U.S. Department of Energy

Office of Electricity

NATIONAL LABORATORY CALL FOR PROPOSALS

Energy Storage Structured Technology Review Laboratory Call

This Lab Call is being issued by the U.S. Department of Energy's Office of Electricity in support of the Energy Storage Grand Challenge

1. OVERVIEW AND PURPOSE

1.1. EXECUTIVE SUMMARY

The energy system has become increasingly complicated with the proliferation of renewable generation and demand for grid flexibility services. Energy storage has an important role to play as we reevaluate and reengineer how we ensure reliability, resiliency, security, and affordability in this increasingly complex and dynamic environment. The Department of Energy (DOE) is working to advance energy storage technologies for both large- (≥1MW) and small- (<1MW) scale applications, and to meet different temporal needs (e.g., short-, medium-, and long-duration). The Energy Storage Grand Challenge (ESGC) is DOE's comprehensive program to accelerate the development, commercialization, and utilization of next-generation energy storage technologies and sustain American global leadership in energy storage. The ESGC is a cross-cutting effort that coordinates storage-related activities across DOE and the National Labs.

DOE's Office of Electricity is issuing this laboratory call ("lab call") to advance ESGC goals by executing a structured review of energy storage technologies to evaluate their technology readiness, their manufacturing readiness, and their adoption readiness to identify trends across the technologies reviewed, for a prescribed set of use cases, evaluated against an established criteria list. Using a provided data collection tool ("tool"), this lab call will deliver the requested information, supported by published references, as populated in the tool ("the deliverable"). The awardee(s) will leverage existing work and subject matter expertise to define the technology candidates (based on a provided list) and apply (and cite) published references to determine a risk rating, a technology readiness level (TRL), and a manufacturing readiness level (MRL), based on the TRL and MRL definitions, use cases, and criteria provided in the tool. The work performed under this lab call and the deliverable will provide insights into the current energy storage landscape and may also reveal critical data and knowledge gaps in the energy storage technology and application landscape.

This opportunity is open to DOE National Labs only. Each lab is allowed a maximum of one submission. A lab may partner with other labs and, together, submit one submission.

1.2. TIMELINE AND PROCESS LOGISITICS

Event	Date
Lab Call Announcement	December 15, 2023
Q&A Session	December 19, 2023
Proposal Submission Deadline	January 9, 2024
Reviews Completed and Selections Announced	January 16 2024
Award Received	February 13, 2024
Round 1 Results Delivered	March 29, 2024
Round 2 Results Delivered	May 3, 2024
Round 3 Results Delivered and All Deliverables Completed	June 3, 2024

Round 1, Round 2, and Round 3 are defined by the list of technologies provided in the Appendix (Table 1) and described in Section 2.2 of this lab call. For each round, the work described in this lab call (see Section 2) shall be completed and submitted to DOE by the date identified in the timeline above.

1.2.1. Proposal Submissions

Completed proposals should be submitted to *ESGC@hq.doe.gov* no later than January 9, 2024, 11:59 pm ET with the subject line: "Energy Storage Structured Technology Review Lab Call Proposal". DOE strongly encourages project teams to submit the required information at least 24 hours in advance of the submission deadline.

1.2.2. Questions During the Open Lab Call Period

Specific questions about this lab call will be addressed during **a virtual Q&A session on Tuesday, December 19, 2023 from 10:30-11:30 am ET.** To register for the virtual Q&A session, please provide your name and email to *ESGC@hq.doe.gov* by 2:00 pm ET on December 18, 2023. Only National Lab participants may attend this session.

1.3. KEY CONSIDERATIONS

1.3.1. Available Funding

There is approximately $500,000 in total funding made available by the Office of Electricity to fund a single proposal by a lab or group of labs responding to this lab call.

1.3.2. CRADAs and FOA Awards

The call for proposals below should NOT be construed as requiring the renegotiation of an existing Cooperative Research and Development Agreement (CRADA) or previously competed funding opportunity announcement (FOA) award in which the lab is a prime or sub-recipient. Labs with CRADAs or FOA awards addressing any of the topic areas below may incorporate that work in proposals they submit in response to the lab call to demonstrate existing capability and leverage existing partnerships with industry and other partners. If the proposal is not selected for funding under this lab call, the work under the CRADA or FOA award will continue—there is no additional risk to the provision of DOE funding.

