

## Definitions of TRLs for Components and Subsystems/Systems

The tables below define the nine Offshore Industry TRLs and give a description of each. The overlapping lines on the left-hand table and the cell shading are meant to graphically demonstrate the progression from pure research to pure development as TRLs increase.

### Technology Readiness Levels (TRLs)

#### Generate Knowledge (Research)

Basic Technology Research	Level 1	Basic principles observed and reported
Research to Prove Feasibility	Level 2	Technology concept and/or application formulated
Technology Development	Level 3	Analytical and experimental critical functions and/or characteristic proof-of-concept
Technology Demonstration	Level 4	Component and/or bench configured subsystem validation in laboratory environment
System/Subsystem Development	Level 5	Component and/or bench configured subsystem validation in relevant environment
System Test and Operation	Level 6	System/subsystem model or prototype demonstration in a relevant environment
System Test and Operation	Level 7	System prototype or system demonstration in an operational environment
System Test and Operation	Level 8	Actual system completed and qualified through test and demonstration
System Test and Operation	Level 9	Actual system proven through successful mission operations

#### Produce Products and Capabilities (Development)

## Discussion of Each TRL Level

The following paragraphs provide a descriptive discussion of each O&G technology readiness level, including an example of the type of activities that would characterize each TRL and the cost to achieve.

### Generate Knowledge (Research)

<b>TRL 1</b>	<p><b>This is the lowest “level” of technology maturation.</b> At this level, scientific research begins to be translated into applied research and development.</p> <p><b>Example:</b> Studies of basic properties of materials (e.g., tensile strength as a function of temperature for a new fiber).</p> <p><b>Cost to Achieve:</b> Very Low ‘Unique’ Cost (investment cost is borne by scientific research programs)</p>
<b>TRL 2</b>	<p><b>Invention begins.</b> Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be ‘invented’ or identified.</p> <p><b>Example:</b> Following the observation of high critical temperature (H<sub>c</sub>) superconductivity, potential applications of the new material for thin film devices (e.g., SIS mixers) and in instrument systems (e.g., telescope sensors) can be defined. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.</p> <p><b>Cost to Achieve:</b> Very Low ‘Unique’ Cost (investment cost is borne by scientific research programs)</p>
<b>TRL 3</b>	<p><b>Active research and development (R&amp;D) is initiated.</b> This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute “proof-of-concept” validation of the applications/concepts formulated at TRL 2.</p> <p><b>Example:</b> Components that are not yet integrated or representative.</p> <p><b>Cost to Achieve:</b> Low ‘Unique’ Cost (technology specific)</p>
<b>TRL 4</b>	<p><b>Basic technological elements must be integrated to establish that the “pieces” will work together to achieve concept-enabling levels of performance for a component and/or bench configured subsystem.</b> This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is relatively “low-fidelity” compared to the eventual system: it could be composed of ad hoc discrete components in a laboratory.</p> <p><b>Example:</b> A TRL 4 demonstration of a new ‘fuzzy logic’ approach to process control might consist of testing the algorithms in a partially computer-based, partially bench-top component (e.g., fiber optic tank level indicators) demonstration in a controls lab using simulated flow inputs.</p> <p><b>Cost to Achieve:</b> Low-to-moderate ‘Unique’ Cost (investment will be technology specific, but probably several factors greater than investment required for TRL 3)</p>
<b>TRL 5</b>	<p><b>Fidelity of the component and/or bench configured subsystem being tested has to increase significantly.</b> The basic technological components must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a ‘simulated’ or somewhat realistic environment. From one-to-several new technologies might be involved in the demonstration.</p> <p><b>Example:</b> “High fidelity” laboratory integration of components. A new type of solar photovoltaic material promising higher efficiencies would at this level be used in an actual fabricated solar array ‘blanket’ that would be integrated with power supplies, supporting structure, etc., and tested in a thermal chamber with solar simulation capability.</p> <p><b>Cost to Achieve:</b> Moderate ‘Unique’ Cost (investment cost will be technology dependent, but likely to be several factors greater than cost to achieve TRL 4).</p>

TRL 6	<p><b>Representative model or prototype system or system — which would go well beyond ad hoc, ‘patch-cord’ or discrete component level bench configured subsystem — would be tested in a relevant environment.</b> At this level, if the only ‘relevant environment’ is the environment of deep water, and then the model/prototype must be demonstrated in deep water. Of course, the demonstration should be successful to represent a true TRL 6. Not all technologies will undergo a TRL 6 demonstration: at this point the maturation step is driven more by assuring management confidence than by R&amp;D requirements. The demonstration might represent an actual system application, or it might only be similar to the planned application, but using the same technologies. At this level, several-to-many new technologies might be integrated into the demonstration.</p> <p><b>Example:</b> Testing a prototype system or system in a high fidelity laboratory environment or in simulated operational environment. In this example, the reason deep water is the ‘relevant’ environment is that buoyancy <u>plus</u> pressure <u>plus</u> thermal environment effects will dictate the success/failure of the system — and the only way to validate the technology is in deep water.</p> <p><b>Cost to Achieve:</b> Technology and demonstration specific; a fraction of TRL 7 if on ground; nearly the same if deep water is required</p>
TRL 7	<p><b>Prototype near or at planned operational system.</b> Requiring demonstration of an actual system prototype in an operational environment, such as in ROV, or deep water. It has not always been implemented in the past. In this case, the prototype should be near or at the scale of the planned operational system and the demonstration must take place in deep water. The driving purposes for achieving this level of maturity are to assure system engineering and development management confidence (more than for purposes of technology R&amp;D). Therefore, the demonstration <u>must be</u> of a prototype of that application. Not all technologies in all systems will go to this level. TRL 7 would normally only be performed in cases where the technology and/or subsystem application is mission critical and relatively high risk.</p> <p><b>Example:</b> Testing the prototype in a test bed ROV.</p> <p><b>Cost to Achieve:</b> Technology and demonstration specific for demonstration system, but a significant fraction of the cost of TRL 8</p>
TRL 8	<p><b>Technology has been proven to work in its final form and under expected conditions.</b> In almost all cases, this TRL represents the end of true system development. By definition, all technologies being applied in actual systems go through TRL 8. In almost all cases, this level is the end of true ‘system development’ for most technology elements.</p> <p><b>Example:</b> Developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications. Might include integration of new technology into an existing system. Loading and testing successfully a new control algorithm into the subsea computer on downhole system while during drilling operation.</p> <p><b>Cost to Achieve:</b> Mission specific; typically highest unique cost for a new technology for actual system</p>
TRL 9	<p><b>Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation.</b> By definition, all technologies being applied in actual systems go through TRL 9. In almost all cases, the end of last ‘bug fixing’ aspects of true ‘system development’. For example, small fixes/changes to address problems found following launch (through ‘600 hours’ or some related date). This might include integration of new technology into an existing system (such operating a new artificial intelligence tool into operational mission control). This TRL does <u>not</u> include planned product improvement of ongoing or reusable systems.</p> <p><b>Example:</b> Using the system under operational mission conditions. New turbine for an existing subsea power generator would not start at TRL 9: such ‘technology’ upgrades would start over at the appropriate level in the TRL system.</p> <p><b>Cost to Achieve:</b> Mission Specific; less than cost of TRL 8 (e.g., cost of deployment plus 600 hours of mission operations)</p>
<p><b>Produce Products and Capabilities (Development)</b></p>	