BLUEMISSION AA

Building a coordination hub to support the mission implementation in the Atlantic and Arctic Basin

Technical Readiness Level

From the conception of an idea to its practical implementation, the Technical Readiness Level (TRL) assesses the maturity of a technological product by applying the necessary indicators to categorize the nine stages of technology readiness. In the maritime sector, technological advancement is increasingly needed as climate change threatens marine ecosystems like coral reefs. New marine technologies actively support environmental monitoring and surveillance, coral and rubble transfer, resilient coral varieties, and data analytics.

	TRL: Technical Readiness Level	
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Stage 1: Conceptualize	3	Analyze and experiment core functions and/or prove key elements of the concept
	2	Create concepts of technology and/or apply technology formulas
	1	Study, discover and set basic assumptions

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Technical Readiness Level

Stage 1: Conceptualize

Step 1: Study, discover and set basic assumptions

At this initial stage, scientific research is translated into practical insights. Researchers study and discover fundamental properties and principles, forming basic assumptions. This often involves conducting foundational experiments and collecting preliminary data to understand key characteristics and establish a theoretical framework for future development.

HOW TO

1. **Identify Research Objectives:**

   Identify the problem, threat or challenge to be addressed. Define the scientific questions and set clear discovery goals.

2. **Conduct Literature Review:**

   Review existing scientific literature to understand current knowledge and identify gaps.

3. **Formulate Hypotheses:**

   Develop basic assumptions and hypotheses based on the initial literature review and define the theoretical framework guiding your research.

4. **Design Initial Experiments:**

   Plan experiments to test hypotheses effectively and investigate fundamental properties.

5. **Collect Preliminary Data:**

   Gather initial data through experiments, observations, or simulations, using appropriate methods and tools for data collection, such as sensors or analytical instruments.

6. **Analyze Data:**

   Interpret the preliminary data to understand basic trends and patterns, validate findings with statistical methods and refine your assumptions.

7. **Document Findings:**

   Record all data, experimental setups, and analyses meticulously.

8. **Integrate Ecological Knowledge:**

   Employ continuous multiparametric monitoring methods to collect biological and environmental data.

9. **Refine Understanding and Technology Needs:**

   Use data to improve your understanding and outline technology needs for further development.

10. **Review and Iterate:**

    Regularly review findings, adjusting and refining the research approach as needed.

EXAMPLE

For instance, studies on the fundamental properties of materials might be conducted at this point. Understanding ecological structures is crucial for ecosystem restoration, yet such knowledge is often lacking. Continuous multiparametric monitoring methods that integrate simultaneous biological and environmental data collection for the widest range of species can provide this essential ecological information.

Step 2: Create concepts of technology and/or apply technology formulas

In this stage, researchers create and define practical applications based on the basic principles identified in the previous step. These concepts remain theoretical, as they are not yet validated by detailed analysis or experimental evidence. This step involves the initial design and feasibility assessment of the technology, setting the foundation for future development and testing.

HOW TO

1. **Define the Practical Application**:

   Identify how principles from Step 1 can solve specific problems and needs and outline potential applications and use cases.

2. **Develop Initial Concepts**:

   Create preliminary designs or models for the technology that address practical constraints and requirements.

3. **Conduct Feasibility Studies**:

   Evaluate concepts through theoretical analyses (concept viability evaluation) and simulations or basic models (testing initial assumptions) to refine them.

4. **Identify Technological Approaches**:

   Explore and assess different technological solutions and approaches for implementing the concepts and assess the potential effectiveness and practicality of each approach.

5. **Document the Conceptual Framework**:

   Record detailed descriptions of the concepts, including theoretical foundations and expected functionalities and prepare documentation that outlines the feasibility and potential impact of the proposed technology.

6. **Plan for Experimental Validation**:

   Outline a roadmap for testing and validating concepts in future TRL steps, identifying necessary resources, tools, and methods needed for future experimental analysis.

EXAMPLE

In the context of ocean restoration, Step 2 might involve conceptualizing scalable restoration methods. These methods should be capable of working effectively at fine spatial scales while covering broad reef areas efficiently. For example, researchers might develop a conceptual design for a robotic system that can deploy coral fragments over large areas with minimal human intervention. This system would need to be labor-efficient, reliable, and easy to operate, requiring minimal professional oversight. During this step, research would focus on creating these concepts and technological approaches before moving to experimental validation.

Step 3: Analyze and experiment core functions and/or prove key elements of the concept

In Step 3 of the maturation process, the focus shifts towards analyzing, experimenting, and proving the core functions and key elements of the concept developed in the earlier stages. This step involves rigorous research and development (R&D) to empirically validate the analytical forecasts and ensure that the technology or concept can perform as expected ("proof-of-concept").

HOW TO

1. **Define Objectives and Hypotheses**:

   Outline objectives to validate the concept's core functions and formulate hypotheses based on prior analytical forecasts and theoretical foundations.