2. TECHNICAL REQUIREMENTS

2.1. OBJECTIVES

The work conducted under this lab call will provide insights in the energy storage technology landscape with respect to a prescribed list of use cases and an established set of criteria. DOE seeks to engage the awardee(s), leveraging their subject matter expertise, to collect information and evaluate energy storage technologies based on published references. The evaluation will yield informed risk ratings, TRLs, and MRLs for each identified technology candidate with respect to each use case. DOE programs will leverage this technology review to identify trends across the energy storage landscape.

2.2. LAB CALL OUTCOME REQUIREMENTS

The awardee(s) shall deliver two independent reviews of each energy storage technology and maintain the results of each set of independent reviews in separate aggregate data collection tool files; the two data collection tool files shall be provided to DOE as the deliverable for this lab call. As outlined in Section 1.2 of this lab call, the deliverable shall be completed in three rounds as defined by the technology candidates identified in the Appendix, with a set of data collection tool files delivered for each round.

Figure 1 in the Appendix provides a schematic illustrating how each technology candidate will be evaluated for each use case, against the defined criteria (informed by specific metrics/targets for that technology use case); it includes the use of the evaluated criteria to generate "heat maps". DOE will generate heat maps to observe trends based on the deliverable from this lab call; the awardee(s) is(are) not required to generate heat maps.

DOE will provide the data collection tool to the awardee(s). It will comprise a Data Entry Form to facilitate data entry, along with the prescribed use cases, the established evaluation criteria, and definitions (e.g., TRLs, MRLs) to guide the structured technology review. Additionally, it will provide the list of technology candidates to be reviewed for this effort and a reference list to be populated by the awardee(s) with the supporting published references. Instructions on using the tool and additional information about its contents will be incorporated into the tool; however, DOE will be available during the period of performance to address questions regarding its use. This lab call is not asking the awardee(s) to build a different tool or make changes to the provided tool, except where noted to provide input as part of the technology review. If a technical issue arises with the tool, please contact DOE for resolution (see Instructions in the tool).

To complete this review, the awardee(s) shall, for each of the seven (7) prescribed use cases, evaluate each of the identified energy storage technologies against a set of established risk criteria, the TRL scale and the MRL scale. The use cases are based on outcomes from the use of energy storage technologies (see Table 2 in the Appendix). The risk criteria are adapted from the DOE Adoption Readiness Levels (*https://www.energy.gov/technologytransitions/adoption-readiness-levels-arl-complement-trl*). The tool defines nineteen (19) criteria across four (4) core risk areas: Value Proposition; Market Acceptance; Resource Maturity; and License to Operate. Table 3 in the Appendix lists the criteria titles, by core risk area. The TRL and MRL definitions are presented in Table 4 and Table 5 of the Appendix, respectively.

The energy storage technologies that will be addressed by this lab call are separated into three rounds (see Table 1 in the Appendix); the reviews for each round may be conducted concurrently. The rounds and the order of the technologies do not indicate any prioritization. The technologies were assigned to rounds based on the anticipated availability of needed information to support the technology review. Round 1 includes twelve (12) technologies; round 2 includes eleven (11) technologies; and round 3 includes eight (8) technologies. (Note: "Round 10" technologies, as labeled in the tool, are not covered by this lab call.) The awardee(s) shall provide descriptions of each technology candidate and note any exclusions in the assigned location within the tool. The awardee(s) will identify supporting references, as instructed, within the tool and tabulate the supporting references in the tool's reference list.

When evaluating the risk criteria for each use case/technology combination, the awardee(s) shall note any relevant specific metrics and/or targets that help inform the risk rating and cite supporting references. Additionally, any relevant notes or other information to explain the risk rating, TRL, and/or MRL determinations shall be captured within the tool.

