U.S. Department of Energy
Office of Electricity
Energy Storage

Request for Information (RFI)

DE-FOA-0003378

Issue Date: May 6, 2024

Program Area: Energy Storage Division, Office of Electricity, U.S. Department of Energy

Title: Manufacturability Pre-Production Design Implications on Energy Storage Technologies RFI

RESPONSES DUE: June 10, 2024

Purpose:

This is a Request for Information (RFI) issued by the U.S. Department of Energy's (DOE) Office of Electricity (OE) Energy Storage Division. The intent of this RFI is to obtain input to inform DOE's research and development activities within the Energy Storage Division relating to pre-production design challenges associated with energy storage technology manufacturability. In this RFI, pre-production refers to energy storage technologies that have a Manufacturing Readiness Level (MRL) of 7 ("Capability to produce systems, subsystems, or components in a production representative environment") or lower (see Appendix, Table 1). MRL 7 indicates that "system detailed design activity is nearing completion" and that "[t]echnologies should be on a path to achieve [a Technology Readiness Level (TR) of 7]" (see Appendix, Table 2). OE is specifically interested in gathering information on domestic pre-production manufacturability challenges that energy storage technology developers face when making design decisions that impact production of the technology, including scaling.

Background:

The Office of Electricity provides leadership to ensure that the Nation's energy delivery system provides reliable, resilient, secure, and affordable electricity. Maintaining a robust electricity grid is critical as the Nation experiences rapid transformation in how electricity is both generated and consumed due to trends in how the generation mix is changing, the amount and location of electricity demand, and increasing number of threats to infrastructure security and reliability. Numerous energy storage technology classes and varieties hold promise for stationary applications but face significant cost and deployment barriers. In OE, the Energy Storage Program accelerates development of bi-directional electrical energy storage technologies to serve as a key component of a reliable, resilient, and affordable future-ready grid[1]. The Energy Storage Program supports applied materials development to identify safe, low-cost, and earth-abundant elements that enable cost-effective stationary storage.

[1] DOE OE Energy Storage Program (https://www.energy.gov/oe/energy-storage)

An important feature of energy storage technology development is establishing and testing manufacturing processes and the manufacturability of the storage technology. The technology development and manufacturing stages are not linear, but iterative, as changes to the pre-production system design to increase manufacturability are required. These design changes can be in the form of strategies, techniques, or tools that improve manufacturability. Pre-production manufacturability challenges may be related to many factors of the energy storage system, component, or subcomponent design, including cost targets and levelized cost of storage (LCOS), commercial viability, synthesis and testing protocols (including safety considerations), equipment and material considerations, geographic or logistical constraints, and end-of-life considerations. Manufacturability of energy storage systems, components, and subcomponents would benefit significantly from early-stage design consideration.

Domestic industrial-scale stationary storage manufacturing capacity is an important aspect of overcoming the challenge of making domestic energy storage technologies cost competitive and overcoming barriers to widespread deployment. For example, for the last few years, manufacturers have been typically sold out of battery modules on a rolling six (6) to twelve (12) month basis, making availability of cells difficult and driving cost increases for the stationary storage market with smaller orders[2]. In another example, a recent DOE analysis indicated that 10-15 GW/year of manufacturing capacity will be needed by 2035 to support mature technology deployment at scale for long duration energy storage[3]. The same long duration energy storage analysis found that compressed air energy storage, liquid air energy storage, and lithium-ion batteries have high risk for manufacturing and assembly capacity, while some varieties of thermal energy storage and electrochemical batteries were found to have medium risk.

Given the challenges outlined above, this RFI seeks information on domestic pre-production manufacturability challenges that energy storage technology developers face when making design decisions that impact technology production, including scaling.

Requested Information:

The purpose of this RFI is to solicit feedback from industry, academia, research laboratories, government agencies, and other stakeholders on challenges related to pre-production design challenges associated with energy storage technology manufacturability. In this RFI, pre-production refers to energy storage technologies that have a Manufacturing Readiness Level (MRL) of 7 ("Capability to produce systems, subsystems, or components in a production representative environment”) or lower (see Appendix, Table 1). MRL 7 indicates that “system detailed design activity is nearing completion” and that “[t]echnologies should be on a path to achieve [a Technology Readiness Level (TR) of 7]” (see Appendix, Table 2). OE is specifically interested in gathering information on domestic pre-production manufacturability challenges

[2] ESGC Cost Performance Report 2022 PNNL-33283, (https://www.pnnl.gov/sites/default/files/media/file/ESGC Cost Performance Report 2022 PNNL-33283.pdf)
[3] DOE, Pathways to Commercial Liftoff: Long Duration Energy Storage, March 2023 (https://liftoff.energy.gov/long-duration-energy-storage)

that energy storage technology developers face when making design decisions that impact production of the technology, including scaling.

