Version: 12/17/22

## Introduction to the Science & Technology (S&T) Risk Matrix

In December 2018, the Department of Energy Deputy Secretary signed the International Science and Technology Engagement Policy memo. The policy memo called for the creation of a Science and Technology (S&T) Risk Matrix. The purpose of the creation of the S&T Risk Matrix was to identify and protect critical emerging research and technologies that do not otherwise have control mechanisms, such as classified information, International Traffic in Arms Regulations, Export Administration Regulations, or 10 CFR Part 810 (Part 810)[1]. The S&T Risk Matrix is intended to highlight areas of emerging and potential concern associated with e.g., economic and/or international competitiveness and *not to overlap or supersede existing controls associated with national security or export controls. Further, the S&T Risk Matrix is intended to be a living document evolving based on ongoing dialogue between DOE and its Laboratories.* The S&T Risk Matrix was updated in December 2022 by the National Laboratory Chief Research Officer group in coordination with the DOE Laboratory Operations Board. In the future annual updates are anticipated.

Per relevant DOE Orders, the S&T Risk Matrix only applies to interactions with and nationals of specified Countries of Risk. At this time, countries of risk are limited to China, Russia, Iran and North Korea.

To date six areas of research have been identified as within scope of the S&T Risk Matrix:

- Quantum Information Science & Technology
- High Performance Computing
- Machine Learning/Artificial Intelligence Science & Technology
- Battery Science & Technology
- Bioscience & Biotechnology
- Accelerator Science & Technology

As part of the annual S&T Risk Matrix review process, the addition of new technology areas to the matrix will be explored.

The S&T Risk Matrix uses a Red/Yellow/Green categorization scheme to quantify the risk associated with a given topic and the resulting level of controls that are required. When evaluating the status of a particular topic within the S&T Risk Matrix, in addition to examining the Red/Yellow/Green tables below, the reviewer must also review the additional information and broader context provided in Appendix 2 of the S&T Risk Matrix. Further, in addition to reviewing relevant content with respect to the S&T Risk Matrix, users of the matrix, consistent with existing practices and processes of their home organizations, must also consult e.g., relevant classification and export control guidance, which are beyond the scope

[1] Part 810 authorization requirement applies to all persons subject to the jurisdiction of the United States who directly or indirectly engage or participate in the development or production of any special nuclear material outside the United States. Pursuant to § 810.3, *Definitions*, the term "persons" does not include DOE. As such, DOE is not required to obtain Part 810 authorizations for its own exports of nuclear technology and assistance. However, DOE must maintain program oversight (federal funding and direction) of such activities undertaken at National Laboratories to ensure consistency with U.S. national security and nonproliferation objectives. See, "*Statement of Advice to Department of Energy (DOE) and National Nuclear Security Administration (NNSA) Laboratories, Plants, and Sites Regarding 10 CFR Part 810 (Part 810) Compliance*".

of this document, in order to understand and implement the full suite of associated controls and protections required by DOE.

In addition to its function of quantifying risk and defining necessary controls and mitigation, the S&T Risk Matrix can also be used as a resource for education and awareness for Laboratory staff, providing insight into when research might move from Green to Yellow, highlighting the need for additional protections so that staff receive appropriate credit and protection for their innovations.

***RED:*** **Definition:** Red (restricted) emerging technology topics have sensitivities associated with economic and/or international competitiveness that could cause significant harm to critical national interests of the United States if shared with a country of risk without appropriate vetting and approval. These red topics are considered "restricted" for purposes of increased vetting and controls involving interaction with Countries of Risk, and their representatives, as defined in various DOE Orders. Access to restricted technologies by Country of Risk nationals or entities requires enhanced vetting and approvals by DOE at both the local/field and HQ levels.

**Additional Protections:** Restricted topic areas trigger compliance requirements with elements of other DOE orders and policies (details are provided in Appendix 1). Laboratories will develop access management plans and ensure regular oversight/monitoring of these restricted projects to ensure they remain appropriately protected throughout their lifecycle. Access management plans for restricted S&T topics shall include at a minimum:

- description of the work that has been identified as restricted
- responsible principal investigator
- physical, logical, and administrative processes that control access to the restricted S&T topics, including as defined in DOE Order 471.7, Controlled Unclassified Information (CUI). Red areas are designated as CUI Basic.
- process by which the restricted S&T will have intellectual property protection prior to release/publication of the work, and appropriate notifications about the release/publication.
- DOE O 241.1B describes the process by which science and technology information (STI) is appropriately identified, categorized, disseminated, and preserved. Requirements for STI are laid out in the Contractor Requirements Document (CRD) to inform each Laboratory's processes, and these processes must include appropriate review and approval steps for restricted S&T topic areas. For research that is determined to be a Restricted S&T topic, notification to the funding DOE Program Office should occur prior to publication.

When possible, Laboratories should use existing protective measures, processes, or programs to implement needed controls on these projects.

***YELLOW:*** **Definition**: Emerging technology topics that have the potential to become red (restricted) from an economic and/or international competitiveness standpoint or represent areas in which enhanced vigilance is appropriate.

**Additional Protections**: Yellow topic areas may require additional controls under certain circumstances. Yellow topics should be thought of as being on a 'watch list.' It is the responsibility of each Laboratory to establish processes for monitoring and controlling technologies in the yellow category. Depending on the technical area, yellow emerging technologies may be defined by a well-defined parameter space; other areas may require the judgement of technical and security SMEs to determine their degree of sensitivity. Laboratories may develop access management plans for projects in yellow technology areas (see elements described under red technology area access management plans). When possible, Laboratories should use existing protective measures or programs to implement needed controls on these projects. Yellow topics may require specific coaching/awareness training of performers and managers on how to engage with, involve and/or share information with individuals from designated countries of risk.

***GREEN:*** **Definition**: Emerging technology topics that do not have particular sensitivities associated with economic and/or international competitiveness. Fundamental scientific studies or technologies at a low technology readiness level (TRL) are often – but not always – in the green category.

**Additional Protections**: Green subjects do not require additional controls beyond those already in place and will be handled with existing mechanisms.

