TRL Report

Work Package 3 – Deliverable 3.1

Delivery date of the deliverable: due 31/03/2014

Lead organisation for this deliverable
IFREMER

Lead author: Jean-François Rolin

Contributors/ colleagues interviewed : Jean-Marc Sinquin, Laurent Delauney, Vincent Dutreuil, Serge Le Reste, Xavier André, Patrice Woerther, Loïc Quemener, Corentin Renaut.

THE OCEAN OF TOMORROW

COOPERATION

NeXOS - Next generation Low-Cost Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management, is funded by the European Commission's 7th Framework Programme - Grant Agreement Nº 614102

DOCUMENT HISTORY		
Edit./Rev.	*Date*	*Name*
Prepared	…	Jean-François Rolin
Checked	…	Christoph Waldmann
Approved	…	Project Coordinator

DISSEMINATION LEVEL	
PU: Public	Deliverable X
PP: Restricted to other programme participants (including the Commission Services)	
RE: Restricted to a group specified by the consortium (including the Commission Services)	
CO: Confidential, only for members of the consortium (including the Commission Services)	(envisaged for some future versions)

Planning

Participant	Person-Months	Contributors	Role in D3.1 /WP3
Ifremer	2	J.F.Rolin and interviewed colleagues	WP responsible
TOTAL	2		

NeXOS Task 3.1 – from the Description of Work

Objectives
Evaluate the technological maturity of sensor systems

Description of Work

- Associated Task 3.1. Engineering specifications and technological maturity; Leader: IFREMER; Duration: M6-M12

The underwater sensing objectives refined by WP 1 will determine the required performance in precision, deployment duration and pressure of the new sensors and general specifications will be issued. The Technology Readiness Level (TRL) will be evaluated for each of the NeXOS sensor systems, leading to basic engineering specifications so that performance can be demonstrated within the duration of the project. The TRL study will use remote interviews and meetings among the NeXOS consortium (including referenced providers) and related projects (EuroARGO, EMSO/ESONET, JERICO, GROOM, etc). It will be based on common practice for sensor choice and enhancement and will critically review the limits and achievements of existing sensors within the market. In parallel to WP5, 6 and 7, this task will perform functional analysis for several multi-sensor architectures and integration scenarios (including multiparameter probe, junction box, profilers and gliders as well as new concepts). The analysis will address the following questions:

- can more parameters be integrated into the sensor system?
- what is the feasibility of self calibration and/or self biofouling control?
- can pre-processing and modifications to sampling procedure be applied locally?
- How the RAMS strategy can contribute to the production of more reliable and cost-efficient sensors?

Input needed

- D1.3: Project implementation plan

D3.1) TLR report: The Technology Readiness Level will be evaluated for each of the NeXOS sensor systems, leading to basic engineering specifications so that performance can be demonstrated within the duration of the project. This deliverable will justify part of the work done in task 3.1 [month 6]

Task work plan

1) (this deliverable) *Evaluate the technological maturity of some sensor systems to check the methodology.*
2) *Keep using this TRL evaluation method during 6 months with as many NEXOS components as possible. Confidentiality will be discussed within TOC or Steering Committee if needed.*
3) *define the general specifications for the different new sensors*

Task timeline (See example below – double click to edit in Excel or compatible)

	Project month				
	M 6	M 6	M 12		M 30
	mars-14	mars-14	sept-14		mars-17
Task 6.4: Environmental Monitoring Programme					
Start					
TRL REPORT					
Functional analysis report					
Update in task 3.5					

Deliverable Structure/Outline

Executive Summary

Proposed as a reference since the submission of NeXOS, the Technological Readiness Level (TRL) is implemented as a metrics for the improvement of equipments (sensor systems but also related platforms and software). A common definition, and a common methodology of determination of the TRL is discussed, proposed and applied for validation on 4 products: one sensor (Recopesca temperature turbidity), one software (Seadataview), one platform (ARVOR CM) and one component (SnO_2 antifouling protection). This defines a method that will be applied in several instances of NeXOS, in relation with functional analysis report, market study, reliability study, and as a tool for Nexos Scientific and technical management (TOC) and evaluation.

The template of TRL estimate is made available in the internal NeXOS intranet web pages under WP3 working section.

1. Introduction

In its initial documents of submission, NEXOS has presented the Technological Readiness Level as a conceptual tool for the support of sensor development and a major indicator for the follow-up of the project. *(See Tables 1 and 2 Hereunder)*

Technology Readiness Level: The concept of Technology Readiness Level (TRL) was developed by NASA and ESA for space systems [http://en.wikipedia.org/wiki/Technology_readiness_level] and has recently introduced in ocean observation to identify the stages that a technology needs to pass in order to bridge the gap between research and development and production/operations. These stages are described in the table below.

TECHNOLOGY READINESS LEVELS [6]

Level	Description
TRL 1	Basic principles of technology observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and laboratory studies to validate analytical predictions
TRL 4	Component and/or basic sub-system technology valid in lab environment
TRL 5	Component and/or basic sub-system technology valid in relevant environment
TRL 6	System/sub-system technology model or prototype demo in relevant environment
TRL 7	System technology prototype demo in an operational environment
TRL 8	System technology qualified through test and demonstration
TRL 9	System technology qualified through successful mission operations

Table 1: TRL definition in NeXOS Submission document and DoW

TABLE 5: NEXOS INNOVATIONS AND NEW TECHNOLOGIES

Ocean optics	Multiwavelength fluorescence matrix sensing through different excitation emission pairs combined with reconfigurable chemometric algorithms providing quasi-EEMS (excitation-emission-matrix spectroscopy). The technology brings flexibility, reliability and compactness to different applications including marine contaminants. Hyperspectral cavity absorption sensing following the PSICAM principle: applicability in long-term field application and new algorithms for phytoplankton discrimination as well as dissolved substances. Carbon cycle and acidification sensing of pH, pCO_2 and alkalinity in a miniaturized and ruggedized setup improved for underway applications
Passive acoustics	High resolution, high sampling rate Analog to Digital conversion through 24 bit $\Sigma\Delta$ IC, which grants a. Wide bandwidth b. high dynamic range c. Very low input noise level The adopted technology (24 bit $\Sigma\Delta$ A/D conversion) will increase dynamic and spectral performance, and multifuntionality, Specific firmware code will be embedded on the sensor interface for signal pre-processing and source localisation
Web Enablement	Implementation of OGC IT standard tools on European ocean sensors, for real-time sensor discovery and monitoring Implementations of SWE 2.0 to facilitate the interaction and data exchange to and from global observation programmes Implementation of Sensor Interface Descriptor model for new and existing ocean sensors.
Sensor interfaces	Hardware and software interface based on new CORTEX architectures for a miniaturised low power and modular design with variable frequency clocks ensuring low power consumption or high performance when needed. Implementation of PUCK protocol for instrument discovery and identification in point to point or networks communications. Implementation of PTP (Precision Time Protocol IEEE Std. 1588) for time synchronization. Open Source software development tools facilitate reprograming or reconfiguring sensor interface functionality.
Antifouling	Biofouling sensor using an innovative optical design. Use of functionalized surfaces on immersed optical components for fouling protection New concept of biofouling control: antifouling protection loop with sensor control.
Other technological Innovations	Once the performances are reached and the production in small series can be envisaged, the main part of the cost comes from housings, mechanical interfaces and mechanical functions. Innovation in this field will come from optimizing the number and complexity of each part in order to reduce machining and mounting time, use of materials with excellent ageing characteristics in seawater and potential low cost production (e.g. casting, moulding).

Table 2: Innovation and new technologies from Submission document and DoW

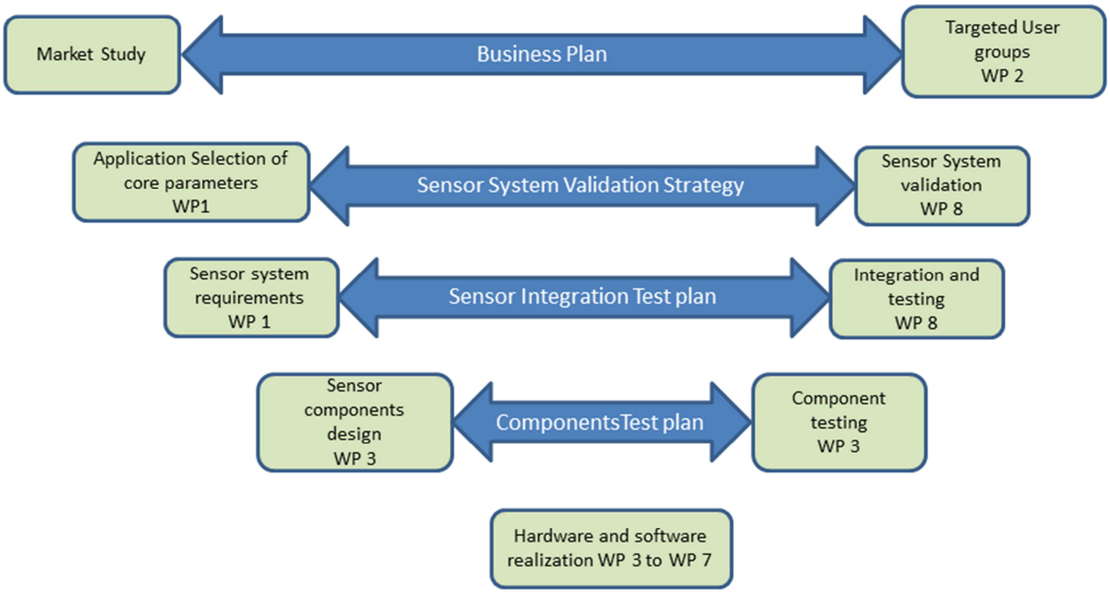


Table 3 : The V-diagram describing the steps in the development process

This V-shape diagram is describing the process of development of NeXOS, linking the specification, the innovation and the validation activities. The TRL estimates as presented in this report will be a major tool to issue a metrics for the increase of maturity achieved by the project throughout the V-shape process.