The awardee(s) should examine existing published literature, datasets, and technical reports to support the risk rating, TRL, and MRL determinations, as well as any specific metrics/targets provided to support the review. The types of data may include, but are not limited to, the following from published references:

- Documented data from materials, systems, subsystems, components, and devices,
- Documented data from field deployments or pilot systems,
- Documented data from characterization and measurement techniques such as spectroscopy and microscopy, and
- Documented data from simulations or theoretical calculations.

If cited references are from restricted access sources (e.g., subscription-based access), this should be noted in the tool when including the reference in the reference list.

Optional deliverable(s): At the conclusion of this project, the awardee(s) may, with mutual agreement with the Office of Electricity, provide additional feedback relevant to this review, including, but not limited to, a list of technologies or technology variants that were not included in the three rounds as part of this lab call, comments on the identified use cases, and comments on the established criteria. This additional feedback must be provided in the form of a written memorandum that includes cited references supporting the feedback. No additional funding will be provided for these optional deliverables and execution priority shall be given to the required deliverable described in this section.

2.3. PROJECT BUDGET

A total of $500,000 will be made available to a single lab awardee or one group of multiple labs. Partnerships among labs are strongly encouraged. It is DOE's view that including more than one lab on a single proposal will allow for more expertise and laboratory capabilities to be engaged in this opportunity. If the award is made to a group of multiple labs, the funding will be evenly split among the recipient labs unless an alternative distribution of funds is agreed to by all participating labs and presented in the proposal.

It is the responsibility of the project team to factor in project costs for all aspects of this project including, but not limited to, costs for staffing & labor and data collection & management infrastructure/systems. The project team may contribute their own additional funding and/or resources to this project.

3. PROPOSAL SUBMISSION

3.1. REQUIREMENTS

To be considered for this lab call, the project team must submit a complete proposal no longer than ten (10) pages. The proposal should describe the project team's strong understanding of the type of data and sources that will be necessary to collect for this review. The proposal should also indicate how the project team will achieve the specific outcomes outlined in the "Lab Call Outcome Requirements" section (Section 2.2) of this document. The proposal must contain the following sections:

3.1.1. Execution Plan

The project team's proposal should outline the approach, methods, and existing/previous related activities to provide the deliverable specified in this lab call. This section of the proposal should include descriptions of how the team will be structured, milestones, proposed tasks, budget, project management information, and any other information that will indicate the project team will be successful in achieving the lab call objectives.

3.1.2. Expertise Demonstration

The project team should demonstrate its sufficient knowledge of the technology candidates and their relevance to the prescribed use cases (e.g., through publications, presentations, expertise recognition). This demonstration should reflect that the project team is capable of evaluating the risk criteria, the TRLs, and the MRLs and making informed determinations.

3.2. REVIEW PROCESS

The DOE staff managing this lab call will conduct a full merit review of submitted proposals to determine which project team will be awarded the requested amount of funding to carry out the work described in this lab call. The merit review process will consist of selected reviewers evaluating the full proposals based on the selection criteria outlined in the next section.

3.3. SELECTION CRITERIA

The selection committee will consider the following factors when evaluating proposals:

3.3.1. Execution Plan (40%)

Proposal demonstrates that the project team has an in depth understanding of the lab call objectives and a plan for collecting data with the tool and making the risk rating, TRL, and MRL determinations, supported by published references. Proposal indicates that the team can manage the project, timelines, ensure quality deliverables, and communicate information to lab call staff at DOE. Proposal indicates an appropriate anticipated budget that provides a sufficient level of detail including a breakdown for costs for key staff, labor, and other subcontracts or resources.

Overall, the proposal demonstrates that the project team is proposing a robust and reasonably comprehensive approach that will lead to the most impactful deliverable under this opportunity.