## Quantum Information Science & Technology

Quantum Information Science and Technology (QIST) is a highly interdisciplinary field that builds on quantum mechanics and information theory to explore the fundamental limits for computation, networking, and sensing. QIST incorporates research in a broad number of areas that include (but are not limited to) materials, computer science, mathematics, laser physics, atomic physics, cryogenics, electrical engineering, systems engineering, and application specific software development. The QIST research, development, and demonstration (RD&D) field has witnessed explosive growth in the last five years, and continues to rapidly progress. Novel quantum applications to sensing, computing and simulation, and communications could potentially disrupt many aspects of current information science and technology, although in many instances realization of these approaches is well in the future. The QIST section of the S&T risk matrix provides guidance in the four broad areas of 'Computing and Simulation,' 'Sensing, Clocks, and Metrology,' 'Communication,' and 'Materials and Fabrication.' For all topics below, information already protected by either classification or export control (or, in some cases vendor-specific non-disclosure agreements) is not reflected here, but scope should be evaluated relative to these controls on a case-by-case basis prior to release or dissemination.

### Computing and simulation

| GREEN | YELLOW |
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| Exploration of QIST foundations – fundamental questions related to the formulation of quantum mechanics and its relation to information.<br><br>New approaches to qubit technology.<br><br>Understanding of environmental influences on qubit performance.<br><br>Room-temperature electronics for high-bandwidth readout and control. | Progress toward technologies that would dramatically improve qubit fidelity to move quantum computing beyond the noisy intermediate-scale quantum (NISQ) era.<br><br>Development of preliminary high-bandwidth and/or cryogenic control and readout of quantum devices or other technologies that could scale quantum computing beyond the NISQ era.<br><br>Development of quantum random number generators. |

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| Digital and analog quantum simulation and optimization.<br><br>Quantum algorithm development for chemistry, computational physics, and machine learning.<br><br>Evaluation of algorithms for small-scale and low-fidelity applications and algorithms for chemistry, materials, particle and other physics, and machine learning.<br><br>Algorithm-specific error mitigation on NISQ devices for chemistry, computational physics, and machine learning.<br><br>Application-specific design of NISQ devices for chemistry, computational physics, and machine learning.<br><br>Quantum memories with improved coherence times.<br><br>NISQ testbeds.<br><br>Quantum simulators (classical computer simulations of quantum computer operation). | Development of quantum algorithms with potential or indirect implications for “red” category research.<br><br>Quantum error correction and logical qubit development<br><br>Roadmaps that make statements about the long-term implementations of quantum computing development.<br><br>Laboratory experiments that run portions of error correction codes on systems of physical qubits that are significantly smaller than what would be needed for fault tolerant operation.<br><br>Programmable gate-based laboratory devices with 50-100 physical qubits.<br><br>Development of large cryogenic refrigerators capable of extended operation below 4.2K and suitable for supporting "red" category quantum computing platforms. |

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| NISQ device operating software.<br><br>Basic research on error correction codes that is architecture-agnostic and with abstract qubit models.<br><br>Demonstration of qubits that achieve breakeven but cannot, without further implementation of error-correction techniques, achieve fault tolerance. | |

| **Sensing, Clocks, and Metrology** |
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| GREEN | YELLOW |
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| General quantum sensing for basic research applications.<br><br>General research into atomic clocks and networked atomic clocks.<br><br>Use of quantum techniques for enhanced microscopy in a laboratory setting. | Development of entangled photonics capabilities useful for long range imaging.<br><br>Development of quantum navigations systems capable of 100 m positional uncertainty.<br><br>Development of quantum clocks with accuracy surpassing ps/day. |

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| | Development of fieldable system components that can enable quantum sensors. |

| **Communication** |
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| GREEN | YELLOW |
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| Development of fundamental building blocks of quantum networks including single and entangled photon sources, single photon detectors, quantum memory, squeezed light sources, and protocols<br><br>Development of error mitigation strategies<br><br>Integration of multiple quantum networking devices<br><br>Fundamental quantum repeater research<br><br>Development and proof-of-principle demonstration of use cases for quantum networks for basic science and sensing applications. | Robust and efficient entanglement distribution at practical data rates.<br><br>Development of quantum cybersecurity technology other than quantum key distribution<br><br>Experimental fault-tolerant quantum communications via quantum error-corrected quantum repeaters |

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| Proof-of-principle demonstration of entanglement distribution, including multi-partite entanglement and entanglement across multiple nodes. | |

| **Materials and Fabrication** |
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| GREEN | YELLOW |
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| Investigation of quantum materials and qubit materials candidates at milli-Kelvin temperatures. | Techniques to dramatically improve qubit fabrication yield without process control (still at the small laboratory level). |
| Investigation of the broad scope of materials for quantum devices such as 2-d topological materials or graphene nanoribbons. | Development of isotope enrichment technologies for materials relevant to QIST. |
| Development of rapid experimental capability to create and characterize quantum materials to determine detailed properties of these materials and their efficacy for use in quantum devices and interfaces. | |

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| Development of materials modeling techniques to predict quantum device performance at relevant resolution.<br><br>Synthesis, characterization, and theory of topological quantum materials including the demonstration and manipulation of Majorana modes.<br><br>Research quantities of enriched stable isotopes that could be used in quantum computing devices.<br><br>Work on individual process control ingredients (e.g., better atomic traps, better lithography control, better morphology).<br><br>Techniques to rapidly characterize quantum-information devices for improvements to materials science or new materials that will move quantum platforms beyond the NISQ era. | |

## High Performance Computing

High Performance Computing (HPC) is a critical technology used for both predictive simulation and large-scale data analysis, essential to national security, scientific discovery, and economic competitiveness. Within the US, the Department of Energy (DOE) and the national laboratory complex have a leadership role in HPC, fielding some of the most powerful computing platforms in the world and providing expertise in computational modeling, data analytics, algorithms, and software. The labs also partner closely with the computing industry, academia, and other government entities to rapidly adopt new commercial innovations at scale and to drive the development of advanced HPC technologies, systems and expertise. DOE labs also partner with other industries and government entities to accelerate the application of HPC to engineering design, drug discovery, infrastructure security, energy security, manufacturing, and a wide array of other applications. HPC is critical to ensuring the safety and security of the nuclear weapons stockpile and to the basic science and applied energy missions of DOE. The HPC section of the S&T risk matrix provides guidance in the areas of system R&D; hardware components and systems; and software, including system software, applications, and libraries. Importantly, when HPC capabilities are used to contribute to another area of S&T, guidance from those areas, not the HPC section, is applicable in determining what topics, if any, are restricted. For all topics below, information already protected by either classification or export control (or, in some cases vendor-specific non-disclosure agreements, which are particularly prevalent in HPC) is not reflected here, but scope should be evaluated relative to these controls on a case-by-case basis prior to release or dissemination.

