.osti.gov/biblio/1172616> (November 5, 2021)
4. Argonne National Laboratory, Fast, Sensitive and Reliable Hydrogen Sensor (ANL-IN-04-077B), <https://www.anl.gov/partnerships/fast-sensitive-and-reliable-hydrogen-sensor-anlin04077b> (November 5, 2021)

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1. Valera-Medina, A., et al., 2018, Ammonia For Power, *Progress in Energy and Combustion Science* 69, 63-102, <https://www.sciencedirect.com/science/article/pii/S0360128517302320> (November 8, 2021)
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3. Bull, M.G., 1968, Development of Ammonia Burning Gas Turbine, *Final Technical Report*, <https://apps.dtic.mil/sti/citations/AD0671667> (November 8, 2021)
4. Evans, B., 2013, *Using Local Green Energy and Ammonia to Power Gas Turbine Generators*, The 10th Annual NH3 Fuel Conference, <https://nh3fuelassociation.org/2013/09/18/using-local-green-energy-and-ammonia-to-power-gas-turbine-generators/> (November 8, 2021)
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References: Subtopic c:

1. EPA, 2021, Industry Sector Emissions, <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#industry> (November 8, 2021)
2. EPA, 2021, Greenhouse Gas Inventory Data Explorer, <https://cfpub.epa.gov/ghgdata/inventoryexplorer/#industry/entiresector/allgas/category/current> (November 8, 2021)
3. Baukal, C.E., 2001, The John Zink Combustion Handbook, *CRC Press*, <https://www.amazon.com/John-Zink-Combustion-Handbook-Industrial/dp/0849323371> (November 8, 2021)
4. Cheng, R.K., Ultra-Clean Low- Swirl Burner for Heating and Power Systems, *LBNL*, https://www.arpa-e.energy.gov/sites/default/files/documents/files/SSDG_Workshop_RobertCheng.pdf (November 8, 2021)

References: Subtopics d and e:

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2. Lieuwen, T., Emerson, B., Espinoza, N. and Noble, B., 2021, Hydrogen Substitution for Natural Gas in Turbines: Opportunities, Issues and Challenges, *Power Engineering*, June 18, 2021, <https://www.power-eng.com/gas/hydrogen-substitution-for-natural-gas-in-turbines-opportunities-issues-and-challenges/#gref> (November 8, 2021)
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References: Subtopic g:

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3. Pan, J., 2021, Improving the activity and stability of Ni-based electrodes for solid oxide cells through surface engineering: Recent progress and future perspectives, *Materials Reports: Energy Volume 1*, Issue 2, May 2021, <https://www.sciencedirect.com/science/article/pii/S2666935821000379> (November 8, 2021)
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5. Shin J.W., et al., 2019, Review on Process-Microstructure-Performance Relationship in ALD-Engineered SOFCs, *J. Phys. Energy* 1 042002, <https://iopscience.iop.org/article/10.1088/2515-7655/ab30a0/pdf> (November 8, 2021)

22. CARBON CAPTURE AND REMOVAL

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

The Carbon Capture Program at the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) is developing both carbon-reducing technologies and negative emissions technologies (NETs) to work toward DOE's goal of a carbon emissions-free power sector by 2035, and to put the United States on a path to a net-zero carbon economy by 2050. NETL researchers have been conducting research and development (R&D) in carbon capture technologies from conceptual engineering and materials design at the bench scale to large-scale testing, accelerating commercially deployable solutions. The program's comprehensive multi-pronged approach leverages fundamental research in materials and chemical sciences, as well as process engineering and field-testing of prototypes, to develop novel carbon dioxide (CO₂) capture technologies and systems.

The DOE/NETL Carbon Capture Program focuses on cost-effective solutions for carbon capture from new and existing natural gas and other fossil fuel-fired power plants, and industrial facilities, as well as solutions for achieving net-negative carbon emissions. R&D addresses both capital and operating costs to improve the economics of carbon capture technologies and provides a solution for reducing the amount of CO₂ in the atmosphere. Over the last decade, the program has developed second-generation technologies that have been validated at pilot scale and are on a development path to be commercial ready by 2025.

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 Carbon Capture Technologies Employing Waste Heat in Regeneration of Materials Used in Direct Air Capture

DAC technologies are not constrained by the availability of the CO₂ source and can be co-located with power plants or industrial facilities to access low-carbon thermal sources, such as waste heat. Grant applications are sought for the development of processes and/or materials that make use of low-grade waste heat for the regeneration of materials used to capture CO₂ directly from atmospheric air. Proposed DAC technologies should focus on heat not commonly utilized by proposed host site. Unutilized waste heat in the industrial and geothermal sectors are of particular interest. Preference will be given to the applications proposing DAC technologies that maximize the use of thermal energy to regenerate DAC materials. DAC technologies that produce large electrical loads such as vacuum swing desorption, should not be part of any application submitted and will be considered non-responsive to the sub-topic.

Questions – Contact: Dustin Brown, dustin.brown@netl.doe.gov

b. Highly Efficient Materials and Processes to Support Disruptive Carbon Capture Technologies for Natural Gas Combined Cycle Power Plants

Among the objectives of the Carbon Capture Program is to support the deep decarbonization of the power sector by developing highly efficient, disruptive carbon capture technologies for Natural Gas Combine Cycle (NGCC) power plants. Grant applications are sought for disruptive approaches that achieve over 95% carbon capture rates for NGCC applications and demonstrate significant progress towards a 20% reduction in the cost of carbon capture versus a reference NGCC plant with carbon capture. The technologies can include both materials and processes used for disruptive carbon capture. New solvent, sorbent, or membrane materials development targeting incremental improvements to any work that is currently being funded in the U.S. DOE Carbon Capture Program portfolio will be considered non-responsive to the sub-topic. Applications are sought only for development of materials and approaches that are NOT included in the current Program portfolio. Applications must show that the proposed approaches have the potential to provide a significant improvement towards the aforementioned objectives of the Carbon Capture Program.

Questions – Contact: Nicole Klingensmith, nicole.shamitko-klingensmith@netl.doe.gov

c. Novel Technologies for Mitigation of Process CO₂ Emissions in the Cement/Steel Sector

Cement and steel production combined account for approximately 15% of global anthropogenic CO₂ emissions. Like power generation facilities, individual production sites are similarly consolidated point sources with similar concentrations of CO₂, providing excellent opportunity to reduce overall sector emissions. Grant applications are sought for (i) process design and techno-economic feasibility analysis, and/or (ii) laboratory proof of concepts of novel process and material technologies that reduce the cost of mitigating CO₂ emissions from process reactions in the manufacture of cement and steel. In contrast, development of technologies for mitigation of CO₂ emissions associated with the generation of heat or electricity for these processes will be considered non-responsive. Additionally, technologies for conventional direct, post-process capture of CO₂ from any stream will be considered non-responsive. Applications should demonstrate that the proposed technology can achieve greater than 95% capture rates and should seek to minimize the cost of the low-carbon cement or steel produced.

Questions – Contact: Mariah Richardson, mariah.richardson@netl.doe.gov

d. Highly Efficient Carbon Capture Technologies for Production of Hydrogen from Natural Gas

Low-cost production of hydrogen from natural gas with highly reduced carbon footprint represents an important pathway in achieving deep decarbonization of power generation, industrial and transportation sectors. Combustion of hydrogen does not produce CO₂ at the point of use, but the current commercial

processes to make hydrogen from natural gas remain carbon intensive. Grant applications are sought for (i) process design and techno-economic feasibility analysis, and/or (ii) laboratory proof of concepts of novel process and material technologies that efficiently capture process CO₂ associated with production of hydrogen from natural gas. Processes may be considered that utilize steam methane reforming (SMR), autothermal reforming (ATR), or other novel approaches for production of hydrogen. Development of technologies for mitigation of CO₂ emissions associated with the generation of heat or electricity for these processes should not be part of any application submitted and will be considered non-responsive to the sub-topic. R&D targeting incremental improvements to any work that is currently being funded in the U.S. DOE Carbon Capture Program portfolio will be considered non-responsive to the sub-topic. Applications are sought only for development of materials and approaches that are NOT included in the current Program portfolio. Applications should demonstrate that the proposed technology can achieve greater than 95% carbon capture efficiency and make significant progress towards achieving a carbon intensity of less than 1 kg CO₂/kg H₂ and a cost of H₂ of \$1/kg H₂.

Questions – Contact: Elliot Roth, elliott.roth@netl.doe.gov

e. Quantification of Ancillary Environmental Benefits of Transformational Carbon Capture Technologies

Implementing transformational point source carbon capture technologies for both industrial and power generation sectors could have significant ancillary environmental benefits, such as reductions in NO_x and SO_x emissions, particulate matter, or hazardous pollutants. However, there is an existing data gap in the understanding and quantification of the co-benefit pollutant reductions of transformational carbon capture technologies. Grant applications are sought for lab- or bench-scale, experimental quantification of pollutants reduction upon implementing transformational carbon capture technologies being developed by the Applicant. Pollutants of interests include NO_x, SO_x, particulate matter or other hazardous flue gas contaminants. Transformational carbon capture technologies of interest include sorbents, membranes, solvents, cryogenic and novel concepts applied to natural gas power generation or industrial sources. Industrial sectors of interest include production of: (i) chemicals, (ii) petrochemicals, (iii) hydrogen from natural gas, (iii) cement and lime, or (iv) iron and steel. Proposed point source carbon capture technology should be able to achieve 95% carbon capture efficiency in the proposed application. The Applicant should proposed test their carbon capture technologies with simulated exhaust containing impurities representative to the proposed application.