3.3.2. Collaboration and Partnerships (20%)

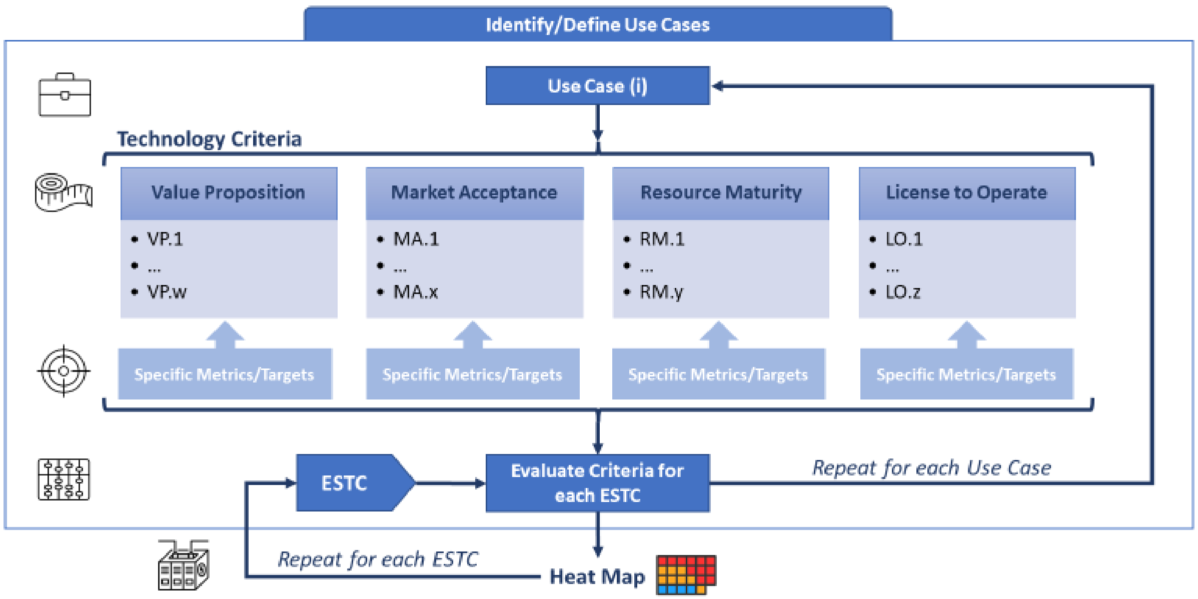
Proposals that include a diverse set of expertise from multiple labs will be considered a strength.

3.3.3. Expertise and Experience (40%)

Proposal describes, in adequate detail, the knowledge, skills, and experience of the key team members and partners that will lead to a successful project. Proposal demonstrates that the project team has a sufficient understanding of storage technology performance characteristics, operational characteristics of use cases for storage technologies, and the core risk areas outlined in this lab call. Overall, the project team shows that they have laid out a convincing path forward to achieve the specified deliverable, including relevant past projects and experiences.

4. APPENDIX

Figure 1. Relationship visualization illustrating the technology review process.



(Notes: Use cases are defined by DOE. ESTC = energy storage technology candidate. Heat maps will be generated by DOE following receipt of the deliverable.)

Table 1. Technology Candidates, by round.

Technology Candidates
ROUND 1
Lithium-ion Battery (LIB)
Sodium Batteries
Lead-acid Batteries (PbA)
Zinc Batteries
Hybrid Flow Battery
Redox Flow Battery (RFB)
Supercapacitors
Iron Batteries
Solid state battery (SSB)
Lithium Metal Batteries
Lithium Sulphur
Sodium Sulphur
ROUND 2
Pumped Storage Hydropower (PSH)
Compressed Air Energy Storage (CAES)
Electro-chemical Capacitors
Liquid Air
Flywheels
Geomechanical
Gravitational Storage
High Temperature Sensible Heat
Low Temperature Storage
Phase Change
Thermo-Photovoltaic
ROUND 3
Hydrogen storage (above ground)
Hydrogen storage (below ground)
Thermochemical
Reversible Fuel Cells
Superconducting magnetic energy storage (SMES)
Chemical Carriers (e.g., Ammonia)
Magnesium Batteries
Aluminum Batteries

(Notes: Round assignments and list order are not intended to convey any prioritization. The awardee(s) will scope each of these technology candidates as part of this review.)

Table 2. Outcome-based use cases.