More specifically, DOE has historically engaged in development/procurement activities with vendors in realization of next-generation systems that are proprietary. Though individual hardware and software components under development by HPC vendors are typically explicitly protected by nondisclosure agreements (NDA), care should be exercised to identify information that could be discerned from publicly-available sources about the details of these components before their release. This could include production software components that are being specifically tailored to run on NDA-protected hardware platforms that might contain Application Programming Interface (API) usage specific to that new hardware, or even explicit workarounds for testing purposes (e.g., “hard-coded” enumerations of new hardware components in a “testing" routine). This could also include performance predictions for software to be run on the new components that appeal to simple scaling arguments, but implicitly include scalings that specify particular architectural features.

### HPC System R&D

| GREEN | YELLOW |
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| General R&D not associated with realization of specific systems, e.g.: | None currently identified that is not otherwise protected |

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| - System management R&D for resilience, energy efficiency.<br><br>- Integration of runtime software with out of band system health and monitoring, and performance counter networks. | |

| **Vendor-Developed Hardware Components (processors, memory/storage, and interconnects) with Lab Co-Design** |
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| GREEN | YELLOW |
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| Note: *Includes all post-release information not covered by NDA*<br><br>Component design details that are publicly available.<br><br>Processor architecture (Instruction Set Architecture, or ISA) and performance characteristics.<br><br>Memory/storage technology interface and performance.<br><br>Interconnect performance characteristics and user level programming interface.<br><br>Lab suggestions for co-design improvements to vendor hardware component designs that are not adopted and are generally applicable. | Lab suggestions for co-design improvements to vendor hardware component designs – prior to adoption/integration into product design. |

*Note: Any performance data or performance analysis for pre-release systems should be covered by NDAs and such information should be embargoed until general availability of the technology.*

| **Lab R&D on HPC Components and Systems** |
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| Conceptual design of HPC, sensors or instruments. This includes any ancillary performance projections, models, or any other analysis of an incomplete or conceptual design.<br><br>Laboratory technical advances that have resulted in awarded patents. | Detailed design (or documentation/blueprint thereof) that includes all design elements and descriptions such that a reader could recreate or manufacture, but has not yet been manufactured, prototyped, or otherwise demonstrated. (See Note)<br><br>Lab designs that warrant filing of technical advances because they are potentially valuable for DOE and US Government use, but have not progressed to patent filing stage. |

| **HPC System Software** |
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| GREEN | YELLOW |
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| General purpose system software (source and executables) developed by a Lab.<br><br>General purpose open-source software (source and executables) used or modified by a Lab. | None currently identified that is not otherwise protected |

| **HPC Application Libraries and Frameworks** |
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| GREEN | YELLOW |
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| Open source libraries and frameworks. | Domain-specific modules of these libraries/frameworks that are designed specifically to benefit applications that may include, but are not limited to, applications that are already covered by export control, classification guidance, intellectual property processes, other sections of the S&T risk matrix or other controls. |

## Machine Learning/Artificial Intelligence Science & Technology

Machine Learning (ML) and Artificial Intelligence (AI) S&T are pervasive in DOE research, touching essentially all of the Department of Energy's programs. Data science research is often intertwined with AI/ML in their respective uses. ML/AI is also an active area of research in industry and academia. The ML/AI section of the S&T risk matrix provides guidance in the areas of foundational algorithm development as well as their application to control systems, societal applications, national security, and energy research. When ML/AI capabilities are used to contribute to another area of S&T, guidance from those areas is also applicable in determining what topics, if any, are restricted. An important rule of thumb is that if the underlying data are restricted, then ML/AI research that utilizes these data as training sets is also restricted. For all topics below, information already protected by either classification or export control (or, in some cases vendor-specific non-disclosure agreements) is not reflected here, but scope should be evaluated relative to these controls on a case-by-case basis prior to release or dissemination.

### Foundational Algorithms and Basic Research

| GREEN | YELLOW |
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| Basic research in machine learning methods and algorithms.<br><br>Methods for combining simulations and machine learning. | If the data on which the algorithms are trained is yellow, (as determined by the matrix section relevant to the data) then the output is yellow. |

### Controls

| GREEN | YELLOW |
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| Basic research on AI and ML for controls | Computing and data network controls that employ multi-segmented layers of security encompassing network isolation and monitoring of critical infrastructure. |

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| | Utilizing best-in-class solutions with both administrative and technical security measures that apply NIST/FISMA controls.<br><br>Security systems that are subject to annual review and testing by applicable governing and industry agencies. |

| **Societal Applications** |
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| GREEN | YELLOW |
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| Specific ML/AI techniques to improve data privacy<br><br>Health applications:<br>• Drug design<br>• Disease detection and classification<br>• Interventions/ Therapeutics/ Personalized Medicine<br>• Basic research in data privacy | Applications involving biometrics or facial recognition |

| **National Security** |
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| GREEN | YELLOW |
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| Research on securing edge models and algorithms | Cyber Security:<br><br>Techniques that use AI/ML/data to emulate legitimate activity in order to obfuscate an attack.<br><br>Counter-artificial intelligence:<br><br>• Methods for detecting adversarial inputs to classifiers<br>• Reverse engineering methods for inferring properties of training data from ML models<br>• Techniques for protecting or exploiting models<br>Techniques for training data poisoning or manipulating ML decision boundaries<br><br>Document Classification support<br><br>Otherwise yellow other than what is identified in red. Examples include techniques to create content as well as review content. |

| **Energy** |
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| GREEN | YELLOW |
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| Basic Research related to | None currently identified that is not otherwise protected |

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| • Autonomous Energy Systems<br><br>• Molecular Design<br>• Algorithm development for Energy Forecasting<br><br>• Subsurface Systems Behavior<br><br>• Automated Feature Identification & Development of high resolution data, and associated methodologies | |

**Battery Science & Technology**

Batteries are a critical technology for the United States due to their potential to disrupt the vehicle market by replacing gasoline cars with electric cars, and to ensure a resilient grid that can adapt to the changing generation mix. In addition, batteries remain a key bottleneck for various military applications including powering forward operating bases, soldiers, sensors, and weapons. Finally, in the future, batteries are expected to become critical for enabling other modes of transportation such as hybrid electric aircraft, marine vessels, and electric trucks. The battery section of the S&T risk matrix provides guidance in the areas of cathodes, anodes, lithium, solid-state electrolytes, charging rates, energy storage, recycling, thermal runaway, lifetime, and technoeconomics. For all topics below, information already protected by either classification or export control (or, in some cases vendor-specific non-disclosure agreements) is not reflected here, but scope should be evaluated relative to these controls on a case-by-case basis prior to release or dissemination.