Questions – Contact: Elliot Roth, elliott.roth@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: Zachary Roberts, zachary.roberts@netl.doe.gov

References: Subtopic a:

1. The National Academies of Sciences, Engineering, Medicine, 2021, Developing a Research Agenda for Carbon Dioxide Removal and Reliable Sequestration, <https://www.nationalacademies.org/our-work/developing-a-research-agenda-for-carbon-dioxide-removal-and-reliable-sequestration> (November 8, 2021)
2. U.S. Department of Energy, 2020, Department of Energy Invests \$72 Million in Carbon Capture Technologies, *US DOE*, <https://www.energy.gov/articles/department-energy-invests-72-million-carbon-capture-technologies> (November 8, 2021)

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References: Subtopics b, c, d, and e:

1. The White House, 2021, Tackling the Climate Crisis at Home and Abroad, *Executive Order 14008 of January 27, 2021*, <https://www.govinfo.gov/content/pkg/FR-2021-02-01/pdf/2021-02177.pdf> (November 8, 2021)

References: Subtopic b:

1. Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, Case B31B, *NETL-PUB-22638*, https://www.netl.doe.gov/projects/files/CostAndPerformanceBaselineForFossilEnergyPlantsVol1BitumCoalAndNGtoElectBBRRev4-1_092419.pdf (November 8, 2021)

References: Subtopic c:

1. IEA, 2020, Cement, IEA <https://www.iea.org/reports/cement> (November 8, 2021)
2. IEA, 2020, Iron and Steel Technology Roadmap, *IEA Technology Report – October 2020*, <https://www.iea.org/reports/iron-and-steel-technology-roadmap> (November 8, 2021)

23. CARBON MANAGEMENT

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

Coal is a domestic resource that has contributed to U.S. economic growth for over a century. However, in a shifting energy generation paradigm, innovation is needed to extract the full economic value from coal and coal-wastes. The Carbon Ore Processing Program delivers solutions to this challenge with novel technologies for producing valuable products from coal-derived sources. The program focuses on developing a spectrum of coal derived products, ranging from high-volume to high-value. Support for laboratory and pilot-scale research and development (R&D) within the program will develop future uses for coal and coal-wastes outside of traditional thermal and metallurgical markets.

The Carbon Utilization Program supports research and development (R&D) to convert CO₂ into value-added products that are equitable, economic, and environmentally-responsible. The program has a broad mandate, supporting the conversion of CO₂ into various products, including but not limited to fuels, organic and inorganic chemicals, food and feeds, polymers and plastics, and construction materials. The program supports all viable conversion pathways, whether biological (algal or microbial), thermochemical, or electrochemical. Areas outside the scope of the program include the use of CO₂ as working fluid (e.g., for enhanced oil recovery or supercritical CO₂ power cycles). The program goal of reducing impacts associated with CO₂ emissions also supports goals as outlined in Section 219 of Executive Order 14008, addressing the disproportionately high and adverse human health, environmental, climate-related and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impacts.

Supported R&D within the Carbon Utilization Program may address any aspect of the conversion process as appropriate for the technology readiness level (TRL) of the concept. From low to high TRLs, this could include evaluations of concept viability, development of catalyst or reactor designs, design for integration with various CO₂ sources, or engineering-scale tests. All supported R&D should be integrated with lifecycle analysis (LCA)

and techno-economic analysis (TEA), as both tools are upstream of the commercial and societal acceptability of CO₂ utilization technologies. The broad program mandate, variety of supported conversion pathways, and tight integration with LCA and TEA allow the Carbon Utilization program to identify the most promising CO₂ conversion technologies.

The carbon storage program is focused on developing tools used during site selection and characterization prior to construction that can accurately and affordably assess potential induced seismicity risk of a commercial-scale CCS operation (>1 million metric tons per year). During these early project phases there is a strong need to understand natural seismicity prior to any CO₂ injection, preferably prior to making large investments in developing the storage project. Current processes to understand induced seismicity risks are highly specialized, labor intensive, time constrained, and expensive. The magnitude of naturally occurring seismic noise also creates an apparent threshold and substantial potential error in identifying and detecting the first motion of seismic events. Because seismicity assessment remains an important factor across the project lifecycle (prior to, during, and after CO₂ injection), an additional consideration should be placed on the robust and rugged nature of the proposed technology(ies) with an outlook that the system incorporating the technology(ies) could be updated or upgraded for use in later phases of the project.

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. Production of Carbon-Metal Composites Incorporating Coal-Derived Materials

Carbon-metal composites are a class of materials that are characterized by the existence of unique phases between the carbon material and metallic backbone. Being more than a simple mixture of carbon materials and metal, carbon-metal composites display properties far superior to what would be suggested by the law of mixing. Carbon-metal composites can display significant improvements in tensile strength, stiffness, hardness, electrical conductivity, and wear rates for metals including but not limited to copper, aluminum, and titanium. Carbon-metal composites can be prepared by a multitude of techniques including powder metallurgy, mixing, electrochemical deposition, chemical vapor deposition, layer by layer assembly, melt infiltration, and a variety of other processing methods. Carbon-metal composites could find use in almost any application where superior material properties justify the price premium, but they are particularly attractive for electrical and electromechanical applications.

Grant applications are sought for the research and development of carbon-metal composites utilizing a coal-derived carbon, whether nanotubes (single or multi-wall), graphene, graphite, carbon fiber, or other coal-derived carbon. Supported R&D must use existing coal-derived carbon materials, applications should not include the development of the coal-derived material as a task within the research. There is no preference as to whether these coal-derived materials are commercial or pre-commercial. The FECM Carbon Ore Processing Program portfolio includes many developers of pre-commercial coal-derived materials, but applicants are free to obtain pre-commercial coal-derived materials from any source. Proposed R&D should describe the carbon material that will be incorporated into the metallic backbone, the incorporation process itself, and the analytical techniques that will be used to characterize interfacial phases within the carbon-metal composite. Proposed R&D must identify a specific end-use application and must tabulate performance targets for the proposed carbon-metal composite. The Phase I work scope must include a test plan to quantify relevant material properties and compare them to target properties identified in the application materials. The global market size for the carbon-metal composite should be estimated as part of the application materials, and a more thorough economic analysis performed as part of the work scope. Finally, proposed technologies should, to the greatest extent practicable, utilize commercial off the shelf technology to minimize technological risk and development time.

Applicants shall focus their applications on:

- Describing, in sufficient detail to allow for evaluation, the process by which that carbon-metal composite is produced and the analytical techniques by which the interfacial phases are characterized
- Identifying a specific end-use application for the carbon-metal composite, including a tabulation of targeted material properties for the selected application
- Describing a test campaign to determine whether the carbon-metal composite meets the technical properties (performance) required for the identified application
- Technologies that yield a carbon-metal composite utilizing an economically justifiable process in the context of the application identified
- Outlining a preliminary techno-economic analysis (TEA) to be completed during Phase I
- Technologies that, to the greatest extent practicable, utilize commercial off the shelf technology
- Ensuring that ES&H concerns surrounding the handling of carbon nano-materials are addressed

Questions – Contact: Brett Hakey, brett.hakey@netl.doe.gov

b. Conversion of CO₂ into Plastics

Over 359 MMt of plastics were produced in 2018. This equates to an annual individual plastic consumption on the order of 44kg/person. The most common uses for plastics were packaging, building and construction, textiles, consumer products, transportation, and electrical/electronic. The most abundant application for plastic is packaging, which also has the shortest product lifetime (time between production and disposal). Common plastic precursors include polyethylene, polypropylene, polystyrene, polyvinylchloride, polyethylene terephthalate, and polyurethanes. Almost all these precursors are fossil-fuel derived; only 4MMt/year (approximately 1%) of total plastic production is bio-based or bio-degradable. Given the scale of plastic production and the near-total reliance on fossil fuels, there is a significant opportunity to reduce carbon emissions by converting CO₂ into plastics.

Grant applications are sought for the research and development of technologies that can economically convert CO₂ into plastic in the form of pellets, foams, or fibers. Technologies must yield a product with a market value sufficient to offset the associated conversion costs. Conversion approaches should be limited to thermal energy whether thermo-chemical (waste heat or resistive heat), microwave, or plasma. The proposed conversion process and associated material and energy flows must be described in sufficient detail to allow for a thorough evaluation of the concept. Applications should outline a life cycle analysis (LCA) to be completed during Phase I for the purposes of characterizing the environmental impact of the technology and potential reduction to carbon emissions. Additionally, applications should outline a techno-economic analysis (TEA) to be completed during Phase I for the purpose of characterizing the economic potential of the technology. A specific application should be identified for the proposed plastic product, including background information on market volumes and values. A test campaign to determine whether the CO₂-derived plastic meets the technical properties (performance) required for the identified application should be described. Finally, proposed technologies should, to the greatest extent practicable, utilize commercial off-the-shelf technology to minimize technological risk and developmental time.

Applicants shall focus their applications on:

- Identifying a specific end-use application for the product and describing a test campaign to determine whether the product meets the technical properties (performance) required for the identified application
- 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), including a counterfactual of the petroleum-based product
- Outlining a preliminary techno-economic analysis (TEA), characterizing the market value of the product relative to the current state of the art
- Technologies that, to the greatest extent practicable, utilize commercial off the shelf technology
- Technologies that have achieved at least TRL 3

Questions – Contact: Naomi O’Neil, naomi.oneil@netl.doe.gov

c. Technology Innovations for Efficient and Effective Passive Seismic Monitoring During Carbon Storage Site Characterization

Grant applications are sought for new technologies to be deployed during site characterization that facilitate easier, better, higher-resolution data acquisition, improved source characterization, and assessment of the potential induced seismicity risks posed to the carbon storage project. These include novel technologies, systems and/or processing techniques. For example, a project could be proposed for developing novel technologies that separate useful seismic signals from other “noise” while improving event sensitivity, accuracy, motion or location determination. Improved geomechanical models and statistics-based probabilistic seismic hazard assessments are not desired. Notice that this AOI differs from the previous AOI focused on development of a “turnkey system” in that this AOI focuses on development of new technologies that could greatly improve turnkey systems based on currently commercial offerings. SBIR applicants are encouraged to leverage other funding opportunities, especially ones that support investment in marginalized communities.