Use Cases	Description/Role of Energy Storage	Example Applications
Improved Power Quality and Supply Reliability	Energy storage may be leveraged to provide regulating and contingency reserves for power system stability (e.g., inertia, frequency regulation) or to address short-term (e.g., <1 hour) capacity gaps, enhancing grid flexibility to ensure the continued reliability, resilience, and security of the electric power system.	• Operating reserve • Storing and smoothing renewable electricity generation • Utility resource planning
Energy Load Management	Energy storage may be leveraged to ensure sufficient electricity supply is available to meet demand, whether for planned capacity requirements or due to dynamic changes in customer demand, as well as stresses from weather, physical, and cyber threats.	• Peak shaving and/or demand response resource • Demand changes (e.g., seasonal, week/weekend) • Integrated long-term energy planning (e.g., balancing VRE) • Facility flexibility, efficiency, and value enhancement • Resource adequacy
Access to Electricity for Isolated Locations	Energy storage may be deployed in grid-disconnected locations (e.g., island, coastal, and remote communities) to provide access to electricity and the ability to leverage local energy supplies (e.g., wind, solar, hydropower, geothermal), and to mitigate against challenges with transported fuel supply disruptions.	• Island black start • Islanded microgrids
Outage Mitigation/Management	Energy storage may be used to mitigate against electricity supply disruptions across the electricity system by providing backup power and or uninterrupted power supply capabilities during unplanned and extended outages, thereby enabling facilities and/or systems to resume and/or maintain operations.	• Microgrid resilience/islanding • Storm preparedness • Backup power • Uninterruptible power supply • Continued operation of critical services and or interdependent infrastructure during extended power outages
Infrastructure Investment Alternatives	Energy storage may be strategically deployed within the bulk power system or local distribution systems to off-set the need for costly, long-term asset or system upgrades.	• Deferring electricity infrastructure (e.g., substations, transmission and distribution lines) investments • Offering a non-wires alternative to new transmission or distribution capacity • Lower cost alternatives to upgrading or expanding

Use Cases	Description/Role of Energy Storage	Example Applications
		existing electricity infrastructure
Reduced Electricity Supply Costs	Energy storage can play a role in shifting electricity from times of high supply and lower cost to times of high demand and higher cost, allowing consumers to meet demand during system peak; additionally, energy storage, in conjunction with renewable energy, can provide reliable access to lower cost energy supplies.	• Price arbitrage opportunities • Reducing end-user demand and demand charges • Time of use support • Renewable power purchase agreements
Mass Electrification	Energy storage can help enable mass electrification of, e.g., heating, transportation, and manufacturing systems by facilitating use of intermittent energy sources and distributed charging system infrastructure.	• Electrified mobility – enabling large-scale adoption of electric vehicles while maximizing beneficial coordination with the power grid

Table 3. Risk criteria defined in the data collection tool; adapted from DOE's ARLs.

Risk Area	Risk Criteria
Value Proposition	Delivered Cost
	Functional Performance
	Ease of Use/Complexity
	Flexibility/Innovation
Market Acceptance	Demand Maturity/Market Openness
	Market Size
	Downstream Value Chain
Resource Maturity	Capital Flow
	Project Development, Integration, and Management
	Infrastructure
	Manufacturing and Supply Chain
	Critical Materials Sourcing
	Workforce
License to Operate	Regulatory Environment
	Policy Environment
	Permitting and Siting
	Environmental and Safety
	Community Perception
	Security

Table 4. DOE Technology Readiness Levels (TRLs).

Technology Readiness Level	**TRL Definition**	**Description**
TRL-1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology.
TRL-2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
TRL-3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants. Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
TRL-4	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants and small scale tests on actual waste. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering. TRL 4 is the first

Technology Readiness Level	TRL Definition	Description
		step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.
TRL-5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity, laboratory scale system in a simulated environment with a range of simulants and actual waste. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.
TRL-6	Engineering/pilot scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering scale prototypical system with a range of simulants. Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment.
TRL-7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete.