2. Reference documents

- *NEXOS DoW*
- *NASA TRL definition (1989, 1995, 2007)* http://esto.nasa.gov/files/trl_definitions.pdf.
- *NATO TRL discussion* http://natorto.cbw.pl/uploads/2010/9/$$TR-HFM-130-ALL.pdf.
- *EC H2020 TRL definition:* http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.
- *Carnot CAPTIVEN scale-* http://www.hydreos.fr/ckfinder/userfiles/files/Pollutec2012/CAPTIVEN.pdf.

3. Finding the NEXOS approach among technology Readiness Level definitions

a. Short history and field of application of TRL

Technology Readiness Levels (TRL's) were invented by NASA after the first failures in the Appolo program. After a few years it was promoted through a paper titled "NASA technology push towards future space mission systems" (Saden, et. al., 1989). It initially included 7levels and was increased to 9 later on. It was understood after a while as an interesting way to address the limits of the technology, reliability and the associated risks. In a troubleshooting process, reasons may come from lack of maturity of the technology of one component.

Readiness level assignment was typically left to the technology developer. When UK Department of Defense was directed to use NASA's TRL process in 2002, they started to refine the methods. Other large institutions proposed variations, adapted to their field.

TRL has been adopted internationally with the use of TRL's at NATO (with specific definitions), ESA, CNES, in Canada, the UK, and Japan. An ISO TRL Working Group (WG) has started to work from an initiative of the British Standards Institute.

In the fields of ocean instrumentation, a few actors started to introduce TRL approach in Europe such as the reference article published by Ralph Prien from Germany in 2007 (Ralph D.Prien - The future of Chemical in-situ sensor -.Marine Chemistry 107 (2007) 422–432). It was introduced in strategic discussions at national level in UK (Gwynn Griffith NOC) and in France (Jean-François Rolin – Instrumentation Review and Perspective – TSM strategic days - La Londe les Maures - December 2007).

Nasa TRL definition as it is now:

Definition Of Technology Readiness Levels

TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space): Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

TRL 7 System prototyping demonstration in an operational environment (ground or space): System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.

TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space): End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.

TRL 9 Actual system "mission proven" through successful mission operations (ground or space): Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Table 4: NASA TRL definition.

The European Commission in the Horizon 2020 in the general annexes G requires to refer to:

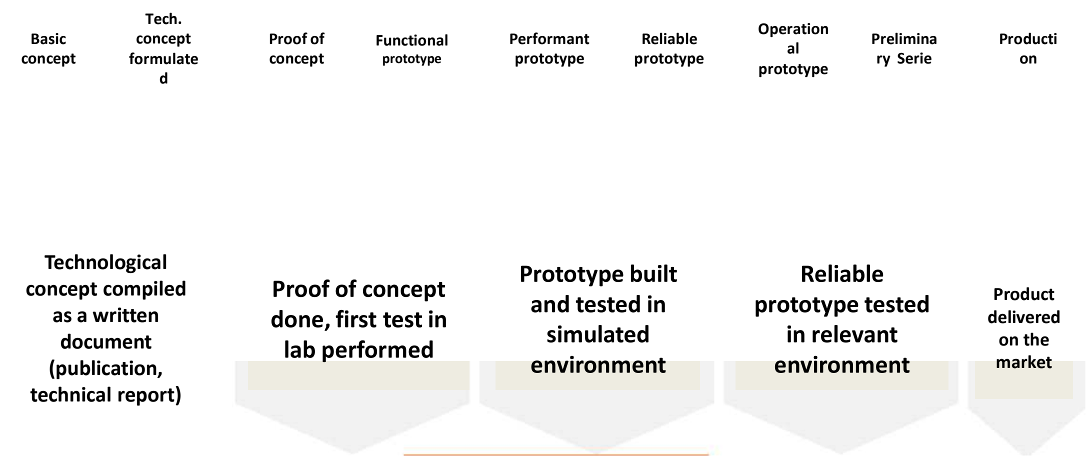
Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified: TRL 1 – basic principles observed   TRL 2 – technology concept formulated   TRL 3 – experimental proof of concept   TRL 4 – technology validated in lab   TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)   TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)   TRL 7 – system prototype demonstration in operational environment   TRL 8 – system complete and qualified   TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Table 5: European Commission Horizon 2020 TRL list

It is totally in agreement with NeXOS definition but less detailed.

b. Simplified or extended TRL scales?

The French project Captiven supported by Agence Nationale pour la Recherche is aiming at stimulating instrumentation for the environment developed by SMEs and research institutes. The choice was made to simplify the TRL scale in order to keep a limited number of categories.



This approach is useful when we need to present rough estimates of TRL and include them in brochures for a large public. But it does not disseminate the actual difficulties in development and is quite sufficient to introduce a discussion between parties. It could be an issue for NeXOS for general market assessment but is in contradiction to the will to follow the advances with a metrics.

On the opposite, NATO introduced a TRL0 when it adopted TRL scale.

TRL0 is: *Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and /or observable facts with only a general notion of military applications or military products in mind. Many levels of scientific activity are included here but share the attribute that the technology readiness is not yet achieved.*

This level is out of the scope of NeXOS. We do not wish to include this early stage level.

For NeXOS, the end of development, corresponding to TRL 9 needs more attention that the early stage. This is presented in § 4 c)

c. Components, sub-systems or systems?

In Nexos we address several size of equipments: sensors, sensor systems, platforms, instrumentation systems, interfaces, systems of systems.

We intend to use TRL in priority for the components of the project corresponding to a deliverable in a Task, a platform mentioned in a scenario or used for validation in WP8 or demonstration in WP9.

Estimate of TRL can be envisaged for the discussion on opportunities in market analysis, comparison of solutions, reliability studies,etc. TRL of components or systems will then be performed.

4. NEXOS TRL questionnaire

a. Description and calculation TRL 1 to TRL 6

A questionnaire made available by nyserda R&D for free use on internet is proposed for the determination of TRL1 to TRL6. It uses a definition very similar to the TRL definitions of the NeXOS DoW. The only difference comes from the TRL 3 where the questionnaire proposes the "proof of concept" as key word, a concept broadly used by original TRL 3 definitions.

Once the 7 tables have been filled-in by answering a series of yes or no questions, a synthetic TRL evaluation between 1 and 6 is calculated, highlighting the weak point. We appreciate this didactic approach.

OVERALL SUMMARY OF TECHNOLOGY READINESS			
1-1)	Have the basic technology processes and principles been observed and reported?	○ YES	◉ NO
1-2)	Has an equipment and process concept been formulated?	○ YES	◉ NO
1-3)	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?	○ YES	◉ NO
1-4)	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?	○ YES	◉ NO
1-5)	Has bench-scale equipment/process testing been demonstrated in a relevant environment?	○ YES	◉ NO
1-6)	Has prototypical engineering scale equipment/process testing been demonstrated in relevant environment, incl. testing safety functions?	○ YES	◉ NO

MARKET AND CUSTOMER NEEDS			
2-1)	Know who cares about the technology (customer, funding source, etc.) (6)	○ YES	◉ NO
2-2)	Customer identified and expressed interest in the application (1,10)	○ YES	◉ NO
2-3)	Customer representative identified to work with development team and participates in requirements generation (11,12)	○ YES	◉ NO
2-4)	Overall system requirements for end user's application known and documented; performance metrics measuring reqt's established (6,7,8)	○ YES	◉ NO
2-5)	Requirements definition with performance thresholds and objectives established for final design (19)	○ YES	◉ NO
2-6)	Operating environment for final commercial system is known (4)	○ YES	◉ NO
2-7)	Analysis of project timing ensures technology will be available when required (13)	○ YES	◉ NO