Questions – Contact: Natalie Iannacchione, natalie.iannacchione@netl.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: Naomi O’Neil, naomi.oneil@netl.doe.gov

References: Subtopic a:

1. Güler, O., Bağcı, N., 2020, A Short Review on Mechanical Properties of Graphene Reinforced Metal Matrix Composites, *Journal of Materials Research and Technology*, January 2020, <https://www.sciencedirect.com/science/article/pii/S2238785419312852> (November 8, 2021)
2. Hidalgo-Manrique, P., Lei, X., Xu, R., et al., 2019, Copper/graphene Composites: A Review, *Journal of Material Science*, 54:12236-12289, <https://link.springer.com/article/10.1007/s10853-019-03703-5> (November 8, 2021)
3. Shin, S.E., Choi, H.J., Hwang, J.Y., et al., 2015, Strengthening Behavior of Carbon/metal Nanocomposites, *Scientific Reports*, 5:16114, <https://www.nature.com/articles/srep16114> (November 8, 2021)

References: Subtopic b:

1. Plastics Europe, 2019, An Analysis of European Plastics Production, Demand and Waste Data, *Plastics: The Facts*, https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts_2019_14102019.pdf (November 8, 2021)

2. Ryberg, M.W., Laurent, A., Hauschild, M., 2018, Mapping of Global Plastics Value Chain and Plastics Losses to the Environment, *UN Environment Program*, <https://www.unep.org/pt-br/node/27212> (November 8, 2021)
3. Geyer, R., Jambeck, J.R., Law, K.L., 2017, Production, Use, and Fate of All Plastics Ever Made, *Sci. Adv.*, 3, <https://www.science.org/doi/10.1126/sciadv.1700782> (November 8, 2021)
4. Center for International Environmental Law, 2019, Plastic and Climate: The Hidden Costs of a Plastic Planet, <https://www.ciel.org/plasticandclimate/> (November 8, 2021)

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2. NRAP, 2021, Passive Seismic Monitoring Tool (PSMT), <https://edx.netl.doe.gov/nrap/passive-seismic-monitoring-tool-psmt/> (November 8, 2021)
3. NRAP, 2021, Short-Term Seismic Forecasting Tool (STSF), <https://edx.netl.doe.gov/nrap/short-term-seismic-forecasting-stsf/> (November 8, 2021)
4. NRAP, 2021, DRAFT Recommended Practices for Managing Induced Seismicity Risk Associated with Geologic Carbon Storage <https://edx.netl.doe.gov/dataset/draft-rec-practices-for-managing-is-risk-associated-with-geologic-carbon-storage> (November 8, 2021)
5. Los Alamos National Laboratory, 2019, Monitoring for Faults at a Critical State of Stress, 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting August 26-30, 2019, <https://netl.doe.gov/sites/default/files/netl-file/Chen-2019CO2review.pdf> (November 8, 2021)

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.

One of the next frontiers for the FES program 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 a number of new scientific phenomena. To achieve these 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. In addition, FES supports partnerships with the private fusion sector to accelerate progress toward the development of fusion energy.

In addition to its fusion energy mission, FES also supports discovery plasma science, which is focused on research at the frontiers of basic and low temperature plasma science and high-energy-density laboratory plasmas. Finally, FES invests in transformational technologies such as artificial intelligence and machine learning (AI/ML) and quantum information science (QIS), that have the potential to accelerate progress in several mission areas.

FES research is guided by the Long-Range Plan “Powering the Future: Fusion and Plasmas” developed by the Fusion Energy Sciences Advisory Committee (FESAC): https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf

Additional resources include:

- A series of community engagement workshops (<https://science.osti.gov/fes/Community-Resources/Workshop-Reports>),
- National Academies reports such as:
 - the 2018 report on a [Strategic Plan for U.S. Burning Plasma Research](#)
 - the 2018 report on [Opportunities in Intense Ultrafast Lasers](#)
 - the [2020 Decadal Assessment of Plasma Science](#) report; and
 - the 2021 report on “Bringing Fusion to the U.S. Grid,” <https://www.nap.edu/catalog/25991/bringing-fusion-to-the-us-grid>

The following topics are restricted to advanced technologies for fusion energy systems, fusion science, technology relevant to magnetically confined plasmas, low temperature plasmas and microelectronics, and high energy density laboratory plasmas.

For additional information regarding the Office of Fusion Energy Sciences priorities, [click here](#).

24. FUSION BLANKET AND TRITIUM FUEL CYCLE

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

The fusion blanket and tritium fuel cycle are critical components required to sustaining the burning plasma fuel. The fusion blanket is required to fuel the burning plasma by breeding tritium while also withstanding the harsh plasma environment. The tritium fuel cycle must effectively cycle and separate tritium to be recycled back into the burning plasma. The goal of this program is to establish the feasibility of designing, constructing and operating a fusion power plant with blanket and fuel cycle that meet demanding objectives for safety, performance, economics, and environmental impact.

Grant applications are sought in the following areas:

a. Dual Cooled Lead Lithium Blanket

Research and development that focuses on, but not limited to, thermophysical/thermo-mechanical responses to neutron irradiation, material degradation, corrosion, breeding efficiency, thermal efficiency, and fabrication and component manufacturing for a dual cooled lead-lithium blanket design with the main goal being to develop a pathway toward effective breeding blanket system.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

b. Helium Cooled Ceramic Breeders

Research and development that focuses on, but not limited to, thermophysical/thermo-mechanical responses to neutron irradiation, material degradation, corrosion, breeding efficiency, thermal efficiency, and fabrication and component manufacturing for a helium cooled ceramic pebble design with the main goal being to develop a pathway toward effective breeding blanket system.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

c. Tritium Fuel Cycle System Components

Research and development that focuses on, but not limited to, super-permeable membranes, hydrogen isotopic separation systems, hydrogen isotopic vacuum pumping systems, and fuel extraction efficiency with the main goal being to develop a pathway toward effective tritium fuel cycle.

Questions – Contact: Guinevere Shaw, guinevere.shaw@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: Guinevere Shaw, guinevere.shaw@science.doe.gov

References:

1. Maingi, R., Lumsdaine, A., Allain, J. P., et al., 2019, Summary of the FESAC Transformative Enabling Capabilities Panel Report, *Fusion Science and Technology*, 75(3), 167-177, <https://www.osti.gov/servlets/purl/1503999> (November 5, 2021)
2. Kessel, C.E., Blanchard, J.P., Davis, A., et al., 2015, The Fusion Nuclear Science Facility, the Critical Step in the Pathway to Fusion Energy, *Fusion Science and Technology*, 68(2), 225-236, [http://www.fusion.ucla.edu/abdou/abdou%20publications/2017/FSTv68.2pg225-236 Kessel et al- The Fusion Nuclear Science Facility the Critical Step.pdf](http://www.fusion.ucla.edu/abdou/abdou%20publications/2017/FSTv68.2pg225-236%20Kessel%20et%20al-The%20Fusion%20Nuclear%20Science%20Facility%20the%20Critical%20Step.pdf) (November 5, 2021)
3. Kessel, C.E., Blanchard, J.P., Davis, A., et al., 2018, Overview of the Fusion Nuclear Science Facility, a Credible Break-in step on the Path to Fusion Energy, *Fusion Engineering and Design*, 135, 236-270, <https://www.sciencedirect.com/science/article/abs/pii/S0920379617306257> (November 5, 2021)

4. Zinkle, S.J., Blanchard, J.P., Callis, R.W., et al., 2014, Fusion Materials Science and Technology Research Opportunities Now and During the ITER Era, *Fusion Engineering and Design*, 89(7-8), 1579-1585, <https://www.sciencedirect.com/science/article/pii/S0920379614001458> (November 5, 2021)

25. 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

New or advanced superconducting magnet concepts are needed for plasma fusion confinement systems. Of particular interest are magnet components, superconducting, structural and insulating materials, or diagnostic systems that lead to magnetic confinement devices which operate at higher magnetic fields (14T-20T), in higher nuclear irradiation environments, provide improved access/maintenance or allow for wider operating ranges in temperature or pulsed magnetic fields.

Grant applications are sought for:

a. Superconducting Magnetic Technology

Innovative and advanced superconducting materials and manufacturing processes that have a high potential for improved conductor performance and low fabrication costs. Of specific interest are materials such as YBCO conductors that are easily adaptable to bundling into high current cables carrying 30-60 kA. Desirable characteristics include high critical currents at temperatures from 4.5 K to 50 K, magnetic fields in the range 5 T to 20 T, higher copper fractions, low transient losses, low sensitivity to strain degradation effects, high radiation resistance, and improved methods for cabling tape conductors taking into account twisting and other methods of transposition to ensure uniform current distribution.

Novel methods for joining coil sections for manufacture of demountable magnets that allow for highly reliable, re-makeable joints that exhibit excellent structural integrity, low electrical resistance, low ac losses, and high stability in high magnetic field and in pulsed applications. These include conventional lap and butt joints, as well as very high current plate-to-plate joints. Reliable sliding joints can be considered.

Innovative structural support methods and materials, and magnet cooling and quench protection methods suitable for operation in a fusion radiation environment that results in high overall current density magnets.

Novel, advanced sensors and instrumentation for monitoring magnet and helium parameters (e.g., pressure, temperature, voltage, mass flow, quench, etc.); of specific interest are fiber optic-based devices and systems that allow for electromagnetic noise-immune interrogation of these parameters as well as positional information of the measured parameter within the coil winding pack. A specific use of fiber sensors is for rapid and redundant quench detection. Novel fiber optic sensors may also be used for precision measurement of distributed and local temperature or strain for diagnostic and scientific studies of conductor behavior and code calibration.