Several foundational principles span all topics with the battery section of the S&T risk matrix. Patenting, publication and presentation are critical to the success of the US battery industry and a proper review process and IP protection will enable red projects to successfully contribute to the US economy. Areas are defined based on project goals and plans and not on achieving/demonstrating a fixed target or performance. Review of projects should occur at least on an annual basis based on proposed work and modifications to project documents like AOPs and prior to start for new projects.

Similarly, some cross-cutting topics are always green:

-Characterization methods, diagnostic and analysis tools, including research and development applications of such tools.
-Computational and modeling tools, directly related to fundamental research and understanding.

- Computational/high throughput discovery of new materials.
- Foundational research related to the structures and properties of materials or components potentially used in battery systems
- Research on fundamental reactions, mechanisms and kinetics of battery constituents/materials.

| **Battery S&T (cathodes)** |
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| Characterization and understanding of degradation and failure mechanism for commercial cathode materials. | Modification of and characterization of commercial cathode materials that i) may enable capacities above 200mAh/g, ii) can operate between 2.0 and 4.5V vs lithium. |

| **Battery S&T (anodes)** |
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| Characterization and understanding of degradation and failure mechanism for commercial anode materials. | Modification of and characterization of commercial anode materials that may enable capacities capacity of greater than 1000 $mAh/cm^3$. |

| **Battery S&T (lithium)** |
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| Studies focused on the understanding of failure mechanisms related to Li metal negative electrodes, for examples, fundamental understanding of striping plating mechanisms and electrolyte stability. | Research into methods that mitigate detrimental aspects of lithium metal stripping and plating and stable solid electrolyte interface stabilization. |

| **Battery S&T (solid state electrolytes)** |
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| Studies focused on the investigation of chemical, physical or mechanical properties of known solid state electrolytes | Studies focused on the development of interface modification and stabilization of solid state electrolytes. |

| **Battery S&T (charging rates)** |
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| Studies which look at the impacts of fast charging on cell | Approaches to accelerated charging of lithium-ion cells which can be easily transferred |

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| performance and degradation rates | across cell designs that enable acceptance of more than 2.5 mAh/cm2 in 10 min or less. |

| **Battery S&T (energy storage)** |
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| Pre-conceptual research into energy storage systems and approaches | Technological approaches that will enable stationary energy storage that can achieve an installed capital cost of less than $200/kWh.<br><br>Novel manufacturing approaches that will reduce production costs and improve performance in batteries that will enable cells to be produced at less than $80/KWh. |

| **Battery S&T (recycling)** |
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| Recycling methods which produce elemental metals at purities below battery grade | Recycling methods which produce products which can be directly fed into a cathode manufacturing process without significant additional purification. |

| **Battery S&T (thermal runaway)** |
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| Pre-conceptual research into thermal runaway systems and approaches | Technological approaches that reduce the risks of thermal runaway in battery storage systems in which, under a defined abuse condition (nail penetration, overvoltage, over temperature, etc.), cell to cell propagation is prevented. |

| **Battery S&T (lifetime)** |
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| Methods developed on commercial cells which do not consider cell design or classify/quantify degradation modes | Transferable methods (across chemistries or use cases) which rely on minimal experimental training data or which classify or quantify specific degradation modes for cells.<br><br>Early-stage materials discovery efforts based on machine learning. |

| **Battery S&T (technoeconomics)** |
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| Technoeconomic and life-cycle assessment of energy storage components and systems. | None currently identified that is not otherwise protected |

## Bioscience & Biotechnology

Bioscience and biotechnology research is an exceptionally broad and rapidly expanding area, supported by many sponsors, including but not limited to the Department of Energy. The bioscience & biotechnology section of the S&T risk matrix provides guidance in the areas of synthetic biology, omics and automation technologies, data and advanced computational biology, biomanufacturing and biomaterials, agricultural and environmental technologies, and biomedical research and technologies. For all topics below, information already protected by either classification or export control (or, in some cases vendor-specific non-disclosure agreements) is not reflected here, but scope should be evaluated relative to these controls on a case-by-case basis prior to release or dissemination. Similarly, reviewers should be cognizant of recommended controls developed by other segments of the biology research community and apply them appropriately.

### Synthetic Biology

**Keywords:** CRISPR, gene editing, genetic modification, protein engineering, gene drive, gain of function, biological parts, transformation, DNA assembly, library, cloning, metabolic engineering, genome-scale modeling

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| Publicly accessible databases, such as registries of standard biological parts, GenBank, and DIVA, which are informatic repositories of microbial strain DNA and protein sequences and designs thereof.<br><br>Publicly available techniques that enable the same genetic construct to be deployed / assessed in parallel across biological phylogeny - currently across some groups of selected non-pathogenic bacteria and fungi for discovery or proof of | Optimization of commercially viable microbial, algal, fungal, viral, and plant chassis using proprietary synthetic biology tools, technologies, and methods to produce biofuels and bioproducts.<br><br>Early (pre-commercial release) access to gene editing reagents from commercial vendors (e.g. vectors, nucleic acid modifying enzymes, genetic code expansion, or gene drives) or early (pre-commercial) access to equipment and/or upgrades |