DESIGN/DEVELOPMENT		
3-1) Physical laws and assumptions used in new technologies defined (2)	○ YES	◉ NO
3-2) Research hypothesis formulated (7)	○ YES	◉ NO
3-3) Know who would perform research and where it would be done (9)	○ YES	◉ NO
3-4) Theoretical or empirical design solution identified with basic elements of technology and initial analysis of major functions included (5,6,11,13)	○ YES	◉ NO
3-5) Potential system/components identified, performance predictions made for each; modeling/simulation only to verify physical properties (2,9,12)	○ YES	◉ NO
3-6) Qualitative idea of risk areas such as cost, schedule, performance (22)	○ YES	◉ NO
3-7) Know what output devices are available, capabilities and limitations of researchers and research facilities, and required experiments (17,19,21)	○ YES	◉ NO
3-8) Preliminary strategy to obtain TRL Level 6 developed (18)	○ YES	◉ NO
3-9) Preliminary system performance characteristics and measures identified and estimated (6)	○ YES	◉ NO
3-10) Science known to extent that mathematical and/or computer models and simulations are possible (5)	○ YES	◉ NO
3-11) Risk areas identified in general terms and risk mitigation strategies identified (24,25)	○ YES	◉ NO
3-12) Design techniques identified/developed; sources of key components for lab testing identified (15,21)	○ YES	◉ NO
3-13) Analysis of present state of the art shows technology fills a need (23)	○ YES	◉ NO
3-14) Scalable prototypes produced (bigger than lab scale) (15)	○ YES	◉ NO
3-15) Conceptual design developed and documented (16)	○ YES	◉ NO
3-16) Initial cost drivers identified (19)	○ YES	◉ NO
3-17) Formal risk management program initiated (21)	○ YES	◉ NO
3-18) Preliminary design engineering begins and prototypes of components created (4,7)	○ YES	◉ NO
3-19) Detailed design drawings completed to support engineering-scale system; ability to acquire all components for final prototype (18,22)	○ YES	◉ NO
3-20) Preliminary cost estimates of commercial product prepared	○ YES	◉ NO
3-21) Performance baseline including total project cost, schedule, and scope completed (6)	○ YES	◉ NO
3-22) Engineering-scale system is high-fidelity functional prototype of operational system (22)	○ YES	◉ NO
3-23) More precise cost estimates prepared for system	○ YES	◉ NO
3-24) Operating limits for components determined (7)	○ YES	◉ NO
3-25) System design specs are complete and ready for detailed design (20)	○ YES	◉ NO

INTEGRATION			
4-1)	Individual parts of the technology work (no real attempt at integration) (16)	○ YES	◉ NO
4-2)	Paper studies indicate that system components should work together (16)	○ YES	◉ NO
4-3)	Modeling and simulation used to simulate some components and interfaces; analysis completed to establish component compatability (5,12)	○ YES	◉ NO
4-4)	Available components assembled into lab scale system; integration studies have begun (10,20)	○ YES	◉ NO
4-5)	System interface issues and requirements known and relationships between major system and sub-systems understood on a lab scale with component	○ YES	◉ NO
4-6)	Integration of modules/functions demonstrated in lab/bench-scale environment (21)	○ YES	◉ NO
4-7)	At engineering scale, relationships between system and subsystems understood and component integration demonstrated (1,11)	○ YES	◉ NO
4-8)	Preliminary design drawings for final system complete (3)	○ YES	◉ NO

TESTING AND VALIDATION			
5-1)	Paper studies confirm basic principles; basic characterization data exists (3,4)	○ YES	◉ NO
5-2)	Initial scientific observations reported in journals/conference proceedings/technical reports (5,8)	○ YES	◉ NO
5-3)	Paper studies show application is feasible and components of technology have been partially characterized (3,8)	○ YES	◉ NO
5-4)	Rigorous analytical studies confirm basic principles; analytical results reported in scientific journals/conference technical reports (14,15)	○ YES	◉ NO
5-5)	Predictions of elements of technology capability validated by analytical studies, lab experiments, and modeling and simulation (3,7,10)	○ YES	◉ NO
5-6)	Lab experiments verify and fully demonstrate feasibility, but not yet at system components level (8, 9,22)	○ YES	◉ NO
5-7)	Individual components and subsystems composed of multiple components tested in lab (3,4)	○ YES	◉ NO
5-8)	Lab experiments in a controlled environment show components work together and demonstrate basic functionality in simulated environment (11,14,18)	○ YES	◉ NO
5-9)	Requirements for technology verification established and include testing and validation of safety functions (5)	○ YES	◉ NO
5-10)	Lab-scale tests using prototype completed and results validate the design; ready for test in relevant environment; lab environment for testing modified to approximate operational environment (9,11,16,27,32)	○ YES	◉ NO

ENVIRONMENTAL AND SAFETY			
6-1)	Key process and safety requirements and associated hazards have begun to be identified (2,14)	○ YES	◉ NO
6-2)	Key process variables fully identified, preliminary hazard evaluations completed/documented; safety control strategies being explored (1,31)	○ YES	◉ NO
6-3)	Range of all relevant physical and chemical properties determined to the extent possible (24)	○ YES	◉ NO
6-4)	Limits for process variables, parameters & safety controls defined; integration demos done incl. testing/validating safety functions (24,31)	○ YES	◉ NO
6-5)	Finalization of required hazardous material forms; identification of system/component level safety controls (26)	○ YES	◉ NO

MANUFACTURING AND SCALE UP			
7-1)	Scaling studies have been started (19)	○ YES	◉ NO
7-2)	Current manufacturability concepts assessed (20)	○ YES	◉ NO
7-3)	Equipment scale-up relationships understood/accounted for in technology development; scaling designs completed (17,23)	○ YES	◉ NO
7-4)	Key manufacturing processes identified and assessed in lab; mitigation strategies identified to address manuf/producibility shortfalls (22,24,27)	○ YES	◉ NO
7-5)	Lab to engineering scale scale-up issues understood and resolved (30)	○ YES	◉ NO
7-6)	Manufacturing processes to make components that are new are validated via demonstration in the lab (8)	○ YES	◉ NO
7-7)	Manufacturing techniques have been defined to the point where largest problems are defined (10)	○ YES	◉ NO
7-8)	Engineering to full-scale scale-up issues understood and resolved (29)	○ YES	◉ NO
7-9)	Critical manufacturing processes have been prototyped and scaling issues that remain are identified and understood (12,16)	○ YES	◉ NO
7-10)	Process and tooling are mature to support fabrication of system and components; at least one product demo has been completed (27,33)	○ YES	◉ NO

nyserda
Energy. Innovation. Solutions.

PON 2458 - Technology Readiness Calculator - Results

TRL Calculator Results

TRL	Questions Answered "Yes"	% Complete	Progress Towards Level
1)	0 of 7	0%	
2)	0 of 10	0%	
3)	0 of 13	0%	
4)	0 of 13	0%	
5)	0 of 13	0%	
6)	0 of 15	0%	

Detailed Results

By Question Section

1. General	1-1)	No
	1-2)	No
	1-3)	No
	1-4)	No
	1-5)	No
	1-6)	No
2. Market Need	2-1)	No
	2-2)	No
	2-3)	No
	2-4)	No
	2-5)	No
	2-6)	No
	2-7)	No
3. Design & Development	3-1)	No
	3-2)	No
	3-3)	No
	3-4)	No
	3-5)	No
	3-6)	No
	3-7)	No
	3-8)	No
	3-9)	No
	3-10)	No
	3-11)	No
	3-12)	No
	3-13)	No
	3-14)	No
	3-15)	No
	3-16)	No
	3-17)	No
	3-18)	No
	3-19)	No
	3-20)	No
	3-21)	No
	3-22)	No
	3-23)	No
	3-24)	No
	3-25)	No
4. Integration	4-1)	No
	4-2)	No
	4-3)	No
	4-4)	No
	4-5)	No
	4-6)	No
	4-7)	No
	4-8)	No
5. Testing and Validation	5-1)	No
	5-2)	No
	5-3)	No
	5-4)	No
	5-5)	No
	5-6)	No
	5-7)	No
	5-8)	No
	5-9)	No
	5-10)	No
6. Safety	6-1)	No
	6-2)	No
	6-3)	No
	6-4)	No
	6-5)	No
7. Manufacturing & Scale	7-1)	No
	7-2)	No
	7-3)	No
	7-4)	No
	7-5)	No
	7-6)	No
	7-7)	No
	7-8)	No
	7-9)	No
	7-10)	No

By Technology Readiness Level

TRL 1	1-1)	No
	2-1)	No
	3-1)	No
	3-2)	No
	3-3)	No
	5-1)	No
	5-2)	No
TRL 2	1-2)	No
	2-2)	No
	3-4)	No
	3-5)	No
	3-6)	No
	3-7)	No
	3-8)	No
	4-1)	No
	5-3)	No
	5-4)	No
TRL 3	1-3)	No
	2-3)	No
	3-9)	No
	3-10)	No
	3-11)	No
	3-12)	No
	3-13)	No
	4-2)	No
	5-5)	No
	5-6)	No
	6-1)	No
	7-1)	No
	7-2)	No
TRL 4	1-4)	No
	2-4)	No
	3-14)	No
	3-15)	No
	3-16)	No
	3-17)	No
	4-3)	No
	4-4)	No
	5-7)	No
	5-8)	No
	6-2)	No
	7-3)	No
	7-4)	No
TRL 5	1-5)	No
	2-5)	No
	3-18)	No
	3-19)	No
	3-20)	No
	4-5)	No
	4-6)	No
	6-3)	No
	7-5)	No
	7-6)	No
	7-7)	No
TRL 6	1-6)	No
	2-6)	No
	2-7)	No
	3-21)	No
	3-22)	No
	3-23)	No
	3-24)	No
	3-25)	No
	4-7)	No
	4-8)	No
	6-4)	No
	6-5)	No
	7-8)	No
	7-9)	No
	7-10)	No