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

References:

1. Office of Fusion Energy Sciences, 2009, Research Needs for Magnetic Fusion Energy Sciences, Report of the Research Needs Workshop (ReNeW), *U.S. Department of Energy*, p. 285-292, http://science.energy.gov/~media/fes/pdf/workshop-reports/Res_needs_mag_fusion_report_june_2009.pdf (November 5, 2021)
2. Minervini, J.V., Schultz, J.H., 2003, U.S. Fusion Program Requirements for Superconducting Magnet Research, *IEEE Transactions on Applied Superconductivity*, Vol. 13, Issue 2, p. 1524-1529, http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1211890 (November 5, 2021)
3. Bromberg, L., Tekula, M., El-Guebaly, L.A., et al, 2001, Options for the Use of High Temperature Superconductor in Tokamak Fusion Reactor Designs, *Fusion Engineering and Design*, Vol. 54, Issue 2, p. 167-180, <https://www.sciencedirect.com/science/article/pii/S0920379600004324> (November 5, 2021)
4. Ekin, J.W., 2006, Appendix Data Tables, *Experimental Techniques for Low-Temperature Measurements: Cryostat Design, Material Properties, and Superconductor Critical-Current Testing*, Oxford University Press, Boulder, CO, p. 212, ISBN13: 978-0-19-857054-7, http://researchmeasurements.com/figures/ExpTechLTMeas_Apdx_English.pdf (November 5, 2021)

26. HIGH ENERGY DENSITY LABORATORY 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

High-energy-density laboratory plasma (HEDLP) physics is the study of ionized matter at extremely high density and temperature, specifically when matter is heated and compressed to a point that the stored energy in the matter reaches approximately 100 billion Joules per cubic meter (the energy density of a hydrogen molecule). This corresponds to a pressure of approximately 1 million atmospheres or 1 Mbar. These extreme conditions are achieved in the laboratory using high power lasers and pulsed power drivers.

A National Academies of Sciences, Engineering, and Medicine 2017 report “Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light” was commissioned to assess the opportunities and to recommend a path forward for U.S. investments in the field of high-intensity lasers. In response to NASEM recommendations, the Fusion Energy Sciences program established LaserNetUS to:

- Advance the frontiers of laser-science research.
- Provide students and scientists with broad access to unique facilities and enabling technologies.
- Foster collaboration among researchers and networks from around the world

a. High Repetition Rates HED Diagnostics

Advances in HEDLP require access to state-of-the-art diagnostics that have the ability to implement Machine Learning (ML) and Artificial Intelligence (AI). This usually requires acquiring large data sets. Applications are sought for the design, development, and implementation of high repetition rate diagnostics (at 10 Hz or higher). The diagnostics of interest include detection of particle and radiation from laser-plasma interactions, HED X-ray and optical probes, HED plasma imaging, and tomography. Applicants are encouraged to carry out the implementation and qualification of the instrument at one of LaserNetUS facilities or its member affiliate.

For more information on the private sector opportunities at LaserNetUS please visit:

<https://www.lasernetus.org/>

Questions – Contact: Kramer Akli, Kramer.akli@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas of diagnostics that address the recommendations in the 2017 National Academy of Sciences report “Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light.”

Questions – Contact: Kramer Akli, Kramer.akli@science.doe.gov

References:

1. LaserNetUS, <https://lasernetus.org/> (November 5, 2021)
2. National Academies of Sciences, Engineering, and Medicine, 2018, *Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light Report*, The National Academies Press, Washington, DC, p. 346, ISBN: 978-0-309-46769-8, <https://www.nap.edu/catalog/24939/opportunities-in-intense-ultrafast-lasers-reaching-for-the-brightest-light> (November 5, 2021)

27. LOW TEMPERATURE PLASMAS AND MICROELECTRONICS

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

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 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 following subtopics:

a. LTP Science and Engineering for Microelectronics and Nanotechnology

This subtopic is focused on improving our current understanding and scientific knowledge in the area of plasma-surface interactions and plasma assisted material synthesis related to advanced microelectronics and

nanotechnology. Current challenges include: controlling the interaction of LTP with a single layer of atoms to manufacture integrated circuits, continued miniaturization of integrated circuits, LTP processing of material surfaces and thin films to enable industrial scale fabrication of advanced microelectronics, synthesis of new materials, nanomaterials, nanotubes, and complex materials, etc. Note: In subsequent years, this topic will be rotated with LTP Science and Technology for Biomedicine

Questions – Contact: Nirmol Podder, Nirmol.Podder@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other emerging areas of plasma applications, including renewal energy applications and efficient production of hydrogen, CO₂ engineering related to economically and permanently removing CO₂ from the environment, plasma assisted breakdown of CO₂, carbon capture and storage technologies, etc.

Questions – Contact: Nirmol Podder, Nirmol.Podder@science.doe.gov

References:

1. Basic Research Needs Workshop for Microelectronics, U.S. Department of Energy, October 23-24, 2018, https://science.osti.gov/-/media/bes/pdf/reports/2018/Microelectronics_Brochure.pdf?la=en&hash=5FEFD0131FA3DA1CC8C3196452D1AFB5558DE720 (November 5, 2021)
2. Plasma: At the Frontier of Scientific Discovery, 2016, Report on the Panell on Frontiers of Plasma Science, U.S. Department of Energy Office of Fusion Energy Science, ch. 5, pp. 85-96, https://science.osti.gov/-/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf?la=en&hash=85B22EBF1CF773FFC969622524D603D755881999 (November 5, 2021)
3. National Academies of Sciences, Engineering, and Medicine, 2021, Plasma Science: Enabling Technology, Sustainability, Security, and Exploration. Washington, DC: The National Academies Press, <https://doi.org/10.17226/25802> (November 5, 2021)
4. 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 (November 5, 2021)

28. TECHNOLOGY FOR FUSION PLASMA SCIENCES

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

Advancing our understanding of how plasmas perform, requires the development of new technologies. These technologies include actuators for plasma profile and stability control, as well as the development of new diagnostics that are more cost effective, more robust, and more accurate than existing diagnostics; as well as new world leading diagnostics.

a. Actuators for Plasma Profile and Stability Control

Steady-state magnetic confinement devices require plasma heating and current drive actuators to generate and sustain stable plasma profiles. This topic aims to develop commercial technologies capable of generating and transmitting the necessary power efficiently. Included are gyrotrons, transmission systems, compact antennas, radio frequency current drive methods, and other candidate technologies that can support steady-state operation of fusion device concepts. Proposed systems must satisfy the following requirements: 1)

localized electron heating and current drive; 2) high efficiency (>65%) at high toroidal magnetic field (> 3T); 3) capable of functioning across a range of magnetic fields (e.g., multi-frequency gyrotrons); 4) >1MW/unit; and 5) compatible with long pulse operation. A high priority is to establish U.S. vendors of these essential technologies especially in the area of long-pulse, megawatt-class gyrotrons for tokamaks and stellarator applications.

Questions – Contact: Matthew Lanctot, matthew.lanctot@science.doe.gov

b. Fiber Optic Bolometer Diagnostic

This subtopic is aimed at applications for fiber optic bolometer diagnostics that are more cost effective and higher performing than current resistive bolometers. The proposer should have contacted a major US facility and done an initial test of the technology on a US fusion facility.

Questions – Contact: Curt Bolton, curt.bolton@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: Curt Bolton, curt.bolton@science.doe.gov

References:

1. Fusion Energy Sciences Workshop, 2015, *Basic Research Needs Workshop on Transients in Tokamak Plasmas*, U.S Department of Energy, June 8-11, 2015 https://science.osti.gov/-/media/fes/pdf/program-news/Transients_Report.pdf (November 8, 2021)

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 three kilometer long Stanford Linear Accelerator capable of generating high energy, high intensity electron and positron beams. The first two kilometers of the linear accelerator are used for the Facility for Advanced Accelerator Experimental Tests (FACET), now undergoing an upgrade called 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. A 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 High Energy Physics community. 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](#).

29. 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

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: Ken Marken, ken.marken@science.doe.gov

b. Structure Wakefield Acceleration (SWFA)

Structure Wakefield Acceleration (SWFA) provides a viable path towards a future HEP linear collider as described in the 2016 SWFA Roadmap [4].

Applications are sought for development of GW-scale rf power generation and GV/m-scale gradient in the short pulse (~10ns), high-frequency (10 GHz – 0.3 THz) regime. Suggested topics include but are not limited to: (1) novel structures or acceleration mechanisms which can potentially sustain GV/m level of beam acceleration; (2) novel structures or acceleration mechanisms which can potentially extract GW level of rf power from multi-GW electron beam power with efficient beam breakup control; (3) fabrication techniques for novel high-gradient, high-frequency structures. Structures considered appropriate for this topic include,

but are not limited to, metallic or dielectric, novel geometry (metamaterial, photonic bandgap, etc.), room temperature or cryogenic.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

c. High Fidelity Modeling of Advanced Accelerator Structures

Advances in materials processing and manufacturing have enabled the design and testing of novel classes of structures (dielectric, metamaterial, photonic bandgap, etc.), featuring improved efficiency, phase-space control, and higher order mode characteristics. The unique geometry and material properties of such systems introduce new challenges for accurately modeling beam and laser-structure interactions. Applications are sought for software tools capable of modeling novel SWFA structures with high fidelity. The successful application will couple these developments with the specific needs for a structure-based or hybrid accelerator concept. Cross-cutting software designs capable of integrating these tools with additional beam transport, multi-physics, or diagnostic capabilities are especially interesting.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

d. Data Infrastructure for the Next Generation of Adaptive Real-Time Controls for Large-Scale Facilities

The next generation of on-line controls and real time feedback systems will heavily rely on AI-based algorithms to speed up optimization and stabilization of complex nonlinear systems, and predict the behavior of unknown systems. Enabling high speed, on-line acquisition and storage of correlated, “ML-ready” data for optimization, model training, and real-time feedback is important for accelerators, large scientific experiments, and broadly in industry. In order to continuously re-train ML models on dynamic systems and adaptively tune the controlled environment to maintain the target performance, time-correlated data needs to be acquired, stored and manipulated at high speeds. In the framework of particle accelerators, the present conventional instrumentation, computing architectures and control systems are not designed to support collection of “ML-ready” data from thousands of instruments in km-scale accelerators. In order to be able to experience the full potential of ML-driven revolution, the entire data flow cycle including infrastructure, data taking, handling, storage and access, needs to be revisited.