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| concept. These capabilities are used in support of basic research, e.g., in establishing the molecules biosynthesized by secondary metabolite clusters for use as biofuels or bioproducts.<br><br>Publicly available methods or genetic tools that manipulate non-hazardous microorganisms for basic research regulating gene expression.<br><br>Design and construction of gRNA expression plasmid libraries (that in conjunction with dCas9 or aCas9 can be used to implement genome-scale gene deactivation or activation studies) that are used in support of basic research, e.g., in mapping phenotype to genotype, functional genomics, and metabolic pathway optimization for proof-of-concept applications in biofuels and bioproducts.<br><br>Internationally distributed microfluidic or nanofluidic devices that enable more automated and higher- | Reagents or equipment that are NOT available in sensitive countries and potentially suitable for reverse engineering. This technology could be widely distributed in the US.<br><br>Demonstration of disruptive synthetic biology methods, tools or technologies at relevant scale that have the potential for significant economic or national security impact (e.g., improved genome editing technologies, DNA cryptography, or viral genome modification to increase payload size and transduction efficiency).<br><br>Booting or rescue technology of synthetic microbes or viruses. |

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| throughput genetic engineering and systems biology of microbes, algae and fungi to produce biofuels and bioproducts.<br><br>Manipulation and optimization of microbes, algae, fungi, viruses and plants using widely and commercially available synthetic biology tools, technologies and methods for the incremental performance improvement of production of biofuels and bioproducts.<br><br>State-of-the-art models for predicting mutations for a desired phenotype (models still must be parametrized on a case-to-case basis). | |

**Omics & Automation Technologies**

**Keywords:** DNA sequencing, genomics, transcriptomics, proteomics, lipidomics, glycomics, metabolomics, metagenomics, metatranscriptomics, metaproteomics, laboratory automation

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| Technologies already commercially available or in the public domain.<br><br>Fundamental research involving omics measurements of biological systems. These can include:<br>• Research on the structure, function, or chemical properties of molecular species that drive prototype technological advancements in analytical measurements or computational pipelines<br>• Omics sample preparation methods that require human intervention or evaluation or those that require multiple hours to accomplish<br>• Incremental advancements in omics instrumentation that still require multiple measurement modes for confident identification (e.g., mass followed by fragmentation with additional mass measurements) and combinations of instrument systems (e.g., vacuum pumps and chromatography systems) | Safeguard development for genome sequencing centers and genome sequence databases to avoid misuse.<br><br>Safeguard development for laboratory automation to avoid misuse (e.g., external control of instrumentation to confound standards and/or data integrity).<br><br>Advances in nucleic acid sequencing technologies that significantly advance the state of the art.<br><br>Development of advancements in omics instrumentation for battlefield, clandestine, or defense applications. |

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| • Small sample size or single cell omics measurement platforms that only measure a single class of biomolecules (e.g., proteins, metabolites)<br>• Research using omics-based measurements and technologies for a mechanistic understanding of biological and environmental systems<br><br>Early-stage technologies that could significantly advance the state of the art for *in situ* omics analyses, including proteomic, transcriptomic, post-transcriptomic, and epigenetic analyses.<br><br>Development of advancements in omics instrumentation that can identify >10,000 chemical species with <1% false discovery in less than 1 minute.<br><br>Development of novel technologies not based in mass spectrometry, hybridization arrays, or sequencing technologies to confidently measure and identify molecular species (non-nucleic acids) from a single sample.<br><br>Development of advancements in omics sample preparation methods that result in analysis of several biomolecules classes from a single sample. | |

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| Development of advances in instrumentation that drive towards miniaturization, self-contained, self-powered, and/or readily portable omics instruments (e.g., for inclusion in Industrial Internet of Things [IIOT] context).<br><br>Development of fully automated instruments that take cells, tissues or other biological matrices as input and provide data results without human interaction. | |

| **Data & Advanced Computational Biology**<br>Key Words: Predictive Models, Medical Counter Measures (MCM), Digital Biosecurity, Signatures, Detection Probes |
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| **GREEN** | **YELLOW** |
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| Technologies already commercially available or in the public domain.<br><br>Fundamental research involving omics measurements of biological systems. These can include:<br><br>• Research on the structure, function, or chemical properties of molecular species that drive prototype technological advancements in analytical | Development of tools used to clean up and identify errors in publicly used biodata sets for activities related to any organisms on US commerce control and export control lists.<br><br>Development of methods to protect data in cloud computing resources |

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| measurements or computational pipelines<br><br>• Omics sample preparation methods that require human intervention or evaluation or those that require multiple hours to accomplish<br><br>• Incremental advancements in omics instrumentation that still require multiple measurement modes for confident identification (e.g., mass followed by fragmentation with additional mass measurements) and combinations of instrument systems (e.g., vacuum pumps and chromatography systems)<br><br>• Small sample size or single cell omics measurement platforms that only measure a single class of biomolecules (e.g., proteins, metabolites) | Development of proprietary or controlled datasets used for MCM development and predictive mechanistic MCM modeling.<br><br>Not publicly available synbio software and workflows (in accordance with U.S. DHHS screening guidance for providers of synthetic nucleic acids) for the screening of DNA sequences against lists of sequences of concern. This includes both software and workflows that pertain to specific signatures, details of (informatic) sensor systems and analysis methods relating to the identification of biological agents. |
| • Research using omics-based measurements and technologies for a mechanistic understanding of biological and environmental systems that serves fundamental or biomedical research | Security of drug products information [e.g., supply chain dependencies, vulnerabilities in the development pipeline, drug product data, regulatory filings, etc.] |
| • Computational and modeling tools; research, development and applications of such tools for fundamental science | Security of databases and computational tools that can be used as training/validation sets for computational applications in MCM |
| • New methods in HPC architecture and AI/ML methods to manipulate, store, model data more efficiently. | MOU controlled health data used in event and epidemiological modeling |

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| Environmental databases of viruses that may contain sequences not readily available from other sources. These databases are used in support of basic science research, e.g., in finding new branches of life and understanding virus/host relationships. | Unpublished and/or proprietary synbio software and workflows (in accordance with U.S. Dept HHS guidelines for providers of synthetic double stranded DNA) for the screening of DNA sequences against lists of organisms and toxins on the select agent and commerce control lists. This includes both software and workflows that pertain to specific signatures, details of (informatic) sensor systems and analysis and annotation methods relating to the identification of biological agents.<br><br>Testing and evaluation of technologies to store, read and display data in a significantly smaller footprint.<br><br>Databases of biological data collected from large population, especially genomic information<br><br>Brain Computer interface and other neurotechnologies<br><br>Genome sequencing, gene banks, and personalized medicine: technology and efforts that are meant to facilitate genetic testing and personalized medicine including “gene banks”<br><br>Cell-based medicine and animal models for disease and brain research |

**Biomanufacturing and Biomaterials**

Keywords: process engineering, bioreactor, supply chain, bioproduction, biocatalysis, pilot scale, commercial scale, mis-use, dual use, extraction and purification, industrial enzymes, biomimetic.