<u>You may answer as few or as many of the questions below as you would like.</u> <u>Please use the numbers and the sub-numbers as headings in your response to the greatest extent possible and refer to the questions in the body of your response. This helps save time for both the responder and the reviewers. Please be as specific as possible in all responses.</u>

DOE is requesting input on the following questions:

1. What are the key pre-production manufacturability challenges creating barriers to domestic production, including scale-up, for energy storage technologies? Please provide specific examples, if possible.
    a. Which class of pre-production energy storage technology (e.g., electrochemical battery) and/or variety (e.g., sodium ion battery)?
    b. Are the manufacturability challenges affecting the energy storage system, component, or subcomponent?
    c. What is the TRL and MRL (see Appendix) of the energy storage system, component, or subcomponent?
    d. Are these challenges that were experienced in the past, challenges that are currently being experienced, or are they anticipated future challenges?

2. What strategies/techniques/tools are used to identify and address pre-production manufacturability challenges (e.g., use of different materials or processes)? Please provide specific examples, if possible.
    a. How long do the strategies/techniques/tools take to implement and at what cost?
    b. How are the strategies/techniques/tools tested and/or validated?

3. What metrics are used to measure pre-production manufacturability improvement?

4. How do pre-production manufacturability challenges affect or relate to the following factors of the energy storage system, component(s), or subcomponent(s) design? Please provide specific examples, if possible.
    a. Cost targets and LCOS,
    b. Overall commercial viability,
    c. Synthesis and testing protocols (including safety considerations),
    d. Equipment/material costs/production/supply chains,
    e. Geographic/logistical constraints,
    f. End-of-life considerations, and/or
    g. Other factors (please describe).

5. How would addressing pre-production manufacturability challenges benefit from collaboration among stakeholders (e.g., through partnerships, consortia)? Please provide specific examples referencing the entities involved, if possible; these may include, but need not be limited to, the following list.
   a. Vendors/Suppliers,
   b. Manufacturers,
   c. Trade associations,
   d. Engineering, procurement, and construction (EPC) contractors,
   e. End users/Offtakers,
   f. Research institutions,
   g. Labor unions, and/or
   h. Others (please describe).

6. What investment level is required to identify, analyze, and address pre-production manufacturing challenges for targeted energy storage technology systems, components, or subcomponents? DOE is interested in understanding the investment level required across several project sizes and durations for different applications. Please provide specific examples, if possible.

Disclaimer and Important Notes:

This is solely a request for information for planning purposes; this RFI is not a Funding Opportunity Announcement (FOA); therefore, DOE is not accepting funding applications at this time. DOE may or may not elect to issue a FOA in the future based on or related to the content and responses to this RFI. There is no guarantee that a FOA will be issued as a result of this RFI. Responding to this RFI does not provide any advantage or disadvantage to potential applicants if DOE chooses to issue a FOA regarding the subject matter.

Any information obtained as a result of this RFI is intended to be used by the Government on a non-attribution basis for planning and strategy development; this RFI does not constitute a formal solicitation for proposals or abstracts. Your response to this notice will be treated as information only. DOE will not respond to individual submissions or publish publicly a compendium of responses. DOE will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. Responses to this RFI will not be viewed as a binding commitment to develop or pursue the project or ideas discussed.

DOE will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that DOE is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind DOE to any further actions related to this topic.

Proprietary Information:

Because information received in response to this RFI may be used to structure future programs and FOAs and/or otherwise be made available to the public, **respondents are strongly advised NOT to include any information in their responses that might be considered business sensitive (e.g., commercial or financial information that is privileged or confidential), trade secrets, proprietary, or otherwise confidential.** If, however, a respondent chooses to submit business sensitive, proprietary, or otherwise confidential information, it must be clearly and conspicuously marked as such in the response.

Freedom of Information Act:

Information included in any submission may still become public via a requirement to disclose under the Freedom of Information Act or other federal law or regulation.