Technology Readiness Level	TRL Definition	Description
TRL-8	Actual system completed and qualified through test and demonstration. Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development.	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An ORR has been successfully completed prior to the start of hot testing.
TRL-9	Actual system operated over the full range of expected conditions. Actual operation of the technology in its final form, under the full range of operating conditions.	The technology is in its final form and operated under the full range of operating conditions. Examples include using the actual system with the full range of wastes in hot operations.

Table 5. Manufacturing Readiness Levels (MRLs).

Manufacturing Readiness Level	Title	Description
MRL-1	Basic Manufacturing Implications Identified	This is the lowest level of manufacturing readiness. The focus is to address manufacturing shortfalls and opportunities needed to achieve program objectives. Basic research (i.e., funded by budget activity) begins in the form of studies.
MRL-2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs. Typically this level of readiness includes identification, paper studies and analysis of material and process approaches. An understanding of manufacturing feasibility and risk is emerging
MRL-3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. This level of readiness is typical of technologies in Applied Research and Advanced Development. Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.
MRL-4	Capability to produce the technology in a laboratory environment	This level of readiness acts as an exit criterion for the Materiel Solution Analysis (MSA) Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. At this point, required investments, such as manufacturing technology development, have been identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks have been identified for building prototypes and mitigation plans are in place. Target cost objectives have been established and manufacturing cost drivers have been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.

Manufacturing Readiness Level	Title	Description
MRL-5	Capability to produce prototype components in a production relevant environment	This level of maturity is typical of the mid-point in the Technology Development Phase of acquisition, or in the case of key technologies, near the mid-point of an Advanced Technology Demonstration (ATD) project. Technologies should have matured to at least TRL 5. The industrial base has been assessed to identify potential manufacturing sources. A manufacturing strategy has been refined and integrated with the risk management plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts have been initiated or are ongoing. Producibility assessments of key technologies and components are ongoing. A cost model has been constructed to assess projected manufacturing cost.
MRL-6	Capability to produce a prototype system or subsystem in a production relevant environment	This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the Engineering and Manufacturing Development (EMD) Phase of acquisition. Technologies should have matured to at least TRL 6. It is normally seen as the level of manufacturing readiness that denotes acceptance of a preliminary system design. An initial manufacturing approach has been developed. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. However, preliminary design has been completed and producibility assessments and trade studies of key technologies and components are complete. Prototype manufacturing processes and technologies, materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment. Cost, yield and rate analyses have been performed to assess how prototype data compare to target objectives, and the program has in place appropriate risk reduction to achieve cost requirements or establish a new baseline. This analysis should include design trades. Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been

Manufacturing Readiness Level	Title	Description
		completed. Long-lead and key supply chain elements have been identified.
MRL-7	Capability to produce systems, subsystems, or components in a production representative environment	This level of manufacturing readiness is typical for the mid-point of the Engineering and Manufacturing Development (EMD) Phase leading to the PostCDR Assessment. Technologies should be on a path to achieve TRL 7. System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. The cost model has been updated with detailed designs, rolled up to system level, and tracked against allocated targets. Unit cost reduction efforts have been prioritized and are underway. Yield and rate analyses have been updated with production representative data. The supply chain and supplier quality assurance have been assessed and long-lead procurement plans are in place. Manufacturing plans and quality targets have been developed. Production tooling and test equipment design and development have been initiated.

Manufacturing Readiness Level	Title	Description
MRL-8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production	This level is associated with readiness for a Milestone C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is complete and sufficiently stable to enter low rate production. All materials, manpower, tooling, test equipment and facilities are proven on pilot line and are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment and are under control and ready for low rate production. Known producibility risks pose no significant challenges for low rate production. Cost model and yield and rate analyses have been updated with pilot line results. Supplier qualification testing and first article inspection have been completed. The Industrial Capabilities Assessment for Milestone C has been completed and shows that the supply chain is established to support LRIP.
MRL-9	Low rate production demonstrated; Capability in place to begin Full Rate Production	At this level, the system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation. Materials, parts, manpower, tooling, test equipment and facilities are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement.

Manufacturing Readiness Level	Title	Description
MRL-10	Full Rate Production demonstrated and lean production practices in place	This is the highest level of production readiness. Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements. Rate production unit costs meet goals, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements are ongoing.