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| Publicly available gene editing and protein expression technologies for microbes, fungi, yeasts, plants, and animals.<br><br>Publicly available in vitro regeneration and propagation techniques.<br><br>Publicly available basic tools for biomanufacturing plant modification and development.<br><br>Bioreactor designs and technologies including inline monitoring and real time monitoring and quality assurance optimization.<br><br>Global regulatory testing standards, advanced process control strategies and raw material characterization.<br><br>Modeling bio-manufacturing scenarios to identify areas for technology innovation.<br><br>Publicly available methods for the separation of components and harvesting logistics at the molecular and tissue levels including methodology and equipment designs.<br><br>New methods for process intensification and quality control techniques | Engineering and optimization of metabolic pathways for commercial bioproduction with significant near-term commercial value.<br><br>Late-stage engineering and optimization of biosynthetic pathways for commercial production of target products that are national security relevant, for example the use of engineered microbes to mine rare earth elements.<br><br>Development of a full process scheme at a pilot or commercial scale for valorization of bio-derived materials into energy, security, or industrial applications.<br><br>Advances in biomanufacturing systems using “plug and play” standard designs for scalable production.<br><br>New sterility assurance processes with commercial value.<br><br>Knowledge management: Integrated knowledge of product and process technology that increases speed to market, cross-product learning, and efficiency throughout product lifecycle. |

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| Enzyme compositions from natural biomass degrading communities (metaproteomes).<br><br>'omics' studies of natural biomass degrading communities.<br><br>Research on model enzyme systems, both natural and engineered.<br><br>Characterization and imaging of enzymes for biomass degradation and upcycling.<br><br>Application and improvement of tools (including software) for computational simulation of microbes, proteins and microbial products.<br><br>General approaches for immobilizing and channeling enzymes in multi-enzyme reactions.<br><br>New approaches for engineering substrate channeling enzymes in multi-enzyme reactions for increased metabolic flux and productivity.<br><br>Current state of the art models for sequence, structure, and function prediction for a desired phenotype<br><br>Sub-cloning and passaging methodology, storage methodology (clones, cells), cell handling methods.<br><br>Fundamental research on catalyst materials, chemistry, structure, and modeling including synthesis and characterization techniques. | Pilot or commercial scale activities on extraction and purification of intermediate products with energy and environmental applications.<br><br>Protein and process optimization at pilot or commercial scale of top performing enzymes that deemed to be especially enabling at commercial scale.<br><br>Late-stage optimization of production protocols of industrial enzymes and biomimetic enzymes that likely to change reactor design, profits, and markets, etc. at the commercial scale.<br><br>Pilot or commercial scale production protocols for catalyst materials, catalyst active phases or supports, and process design for biomanufacturing systems with significant, near-term commercial value.<br><br>Pilot or commercial scale production of biomaterials and processes that substantially outperform present market alternatives.<br><br>Modeling and simulation that specifically supports design and optimization of proprietary reactors or separation systems to produce novel biomaterials. |

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| Fundamental research on biomaterials such as nanocellulose and other plant-based polymers.<br><br>Research and development of the production of bio-derived materials from natural and engineered organisms.<br><br>Development of theory and simulation methods that describe the behavior of biomaterials. | |

**Agricultural & Environmental Technologies**

Key words: 3-D printing of foods, bioenergy crop, cellular agriculture, field trial, genome-wide associations, genotype, germplasm, marker-assisted plant breeding, microbiome, phenotype, propagules, robotics, seeds, transformation, UAV hyperspectral detection, vertical agriculture

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| Research on publicly accessible germplasm or germplasm intended to be made publicly available, i.e., research on component or system validation at Laboratory-scale, to establish proof of concept, and to understand basic biological mechanisms.<br><br>Determining the function of individual genes and gene combinations and/or linking genotypes to phenotypes using germplasm, as described above.<br><br>Analysis of samples from laboratory scale systems or of devitalized samples from research field trials and pilot scale processing.<br><br>The use of published and/or publicly available transformation and gene editing technologies.<br><br>Plant breeding technologies for specific traits including the use of Genome-Wide Association Studies | Technology demonstration on germplasm at the engineering/pilot scale in a relevant environment, including field testing.<br><br>Demonstration and deployment of high-efficiency, high-throughput, crop transformation technology at pre-commercial scale.<br><br>Pilot-scale development of processing technologies for bioenergy crop species. |

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| and the development of marker-assisted breeding techniques.<br><br>Emerging technologies including "Cellular Agriculture" for protein production; 3-D printing of foods; vertical agriculture; microbiome research to support plant health; UAV hyperspectral and biosensor technologies: and the use of robotics and AI/ML in harvesting technologies are currently green but should be reviewed in the future for potential economic security risks. | |

**Biomedical Research and Technologies**

Key Words: Diagnostics, Treatments, Medicine, Bioengineering, Cognitive Sciences,

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| Fundamental biology research into cellular mechanisms of host function and response to various stimuli such as pathogens, radiation, etc.<br><br>High-throughput screening tools for R&D:<br>• Biomarker identification, verification, validation<br>• Epigenetics<br>• Small molecule inhibitor/activator screens<br>• Lab automation<br><br>Instrumentation for R&D and clinical measurements:<br>• Microarrays<br>• Flow cytometry<br>• Bioimaging and microscopy<br>• Label free screening assays<br>• Molecular reagents for plate-type assays<br><br>Implementation of AI systems using HPC to inform clinical decisions and optimize health<br><br>Biomaterials/Biosynthetic polymers: | Applied research resulting in therapeutics and vaccine design for clinical trials and human treatment<br>• Immunomodulation<br>• Mosaic vaccine design<br>• Crispr gene editing tools<br><br>Delivery systems for therapeutics and vaccines for regulated material:<br>• Nanomaterials<br>• Microneedles<br>• Targeted *in vivo* delivery<br>• Systems designed to cross the blood-brain barrier<br>• Safety / toxicity evaluations of delivery systems<br><br>Platform technologies:<br>• Implantable bionics<br>• Wearable sensors with *in situ* data analytics<br>• Multiplexed, point-of-care, fieldable devices<br>• Monoclonal antibody design and development, natural and synthetic<br><br>Neuroscience<br>• Human brain mapping studies/methods<br>• Early evaluation of new treatment technologies |