Applications are sought for the development of a system that integrates distributed timing and high speed instruments into a SCADA (Supervisory Control And Data Acquisition) system that supports heterogeneous data (vectors, images and tabular, etc....). Data should be synchronized throughout the facility, collected and made available to AI programs for analysis, with the goal of optimization of accelerator operations and on-line feedback. The system should be compatible with common control software environments used in large-scale experimental facilities such as EPICS or similar software.

Questions – Contact: Ken Marken, ken.marken@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: Ken Marken, ken.marken@science.doe.gov

References:

1. Hunt-Stone, K., Arinello, R., Doss, C., et al., 2021, Electro-optic Sampling Beam Position Monitor for Relativistic Electron Beams, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 999, 165210,

- <https://www.sciencedirect.com/science/article/abs/pii/S0168900221001947?via%3Dihub> (November 5, 2021)
2. Osterhoff, J., Sokollik, T., Nakamura, K., et al., 2010, Transport and Non-Invasive Position Detection of Electron Beams from Laser-Plasma Accelerators, *AIP Conference Proceedings* 1299, 575, <https://aip.scitation.org/doi/abs/10.1063/1.3520390> (November 5, 2021)
 3. Litos, M., Adli, E., An, W., et al., 2014, High-efficiency Acceleration of an Electron Beam in a Plasma Wakefield Accelerator, *Nature* 515, 92, <https://www.nature.com/articles/nature13882>.
 4. Advanced Accelerator Development Strategy Report: DOE Advanced Accelerator Concepts Research Roadmap Workshop, *U.S. Department of Energy Office of Science*, Feb 03, 2016, <https://www.osti.gov/biblio/1358081-advanced-accelerator-development-strategy-report-doe-advanced-accelerator-concepts-research-roadmap-workshop> (November 5, 2021)
 5. Vay, J.-L., Huebl, A., Lehe, R., et al., 2021, Modeling of Advanced Accelerator Concepts, *Journal of Instrumentation* 16 T10003 DOI: 10.1088/1748-0221/16/10/T10003, <https://iopscience.iop.org/article/10.1088/1748-0221/16/10/T10003> (November 5, 2021)
 6. Ratner, D., Sumpter, B., Alexander, F., et al., 2019, Basic Energy Sciences Roundtable on Producing and Managing Large Scientific Data with Artificial Intelligence and Machine Learning, *U.S. Department of Energy Office of Science*, <https://www.osti.gov/biblio/1630823> (November 5, 2021)
 7. John, J.S., Herwig, C., Kafkes, D., et al., 2021, Keller, Real-Time Artificial Intelligence for Accelerator Control: A Study at the Fermilab Booster, *Phys. Rev. Accel. Beams* ArXiv:2011.07371, <https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.24.104601?ft=1> (November 5, 2021)

30. 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

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 are 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. Applicants are encouraged to develop RF power sources that operate at widely used frequencies (e.g., frequencies used at the large Office of Science accelerator user facilities.).

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.

For normal conducting accelerators, microsecond-pulsed high-peak-power sources are needed that operate at L-band or higher frequencies. The peak output power of individual sources is flexible but must be compatible with delivering ~100 MW-peak/meter to compact accelerators. The source must support >0.1% duty factor operation.

For superconducting accelerators, both millisecond-pulsed and CW sources are needed that operate at frequencies in the UHF and L-band ranges. The peak output power of individual sources is flexible but must be compatible with delivering ~100 kW-average/meter to high power accelerators. If the source is not CW capable, it must support >5.0% duty factor operation.

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

c. Auxiliary Components and Instrumentation for SRF Cavities

Grant applications are sought to develop:

1. New cost-efficient and improved reliability designs of high-power and low-power components - input couplers, circulators, windows, tuners, etc., in the frequency range of 325 MHz to 1.3 GHz.
2. New and improved methods for cavity diagnostics in a cryomodule that would aid in preserving the high performance achieved by SRF cavities during vertical tests throughout the SRF cryomodule assembly, commissioning and operation, including in situ quality factor measurements, inexpensive sensors for residual magnetic field measurements at cryogenic temperatures, novel sensors for helium pressure, flow, and level based on fiber optics or other technologies, vibration sensors operating in a cryogenic environment, distributed radiation and dark current/field emission sensors using fiber optics at cryogenic temperatures.
3. New cavity tuner concepts for Lorentz force detuning and microphonics mitigation (for example, ferroelectric, electromagnetic, etc.).
4. Algorithms and electronics for resonance control of the narrow-band SRF cavities to counteract Lorentz-force detuning and microphonic noise in pulsed and CW operation regimes.

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:

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31. 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

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 ultrafast lasers capable of high average power (kilowatt-class) operating at the high electrical-to-optical efficiency (>20%) needed for advanced accelerator applications.

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	$< 5^\circ$	N/A	$< 5^\circ$	N/A
Wavelength Tunability Range	0.1%	0.1%	10%	0.1%

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

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 motivates 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).

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

b. Additive Manufacturing of Laser Materials for High-Average-Power Ultrashort Pulse lasers

To achieve high average power and high peak power will require new gain materials with superior damage threshold, dopant density, optical bandwidth, and thermal properties. Sintered laser gain materials for ultrafast lasers offer promise of achieving many of these characteristics. Candidate materials must achieve broad bandwidth ($> 10\%$), high peak power (> 10 TW), and endure sustained high average power ($> \text{kW}$) operation.

Applications to develop additive manufacturing (AM) methods suitable for fabrication of bulk laser gain materials that incorporate advance features such as gain-tailoring and composite (multicomponent) materials that are sought. Such multicomponent composite materials, including ceramics, can provide three-dimensional tailoring of the refractive index, doping concentration and thermal properties to enable more advanced laser designs.

Applications must aim to develop manufacturing techniques capable of producing very high-quality laser gain media with large apertures (e.g., greater than 4 cm diameter). Applications to develop techniques capable of producing precisely controlled spatial gain profiles are strongly encouraged.

The successful application will include optical characterization of finished ceramic samples to demonstrate the optical qualities of the sample, including measurements of spectral absorption, transparency (scattering), and accuracy of the doping profile. A demonstration of lasing of the sample ceramic material or composite optic over a small aperture is considered definitive and is highly preferred. Sesquioxide ceramics are preferred, but other materials (e.g., polycrystalline sapphire) will be considered.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

c. Aperture-Scalable High Performance Diffraction Gratings

Diffraction gratings are employed in high energy laser systems in several ways, including pump wavelength stabilization, spectral beam combining, pulse compression, and near-field spatial filtering. These components are of critical importance in enabling high average power petawatt-class laser systems. Large-apertures are needed (greater than 10 cm x 10 cm) while maintaining excellent uniformity (<quarter wave of distortion over the active aperture), good bandwidth performance (>5% minimum, with >10% preferred), high diffraction efficiency (>95% at 1 micron or >90% at 10 microns), and high optical damage threshold (>0.5 J/cm² at 1 ps or >10 J/cm² at 1 ns).

Applications are sought that include work to develop new grating substrate technologies (e.g., ceramics with or without embedded cooling), advance ceramic substrate polishing techniques, and improve optical and thermal performance through developments in advanced modeling. Of particular interest are technologies which enable such improvements while reducing the cost of such components.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

d. Large Format Faraday Isolators for High Power Ultrafast Laser Systems

The development of kilowatt-class ultrafast laser systems will necessitate the development of large-aperture low-loss Faraday isolators capable of handling high repetition rate use with high peak power ultrafast laser systems. Optical components must operate reliably with a continuous pulse train of Joule-class, sub-picosecond length laser pulses at Tm wavelengths. Optical components must preserve very high beam quality (M-squared<1.2) and operation must be thermomechanically stable (i.e. minimal beam steering, minimal thermal lensing, and minimal degradation of the basic function of the device) over the entire average power range from 0 to 100%.

Applications are sought to develop a large-aperture low-loss Faraday isolator capable of handling 1 kW of continuous input power centered at Tm wavelengths, with a pulse format of 1 kHz, 1 Joule, 100 fsec pulses. Transmission must exceed 95% and isolation must exceed 30 dB across the entire 5% bandwidth. A credible technical path to extend the design to 100 kW average power must be outlined in the application.