Consistent with 10 CFR 1004.11, DOE requires that any person submitting information that they believe to be confidential and exempt by law from public disclosure should submit **two well-marked copies**: one copy of the document marked "confidential" which must clearly and conspicuously identify the business sensitive, trade secrets, proprietary, or otherwise confidential information, and one copy of the document marked "non-confidential" with the information believed to be confidential deleted. **Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise.** The Government is not liable for the disclosure or use of unmarked information and may use or disclose such information for any purpose.

If you choose to provide business sensitive, trade secrets, proprietary, or otherwise confidential information, you must include a cover sheet marked as follows identifying the specific pages containing business sensitive, trade secrets, proprietary, or otherwise confidential information:

> **Notice of Restriction on Disclosure and Use of Data**: Pages [List Applicable Pages] of this response may contain business sensitive, trade secrets, proprietary, or otherwise confidential information that is exempt from public disclosure. Such information shall be used or disclosed only for the purposes described in this RFI DE-FOA-0003378. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

In addition, (1) the header and footer of every page that contains business sensitive, trade secrets, proprietary, or otherwise confidential information must be marked as follows: "Contains Business Sensitive, Trade Secrets, Proprietary, or Otherwise Confidential Information Exempt from Public Disclosure" and (2) every line and paragraph containing such information must be clearly marked with double brackets or highlighting. DOE will make its own determination about the confidential status of the information and treat it according to its determination.

Evaluation and Administration by Federal and Non-Federal Personnel

Federal employees are subject to the non-disclosure requirements of a criminal statute, the Trade Secrets Act, 18 USC 1905. The Government may seek the advice of qualified non-Federal personnel. The Government may also use non-Federal personnel to conduct routine, nondiscretionary administrative activities. The respondents, by submitting their response, consent to DOE providing their response to non-Federal parties. Non-Federal parties given access to responses must be subject to an appropriate obligation of confidentiality prior to being given the access. Submissions may be reviewed by support contractors and private consultants.

Request for Information Response Guidelines

Responses to this RFI must be submitted electronically to: RFI3378@NETL.DOE.GOV with the subject line "DE-FOA-0003378_RFI" no later than 8:00 p.m. (ET) on JUNE 10, 2024.

Responses must be provided as attachments to an email. It is recommended that attachments with file sizes exceeding 25 MB be compressed (i.e., zipped) to ensure message delivery. Responses must be provided as a Microsoft Word (*.docx) or Adobe Acrobat (*.pdf) attachment to the email, no more than 15 pages in length, 12-point font, 1-inch margins. Only electronic responses will be accepted.

Format Guidance for RFI submission

For ease of replying and to aid categorization of your responses, **please copy and paste the RFI questions, including the question numbering, and use them as an outline for your response**. Respondents may answer as many or as few questions as they wish and may delete unanswered questions.

Respondents are requested to provide the following information at the start of their response to this RFI:

1. Contact person's first and last name;
2. Contact person's title;
3. Contact person's organization/institution name, street address, city, state, and zip code;
4. Contact person's phone number and email address;
5. Which organization type best categorizes your organization?
    a. Energy storage system technology developer,
    b. Energy storage system component or subcomponent technology developer,
    c. Other energy sector vendor solution providers,
    d. Not-for-profit national trade association,

e. Electric cooperative utility,

f. Electric municipal/public power utility,

g. Small investor-owned electric utility (<4,000,000-megawatt hours electricity sales per year),

h. Other investor-owned electric utility,

i. Other energy provider (solar, wind, hydropower, etc.),

j. Oil and natural gas company, or

k. Other (please describe).

On behalf of the OE Team, thank you in advance for providing your input on this important topic and contributing to the U.S. DOE's success in achieving its objectives.

Appendix

Table 1. DOE Manufacturing Readiness Levels (MRLs)[4]

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

[4] DOD, Manufacturing Readiness Level (MRL) Deskbook, 2011 https://www.dodmrl.com/MRL_Deskbook_V2.pdf

Manufacturing Readiness Level	Title	Description
		performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.
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.

Manufacturing Readiness Level	Title	Description
		Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been 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.
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

Manufacturing Readiness Level	Title	Description
		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.

Table 2. DOE Technology Readiness Levels (TRLs)[5]

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	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

[5] GAO, Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects, 2016 https://www.gao.gov/assets/gao-16-410g.pdf

Technology Readiness Level	TRL Definition	Description
	laboratory environment	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 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

Technology Readiness Level	TRL Definition	Description
		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.
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.