

Technology Readiness Level (TRL) Assessment Tool

This TRL Assessment Tool groups nine technology readiness levels (TRLs) into four broader technology development stages:

1. Fundamental Research
2. Research and Development
3. Pilot and Demonstration
4. Early Adoption

The Tool provides a description of each TRL along with a checklist to determine if the technology is at that specific TRL.

Guiding principles

The following principles should be applied when determining the TRL of a technology:

- **Start with the broader Technology Development Stage:** When determining a TRL, it is best to start with the general development stage of the technology before assessing the specific TRL.
- **Err on the side of conservative:** If there are uncertainties as to whether a technology is at a certain TRL, the lower TRL should be assigned.
- **Ensure the operating environment is well understood:** A key aspect of the various TRLs is the testing environment of a technology. It is important to be clear in understanding the real-world conditions expected and if and how the testing environment (e.g., laboratory, simulated or operational) represents these conditions.
- **A TRL is only valid for the specific operational environment for which it was tested:** If a developed technology is to be deployed in an operational environment that was different than the one it was tested for, the technology would no longer be considered fully developed and would need to be tested and refined for the new operational environment to be considered at the same TRL.

Important distinction: A technology is said to have **achieved a specific TRL** if it has met the requirements for that level and all prior levels. A technology is said to be **at a certain TRL** if the research team is currently working on achieving the requirements specific to that level.

For the purposes of federal clean technology programs and opportunities, proponents and programs should use the TRL measurement scale to describe the TRL the research team is currently working to achieve (i.e. the **TRL the technology is currently at**).

Technology Readiness Levels (TRL) chart¹

Technology Development Stage	TRL	Definition	Description	Checklist of activities to achieve this level
Fundamental Research	1	Basic principles observed and reported	Scientific research begins with properties of a potential technology observed in the physical world. These basic properties are being reported in the literature.	<input type="checkbox"/> Basic research activities have been conducted and basic principles have been defined <input type="checkbox"/> Principles and findings have been published in the literature (e.g., research articles, peer-reviewed papers, white papers)
	2	Technology and/or application concept formulated	Applied research begins with identification of practical applications of basic scientific principles. There is an emphasis on understanding the science better and corroborating the basic scientific observations made during TRL 1 work. Analysis of the feasibility of speculative applications is being conducted and reported in scientific studies.	<input type="checkbox"/> Applications of basic principles have been identified <input type="checkbox"/> Applications and supporting analysis have been published in the literature (e.g., analytical studies, small code units for software, papers comparing technologies)
Research and Development	3	Experimental proof of concept	Active research and development begins. The applications are being moved beyond the paper stage to experimental work. Feasibility of separate technology components are being validated through analytical and laboratory studies. There is not yet an attempt to integrate components into a complete system.	<input type="checkbox"/> Proof of concept and/or analytical and experimental critical function has been developed <input type="checkbox"/> Separate components have been validated in a laboratory environment
	4	Validation of component(s) in a laboratory environment	Basic technological components are integrated “ad-hoc” to establish that they will work together in a laboratory environment . The “ad-hoc” system would likely be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment in order to function.	<input type="checkbox"/> “Ad-hoc” integrated components, sub systems and/or processes have been validated in a laboratory environment <input type="checkbox"/> How “ad-hoc” integration and test results differ from the expected system goals is understood

¹ Adapted from IEA (2020), U.S. GAO (2020). U.S. Department of Energy (2015), U.S. Department of Transportation (2015), U.S. Department of Defence (2010), European Commission (2017), and NYSERDA (2018), BCIP (2017).