Questions – Contact: Eric Colby, eric.colby@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: Eric Colby, eric.colby@science.doe.gov

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32. 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

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 Superconducting Wire and Cable Technologies for Magnets

Grant applications are sought to develop improved superconducting wire for magnets that operate at 16 Tesla (T) and higher. Applications should address production scale (> 3 km continuous lengths) wire technologies at 16 to 25 T and demonstration scale (>1 km lengths) wire technologies at 25 to 50 T. Current densities should be at least 400 amperes per square millimeter of strand cross-section (often called the engineering current density) at the target field of operation 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. Vacuum requirements in accelerators and storage rings favor operating temperatures below 20 K, so high-temperature superconducting wire technologies will be evaluated only in this temperature range. Of specific interest are the HTS materials Bi₂Sr₂CaCu₂O₈ (Bi-2212) and (RE) Ba₂Cu₃O₇ (ReBCO) that are engineered for high field magnet applications. Also of interest are innovative processing methods and/or starting materials that significantly improve performance and lower the cost of Nb₃Sn magnet conductor. 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 or higher operating field;
- 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/mm², 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. Magnet Quench Detection Systems

Grant applications are sought to develop quench detection systems based on machine learning techniques and FPGA electronics. While the test bed can be low temperature superconducting (LTS) magnets the goal is to have such systems suitable for high temperature superconducting (HTS) magnets. A potential system should be able to utilize multiple input sources, be at least 99% efficient without using coil voltages (resistance growth) and give less than 0.1% false triggers. If used in LTS it should be at least two times faster than standard quench detection based on differential voltage signals alone. In HTS it should allow detection of quenches in time to protect the conductor while operating at design conditions and parameters.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

c. 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

d. Non-Invasive Imaging of Interfacial Bonding and Mechanical Failure Modes in High-Field Magnets

Magnet training and performance limitations in superconducting magnets can often be attributed to thermal disturbances associated with the magnetic forces during energization. Leading sources of the thermal disturbances are interface debonding, slipping, and cracking of impregnation materials.

Applications for novel non-invasive diagnostic systems are sought that can be used to identify interfacial debonding and/or cracks in magnet coils. The diagnostics must be capable of probing to depths of many mm (preferably 2-4cm), and be sufficiently portable to probe different areas on coils of lengths >1m. Techniques may include x-ray and ultrasound, preferably compatible with use at cryogenic temperatures allowing for in-situ operation during magnet powering tests

Questions – Contact: Ken Marken, ken.marken@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: Ken Marken, ken.marken@science.doe.gov

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33. 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

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 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 high energy physics 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 encouraged where appropriate. 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 CMOS Sensors and Engineered Substrates for Detectors at High Energy Colliders

Silicon detectors for high energy 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 also for new applications such as high granularity calorimetry, lower manufacturing cost is needed.

For use in high energy physics, detectors 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 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.

Also of interest are low to moderate gain ($\times 10$ -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.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

b. High-Density Chip Interconnect Technology

With the large channel counts and fine granularity of high energy physics detectors, there is an ever-increasing need for new technologies for higher-density interconnects. Grant 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 $\sim 2 \times 2$ cm²) 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-silicon vias or other methods. Present commercial chip packaging and mounting technologies can, at cryogenic temperatures, put mechanical stress on the silicon die which distort 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. Radiation-Hard High-Bandwidth Data Transmission for Detectors at High Energy Colliders

Detector data volumes at future colliders will be nearly 100 times more than today. Single subdetectors will have to transmit 10s to 100s of Tbps. While commercial off the shelf data transmission solutions will deliver the needed performance in the near future, these products cannot be used in future colliders for two main reasons: they will not function in a high radiation environment (hundreds of Mrad), and they are in general too massive to be placed inside detectors, where added mass degrades the measurements being made. Two main industrial developments are therefore of interest: very low mass, high bandwidth electrical cables, and radiation hard optical transceivers.

Electrical cables may be twisted pair, twinax, etc., with as low as possible mass (and therefore small size) while compatible with multi-Gbps per lane transmission over distances up to 10m. Cable fabrication using aluminum, copper clad aluminum, or non-metallic conductors (such as CNT thread), is of interest. Many dielectrics are not radiation hard, so fabrication with non-standard dielectrics is important.

Optical transceivers up to 100 Gbps will be needed. Many off the shelf commercial products meet or exceed the required bandwidth, but contain circuits that fail when exposed to ionizing radiation doses of hundreds of Mrad. Radiation hardened versions of commercial transceivers (or equivalent) are therefore of interest, where

radiation hardness is achieved without adding mass or increasing size, for example by design changes to the integrated circuits used, specifically radiation hard device modeling and library development of deep sub-micron CMOS fabrication processes.

Wireless transmission of data and control signals may provide unique opportunities for future HEP experiments by removing partially or completely all the cables and connectors in the detectors. In order to be applicable for the silicon tracking detectors of future collider experiments, the critical step is to develop high-performance wireless transmitters and receivers for wave bands suitable for high data rates (10 Gbps or higher per link) over a short distance (~ 1 m), and to demonstrate the scalability to many links ($> 10,000$). Such a large wireless data transmission system may need operate in a strong magnetic field (> 2 T); the radiation created by the beam (100s Mrad); the RF noise/interference created by neighbor cells; the signal crosstalk and multi-path propagation on metallic parts of the detector; and variations of temperature and humidity.

Applications that do not address the required level of radiation hardness will be considered non-responsive.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

d. 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 controls 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 $\sim 500,000$ superconducting detector elements, to axion dark matter searches with similar channel counts to reach to high axion masses, to large-scale phonon-based WIMP 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 better), high-sampling rate (200 kHz or better) 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

e. High-Channel Count Electronic Tools for Picosecond Timing

High precision timing measurements in next generation detectors will require the development of circuitry to measure time to 1 ps or better over channel counts that may exceed 100,000. In addition, a method to distribute a stable reference clock with jitter of 5 ps or less and precise frequency stabilization is needed. Such a clock system needs to distribute the clock to multiple detector components distributed by distances of order ten to twenty meters. Custom radiation-hard ASIC devices will eventually be needed for many such high precision uses, but non-radiation hard demonstration systems meeting ps sensitivity and stability are of immediate interest.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

f. 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

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34. 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

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 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 high energy physics 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 encouraged where appropriate. 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

Detectors for particle physics need to cover large areas with highly sensitive photodetectors. Experiments require combinations of the following properties: 1) Wavelength sensitivity in the range 100 to 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) Compatible 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-pixelated, 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 the wide-band gap 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

High Energy Physics utilizes scintillating materials for large calorimeters in colliding beam and intensity frontier experiments as well as 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 ($>100 \text{ cm}^3$), bright ($>10,000 \text{ ph/MeV}$), fast (tens of ns), radiation-hard (tens to hundreds of Mrad) crystals or ceramics with high density ($>6 \text{ g/cm}^3$) are of interest for intensity frontier experiments as well as colliding beam experiments if high-volume (multi- m^3), cost-effective (few $\$/\text{cm}^3$) production methods can be developed.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

c. High-Strength, High-Radiopurity Materials

Sensitivity of High Energy Physics (HEP) detectors searching for dark matter is ultimately limited by material intrinsic radioactive backgrounds [18, 19, 20, 21]. As next generation direct-detection dark matter experiments will aim at unprecedented sensitivities, material radiopurity requirements will become ever more stringent. There is a need for a variety of extremely radiopure materials.

The most concerning material-intrinsic radioactive backgrounds are from natural contaminations of primordial radionuclides K-40, Th-232, U-238, and the progeny in their decay chains [22]. Typical contaminations in off-the-shelf materials are at parts per billion (ppb) to parts per million (ppm) levels. Ultra-pure materials with contaminations of K-nat, Th-232, U-238, and their progeny below one part per trillion (ppt) for most

components, and part per quadrillion (ppq) for critical components (i.e., components near the active portion of the detector) are required in order to attain dark matter detector target sensitivities.

In addition to extremely high levels of radiopurity, some materials to be used for HEP detectors need to possess superior mechanical properties (e.g., high tensile strength). As an example, copper is a frequently utilized material in the field due to the ability to be made with extremely high radiopurity (e.g., <100 ppq for U and Th) [23, 24]. There is an ever-growing need for a wide range of other materials of such high radiopurity, not just in HEP but also in other fields (e.g., semiconductor, biomedical, space, computing).

Businesses possessing R&D or small-run production capacity, access to dedicated infrastructures and instrumentation (e.g., chemical processing laboratories, cleanrooms, gloveboxes, and high temperature furnaces), and businesses with the ability to control raw material sourcing and adjust production processes to mitigate or eliminate possible sources of contamination have the potential to develop one-of-a-kind materials of superior radiopurity and mechanical performance that serve the needs of the low-background research community. Applications are sought to develop methods and processes to produce:

- Structural materials, specifically metals and metal alloys, with high radiopurity (K, Th, and U content below 1 ppt) and strength higher than the current state of the art (electroformed copper, above 100 MPa). Structural materials are often required in quantities ranging from 1 kg to 1000 kg and above.
- High radiopurity filler metals (i.e., for welding, soldering, or brazing methods) with K, Th, and U content below 1 ppt. Such materials are typically required in relatively small masses, of the order of 10-1000 g.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

d. Advanced Composite Materials

Ultimate-performance mechanical materials for precision support and cooling are of general interest for HEP detectors. Mechanical structures are used to hold detector elements with micron precision and stability, with as close to zero mass as possible. Of interest are: novel low-mass materials with high thermal conductivity (>20 Wm/K for 0.1 g/cc) and stiffness; adhesives with very high thermal conductivity (>5 Wm/K) and radiation tolerance (>100 Mrad); low mass composite materials with good electrical properties for shielding, data transmission or power conduction; and radiation tolerant (>100 Mrad) low loss dielectric materials. Improvements to manufacturing processes to take advantage of new or recently developed materials, and performance and stability from room temperature to cryogenic temperatures (70 K and 4 K) are of interest. Also of interest are light-weight, radiation-hard carbon fiber structures (or other metamaterials) with Negative Thermal Conductivity for more efficient cooling of collider tracking detectors and better shielding from thermal noise in Cosmic Microwave Background or Dark Matter experiments.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

e. New Cryogenic Cooling Solutions for Low-Temperature Experiments

Cryogenic detectors operating large arrays of semiconductor sensors (CCDs, skipper-CCD, CMOS) at temperatures around 140 K are being planned for dark matter searches, neutrino reactor experiments, and the monitoring of nuclear materials. An important challenge in this next generation of detectors is the cooling system for tens of thousands of sensors with cold front-end electronics with a total thermal load of ~1 kW. Additionally, the sensors need to operate with ultra-low radiation background, with significant shielding to achieve less than 1 event/kg/day/keV (DRU) of background. The current solutions are based on conductive cooling through highly polished mechanical surfaces, which is expensive and does not scale to detector arrays with many thousands of individual sensors. Applications are sought for the development of alternative techniques for large, low-background cryogenic experiments, with the goal of producing systems capable of

operating ~10,000 individual semiconductor sensors with a total active mass of ~10 kg and a heat load of ~1kW at a cost below \$1M.