2. **Design Experiments**:

   Develop a detailed lab plan, selecting appropriate methods and tools. Identify controls and variables for accurate, reproducible measurements. Design analytical studies to contextualize the technology, possibly using simulations, statistical analyses, or comparative studies.

3. **Conduct Experiments and Data Collection**:

   Implement the experiments as planned, using precise instruments and methodologies. Gather empirical data meticulously, ensuring accuracy and consistency. Maintain detailed records of all experimental conditions and observations.

4. **Analyze Results**:

   Analyze the data using statistical and computational tools, identifying patterns correlations, and deviations and validating significance. Compare findings with initial forecasts and place them in the broader context of the field.

5. **Validate Proof-of-Concept**:

   Confirm that the concept's core functions, and key elements work as intended, documenting the entire process, including methodologies, data, analyses, and conclusions.

6. **Iterate and Refine:**

   Use experimental insights to refine and, if necessary, retest the concept to address any discrepancies or unexpected results.

7. **Prepare for Next Steps**

   Compile reports summarizing findings, proof-of-concept validation, and implications, while outlining next steps like scaling up, field tests, or pursuing funding and partnerships.

EXAMPLE

The table below presents specific technologies for marine restoration, offering more detailed examples than the previous step and highlighting opportunities for further development.

Technology required for at-scale reef restoration

Reef Restoration	Technology
1. **Rubble Stabilisation, Substrate Preparation**	Mechanized methods of applying biochemical treatments, physical material handling mechanization.
2. **Aquaculture/nursery facilities, collection of wild spawn**	In facility material handling and monitoring, larval slick location and harvesting
3. **Transport and plant young corals, fragments**	Vessels and vehicles to transport and plant young corals, semi-automated methods to identify suitable fine-scale planting locations
4. **In-situ Treatments**	Vehicles to apply in-situ (underwater) treatments
5. **Cooling and shading, predator removal**	Physical shading structures, atmospheric modification vessels, underwater vehicles to identify, monitor and eradicate biota.

Stage 2: Prototype

Step 4: Test key components in laboratory conditions

Step 4 focuses on testing key components in controlled laboratory conditions to verify their functionality and identify any issues. This stage ensures the components meet performance expectations and are ready for more complex testing or real-world applications. However, if lab testing is not feasible, move on to Step 5: Conduct an in-situ test, with thorough risk assessments and preventative measures in place to address potential issues.

HOW TO

1. **Identify Key Components:**

   Select the specific elements or subsystems that are critical to the technology's function.

2. **Design Laboratory Tests:**

   Develop test plans detailing parameters, conditions, and metrics for performance assessment.

3. **Conduct Controlled Testing:**

   Execute tests in a lab environment, ensuring conditions mimic potential real-world scenarios.

4. **Analyze Results:**

   Evaluate performance data, comparing it against expected outcomes to confirm functionality.

5. **Document and Iterate:**

   Record findings and refine components before progressing to more complex testing phases.

EXAMPLE

An example of marine restoration technology at Step 4 is experimental oyster reef restoration. At this stage, the technology has already been validated in earlier steps. Now, the key components, such as reef structures and oyster larvae, are integrated and tested together in a controlled lab environment. These tests are conducted in simulated or semi-realistic settings that mimic natural conditions, such as water flow and salinity, to evaluate how well the components work together before moving to real-world application.

Step 5: Extend the key component test from laboratory to other relevant circumstances

Step 5 involves testing the key components outside the laboratory in real-world or simulated environments to evaluate performance under diverse conditions. This step helps to understand how the technology behaves in practical settings and identify any issues that might not have been apparent in controlled lab conditions. By extending testing to these environments, you can assess the technology's reliability, effectiveness, and scalability, making necessary adjustments based on observed performance and environmental interactions.

HOW TO

1. **Identify Testing Environments:**

   Select real-world or simulated environments that closely resemble the conditions where the technology will be used.

2. **Design Test Protocols:**

   Develop protocols that outline how the technology will be tested in these new environments, including specific conditions and performance metrics.

3. **Implement Testing:**

   Conduct the tests according to the protocols, ensuring accurate data collection and monitoring.

4. **Analyze Performance:**

   Evaluate the technology's performance in these new settings, comparing it to laboratory results and expected outcomes.

5. **Refine and Iterate:**

   Use the insights gained to make necessary adjustments and improvements to the technology before further scaling up.

EXAMPLE

For artificial coral reefs, Step 5 would involve testing the reef structures in coastal waters or controlled marine environments rather than just the lab. This might include deploying the reefs in various marine conditions to monitor their impact on local ecosystems, assess their durability, and ensure they provide the intended ecological benefits. Data collected would help refine the reef design and improve its effectiveness in real-world conditions.

Step 6: Test models of core system and subsystems or models in relevant circumstances

Step 6 involves testing models of the core system and subsystems in real-world or simulated environments. This step evaluates how well the integrated system performs under relevant conditions, helps identify potential issues, and ensures that all components work together effectively before moving towards full-scale deployment or commercialization.