Synthetic table calculated by the EXCEL sheet.

b. Next steps from TRL 7 to TRL 9

A continuation of the questionnaire, proceeding TRL by TRL is proposed for the 3 next levels once TRL6 is acquired.

nexos

Technology Readiness Calculator TRL7 issues

SYSTEM TECHNOLOGY PROTOTYPE DEMO IN AN OPERATIONAL ENVIRONMENT		
VII-1) Pressure tests with safety coefficient	○ YES	◉ NO
VII-2) Temperature, vibration and other environment tests	○ YES	◉ NO
VII-3) Interface with platform is validated	○ YES	◉ NO
VII-4) Functional tests in simulated environment	○ YES	◉ NO
VII-5) Functional tests at sea (short or shallow)	○ YES	◉ NO
VII-6) Prototypical engineering scale equipment/process demonstrated in various environment conditions and various functional configurations, incl. testing safety functions?	○ YES	◉ NO

Applicant Name:

Comments

nexos

Technology Readiness Calculator TRL8 issues

SYSTEM TECHNOLOGY QUALIFIED THROUGH TEST AND DEMONSTRATION		
VIII-1) Tested in all environmental conditions	○ YES	◉ NO
VIII-2) Manufacturing issues solved for several products	○ YES	◉ NO
VIII-3) Several demonstrations performed	○ YES	◉ NO
VIII-4) Operated by one end used at least	○ YES	◉ NO
VIII-5) Commercial system available	○ YES	◉ NO
VIII-6) Manufacturing and user documentation established	○ YES	◉ NO

nexos

Technology Readiness Calculator TRL9 issues

SYSTEM TECHNOLOGY QUALIFIED THROUGH SUCCESSFULL MISSION OPERATION		
IX-1) Experience in a full range of operating conditions	○ YES	◉ NO
IX-2) Manufacturing performed for several contracts	○ YES	◉ NO
IX-3) Operation by several end users	○ YES	◉ NO
IX-4) Functional tests in simulated environment	○ YES	◉ NO
IX-5) Several commercial contracts	○ YES	◉ NO
IX-6) User group and/or FAQ and/or report/publication by user	○ YES	◉ NO

c. Various uses/market according to equipment (9+)

Being at the forefront of innovation and high-tech, the inventor of TRL at NASA or the promoters inside the weapon sytems of NATO considered the proof in operation stage as a final one. In more trivial industrial fields, several hierarchies may be found. A TRL 9 recognized in one field (home kitchen) may not be sufficient for another commercial application such as the kitchen of a restaurant.

Oceanography was started by Navy engineers and the references of readiness were military. Since the end of the 80s, a new generation of instrument was able to promote more cost efficient technical solutions. NEXOS ambition is to proceed in this direction in order to “improve the temporal and spatial coverage, resolution and quality of marine observations”. Our NEXOS TRL9 is the fulfilment of the cost efficency and reliability objectives of the project.

Nevertheless, some industries are not satisfied with the oceanography references in term of robustness, size and capital base of the provider, security specifications,... In this case, NEXOS TRL 9 “System technology qualified through successful mission operations” may not be sufficient to ensure the H2020 TRL 9 “Full commercial application”. It is probably because an industrial field will not recognize qualification capacities of “mission operations” that are not from the same industrial field.

For the sake of this report and further uses in these special cases of reliability (WP3) and market studies (WP2) in NEXOS, we will mention a 9+ level with a reference to the specific market.

TRL9+ OIL AND GAS

TRL9+ DEFENCE

TRL9+ FISHERY

TRL9+ MARINE RENEWABLE ENERGIES

....

d. Methodology of use: interview and/or working sessions with specialists

The questionnaire has been used in two manners: either as an interview with the project responsible or during a project meeting with more specialists present. Both conditions are adequate. We suggest to use the occasion of a project meeting when possible because the more collective estimation is shared by the group and will motivate them for corrective actions.

5 Key components for TRL estimate for the Task 3.1

The TRL of the following components will be evaluated during the Task 3.1. Those in red are used as reference for the present deliverable.

a. *Optical sensor systems;*

NEXOS WP5 starting products

(FRANATECH)

(TRIOS)

(HZG)

(NIVA)

Other projects

CHEMINI (EXOCET-D/*Ifremer)* for comparison purpose

b. *Passive acoustics sensor systems;*

NEXOS A1 for NeXOS WP6

c. *Ecosystem approach to fisheries management sensor systems (EAF);*

RECOPESCA turbidity (NEXOS WP7 starting product/nke) is chosen because the temperature oxygen and temperature fluorescence probes are not specified yet.

d. *Sensor anti-fouling;*

Chlorination system (NEXOS WP3 starting product/nke,*Ifremer*). This component is an important issue (NeXOS WP3). Unlike previously developed technologies such as chlorination, the project is

e. *Sensor interface interoperability;*

Seadataview (EUROFLEETS/*Ifremer*). This software and the associated computer architecture are developed by EUROFLEETS 2 project for research vessels. The interface with Recopesca board unit will allow the implementation of NeXOS WP4 concepts.

(52N)

f. *Platform.*

ARVOR CM (EuroARGO-JERICO/nke,*Ifremer*) which is derived from the ARVOR Argo float for coastal use with multi sensor capabilities. This platform will be used in NeXOS.

Glider (GROOM/US trade marks)

Ferry box (JERICO/$)

6 Results per equipment

1) Ecosystem approach to fisheries management sensor systems (EAF);

RECOPESCA turbidity (NEXOS WP7 starting product/nke)

The level is strictly TRL 5. Solving weaknesses in performance baselines will bring it to TRL8. Solving the severity level of shock test issue in addition would bring it to TRL9.

2) Sensor anti-fouling;

Chlorination system (NEXOS WP3 intended product/nke,*Ifremer*)

The level is TRL2. Next topics to address are risk mitigation strategy and pressure tests. Proofs of achievement are advanced up to TRL7 questions concerning environment constraints but results are lacking for producibility issues and the validation of low impact of by-products.

3) Sensor interface interoperability and software;

Seadataview (EUROFLEETS/*Ifremer*)

The level is TRL 2. TRL3 can be easily achieved while involving end users in the specification process in the EUROFLEETS community and performing an initial risk analysis.

In general and especially the page 5 of the questionnaire, the simulations, lab experiments and modelling are not criteria suited for software.

4) Platform.

ARVOR CM (EuroARGO-JERICO/nke,*Ifremer*)

ARVOR basic version has a TRL 9 and is recognized as a profiling float for ARGO international network meaning continuous production.

The strict TRL estimate for ARVOR CM is TRL1. It may be easily improved through (i) initiating and implementing a risk management program and (ii) in the marketing domain, establish performance metrics shared with end users. The ARVOR CM inheritates assets tending to TRL 7 coming from the design of the ARVOR basic version.

7 Synthetic view

a. Limits of the exercise

The TRL analysis with a simple questionnaire is not a complete study. Functional analysis, reliability analysis,… will bring additional input.

b. Trends

We can see from the first cases that some issues such as safety, client involvement and risk analysis are less often treated at an early stage than for instance environmental tests.

We will have to see during the next months if these tendencies are confirmed.

c. Special cases

The TRL analysis performed on a software reveals that many questions are easily achieved because developers are used to apply Quality Assurance methods to produce software codes. Some questions are not suited for software. Anyway, the method of TRL assessment is able to reveal lacks and the estimate of TRL is reasonable with respect to the general progress of the development.

8 Discussion on the NEXOS objectives in term of increased readiness

The V-diagram (Table3) shows the serie of steps of development in NeXOS. It is suggested to use TRL at several stages:

- initial evaluation of the state of the art inside the NeXOS consortium as most of the developments start after feasibility assessment and aim at increasing TRL. This must be estimated by the developers and be considered as a way to express their individual objectives during the Project duration.

- objectives for NeXOS developments as expressed by the DoW can be presented in term of TRL increase

- Some ítem in the questionnaire show weak points. If they concern reliability thay may be solved with the help of WP3 and WP4. If they concern simulated environment, they may be solved with contribution of WP3. If they concern validation, they are in the scope of WP8. If they concern demonstration, they are in the scope of WP9. If they concern market or relations to clients, they may be addressed by WP2 and/or WP1. A plan to solve weak points would help the developper.

9 Conclusions

The template of TRL estimate is made available in the internal NeXOS intranet web pages under WP3 working section.

The basis of a metrics of NeXOS technological development using TRL has been established.

The final validation of the method used for TRL will be continued during the second part of Task 3.1:

- It will be applied to 7 sensor system, software or platform of NeXOS interest.
- It will be compared with the market maturity to be addressed by the market study in Work package 2 (D2.1 Market Assessment)
- It will be used by the engineering specifications (D3.2) to establish the target of TRL increase for each product.

What NeXOS participants need to know before TRL increase assessment of Task 3.5 is performed (due month 39):

- the TRL estimate is done on declarative principles. It is neither binding the interviewer nor the developer who is interviewed, neither legally nor morally.
- the TRL figures will not be published outside the NeXOS consortium without acceptance of the developer. If a more strict confidentiality is required by private partner, the request will be submitted to the NeXOS TOC.
- one of the more interesting outcome for the TRL estimate exercise is to identify the issues which have not been solved (sometimes simply forgotten). By solving them, one or often more TRL levels can be earned.