A vibration-free environment is essential for various QIS and HEP experiments such as direct dark matter searches operating at temperatures below 0.1 K. Existing cooling solutions from vendors, like the “Helium-Battery” concept provide vibration-free operation but only for a limited amount of time. Applications are sought for new concepts for a “dry” dilution refrigerator (utilizing, for example, pulse tube technology) that operates continuously in a vibration-free mode ($<10^{-7}$ g/sqrt(Hz), with $g=9.81$ m/s², in the 5-20 kHz range) at temperatures around 10 milli-Kelvin.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

f. 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

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35. QUANTUM INFORMATION SCIENCE (QIS) SUPPORTING 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

Quantum science and instrumentation for next-generation computing, information, and other fields—the core of "quantum information science" (QIS)—are developing rapidly and present numerous opportunities for impacts in high energy physics. Quantum sensors and controls, analog simulation, and qubit systems that specifically rely on or exploit superposition, entanglement, and squeezing of physical states are of particular interest. This topic focuses on key technologies to support quantum information systems that build on experience in high energy physics experimental systems, and on further development of quantum information

systems for application in precision measurement, simulation, and computation that advances high energy physics research.

Grant applications are sought in the following subtopics:

a. Design and Fabrication of Microdisk Optical Resonators Supporting Very High-Q Optical Modes

A challenge in the realization of quantum transduction devices with high fidelity is the achievement of high efficiency in the conversion from the microwave to the optical regimes and vice-versa. Transduction devices operating at the quantum threshold will be the first building block toward the realization of a distributed quantum network. Low-mass experiments based on microwave cavities for dark photon and axion detection will also benefit from this new class of quantum sensors. Lithium Niobate is an electro-optic material, commonly used in optical modulators. Because of the low loss at RF and optical frequencies, high electro-optic coefficient make this material very suitable for electro-optical devices and applications in quantum transduction. The electro-optic characteristics strongly depend on design and fabrication process (e.g., crystal cut and polishing). Optical resonators with Quality factor (Q) above 10^7 made from electro-optic materials can boost the conversion efficiency and enable quantum computing applications in the presence of relatively high laser pump power on the order of milli-watts. These microdisks could eventually be developed also from other materials with electro-optic properties, e.g., Aluminum nitride (AlN).

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

b. High Efficiency Photodetectors and Homodyne Detectors

While substantial quantum squeezing and entanglement can be produced optically, high efficiency photodetection in cryogenic and other environments is necessary in order to make use of it. High detection efficiency is also vital to quantum networks of sensors. Applications are sought for high efficiency (>95%) low-noise (<100 microWatt noise equivalent power) photodetectors and balanced homodyne detectors (with common mode rejection ratio >45 dB); noise equivalent power is desired such that optical powers of ≤ 1 mW provide 10 dB of clearance above the electronics noise floor in balanced detectors as observed in noise sidebands extending to >10 MHz bandwidths.

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

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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 these three mission priorities 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 priorities, [click here](#).

36. 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

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. Materials Protection Accounting and Control for Domestic Fuel Cycles

The Materials Protection, Accounting and Control Technology (MPACT) program seeks to develop innovative technologies, analysis tools, and advanced integration methods to enable U.S. domestic nuclear materials management and safeguards for emerging nuclear fuel cycles. Specifically, MPACT develops innovative

technologies and tools which enable the integration of safeguards and security features into the design and operation of nuclear fuel cycles. Examples include processes such as advanced reactor fuel recycling via aqueous or electrochemical means, advanced reactor fuel fabrication, and other process control applications.

Grant applications are requested for:

- Inert Hot Cell Gamma Spectroscopy. Medium/high resolution (3-7%) gamma spectroscopy systems that can operate in a dry inert (e.g., Ar) hot cell. Development of such system would assist in hot cell surveys, material location & identification, and potentially material quantification for NMAC.
- Actinide Sensitive Materials Research. Identify and develop materials with actinide-selective sensitivities for advanced fuel cycle applications. These applications may include high temperatures, molten salts, liquid sodium, or liquid lead. Identifying and characterizing materials that may demonstrate actinide sensitivity under these conditions will advance U.S. NMAC capabilities for future reactors by qualitatively or quantitatively indicating actinide concentrations.
- Neutron detectors. Neutron detectors for Nuclear Material Accountancy and Control (NMAC) traditionally are ^3He , ^{10}B , or ^6Li based due to the large thermal neutron cross section and detector infrastructure that enables neutron multiplicity measurements. However, optimization of these detector designs has not occurred for high-rate applications (high neutron, high gamma, or high neutron and gamma). Recent pushes to directly measure Pu in spent fuel have focused on overall system designs, but not sub-component (detector-level) optimization. This optimization has the potential to significantly advance neutron assay with benefits to NMAC needs at the back end of the nuclear fuel cycle (Pu verification in spent fuel, storage, reprocessing, and waste).
- Acquisition electronics for neutron assay systems. Current preamplifiers for assay systems utilize mature technology, but commercially available electronics do not exploit amplifier component advances over the past decade. It should be possible to develop preamplifier electronics that have 1) zero deadtime, 2) effectively discriminate between neutron and gamma pulses, and 3) enable independent neutron and gamma counting with neutron multiplicity capabilities. Additionally, these preamplifiers should be rugged, able to operate under industrial conditions and over a wide humidity range.

Grant applications that address border security or remote monitoring are not sought.

Questions – Contact: Michael Reim, michael.reim@nuclear.energy.gov

b. 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

c. 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

d. 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 operations
- Development of a small electromagnetic pump that could be tested in a high temperature prototypic environment.

Questions – Contact: Brian K. Robinson, Brian.Robinson@nuclear.energy.gov

e. 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: Brian K. Robinson, Brian.Robinson@nuclear.energy.gov

f. 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 hygroscopic, 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: Brian K. Robinson, Brian.Robinson@nuclear.energy.gov

g. 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/>

Questions – Contact: Janelle Eddins, Janelle.Eddins@nuclear.energy.gov

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

In addition, grant applications are requested for modifying existing or developing new robotics that can withstand:

- Radiation levels in and around the nuclear reactor
- Temperature and pressure conditions present in nuclear plants

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.

Questions – Contact: Janelle Eddins, Janelle.Eddins@nuclear.energy.gov

h. Advanced Methods and Manufacturing Technologies (AMMT) Program

The AMMT program has been established to maintain U.S. leadership in the development of materials and manufacturing technologies for nuclear energy applications. This program will support nuclear reactor technology developers by providing access to materials and capabilities to produce components that improve safety, reliability, and are more cost effective to manufacture.

The AMMT program is seeking applications that can enhance the economics and flexibility of advanced manufacturing technologies for nuclear energy applications. Applications should include the development and maturation of manufacturing technologies that facilitate modular designs, construction, enhancement of the modular manufacturing technologies, or applications that facilitate a decreased necessity of field modifications.

Questions – Contact: Dirk Cairns-Gallimore, dirk.cairns-gallimore@nuclear.energy.gov

i. 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 Assisted Stress Corrosion Cracking (IASCC) is a major concern for materials degradation in light water reactors, affecting iron-based and nickel-based alloys that are employed in many applications in the reactor core. The phenomenon which appears as intergranular cracking evolves in time due to the effects of fast neutrons and the influence of ionizing radiation on the environmental chemistry. Despite extensive efforts no acceptable methods for in-situ monitoring of crack initiation and growth exist. Applications are sought focused on developing in-situ sensors and diagnostic equipment for crack initiation in testing under reactor environments of high temperature, radiation, and pressure. Of particular interest are techniques based on advanced electrochemical methods such as electrochemical impedance spectroscopy. Applications based other approaches such as optical or acoustic methods will also be accepted.

Questions – Contact: Tansel Selekler, Tansel.Selekler@nuclear.energy.gov

For more information on the NSUF program visit <https://nsuf.inl.gov/>

j. Cybersecurity Technologies for Protection of Nuclear Critical Systems

The U.S. Department of Energy 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 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.

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

k. Cost Analysis for Thermal Distribution and Storage Components

Third party cost analysis of molten salt thermal distribution components or conceptual thermal distribution component design embodiments for utilization of heat produced by a nuclear reactor is needed to inform utilities, plant owners, component developers, and system designers of expected costs when projected to various manufacturing volumes and scales. These components include thermally driven heat pumps; heat engines; thermal storage vessels and media; heat exchangers; piping; insulation; and fluids for design concepts around 1, 3, 60, 300 MWth heat offtake at 550 C with 12-, 240-, 1200-, and 3600-MWh thermal storage capacity between 450 and 550C. Rigorous bottom-up costing is required for components that are not considered commodities or have at least 3 suppliers. Bottom-up costing includes labor, energy, materials, and equipment costs for manufacturing, fabrication or construction of components and systems. The basis for these cost components requires thorough understanding and documentation of a manufacturing, fabrication, or construction method for each system component. System components are defined based on a reference conceptual design embodiment meeting specified design requirements. Discussions and quotes with several vendors or purchase documentation is necessary for components that would be purchased (commodities or parts that have at least 3 suppliers), with 3rd party information sources that refer to original current data sources.