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| • Regenerative repair/wound healing<br><br>Basic research on implanting biological signals into synthetic polymers<br><br>- | (e.g., graphene based, cognitive prosthetics)<br>• Development of brain-computer interfaces<br>▪ Materials<br>▪ Molecular tools<br>▪ Communications<br><br>Biomaterials/Biosynthetic polymers:<br><br>• 3D printing of biological materials that can replace human components<br>• Development and implementation of medical implants technology involving material characteristics and basic function<br><br>Fabrication methods for biomedical technologies:<br><br>• Advanced methods and automation for nano- and microfabrication of medical devices or therapeutic delivery systems |

## Accelerator Science & Technology

The current breadth of particle accelerator technology began in the 1930's and continues to see dramatic advancement of capabilities through the development of novel concepts and technological improvements. Since their conception, accelerators have been instruments of discovery and scientific advancement, evidenced by the fact that almost one third of the Nobel Prizes granted in physics have been connected to the interaction of accelerated particles, particle detection, or the advancement of accelerator technology. Over the course of 90 years of internationally cooperative and competitive development, machine energies have increased by a factor of 10,000,000,000,000. This technology has many important applications in medicine and industry, with more than 40,000 accelerators operating around the world and total accelerator sales of about US$5B. Advanced accelerator technology continues to be developed in the US, largely at DOE national laboratories and at universities, with important anticipated applications in scientific research, industrial and medical processes, and national security. Accelerator technology plays a crucial role in many scientific areas where the US currently has significant technological advantages over other countries. Achieving the right balance of open participation in international development efforts, and discretion in disclosing select aspects of application-related knowledge, enables the US to maintain its advantages and continue to realize the commercial and intellectual-property based economic benefits.

The accelerator science & technology section of the S&T risk matrix provides guidance in the areas of supercomputing radio frequency technology, laser and plasma acceleration, superconducting magnets, cryogenic plan design and operation, advanced light source technologies, very high current electron and hadron beams, and the application of accelerators to nuclear systems and isotope production. When accelerator capabilities are used to contribute to another area of S&T, guidance from those areas is also applicable in determining what topics, if any, are restricted. For all topics below, information already protected by either classification or export control (or, in some cases vendor-specific non-disclosure agreements) is not reflected here, but scope should be evaluated relative to these controls on a case-by-case basis prior to release or dissemination.

### Superconducting Radio Frequency Technology

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| Basic research applications. including:<br><br>SRF accelerators for future HEP and NP colliders, neutrino facilities, and rare isotope research.<br><br>Generic SRF research on niobium surface modification, new | Development of SRF cryomodules using high-Q and/or high-gradient cavities: for CW applications Q > $10^{11}$ at intermediate gradients of 15 to 25 MV/m at 1,300 MHz in the frequency range from 650 to 1,500 MHz; for pulsed applications Q > $5{\cdot}10^{10}$ at gradients of > 50 MV/m at |

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| materials, coating and processes toward achieving higher Q and/or gradient, unless performed specifically for a project/application.<br><br>Generic cryomodule engineering and cleanroom assembly techniques.<br><br>R&D on narrowband SRF cavity resonance control.<br><br>Research and development on conduction-cooled (T = 4 K or greater) SRF cavities and systems. | 1,300 MHz in the frequency range from 650 to 1,500 MHz.<br><br>Conduction-cooled (T=4K or greater) SRF cavities and systems for industrial/medical/security applications. |

**Laser and Plasma Wakefield Acceleration**

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| Plasma target gas valves and capillaries ionized by lasers or >100 ns discharges, systems are being built with commercial components. Small niche markets in the accelerator community; some potential for future licenses.<br><br>Wake accelerating structure excitation and particle injection, beam control. Basic research with physical concepts being developed and used in the research community, potential for long term market in accelerator applications.<br><br>Diagnostics including for radiation sources and positron production. Basic concepts are being developed and used to measure | Integrated systems beyond the laboratory proof-of-principle stage of development with application potential in near term markets (<5 y away) |

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| and support area (2), similar status.<br><br>Applications: High Energy Physics Colliders, Thomson MeV photon sources, and Free Electron Laser type coherent photon sources. Basic research with physical concepts being developed and used in research community, potential for long term markets (>10 y away) in accelerator applications and markets in scientific, imaging & detection (nonproliferation, industrial, medical). | |

| **Superconducting Magnets** |
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| Basic research thrusts, including:<br><br>Development of diagnostics and the associated signal analysis that provides feedback to magnet design.<br><br>The development of improved NbTi magnet fabrication techniques.<br><br>Development of high and very high field accelerator magnets needed for basic science applications. | Research with potential near-term (<5 years) commercial applicability, such as:<br><br>Advanced superconducting materials with high transition temperature (>10K) and high critical field (>15T), including material science and processing optimization, intended to enhance conductor performance.<br><br>High field magnet technologies (>12T) with identified commercial applications – for example, high-field NMR solenoids.<br><br>Advanced design tools (non-open source), including modeling techniques, that enable advancement of magnet designs. |

| **Cryogenic Plant Design and Operation** |
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| Basic research thrusts, including:<br><br>Studies of materials properties at low temperatures, design optimization of cryo-cycles and cryo-equipment. | None currently identified that is not otherwise protected |

| **Advanced Light Source Technologies** |
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| Basic research and long-term R&D on fundamental lightsource techniques, including:<br><br>Fast, high power pulse electronics (<10 ns rise and fall time) and associated kicker magnet concepts.<br><br>General designs and beam physics concepts for storage rings (including ultrahigh brightness storage ring lattices as well as storage rings for hadrons and other particles for scientific applications) expressed in abstract mathematical or optical design form, possibly including elements such as integrable nonlinear optics technology, optical stochastic or other cooling methods, beam polarization control, etc. | 4th generation storage ring integrated designs and design tools.<br><br>Application/project specific design implementations of advanced beam physics concepts for storage rings, FELs, and ultrahigh brightness storage rings.<br><br>New ultrabright electron photocathodes to optimize the performance of FEL facilities.<br><br>Coatings and processes for small diameter vacuum components that are critical for the next generation light sources and FELs.<br><br>Developing next generation superconducting undulators, including conduction cooling technology. |