Technology Development Stage	TRL	Definition	Description	Checklist of activities to achieve this level
	5	Validation of semi-integrated component(s) in a simulated environment	The integrated basic technological components are performing for the intended applications in a simulated environment . Configurations are being developed but can undergo fundamental changes. The technology and environment at TRL 5 is more similar to the final application than TRL 4.	<input type="checkbox"/> Semi-integrated component(s)/ subsystems or processes have been validated in a simulated environment <input type="checkbox"/> How the simulated environment differs from the expected operational environment and how the test results compare with expectations is understood
Pilot and Demonstration	6	System and/or process prototype demonstrated in a simulated environment	A model or prototype , that represents a near desired configuration, is being developed at a pilot scale, generally smaller than full scale. Testing of the model or prototype is being conducted in a simulated environment .	<input type="checkbox"/> Pilot scale model or prototype developed <input type="checkbox"/> Pilot scale model or prototype system is near the desired configuration in performance, and volume but generally smaller than full scale <input type="checkbox"/> Pilot scale prototype or model system has been demonstrated in a simulated environment <input type="checkbox"/> How the simulated environment differs from the operational environment , and how results differed from expectations is understood
	7	Prototype system ready (form, fit and function) demonstrated in an appropriate operational environment	A full scale prototype is being demonstrated in an operational environment but under limited conditions (i.e., field tests). At this stage, the final design is very close to completion.	<input type="checkbox"/> Full scale prototype with ready form, fit and function developed <input type="checkbox"/> Full scale prototype demonstrated in an operational environment but under limited conditions
	8	Actual technology completed and qualified through tests and demonstrations	Technology is being proven to work in its final form and under expected conditions. This stage commonly represents the end of technology development. At this stage, operations are well understood, operational procedures are being developed, and final adjustments are being made.	<input type="checkbox"/> Final configuration of the technology developed <input type="checkbox"/> Final configuration successfully tested in an operational environment <input type="checkbox"/> Technology's ability to meet its operational requirements has been assessed and problems documented; plans, options, or actions to resolve problems have been determined

Technology Development Stage	TRL	Definition	Description	Checklist of activities to achieve this level
Early Adoption	9	Actual technology proven through successful deployment in an operational environment	Actual application of the technology in its final form is being conducted under a full range of operational conditions. Sometimes referred to as “system operations”, this stage is where technology is further refined and adopted.	<input type="checkbox"/> The technology has been successfully deployed and proven under a full range of operational conditions <input type="checkbox"/> Operational, test and evaluation reports have been completed
Commercially Available		Technology development is complete	Technology is openly available in the marketplace and/or has been sold directly to a buyer in the public or private sector, in its current state or service offering for non-testing or development purposes. The technology is commercial and competitive but may need further integration efforts for wide spread adoption.	<input type="checkbox"/> The technology is openly available in the marketplace and/or has been sold in its current state of service offering for non-testing or development purposes.

Key terms²

Scientific research: research aimed at expanding the base of theoretical scientific knowledge and predictions that have universal applicability

Applied research: the application of scientific knowledge to solve specific practical problems or answer certain questions

Research and development: systemic work designed to produce new products, techniques or processes or improve existing products, techniques or processes

Proof of concept: analytical and experimental demonstration of hardware/software concepts.

Model: a reduced scale, functional form of a system, near or at operational specification

Prototype: the first early representation of the system which offers the expected functionality and performance expected of the final implementation

Laboratory environment: a fully controlled test environment where a limited number of functions and variables are tested. Tests in a laboratory environment are solely for the purpose of demonstrating the underlying principles of technical performance (functions), without respect to the impact of environment

Simulated environment: a relevant working environment with controlled realistic conditions, generally outside of the lab. If the technology will be used in various environments (e.g., the Arctic and Southern Canada), the technology must be developed and tested in a simulated environment for all conditions.

Operational environment: “real-world” environment with conditions associated with typical use of the product and or process. If the technology will be used in various environments (e.g., the Arctic and Southern Canada), the technology must be developed and tested in each operational environment.

² Adapted from: U.S. National Science Foundation (2018), U.S. Department of Energy (2015), U.S. Department of Transportation (2015), SBIR (2014)

References and resources

Important note: The Clean Growth Hub led the development of this tool under its responsibilities for the Administrative Data component of the Government of Canada's Clean Technology Data Strategy³.

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[U.S. SBIR] U.S. Small Business Innovation Research program (2014) Select Appendices: Appendix A Technology Readiness Level (TRL) Descriptions.

³ Government of Canada's Clean Technology Data Strategy. Available at:
https://www.ic.gc.ca/eic/site/099.nsf/eng/h_00019.html