Questions – Contact: Jason Marcinkoski, Jason.Marcinkoski@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
- large-scale energy users such as automobile manufacturing, steel, aluminum, ammonia, chlor-alkali plants

Questions – Contact: Jason Marcinkoski, Jason.Marcinkoski@nuclear.energy.gov

m. 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: Rebecca Onuschak, Rebecca.Onuschak@nuclear.energy.gov

n. 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 defined as low power (generally <20 MW thermal) reactors that are easily transported to and from an application site (such as remote locations) and are based on a range of reactor technologies. 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

o. Advanced and Small Reactor Physical Security Cost Reduction

Advanced and small nuclear reactors will not be competitive with natural gas plants 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. Advanced reactors may be able to rely more on local law enforcement. New ideas or past work that has evaluated these types of cost

reductions should be considered, 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: Alison Hahn, alison.hahn@nuclear.energy.gov

p. 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 ATF LWR fuel cladding/assembly concepts that have the potential to support achieving very-high 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.”

Grant applications may use non-fueled surrogate materials to simulate uranium, plutonium, and minor actinide bearing fuel pellets.

Questions – Contact: Frank Goldner, Frank.Goldner@nuclear.energy.gov

q. 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:

- 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. Irradiation experiments in Material Test Reactors should be considered as a valuable target for the technology demonstration and the definition of design requirements for near term deployment. The following are examples of technical areas of interest: distributed or multi-point measurement of neutron flux in-situ during operation; distributed or multi-point measurement of nuclear fuel and reactor components temperature during operation; measurement of fission gas products inside nuclear fuel pins; measurement of dimensional changes of nuclear fuel and components during irradiation experiments in Material Test Reactors.

- Advanced control systems that increase nuclear plant system reliability, availability, and resilience including the ability to detect and manage faults in 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: nuclear power plant security, homeland defense or security, or reactor building/containment enhancements; radiation health physics dosimeters (e.g., neutron or gamma detectors), and radiation/contamination monitoring devices; U. S. Nuclear Regulatory Commission probabilistic risk assessments or reactor safety experiments, testing, licensing, and site permit issues.

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>

r. 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: Daniel Nichols, daniel.nichols@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. Proposals 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

t. Thermally Driven Mechanical Heat Pumps for Thermal Storage and Industrial Applications

Low cost, highly durable thermal storage systems have the potential to enable nuclear power plants to provide flexible dispatch of electricity on the grid, while maintaining high capacity factors for the reactors and fuel. However, thermal storage capacity is limited by the temperature range of light water reactors, and the influence of heat quality or temperature on heat engine efficiency. Secondly, thermal storage may be used for industrial process or chemical process heat. While many processes can be served with lower quality heat, several of these processes require higher temperatures.

DOE is seeking to understand the potential to boost the quality or temperature of heat produced by lower temperature light water reactors. Concepts for using a 150, 300, 450, 600, 750 MWth, 250 C LWR heat source to drive an expander used to compress a working fluid to boost the heat from 250 to 500, 750 and 1000 C. Alternative solutions can consider tying into the existing turbine shaft to drive the compressor rather than using an independent expander. In the alternative case, additional heat would be available for boosted offtake in order to maintain performance of the primary turbine.

Questions – Contact: Jason Marcinkoski, Jason.Marcinkoski@nuclear.energy.gov

References: Subtopic p:

1. Advanced Fuel Campaign 2020 Accomplishments Report, 2020, *Idaho National Laboratory*, https://nuclearfuel.inl.gov/afp/2020%20Accomplishments%20Report/inc/pdf/20-50497-R4_AFC_2020_Accomplishments_WEB.pdf (November 5, 2021)

37. ADVANCED TECHNOLOGIES FOR NUCLEAR WASTE

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

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. Spent Fuel and Waste Science and Technology, 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. Spent Fuel and Waste Science and Technology, 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. Therefore, DOE is interested in developing innovative methods for interrogation of the DSC internal conditions to provide assurance that the safety functions continue to be met.

DOE invites applications on developing innovative methods for periodic measurement/inspection of internal conditions within such DSC. Note that penetrations through the canister wall, which might result in leakage of the internal inert atmosphere, are not allowed. Options for performing interrogation of the internal conditions include:

- All sensors and equipment are external to the canister.
- Small sensors located inside the canister that send signals through the canister wall to equipment located external to the canister.

Options are complicated by the various conditions the DSC encounter, geometric and material limitations, and the internal conditions in which sensors/monitors would be required to perform. These internal conditions include:

- survive under water or in very dilute boric acid, during vacuum drying (pressures down to ~1 torr), temperatures up to 400°C, helium backfill pressures varying from ~0.8 atm to 8 atm, and radiation dose up to 500 Gy/hr
- Internal sensors must be very small (preferably credit card size) and cannot interfere with the loading or retrievability of fuel assemblies, must be compatible with internal components (e.g., not result in corrosion, introduce organics, etc.) and must be self-powered or receive power externally without canister penetrations.

For external sensors and/or equipment, monitoring during storage (i.e., while the DSC is in an overpack) can be accomplished with instruments temporarily inserted into the very small annular space between the canister and the overpack via the inlet or outlet vents in the overpack.

It is envisioned that after transportation as the canister is being moved from the transportation cask to a new storage overpack, the geometric limitations for external equipment will be lessened, but dose and shielding requirements will still dictate equipment accessibility.

Research applications are sought to develop sensor and monitoring technologies, including the power supply, through-wall signal transmission, and signal interpretation, for periodic inspection of DSC internal conditions, accounting for the conditions and requirements outlined above, with a focus on:

- Detection of helium leakage
- Monitoring internal pressured
- Detection of water (either as free or water vapor)
- Monitoring gas composition
- Helium vs helium/air mixtures vs air
- Xe or Kr release (to identify if cladding failures occur)
- Hydrogen detection (to identify radiolysis or corrosion)
- Monitoring temperature profiles (mostly as a means for detecting loss of inert environment)
- Monitoring dose (mostly as a means for identifying any fuel relocation)

Questions – Contact: John Orchard, John.Orchard@doe.gov

38. MATERIAL RECOVERY AND WASTE FORM DEVELOPMENT

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

The Material Recovery and Waste Form Development program supports innovative methods to recover valuable elements from used nuclear fuel and manage the resulting wastes. The program employs a science-based approach to foster innovative and transformational technology solutions and applies unique nuclear fuel cycle chemistry expertise and technical capabilities to a broad range of civil nuclear energy applications. These chemical technologies, when combined with advanced reactors and their fuels, form the basis of advanced fuel cycles for sustainable and potentially growing nuclear power in the U.S.

a. Metal Organic Framework Manufacturing Technology

Metal organic frameworks (MOF) have been demonstrated to offer improved properties for separations media compared to traditional materials. However, their manufacture is still not widely available. To increase technology readiness of MOFs application to nuclear waste separations activities, commercial manufacturing of this class of materials is needed. This research topic is to develop continuous processes for cost

competitive fabrication of selected MOFs. Example MOF's to be processed include calcium 4,4'-sulfonyldibenzoate (CaSBD), fluorinated MOF with copper (FMOF-Cu = Cu 4,4'-hexafluoroisopropylidenebisbenzoate, H₂ 4,4'-hexafluoroisopropylidenebisbenzoate), and Copper Adamantane Tetracarboxylate (Cu₂ATC).¹⁻³ Specific scope items include:

- Develop a process for continuous processing of targeted MOF(s)
- Demonstrate continuous process of targeted MOF at an appropriate scale (to be specified and justified in application)
- Characterize resulting MOF for crystal structure and any applicable properties of interest (e.g., Xe capacity)
- Propose next steps to develop, demonstrate, and implement commercial production.

Questions – Contact: Kimberly Gray, Kimberly.Gray@nuclear.energy.gov

b. Phosphate-based Salt Waste Dechlorination and Immobilization Process Technology

Chloride matrix high-level wastes (HLW) may be generated from electrochemical separations of metallic advanced reactor fuel or chloride-based molten salt reactors. The chlorine limits the loading of HLW in typical (oxide) waste forms and will likely be cost effective to recycle (especially in the case of isotopically enriched Cl).^{4,5} The Office of Nuclear Energy has sponsored scoping experiments showing promise for the dechlorination of these streams using a phosphate precursor such as ammonium dihydrogen phosphate (ADP, NH₄H₂PO₄).^{6,7} The resulting phosphate waste can be readily converted to a durable iron-phosphate waste glass and the ammonium chloride can be recycled into fresh salt. A single integrated unit is needed to demonstrate this process and mature the technology. Proposed projects should design and test a system capable of dechlorinating salt waste, reacting the NH₄Cl with a solid getter to form a chloride recycle stream and convert the phosphate into an iron-phosphate waste glass. Successful completion of this project will include:

- the design of a scaled system (potentially multiple units) with the scale suggested and justified in the application,
- selection of materials for system fabrication (testing if needed),
- system construction,
- testing of single units and complete system, and
- characterization of products.

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c. Krypton Separations Technology

The U.S. uniquely requires capture and storage of krypton-85 from fuel cycle systems.⁸ A number of technologies have been proposed to capture Kr-85 including cryogenic distillation, fluorocarbon absorption, CO₂ absorption, selective physical absorption on solid getters.^{9,10} Each of these processes have shown some success although there are challenges with the cost of implementing these technologies in shielded radioactive environments with the associated safe systems. The Department invites grant applicants to propose advancements to these methods to reduce the cost of Kr-85 management from fuel cycle facilities including reprocessing plants and molten salt reactors. The krypton capture method must be efficiently included as part of an integrated off-gas treatment for these facilities such as those summarized previously (for example see references 5, 9, and 11). The applicant is requested to include in the application the off-gas system by which they propose to implement their technology and quantitatively how success in their technology will yield a separations process that will be lower cost than those currently available.

Questions – Contact: Kimberly Gray, Kimberly.Gray@nuclear.energy.gov

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