The 2nd Ordinary Project meeting on April 1st 2014 supported the idea to use the present document as a basis to promote a common TRL estimation between the 4 “intercooperation projects” (NeXOS, SenseOcean, Commonsense, Schema).

10 Bibliography

- "NASA technology push towards future space mission systems" (Saden, et. al., 1989)
- "Did I Ever Tell You About The Whale? or Measuring Technology Maturity "- William Nolte IAP ."
- GAO, (26 October 1999), *Presentation to the S&T Conference on the Transition of Technology to Acquisition*.
- GAO, (October 2001), *Joint Strike Fighter Acquisition – Mature Critical Technologies Needed to Reduce Risk*, GAO-02-39.
- Ralph D.Prien - The future of Chemical in-situ sensor -.Marine Chemistry 107 (2007) 422–432

Appendix 1

Initial TRL of Recopesca temperature – turbidity probe.

nyserda
Energy. Innovation. Solutions.

PON 2458 - Technology Readiness Calculator - Results

Applicant Name:
Ifremer and nke

TRL Calculator Results

TRL	Questions Answered "Yes"	% Complete
1)	7 of 7	100%
2)	10 of 10	100%
3)	13 of 13	100%
4)	13 of 13	100%
5)	13 of 13	100%
6)	14 of 15	93%

Comments

OVERALL SUMMARY OF TECHNOLOGY READINESS

RECOPESCA products designed by Ifremer and nke, are including pressure temperature probes, temperature pressure salinity probes and temperature pressure turbidity probes.
TRL ESTIMATION FOR TEMPERATURE-PRESSURE-TURBIDITY Recopesca PROBES

MARKET AND CUSTOMER NEED

0

DESIGN AND DEVELOPMENT

0

INTEGRATION

0

TESTING AND VALIDATION

0

ENVIRONMENTAL AND SAFETY

0

MANUFACTURING AND SCALE UP

0

Detailed Results

By Question Section

1. General	1-1)	Yes
	1-2)	Yes
	1-3)	Yes
	1-4)	Yes
	1-5)	Yes
	1-6)	Yes
2. Market Need	2-1)	Yes
	2-2)	Yes
	2-3)	Yes
	2-4)	Yes
	2-5)	Yes
	2-6)	Yes
	2-7)	Yes
3. Design & Development	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	Yes
	3-9)	Yes
	3-10)	Yes
	3-11)	Yes
	3-12)	Yes
	3-13)	Yes
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	Yes
	3-18)	Yes
	3-19)	Yes
	3-20)	Yes
	3-21)	No
	3-22)	Yes
	3-23)	Yes
	3-24)	Yes
	3-25)	Yes
4. Integration	4-1)	Yes
	4-2)	Yes
	4-3)	Yes
	4-4)	Yes
	4-5)	Yes
	4-6)	Yes
	4-7)	Yes
	4-8)	Yes
5. Testing and Validation	5-1)	Yes
	5-2)	Yes
	5-3)	Yes
	5-4)	Yes
	5-5)	Yes
	5-6)	Yes
	5-7)	Yes
	5-8)	Yes
	5-9)	Yes
	5-10)	Yes
6. Safety	6-1)	Yes
	6-2)	Yes
	6-3)	Yes
	6-4)	Yes
	6-5)	Yes
7. Manufacturing & Scale	7-1)	Yes
	7-2)	Yes
	7-3)	Yes
	7-4)	Yes
	7-5)	Yes
	7-6)	Yes
	7-7)	Yes
	7-8)	Yes
	7-9)	Yes
	7-10)	Yes

By Technology Readiness Level

TRL 1	1-1)	Yes
	2-1)	Yes
	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	5-1)	Yes
	5-2)	Yes
TRL 2	1-2)	Yes
	2-2)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	Yes
	4-1)	Yes
	5-3)	Yes
	5-4)	Yes
TRL 3	1-3)	Yes
	2-3)	Yes
	3-9)	Yes
	3-10)	Yes
	3-11)	Yes
	3-12)	Yes
	3-13)	Yes
	4-2)	Yes
	5-5)	Yes
	5-6)	Yes
	6-1)	Yes
	7-1)	Yes
	7-2)	Yes
TRL 4	1-4)	Yes
	2-4)	Yes
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	Yes
	4-3)	Yes
	4-4)	Yes
	5-7)	Yes
	5-8)	Yes
	6-2)	Yes
	7-3)	Yes
	7-4)	Yes
TRL 5	1-5)	Yes
	2-5)	Yes
	3-18)	Yes
	3-19)	Yes
	3-20)	Yes
	4-5)	Yes
	4-6)	Yes
	6-3)	Yes
	7-5)	Yes
	7-6)	Yes
	7-7)	Yes
TRL 6	1-6)	Yes
	2-6)	Yes
	2-7)	Yes
	3-21)	No
	3-22)	Yes
	3-23)	Yes
	3-24)	Yes
	3-25)	Yes
	4-7)	Yes
	4-8)	Yes
	6-4)	Yes
	6-5)	Yes
	7-8)	Yes
	7-9)	Yes
	7-10)	Yes

nexos

Technology Readiness Calculator TRL7 issues

SYSTEM TECHNOLOGY PROTOTYPE DEMO IN AN OPERATIONAL ENVIRONMENT

VII-1) Pressure tests with safety coefficient	(●) YES	(○) NO
VII-2) Temperature, vibration and other environment tests	(●) YES	(○) NO
VII-3) Interface with platform is validated	(●) YES	(○) NO
VII-4) Functional tests in simulated environment	(●) YES	(○) NO
VII-5) Functional tests at sea (short or shallow)	(●) YES	(○) NO
VII-6) Prototypical engineering scale equipment/process demonstrated in various environment conditions and various functional configurations, incl. testing safety functions?	(●) YES	(○) NO

Applicant Name:

Ifremer and nke

Comments

The condition of use are very difficult due to shocks on the fishing vessels. Limitation of measurement near the sea floor prevent from use on board benthic trawlers.

Technology Readiness Calculator TRL8 issues

SYSTEM TECHNOLOGY QUALIFIED THROUGH TEST AND DEMONSTRATION

	YES	NO
VIII-1) Tested in all environmental conditions	○	●
VIII-2) Manufacturing issues solved for several products	●	○
VIII-3) Several demonstrations performed	●	○
VIII-4) Operated by one end used at least	●	○
VIII-5) Commercial system available	●	○
VIII-6) Manufacturing and user documentation established	●	○

Applicant Name:
Ifremer and nke

Comments
Shock tests performed are the standard ones.

SYSTEM TECHNOLOGY QUALIFIED THROUGH SUCCESSFULL MISSION OPERATION		
IX-1) Experience in a full range of operating conditions	(●) YES	( ) NO
IX-2) Manufacturing performed for several contracts	( ) YES	(●) NO
IX-3) Operation by several end users	( ) YES	(●) NO
IX-4) Functional tests in simulated environment	(●) YES	( ) NO
IX-5) Several commercial contracts	( ) YES	(●) NO
IX-6) User group and/or FAQ and/or report/publication by user	( ) YES	(●) NO

Applicant Name:
Ifremer and nke

Comments
Unlike the other Recopesca probes used by several clients , the Temperature-Pressure-Turbidity have been operated by several shipsbut only through one contract with regional operational oceanography project Previmer.

Technology Readiness Calculator TRL9+ (not official, for the sake of NeXOS only)

SYSTEM TECHNOLOGY ACCEPTED IN A DEMANDING MARKET

		YES	NO
1)	Oil and gas	○	●
2)	Fisheries	●	○
3)	Defense	○	●
4)	Marine Renewables	○	●
5)		○	●
6)	Other	○	●

Applicant Name:

Ifremer and nke

Comments

Targeted industry is fishery. Other Recopesca components are already accepted. Temperature pressure turbidity is under evaluation still.

