Technology Maturation Plan Template

A TMP is a planning tool that summarizes the necessary research and development (R&D) steps to advance the maturation of a specified technology to a targeted technology readiness level (TRL) and Manufacturing Readiness Level (MRL) and defines the key performance metrics that will be used to determine if the targeted TRL/MRL has been successfully achieved. A TMP also documents the current TRL/MRL of the specified technology, defines the ultimate commercial application of the technology, and conceptualizes a future commercialization pathway in terms of additional R&D, resources and schedule. A TMP is a high-level summary document. It is not a collection of detailed test plans.

DOE/OE uses TMPs to enhance its stewardship of R&D project portfolios and improve the value of the technologies it supports. TMPs help DOE/OE to:

* Ensure that research questions are resolved in the least expensive and least risky R&D setting (i.e., scale, degree of integration, environment, fidelity)
* Focus technology development on the performance metrics that are most important for technical and economic success (at component and system levels)
* Identify R&D gaps and critical components that are lagging in maturity
* Ensure that R&D projects address what is required for integration into higher-level systems
* Make informed decisions at critical stages of research (e.g., moving a technology from a laboratory project to a larger-scale pilot project)
* Improve the balance of project portfolios in terms of technology types, pathways, TRLs, MRLs, redundancy, etc., to mitigate risks and increase the likelihood of R&D success, and
* Forecast the cost and duration of technology development through demonstration and commercialization.

*\*\*\*BEGINNING OF TEMPLATE\*\*\**

**TECHNOLOGY MATURATION PLAN**

**for *Aligning Manufacturability & Pre-production Design***

*{Date Prepared}*

**SUBMITTED UNDER NOTICE OF FUNDING OPPORTUNITY**

DE-FOA-#######

**SUBMITTED BY**

*{Organization Name}*

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**SUBMITTED TO**

U.S. Department of Energy

National Energy Technology Laboratory

**1.0 INTRODUCTION**

**1.1 Purpose of the Project**

*Provide a brief summary of the project’s objectives as related to maturation of the proposed technology.*

**1.2 Define the Technology**

*Identify the specified technology and describe all the critical components and/or subsystems that comprise it. State whether the current project will test: (1) the total, integrated technology, or (2) one or more critical subsystems or components of the technology. If the latter, identify which critical subsystems and/or components will be tested.*

*Technology maturation is quantified by assessing the specified technology. To clearly and consistently apply the readiness level definitions, one must first precisely identify what technology is being assessed. Since most technologies can be viewed as subsystems (“levels”) within larger systems, multiple choices are available for defining the technology. However, note that the choice of the “level” of the technology affects how the TRL and MRL are assessed (see example below).*

*For example: A TRL 3 is achieved for the specified technology when analytical performance predictions for each of the technology’s critical[[1]](#footnote-1) components have been validated in separate experiments (i.e., without integration across components). A TRL 4 or 5 is achieved for a given technology when the targeted performance requirements for each of its critical, multi-component subsystems (or the entire technology) have been validated in a laboratory environment (TRL 4) or relevant environment (TRL 5) with integration of some or all components. Achieving TRLs 6 to 9 requires testing of the entire, fully integrated, technology.*

*To further clarify, consider, for example, a fuel cell stack. Its critical components are multiple, identical fuel cells. In turn, the critical components of each fuel cell are an anode, cathode and electrolyte. If one wished to assess the technology readiness of the fuel cell stack, the technology would be defined as an integrated system of multiple fuel cell subsystems, and a TRL 6 could only be achieved by successfully testing an entire stack of integrated fuel cells. However, if one instead wished to assess the technology readiness of only the fuel cell, the technology would be defined as an integrated system of cathode, anode and electrolyte components, and a TRL 6 could be achieved by successfully testing just a single, integrated fuel cell. In both cases, achievement of TRL 6 could be claimed, but only in the context of the properly specified technology.*

**1.3 Commercial Application**

*Provide a one-paragraph description of the targeted commercial application(s) of the technology.*

**2.0 MATURATION OF THE TECHNOLOGY**

**2.1 Beginning Technology Readiness Level (TRL) and** **Manufacturing Readiness Level (MRL) of the Technology**

*Briefly summarize the prior research that matured the technology to its current state.*

*Using the TRL descriptions in Appendix 1 and the MRL descriptions in Appendix 2, specify the current (i.e., pre-project) TRL and MRL of the technology.*

*Justify the specified TRL and MRL by explaining how all the required aspects have been achieved. To align with a certain TRL and MRL, all aspects of the associated TRL or MRL description must be met.*

**2.2 Target TRL and MRL of the Technology**

*Identify the TRL and MRL that the project plans to attain. To attain a certain TRL and MRL, all aspects of the associated TRL or MRL description must be met. If the project proposes to advance the TRL and MRL by more than one level, explain if that will be accomplished in stages (i.e., first one TRL, then the next) or by skipping a TRL and MRL. If the latter, explain how any increased technical, cost and schedule risks associated with skipping a TRL and MRL will be mitigated.*

**2.3 Proposed Research to Mature the Technology**

*Briefly summarize the proposed research steps and how they will mature the technology to the targeted readiness levels.*

*Identify each of the key performance attributes that will be assessed during the research along with the corresponding, quantifiable performance requirements that must be achieved to attain the targeted TRL(s) and MRL(s). Explain how the key performance attributes were selected and how the corresponding requirements were determined. Be as specific as practical on any supporting technical/economic assessments. As a general principle, all key performance requirements that may be appropriately tested at a particular readiness level must be substantially met, thereby supporting the feasibility of commercial success/goal achievement, prior to proceeding to the subsequent readiness level.*

**2.4 Potential Post-Project Maturation and Commercialization of the Technology**

*Assuming the project successfully attains the targeted TRL and MRL, describe what additional (post-project) work would be required to mature the technology to the next TRL and MRL. Identify the key performance requirements and goals/measures that would need to be achieved. If possible, provide rough estimates of the cost and duration of the research required to attain the next readiness levels. Describe your organization’s potential role in a commercialization strategy for the technology.*

**3.0 REFERENCES**

*List all reference materials supporting the technology assessment, including the definitions of TRLs and MRLs (provided below).*

Government Accountability Office, Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Project, 2016 (<https://www.gao.gov/assets/gao-16-410g.pdf>).

U.S. Department of Defense, Manufacturing Readiness Level (MRL) Deskbook, 2011 (<https://www.dodmrl.com/MRL_Deskbook_V2.pdf>).

*\*\*\*END OF TEMPLATE\*\*\**

Appendix 1: Technology Readiness Levels (TRL)

Source: Government Accountability Office, Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Project, 2016 (<https://www.gao.gov/assets/gao-16-410g.pdf>).

| **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 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. |
| 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. |

Appendix 2: Manufacturing Readiness Levels (MRL)

Source: U.S. Department of Defense, Manufacturing Readiness Level (MRL) Deskbook, 2011 (<https://www.dodmrl.com/MRL_Deskbook_V2.pdf>).

| **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. |
| 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 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 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. |
| 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. |

1. A component or subsystem of a technology is considered critical if it is new, novel, and necessary for the technology to meet its anticipated operational performance requirements or poses major cost, schedule, or performance risk during design or demonstration. Note that a component that is fully mature and non-critical for an established application or operational environment may be considered critical if it is incorporated into a new application or operational environment. [↑](#footnote-ref-1)