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| High accuracy and bandwidth electron beam position monitors and electronics. | |

| **Very High Current Beam Technologies: Electron Beams** |
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| Basic research on electron source technologies and energy recovery linacs (ERLs) | None currently identified that is not otherwise protected |

| **Very High Current Beam Technologies: Hadron Beams** |
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| Basic research thrusts including:<br><br>Negative ion sources developed for applications such as ITER or DEMO with very high currents, >>1 A, pulsed, but modest current density.<br><br>H- source for injection into accelerators with modest CW and pulsed currents. | $H^-$ and proton sources capable to produce high currents (approaching 250 mA CW and 120 mA pulsed) with current density above 125 mA/cm2 CW, 1.6 A/cm2 pulsed, and high reliability.<br><br>System designs of adaptive and machine learning techniques toward autonomous control and/or achieving the overall reliability of the facility to 99% and beyond.<br><br>Technologies for proton beam power >5 MW and <10 MW. |

| **Accelerator-based Nuclear Systems** |
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| None currently identified that is not otherwise protected | None currently identified that is not otherwise protected |

| **Accelerator-based Isotope Production** |
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| Foundational accelerator physics and radiochemistry research of potential relevance to isotope production but for which targetry and separations optimization has not yet begun. | None currently identified that is not otherwise protected |

# Appendix 1: Associated DOE Orders and Policies Involving the S&T Risk Matrix

Order 142.3B – Unclassified Foreign National Access Program

A determination of access approval is required before each access request is granted and must ensure that any identified risk to the Government associated with the access granted has been appropriately evaluated and mitigated, including a review against the Science and Technology (S&T) Risk Matrix.

Country of Risk foreign nationals' access to certain restricted technology or information as identified in the S&T Risk Matrix must undergo an enhanced review process (see below).

Requests for access to conduct research under a User Agreement at an Office of Science, Energy Efficiency Renewable Energy, or Nuclear Energy User Facility at a non-NNSA DOE laboratory are exempt from the review requirements related to the S&T Risk Matrix discussed below.

1. A request for access is reviewed by the site, in coordination with the Head of the cognizant DOE Field Element, to determine if the access request is in an area identified as restricted in the current S&T Risk Matrix before submitting the proposed access request through the standard access request review and approval process promulgated by this Order. When an access request is from a Country of Risk foreign national and in an area identified as restricted in the current S&T Risk Matrix, the cognizant DOE Field Element must agree to proceed with the enhanced review process. Absent this agreement the proposed access request is not pursued any further.
2. When the Head of the cognizant DOE Field Element agrees to proceed with the enhanced review process, a justification and clear description of why the access request benefits the U.S. must be prepared. The access request must then be submitted through the appropriate PSO and CSO, with final approval/disapproval being provided by the cognizant Under Secretary or their designee.
3. Completion of specialized enhanced vetting conducted by the DOE Office of Intelligence and Counterintelligence (IN) is required prior to final approval of the access request. A copy of the request, along with the required additional information, must be submitted to the cognizant local CI office to support the review. Indices checks will be conducted as part of the specialized enhanced vetting process; therefore, it is recommended the request be submitted 45 days prior to the start date of the access request.
4. DOE may consider broad approvals for specific categories of these types of access requests, such as those supported under government-to-government agreements and in line with National Security Council policy guidance, to ensure existing priorities are not unduly impeded.

Order 241.1B – Scientific and Technical Information Management

The Contractor reviews S&T Information generated under the contract to determine appropriate release and handling and apply any necessary statutory or program-driven announcement and/or availability restrictions, including those related to nonproliferation, national security, export control, intellectual property, protected Personally Identifiable Information and privacy. In addition, the Contractor must apply to the STI product any restrictive markings required, include any required legal disclaimers, and, for STI products resulting from DOE-funded work, identify the sponsor as follows: U.S. Department of Energy, [name of DOE program office], [name of DOE subprogram].

*Note: Although this order doesn't specifically include reference to the S&T Risk Matrix at this time, the Contractor Requirements Document will be modified as needed, and places the responsibility of determining the process by which S&T Information is reviewed, marked, and controlled, associated with the publication/ release of S&T Information. For research that is determined to be a Restricted S&T topic, this should include a notification to the funding DOE Program Office prior to publication.*

Order 481.1E – Strategic Partnership Projects

The S&T Risk Matrix must be reviewed for each proposed engagement with a foreign entity from a Country of Risk to determine if the engagement is in an area identified as restricted. Project exemption requests for foreign-sponsored work with entities from Countries of Risk in areas identified as restricted in the current S&T Risk Matrix must be submitted to the cognizant Under Secretary or his/her designee. Exemptions must be approved by the cognizant Under Secretary or his/her designee prior to initiating a review of foreign-sponsored work under DOE P 485.1A.

Order 483.1B – DOE Cooperative Research and Development Agreements

Review the current Science and Technology (S&T) Risk Matrix for each proposed foreign CRADA project with a foreign entity from a Country of Risk, to determine if that project is in an area identified as restricted. Proceeding with such a CRADA requires an exemption request through the field element, CSO, and PSO for cognizant Under Secretarial approval.

Policy 485.1A – Foreign Engagements with DOE National Laboratories

Restricts DOE National Laboratories from conducting foreign engagements with Countries of Risk in the scientific and technology areas identified as restricted in the current Science and Technology (S&T) Risk Matrix unless an exemption is granted by the Department.

Order 550.1 – Official Travel

Requires a review of the S&T Risk Matrix, for all proposed official foreign travel to a Country of Risk to determine if the travel involves areas identified in the S&T Risk Matrix as restricted.

DOE Order 471.7 – Controlled Unclassified Information

While this Order does not specifically invoke the S&T Risk Matrix, it provides the requirements for how restricted information identified within the S&T Risk Matrix, which is designated as Controlled Unclassified Information Basic, is properly safeguarded.