Appendix 2

Initial TRL of antifouling SnO_2

Technology Readiness Calculator (Page 1 of 7)

OVERALL SUMMARY OF TECHNOLOGY READINESS

		YES	NO
1-1)	Have the basic technology processes and principles been observed and reported?	◉	○
1-2)	Has an equipment and process concept been formulated?	◉	○
1-3)	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?	◉	○
1-4)	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?	◉	○
1-5)	Has bench-scale equipment/process testing been demonstrated in a relevant environment?	◉	○
1-6)	Has prototypical engineering scale equipment/process testing been demonstrated in relevant environment, incl. testing safety functions?	○	◉

Applicant Name:
NEXOS ANTIFOULING SNO2

Technology Readiness Calculator (Page 2 of 7)

MARKET AND CUSTOMER NEEDS

		YES	NO
2-1)	Know who cares about the technology (customer, funding source, etc.) (6)	◉	○
2-2)	Customer identified and expressed interest in the application (1,10)	◉	○
2-3)	Customer representative identified to work with development team and participates in requirements generation (11,12)	◉	○
2-4)	Overall system requirements for end user's application known and documented; performance metrics measuring reqt's established (6,7,8)	◉	○
2-5)	Requirements definition with performance thresholds and objectives established for final design (19)	○	◉
2-6)	Operating environment for final commercial system is known (4)	◉	○
2-7)	Analysis of project timing ensures technology will be available when required (13)	◉	○

Technology Readiness Calculator (Page 3 of 7)

DESIGN/DEVELOPMENT		
3-1) Physical laws and assumptions used in new technologies defined (2)	◉ YES	○ NO
3-2) Research hypothesis formulated (7)	◉ YES	○ NO
3-3) Know who would perform research and where it would be done (9)	◉ YES	○ NO
3-4) Theoretical or empirical design solution identified with basic elements of technology and initial analysis of major functions included (5,6,11,13)	◉ YES	○ NO
3-5) Potential system/components identified, performance predictions made for each; modeling/simulation only to verify physical properties (2,9,12)	◉ YES	○ NO
3-6) Qualitative idea of risk areas such as cost, schedule, performance (22)	◉ YES	○ NO
3-7) Know what output devices are available, capabilities and limitations of researchers and research facilities, and required experiments (17,19,21)	◉ YES	○ NO
3-8) Preliminary strategy to obtain TRL Level 6 developed (18)	◉ YES	○ NO
3-9) Preliminary system performance characteristics and measures identified and estimated (6)	◉ YES	○ NO
3-10) Science known to extent that mathematical and/or computer models and simulations are possible (5)	○ YES	◉ NO
3-11) Risk areas identified in general terms and risk mitigation strategies identified (24,25)	○ YES	◉ NO
3-12) Design techniques identified/developed; sources of key components for lab testing identified (15,21)	◉ YES	○ NO
3-13) Analysis of present state of the art shows technology fills a need (23)	◉ YES	○ NO
3-14) Scalable prototypes produced (bigger than lab scale) (15)	◉ YES	○ NO
3-15) Conceptual design developed and documented (16)	◉ YES	○ NO
3-16) Initial cost drivers identified (19)	◉ YES	○ NO
3-17) Formal risk management program initiated (21)	○ YES	◉ NO
3-18) Preliminary design engineering begins and prototypes of components created (4,7)	◉ YES	○ NO
3-19) Detailed design drawings completed to support engineering-scale system; ability to acquire all components for final prototype (18,22)	◉ YES	○ NO
3-20) Preliminary cost estimates of commercial product prepared	○ YES	◉ NO
3-21) Performance baseline including total project cost, schedule, and scope completed (6)	○ YES	◉ NO
3-22) Engineering-scale system is high-fidelity functional prototype of operational system (22)	○ YES	◉ NO
3-23) More precise cost estimates prepared for system	○ YES	◉ NO
3-24) Operating limits for components determined (7)	◉ YES	○ NO
3-25) System design specs are complete and ready for detailed design (20)	◉ YES	○ NO

Comments
NEXOS ANTIFOULING SNO2 - COST ESTIMATES ARE NOT YET FULLY ADDRESSED

Technology Readiness Calculator (Page 4 of 7)

INTEGRATION

		YES	NO
4-1)	Individual parts of the technology work (no real attempt at integration) (16)	◉	○
4-2)	Paper studies indicate that system components should work together (16)	◉	○
4-3)	Modeling and simulation used to simulate some components and interfaces; analysis completed to establish component compatability (5,12)	◉	○
4-4)	Available components assembled into lab scale system; integration studies have begun (10,20)	◉	○
4-5)	System interface issues and requirements known and relationships between major system and sub-systems understood on a lab scale with component	◉	○
4-6)	Integration of modules/functions demonstrated in lab/bench-scale environment (21)	◉	○
4-7)	At engineering scale, relationships between system and subsystems understood and component integration demonstrated (1,11)	◉	○
4-8)	Preliminary design drawings for final system complete (3)	○	◉

Technology Readiness Calculator (Page 5 of 7)

TESTING AND VALIDATION

		YES	NO
5-1)	Paper studies confirm basic principles; basic characterization data exists (3,4)	◉	○
5-2)	Initial scientific observations reported in journals/conference proceedings/technical reports (5,8)	◉	○
5-3)	Paper studies show application is feasible and components of technology have been partially characterized (3,8)	◉	○
5-4)	Rigorous analytical studies confirm basic principles; analytical results reported in scientific journals/conference technical reports (14,15)	◉	○
5-5)	Predictions of elements of technology capability validated by analytical studies, lab experiments, and modeling and simulation (3,7,10)	◉	○
5-6)	Lab experiments verify and fully demonstrate feasibility, but not yet at system components level (8, 9,22)	◉	○
5-7)	Individual components and subsystems composed of multiple components tested in lab (3,4)	◉	○
5-8)	Lab experiments in a controlled environment show components work together and demonstrate basic functionality in simulated environment (11,14,18)	◉	○
5-9)	Requirements for technology verification established and include testing and validation of safety functions (5)	◉	○
5-10)	Lab-scale tests using prototype completed and results validate the design; ready for test in relevant environment; lab environment for testing modified to approximate operational environment (9,11,16,27,32)	◉	○

Technology Readiness Calculator (Page 6 of 7)

ENVIRONMENTAL AND SAFETY			
6-1)	Key process and safety requirements and associated hazards have begun to be identified (2,14)	◉ YES	○ NO
6-2)	Key process variables fully identified, preliminary hazard evaluations completed/documented; safety control strategies being explored (1,31)	○ YES	◉ NO
6-3)	Range of all relevant physical and chemical properties determined to the extent possible (24)	◉ YES	○ NO
6-4)	Limits for process variables, parameters & safety controls defined; integration demos done incl. testing/validating safety functions (24,31)	◉ YES	○ NO
6-5)	Finalization of required hazardous material forms; identification of system/component level safety controls (26)	○ YES	◉ NO

Comments

AN HSE EVALUATION IS NEEDED FOR CHEMICALS PRODUCED DURING THE ELECTROCHEMICAL REACTIONS

MANUFACTURING AND SCALE UP		
7-1) Scaling studies have been started (19)	○ YES	◉ NO
7-2) Current manufacturability concepts assessed (20)	◉ YES	○ NO
7-3) Equipment scale-up relationships understood/accounted for in technology development; scaling designs completed (17,23)	○ YES	◉ NO
7-4) Key manufacturing processes identified and assessed in lab; mitigation strategies identified to address manuf/producibility shortfalls (22,24,27)	○ YES	◉ NO
7-5) Lab to engineering scale scale-up issues understood and resolved (30)	○ YES	◉ NO
7-6) Manufacturing processes to make components that are new are validated via demonstration in the lab (8)	◉ YES	○ NO
7-7) Manufacturing techniques have been defined to the point where largest problems are defined (10)	○ YES	◉ NO
7-8) Engineering to full-scale scale-up issues understood and resolved (29)	○ YES	◉ NO
7-9) Critical manufacturing processes have been prototyped and scaling issues that remain are identified and understood (12,16)	○ YES	◉ NO
7-10) Process and tooling are mature to support fabrication of system and components; at least one product demo has been completed (27,33)	○ YES	◉ NO

Comments

FOR CONFIDENTIALITY REASONS, THE SCALE UP OF SOME MANUFACTURING PROCESSES HAVE NOT BEEN ADRESSED YET

TRL Calculator Results

TRL	Questions Answered "Yes"	% Complete	Progress Towards Level
1)	7 of 7	100%	
2)	10 of 10	100%	
3)	10 of 13	77%	
4)	9 of 13	69%	
5)	9 of 13	69%	
6)	6 of 15	40%	

Detailed Results

By Question Section

1. General	1-1)	Yes
	1-2)	Yes
	1-3)	Yes
	1-4)	Yes
	1-5)	Yes
	1-6)	No
2. Market Need	2-1)	Yes
	2-2)	Yes
	2-3)	Yes
	2-4)	Yes
	2-5)	No
	2-6)	Yes
	2-7)	Yes
3. Design & Development	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	Yes
	3-9)	Yes
	3-10)	No
	3-11)	No
	3-12)	Yes
	3-13)	Yes
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	No
	3-18)	Yes
	3-19)	Yes
	3-20)	No
	3-21)	No
	3-22)	No
	3-23)	No
	3-24)	Yes
	3-25)	Yes
4. Integration	4-1)	Yes
	4-2)	Yes
	4-3)	Yes
	4-4)	Yes
	4-5)	Yes
	4-6)	Yes
	4-7)	Yes
	4-8)	No
5. Testing and Validation	5-1)	Yes
	5-2)	Yes
	5-3)	Yes
	5-4)	Yes
	5-5)	Yes
	5-6)	Yes
	5-7)	Yes
	5-8)	Yes
	5-9)	Yes
	5-10)	Yes
6. Safety	6-1)	Yes
	6-2)	No
	6-3)	Yes
	6-4)	Yes
	6-5)	No
7. Manufacturing & Scale	7-1)	No
	7-2)	Yes
	7-3)	No
	7-4)	No
	7-5)	No
	7-6)	Yes
	7-7)	No
	7-8)	No
	7-9)	No
	7-10)	No