HOW TO

1. **Develop Models:**

   Create detailed models of the core system and subsystems based on previous tests and designs.

2. **Select Testing Environments:**

   Choose real-world or simulated environments that accurately represent the conditions where the technology will be used.

3. **Design Test Scenarios:**

   Outline scenarios and protocols for testing the models, including conditions and performance metrics.

4. **Conduct Testing:**

   Implement the tests, monitoring the performance of both the core system and subsystems in the chosen environments.

5. **Analyze Results:**

   Evaluate how well the integrated system and its components perform, identifying any issues or improvements needed.

6. **Refine and Adjust:**

   Adjust the system based on test results to improve functionality and integration.

EXAMPLE

Artificial reef systems are tested in actual marine environments to evaluate their performance. For example, testing 3D-printed substrates for oyster reef restoration involves deploying scaled-down prototypes in coastal areas. This approach assesses how well the reef structures, coral attachment systems, and artificial fish habitats function under natural conditions, interact with marine life, and endure environmental stresses. The data gathered helps refine the design and functionality of the full-scale reef system, ensuring it operates effectively in real-world settings.

Stage 3: Develop & Test

Step 7: Test prototype in field

Step 7 involves testing the prototype of the technology in real-world field conditions to evaluate its performance, reliability, and functionality outside the controlled environment. This step assesses how the prototype operates under actual usage scenarios and environmental factors, providing critical insights for further development and refinement before full-scale deployment.

HOW TO

1. **Prepare Prototype:**

   Finalize and prepare the prototype for field testing, ensuring it is fully functional and representative of the intended design.

2. **Select Field Sites:**

   Choose field locations that closely match the conditions where the technology will be deployed.

3. **Design Test Plan:**

   Develop a detailed plan for field testing, including specific scenarios, performance metrics, and data collection methods.

4. **Conduct Field Tests:**

   Deploy the prototype and monitor its performance, noting any issues or areas for improvement.

5. **Analyze Field Data:**

   Evaluate the prototype's performance based on data collected in the field, comparing it to expected outcomes and lab results.

6. **Refine and Optimize:**

   Use insights from field tests to adjust and enhance the prototype before scaling up.

EXAMPLE

For deploying an artificial reef, Step 7 would involve placing a full-scale prototype of the reef system in a natural marine environment. This would include monitoring its integration with local marine life, assessing its durability and functionality in varying conditions, and collecting data on its ecological impact. The findings would be used to refine the reef design and ensure it meets performance expectations before larger-scale deployment.

Step 8: Complete product certification

Step 8 involves completing the product certification process to ensure that the technology meets all required standards and regulations for its intended use. This step verifies that the technology is safe, effective, and compliant with industry standards, paving the way for commercial release and widespread adoption.

HOW TO

1. **Identify Certification Requirements**:

   Research and understand the relevant standards, regulations, and certifications required for the technology.

2. **Prepare Documentation**:

   Gather and organize all necessary documentation, including test results, safety assessments, and technical specifications.

3. **Submit for Certification**:

   Apply for certification with the appropriate regulatory bodies or certification agencies, providing required documentation and information.

4. **Undergo Evaluation**:

   Work with certifying organizations as they review and test the technology to ensure it meets all standards and requirements.

5. **Address Feedback**:

   Make any necessary adjustments or improvements based on feedback from the certification process.

6. **Obtain Certification**:

   Secure the official certification, confirming that the technology is ready for commercial use and complies with all relevant standards.

EXAMPLE

For an artificial reef, this step would involve obtaining certification to ensure the reef materials and design meet environmental and safety standards. This might include certifications for ecological impact, material safety, and compliance with marine conservation regulations. Completing this process ensures the reef can be deployed widely and safely in marine environments.

Step 9: Ready to be delivered and used

Step 9 involves finalizing the technology for delivery and use, ensuring it is fully prepared for deployment and operation in its intended environment. This step confirms that the technology is ready for widespread application, having passed all prior tests, certifications, and validations.

HOW TO

1. **Finalize Production**:

   Complete any remaining production or assembly tasks, ensuring the technology meets quality and performance standards.

2. **Prepare for Deployment**:

   Arrange logistics for distribution and installation, including packaging, transport, and site preparation.

3. **Ensure Support**:

   Set up necessary support systems, such as user training, maintenance services, and customer support.

4. **Conduct Final Checks**:

   Perform last-minute inspections and tests to verify that the technology is functioning correctly and is ready for use.

5. **Launch Technology**:

   Officially deploy and deliver the technology to the end users, ensuring all aspects of the installation and setup are completed.

EXAMPLE

At this stage, marine restoration technologies like coral outplanting techniques and artificial reefs are fully deployed and operational. The widespread use of coral outplanting has proven effective in enhancing coral survival and growth in natural reef settings. This step involves finalizing the structures for deployment, organizing transportation to the installation site, and preparing for placement in the ocean. This may also include integrating new technology into existing systems, setting up support for monitoring and maintenance, and officially launching the reef for marine conservation efforts.


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