By Technology Readiness Level

TRL 1	1-1)	Yes
	2-1)	Yes
	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	5-1)	Yes
	5-2)	Yes
TRL 2	1-2)	Yes
	2-2)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	Yes
	4-1)	Yes
	5-3)	Yes
	5-4)	Yes
TRL 3	1-3)	Yes
	2-3)	Yes
	3-9)	Yes
	3-10)	No
	3-11)	No
	3-12)	Yes
	3-13)	Yes
	4-2)	Yes
	5-5)	Yes
	5-6)	Yes
	6-1)	Yes
	7-1)	No
	7-2)	Yes
TRL 4	1-4)	Yes
	2-4)	Yes
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	No
	4-3)	Yes
	4-4)	Yes
	5-7)	Yes
	5-8)	Yes
	6-2)	No
	7-3)	No
	7-4)	No
TRL 5	1-5)	Yes
	2-5)	No
	3-18)	Yes
	3-19)	Yes
	3-20)	No
	4-5)	Yes
	4-6)	Yes
	6-3)	Yes
	7-5)	No
	7-6)	Yes
	7-7)	No
TRL 6	1-6)	No
	2-6)	Yes
	2-7)	Yes
	3-21)	No
	3-22)	No
	3-23)	No
	3-24)	Yes
	3-25)	Yes
	4-7)	Yes
	4-8)	No
	6-4)	Yes
	6-5)	No
	7-8)	No
	7-9)	No
	7-10)	No

Technology Readiness Calculator TRL7 issues

SYSTEM TECHNOLOGY PROTOTYPE DEMO IN AN OPERATIONAL ENVIRONMENT		
VII-1) Pressure tests with safety coefficient	○ YES	◉ NO
VII-2) Temperature, vibration and other environment tests	○ YES	◉ NO
VII-3) Interface with platform is validated	◉ YES	○ NO
VII-4) Functional tests in simulated environment	◉ YES	○ NO
VII-5) Functional tests at sea (short or shallow)	◉ YES	○ NO
VII-6) Prototypical engineering scale equipment/process demonstrated in various environment conditions and various functional configurations, incl. testing safety functions?	○ YES	◉ NO

Appendix 3

Initial TRL of Seadataview

TRL Calculator Results

TRL	Questions Answered "Yes"	% Complete	Progress Towards Level
1)	7 of 7	100%	
2)	9 of 10	90%	
3)	10 of 13	77%	
4)	9 of 13	69%	
5)	8 of 13	62%	
6)	6 of 15	40%	

Detailed Results

By Question Section

1. General	1-1)	Yes
	1-2)	Yes
	1-3)	Yes
	1-4)	Yes
	1-5)	Yes
	1-6)	Yes
2. Market Need	2-1)	Yes
	2-2)	Yes
	2-3)	No
	2-4)	No
	2-5)	Yes
	2-6)	Yes
	2-7)	Yes
3. Design & Development	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	Yes
	3-9)	Yes
	3-10)	Yes
	3-11)	No
	3-12)	Yes
	3-13)	Yes
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	No
	3-18)	No
	3-19)	No
	3-20)	Yes
	3-21)	No
	3-22)	No
	3-23)	No
	3-24)	Yes
	3-25)	No
4. Integration	4-1)	Yes
	4-2)	Yes
	4-3)	Yes
	4-4)	Yes
	4-5)	Yes
	4-6)	Yes
	4-7)	No
	4-8)	No
5. Testing and Validation	5-1)	Yes
	5-2)	Yes
	5-3)	Yes
	5-4)	No
	5-5)	No
	5-6)	Yes
	5-7)	Yes
	5-8)	No
	5-9)	No
	5-10)	No
6. Safety	6-1)	Yes
	6-2)	No
	6-3)	Yes
	6-4)	No
	6-5)	No
7. Manufacturing & Scale	7-1)	Yes
	7-2)	Yes
	7-3)	Yes
	7-4)	Yes
	7-5)	Yes
	7-6)	No
	7-7)	Yes
	7-8)	Yes
	7-9)	Yes
	7-10)	No

By Technology Readiness Level

TRL 1	1-1)	Yes
	2-1)	Yes
	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	5-1)	Yes
	5-2)	Yes
TRL 2	1-2)	Yes
	2-2)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	Yes
	4-1)	Yes
	5-3)	Yes
	5-4)	No
TRL 3	1-3)	Yes
	2-3)	No
	3-9)	Yes
	3-10)	Yes
	3-11)	No
	3-12)	Yes
	3-13)	Yes
	4-2)	Yes
	5-5)	No
	5-6)	Yes
	6-1)	Yes
	7-1)	Yes
	7-2)	Yes
TRL 4	1-4)	Yes
	2-4)	No
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	No
	4-3)	Yes
	4-4)	Yes
	5-7)	Yes
	5-8)	No
	6-2)	No
	7-3)	Yes
	7-4)	Yes
TRL 5	1-5)	Yes
	2-5)	Yes
	3-18)	No
	3-19)	No
	3-20)	Yes
	4-5)	Yes
	4-6)	Yes
	6-3)	Yes
	7-5)	Yes
	7-6)	No
	7-7)	Yes
TRL 6	1-6)	Yes
	2-6)	Yes
	2-7)	Yes
	3-21)	No
	3-22)	No
	3-23)	No
	3-24)	Yes
	3-25)	No
	4-7)	No
	4-8)	No
	6-4)	No
	6-5)	No
	7-8)	Yes
	7-9)	Yes
	7-10)	No

Appendix 4

Initial TRL of Arvor CM

OVERALL SUMMARY OF TECHNOLOGY READINESS		
1-1)	Have the basic technology processes and principles been observed and reported?	◉ YES ○ NO
1-2)	Has an equipment and process concept been formulated?	◉ YES ○ NO
1-3)	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?	◉ YES ○ NO
1-4)	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?	◉ YES ○ NO
1-5)	Has bench-scale equipment/process testing been demonstrated in a relevant environment?	◉ YES ○ NO
1-6)	Has prototypical engineering scale equipment/process testing been demonstrated in relevant environment, incl. testing safety functions?	◉ YES ○ NO

MARKET AND CUSTOMER NEEDS		
2-1)	Know who cares about the technology (customer, funding source, etc.) (6)	◉ YES ○ NO
2-2)	Customer identified and expressed interest in the application (1,10)	◉ YES ○ NO
2-3)	Customer representative identified to work with development team and participates in requirements generation (11,12)	◉ YES ○ NO
2-4)	Overall system requirements for end user's application known and documented; performance metrics measuring reqt's established (6,7,8)	○ YES ◉ NO
2-5)	Requirements definition with performance thresholds and objectives established for final design (19)	○ YES ◉ NO
2-6)	Operating environment for final commercial system is known (4)	◉ YES ○ NO
2-7)	Analysis of project timing ensures technology will be available when required (13)	◉ YES ○ NO

DESIGN/DEVELOPMENT		
3-1) Physical laws and assumptions used in new technologies defined (2)	◉ YES	○ NO
3-2) Research hypothesis formulated (7)	◉ YES	○ NO
3-3) Know who would perform research and where it would be done (9)	◉ YES	○ NO
3-4) Theoretical or empirical design solution identified with basic elements of technology and initial analysis of major functions included (5,6,11,13)	◉ YES	○ NO
3-5) Potential system/components identified, performance predictions made for each; modeling/simulation only to verify physical properties (2,9,12)	◉ YES	○ NO
3-6) Qualitative idea of risk areas such as cost, schedule, performance (22)	◉ YES	○ NO
3-7) Know what output devices are available, capabilities and limitations of researchers and research facilities, and required experiments (17,19,21)	◉ YES	○ NO
3-8) Preliminary strategy to obtain TRL Level 6 developed (18)	○ YES	◉ NO
3-9) Preliminary system performance characteristics and measures identified and estimated (6)	◉ YES	○ NO
3-10) Science known to extent that mathematical and/or computer models and simulations are possible (5)	◉ YES	○ NO
3-11) Risk areas identified in general terms and risk mitigation strategies identified (24,25)	○ YES	◉ NO
3-12) Design techniques identified/developed; sources of key components for lab testing identified (15,21)	◉ YES	○ NO
3-13) Analysis of present state of the art shows technology fills a need (23)	◉ YES	○ NO
3-14) Scalable prototypes produced (bigger than lab scale) (15)	◉ YES	○ NO
3-15) Conceptual design developed and documented (16)	◉ YES	○ NO
3-16) Initial cost drivers identified (19)	◉ YES	○ NO
3-17) Formal risk management program initiated (21)	○ YES	◉ NO
3-18) Preliminary design engineering begins and prototypes of components created (4,7)	◉ YES	○ NO
3-19) Detailed design drawings completed to support engineering-scale system; ability to acquire all components for final prototype (18,22)	◉ YES	○ NO
3-20) Preliminary cost estimates of commercial product prepared	◉ YES	○ NO
3-21) Performance baseline including total project cost, schedule, and scope completed (6)	○ YES	◉ NO
3-22) Engineering-scale system is high-fidelity functional prototype of operational system (22)	○ YES	◉ NO
3-23) More precise cost estimates prepared for system	◉ YES	○ NO
3-24) Operating limits for components determined (7)	◉ YES	○ NO
3-25) System design specs are complete and ready for detailed design (20)	◉ YES	○ NO

INTEGRATION		
4-1)	Individual parts of the technology work (no real attempt at integration) (16)	◉ YES ○ NO
4-2)	Paper studies indicate that system components should work together (16)	◉ YES ○ NO
4-3)	Modeling and simulation used to simulate some components and interfaces; analysis completed to establish component compatability (5,12)	◉ YES ○ NO
4-4)	Available components assembled into lab scale system; integration studies have begun (10,20)	◉ YES ○ NO
4-5)	System interface issues and requirements known and relationships between major system and sub-systems understood on a lab scale with component	◉ YES ○ NO
4-6)	Integration of modules/functions demonstrated in lab/bench-scale environment (21)	◉ YES ○ NO
4-7)	At engineering scale, relationships between system and subsystems understood and component integration demonstrated (1,11)	◉ YES ○ NO
4-8)	Preliminary design drawings for final system complete (3)	◉ YES ○ NO

TESTING AND VALIDATION		
5-1)	Paper studies confirm basic principles; basic characterization data exists (3,4)	◉ YES ○ NO
5-2)	Initial scientific observations reported in journals/conference proceedings/technical reports (5,8)	◉ YES ○ NO
5-3)	Paper studies show application is feasible and components of technology have been partially characterized (3,8)	◉ YES ○ NO
5-4)	Rigorous analytical studies confirm basic principles; analytical results reported in scientific journals/conference technical reports (14,15)	◉ YES ○ NO
5-5)	Predictions of elements of technology capability validated by analytical studies, lab experiments, and modeling and simulation (3,7,10)	◉ YES ○ NO
5-6)	Lab experiments verify and fully demonstrate feasibility, but not yet at system components level (8, 9,22)	◉ YES ○ NO
5-7)	Individual components and subsystems composed of multiple components tested in lab (3,4)	◉ YES ○ NO
5-8)	Lab experiments in a controlled environment show components work together and demonstrate basic functionality in simulated environment (11,14,18)	◉ YES ○ NO
5-9)	Requirements for technology verification established and include testing and validation of safety functions (5)	◉ YES ○ NO
5-10)	Lab-scale tests using prototype completed and results validate the design; ready for test in relevant environment; lab environment for testing modified to approximate operational environment (9,11,16,27,32)	◉ YES ○ NO

ENVIRONMENTAL AND SAFETY		
6-1)	Key process and safety requirements and associated hazards have begun to be identified (2,14)	◉ YES ○ NO
6-2)	Key process variables fully identified, preliminary hazard evaluations completed/documented; safety control strategies being explored (1,31)	◉ YES ○ NO
6-3)	Range of all relevant physical and chemical properties determined to the extent possible (24)	◉ YES ○ NO
6-4)	Limits for process variables, parameters & safety controls defined; integration demos done incl. testing/validating safety functions (24,31)	◉ YES ○ NO
6-5)	Finalization of required hazardous material forms; identification of system/component level safety controls (26)	○ YES ◉ NO

Technology Readiness Calculator (Page 7 of 7)

MANUFACTURING AND SCALE UP		
7-1)	Scaling studies have been started (19)	◉ YES ○ NO
7-2)	Current manufacturability concepts assessed (20)	◉ YES ○ NO
7-3)	Equipment scale-up relationships understood/accounted for in technology development; scaling designs completed (17,23)	◉ YES ○ NO
7-4)	Key manufacturing processes identified and assessed in lab; mitigation strategies identified to address manuf/producibility shortfalls (22,24,27)	◉ YES ○ NO
7-5)	Lab to engineering scale scale-up issues understood and resolved (30)	◉ YES ○ NO
7-6)	Manufacturing processes to make components that are new are validated via demonstration in the lab (8)	◉ YES ○ NO
7-7)	Manufacturing techniques have been defined to the point where largest problems are defined (10)	◉ YES ○ NO
7-8)	Engineering to full-scale scale-up issues understood and resolved (29)	◉ YES ○ NO
7-9)	Critical manufacturing processes have been prototyped and scaling issues that remain are identified and understood (12,16)	◉ YES ○ NO
7-10)	Process and tooling are mature to support fabrication of system and components; at least one product demo has been completed (27,33)	◉ YES ○ NO

TRL Calculator Results

TRL	Questions Answered "Yes"			% Complete	Progress Towards Level
1)	7	of	7	100%	
2)	9	of	10	90%	
3)	12	of	13	92%	
4)	11	of	13	85%	
5)	12	of	13	92%	
6)	12	of	15	80%	

Detailed Results

By Question Section

1. General	1-1)	Yes
	1-2)	Yes
	1-3)	Yes
	1-4)	Yes
	1-5)	Yes
	1-6)	Yes
2. Market Need	2-1)	Yes
	2-2)	Yes
	2-3)	Yes
	2-4)	No
	2-5)	No
	2-6)	Yes
	2-7)	Yes
3. Design & Development	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	No
	3-9)	Yes
	3-10)	Yes
	3-11)	No
	3-12)	Yes
	3-13)	Yes
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	No
	3-18)	Yes
	3-19)	Yes
	3-20)	Yes
	3-21)	No
	3-22)	No
	3-23)	Yes
	3-24)	Yes
	3-25)	Yes
4. Integration	4-1)	Yes
	4-2)	Yes
	4-3)	Yes
	4-4)	Yes
	4-5)	Yes
	4-6)	Yes
	4-7)	Yes
	4-8)	Yes
5. Testing and Validation	5-1)	Yes
	5-2)	Yes
	5-3)	Yes
	5-4)	Yes
	5-5)	Yes
	5-6)	Yes
	5-7)	Yes
	5-8)	Yes
	5-9)	Yes
	5-10)	Yes
6. Safety	6-1)	Yes
	6-2)	Yes
	6-3)	Yes
	6-4)	Yes
	6-5)	No
7. Manufacturing & Scale	7-1)	Yes
	7-2)	Yes
	7-3)	Yes
	7-4)	Yes
	7-5)	Yes
	7-6)	Yes
	7-7)	Yes
	7-8)	Yes
	7-9)	Yes
	7-10)	Yes

By Technology Readiness Level

TRL 1	1-1)	Yes
	2-1)	Yes
	3-1)	Yes
	3-2)	Yes
	3-3)	Yes
	5-1)	Yes
	5-2)	Yes
TRL 2	1-2)	Yes
	2-2)	Yes
	3-4)	Yes
	3-5)	Yes
	3-6)	Yes
	3-7)	Yes
	3-8)	No
	4-1)	Yes
	5-3)	Yes
	5-4)	Yes
TRL 3	1-3)	Yes
	2-3)	Yes
	3-9)	Yes
	3-10)	Yes
	3-11)	No
	3-12)	Yes
	3-13)	Yes
	4-2)	Yes
	5-5)	Yes
	5-6)	Yes
	6-1)	Yes
	7-1)	Yes
	7-2)	Yes
TRL 4	1-4)	Yes
	2-4)	No
	3-14)	Yes
	3-15)	Yes
	3-16)	Yes
	3-17)	No
	4-3)	Yes
	4-4)	Yes
	5-7)	Yes
	5-8)	Yes
	6-2)	Yes
	7-3)	Yes
	7-4)	Yes
TRL 5	1-5)	Yes
	2-5)	No
	3-18)	Yes
	3-19)	Yes
	3-20)	Yes
	4-5)	Yes
	4-6)	Yes
	6-3)	Yes
	7-5)	Yes
	7-6)	Yes
	7-7)	Yes
TRL 6	1-6)	Yes
	2-6)	Yes
	2-7)	Yes
	3-21)	No
	3-22)	No
	3-23)	Yes
	3-24)	Yes
	3-25)	Yes
	4-7)	Yes
	4-8)	Yes
	6-4)	Yes
	6-5)	No
	7-8)	Yes
	7-9)	Yes
	7-10)	Yes

Technology Readiness Calculator TRL7 issues

SYSTEM TECHNOLOGY PROTOTYPE DEMO IN AN OPERATIONAL ENVIRONMENT

	YES	NO
VII-1) Pressure tests with safety coefficient	◉	○
VII-2) Temperature, vibration and other environment tests	○	◉
VII-3) Interface with platform is validated	◉	○
VII-4) Functional tests in simulated environment	◉	○
VII-5) Functional tests at sea (short or shallow)	○	◉
VII-6) Prototypical engineering scale equipment/process demonstrated in various environment conditions and various functional configurations, incl. testing safety functions?	○	◉

Technology Readiness Calculator TRL8 issues

SYSTEM TECHNOLOGY QUALIFIED THROUGH TEST AND DEMONSTRATION

	YES	NO
VIII-1) Tested in all environmental conditions	○	◉
VIII-2) Manufacturing issues solved for several products	◉	○
VIII-3) Several demonstrations performed	○	◉
VIII-4) Operated by one end used at least	○	◉
VIII-5) Commercial system available	○	◉
VIII-6) Manufacturing and user documentation established	◉	○

Technology Readiness Calculator TRL9 issues

SYSTEM TECHNOLOGY QUALIFIED THROUGH SUCCESSFULL MISSION OPERATION		
IX-1) Experience in a full range of operating conditions	○ YES	◉ NO
IX-2) Manufacturing performed for several contracts	○ YES	◉ NO
IX-3) Operation by several end users	○ YES	◉ NO
IX-4) Functional tests in simulated environment	◉ YES	○ NO
IX-5) Several commercial contracts	○ YES	◉ NO
IX-6) User group and/or FAQ and/or report/publication by user	○ YES	◉ NO