1.0 Purpose

The following is a document that discusses the proposed TRL levels for the Water and Equipment Policy Center – I/UCRC located in Wisconsin (U. Wisconsin, Milwaukee, and Marquette University). This document is currently a draft document, for review by other industrial members.

The WEP IUCRC has asked Professors / Principal Investigators to include a Technology Readiness Level designation in their proposals. However, over the last few months, it has been clear that the TRL levels are not well understood.

2.0 Introduction

The Technology Readiness Level (TRL) Assessment (TRA) was proposed and used by many government entities to conduct appropriate critical decisions. The TRA is typically used to understand and evaluate technologies that are being evaluated for use in large capital projects. While the term "technology" is used, the TRL is typically used for an engineered system. The use of TRL's and TRA's at the Department of Energy (DOE) was recently integrated into their programs. The DOE uses TRLs and TRAs to prevent the purchase of technologies that are not fully tested and proven in real-world applications. In the past, several technologies were purchased and utilized that required substantial re-working and additional investment to make them viable for use.

The WEP Program would like PIs to self-assign TRLs to their technologies to better inform the industrial members on the progress of research. The TRLs serve as a "stage-gate" approach to funding for WEP.

3.0 Overall TRL Guide

The guide presented below is a general overview of the IAB's expectations for TRL. Detailed descriptions will be presented in Section 4. This was adapted from: *Technology Readiness Assessment Guide. Department of Energy. DOE G 431.3-4A September 15, 2011.*

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description of a Technology that has achieved the TRL Level	Technology Scale	Organization Expectation
Technology Commercialized and Operating	TRL 9	**Commercial Deployment** Technology is being sold as part of a final product and operated over the full range of expected conditions.	Actual operation of the technology in final, optimized form and conditions.	Full	Industry
Technology Commissioning	TRL 8	**Commercial Demonstration** Technology fully integrated with product or product process. Qualified through final validation testing.	Technology has been proven successful as part of final product/ process. Optimization of the product complete. Commissioning includes variation of conditions.	Full	Industry
	TRL 7	**Commercial Transition** Technology demonstrated at full-scale as separate component or subsystem. Demonstrated in actual conditions.	Prototype of the full-scale system. Requires demonstration of actual system in environment. Demonstrated technology which needs integration and possible optimization.	Full	Industry
Technology Demonstration	TRL 6	**Viability Demonstration** Technology demonstration as a model or proto-type in relevant environment. In process of being transferred to industrial partner.	Technology IP is completed and transfer of all knowledge and technology to industrial partner is completed. Technology tested in actual or relevant environment.	Engineering / Pilot	Industry with minor academic consultation
Technology Development	TRL 5	**Technology Development** Technology is used in a laboratory-scale form and exposed to relevant or actual conditions. Technology optimized on small scale.	Basic technology is well understood by PI and limitations known. The technology is utilized in prototype or final form but may need optimization for higher scales. Optimization of the technology in the system / form should be completed.	Laboratory	Academia with industrial collaboration
	TRL 4	**Lab Scale Development** Individual component validation in laboratory environment.	Technology is shown to achieve goals in laboratory, typically in a non-representative environment. Some components have been integrated for initial testing	Laboratory	Academia with minor industrial collaboration
	TRL 3	**Feasibility Demonstration** Initial proof of concept testing regarding initial technology components	Initial development of technology has been completed. Basic components of the technology are well understood.	Laboratory	Academia
Basic Technology Research	TRL 2	**Development of Technology Application** Technology concept and or application formulated.	Intellectual property is developed to bring a solution to a challenge.	Paper Studies	Academia
	TRL 1	**Literature Search** Technological challenge evaluated.	General understanding of the principles surrounding the technological challenge.	Paper Studies	Industry describes challenge, academics rephrase challenges to develop solutions.

BLUE Highlights represent the expectation from IAB for WEP TRLs. Project proposals for WEP should be at a minimum of TRL-2 and a Maximum of TRL 5. Projects considered for second rounds of funding may include TRL-6 to finalize technology transfer.

4.0 Detailed TRL Explanation

Until a technology readiness assessment has been made, the technology is in the TRL and has not *achieved* the TRL. In order to achieve the TRL, an assessment documenting all of the deliverables must be completed.

TRL 1 and TRL 2 are paper studies. From the DOE perspective, it is a down-selection of technologies. Since WEP is developing technologies, it makes sense to redefine these to include literature and IP reviews.

As WEP should be focused on early non-competitive research, the heart of WEP will be laboratory studies focusing on TRL 3, 4 and 5.

TRL 6, 7, 8 and 9 all center around operational scales of systems. In general, there are some cases in which the PI may be able to achieve TRL 6. However, it is probably not best as TRL 6 should be considered a "competitive technology" level. For example, a sensor could be developed, prototyped and run in an engineering scale. But for the tests to be conducted in a relative environment, we would expect to see significant collaboration by industry.

4.1 TRL-1

Technology Readiness Level 1 is about understanding the challenge for the industry. Often the challenge is not presented in the right way. For example, someone could say "selenium removal is a problem in our industry." While this statement is correct, the technical basis is not even partially articulated. TRL 1 should be broad but should consider technological basics.

To achieve a TRL of 1 the following must be accomplished:

1. The technological challenge must be defined. Propose that this challenge is defined by the IAB in the form of an RFP.
2. The PI should conduct a literature search looking, in general, about how the challenge is being treated. The PI should be able to answer the following questions: what are the key aspects of the technical problem? What general solutions have been attempted? What technologies failed to address this situation and why did those technologies fail?
3. The PI should be able to categorize solutions in broad strokes:

   Example: The treatment of arsenic has been addressed by three general categories of technologies:

   1. Biological Treatment
   2. Sorption
      a. Ion exchange
      b. Adsorption
   3. Co-precipitation and filtration
4. The following Table is suggested to be filled out by the PI in their general overview:

Environment	Challenges	Requirements	Current Solutions

Example:

Environment	Challenges	Requirements	Current Solutions
As in Drinking Water	Si, V, P contamination	< 5 ppb (US EPA)	Adsorption by X Reverse Osmosis NF
As in industrial waste water	High pH environment	< 5 ppb	Adsorption by X Reverse Osmosis NF

EXPECTATION:

The expectation is that TRL be completed before any proposals. It would be expected that this would take up between 2-3 weeks of time.

4.2 TRL-2

TRL-2: Technology Readiness Level 2 is about determining a potential solution. This is where the "invention" begins. Once the basic challenges are better understood and the other technologies are known on a high level, the PI must understand and use their expertise to come up with a solution. The PI should narrow down the potential projects and develop a proposal to address the concerns listed in the RFP.

To achieve a TRL of 2 the following must be accomplished:

1. Complete a detailed literature review document. If no review in the last 5 years is available, the PI may want to consider publishing the review document. The document should be the basis for the introduction and references in the proposal.
2. Complete a preliminary IP Review. While this should be included in the literature review, listing this separately underscores the importance of the IP review. The IP review will provide a basis for completing other tasks in this list. Suggest using SciFinder or Google Patents / Scholar.
    i. Who has patents in this field, are they continuing to patent?
    ii. What patents are expired and allow us to practice without a license?

iii. What holes are there in the current IP that may allow us to patent.

3. Form a clear and definite hypothesis that could be tested and evaluated.
4. File an Invention Disclosure on the conception of the invention.

Example: The use of zeolites coated with chalcogenides, or chalcogenide complexes, will increase the capacity of the zeolite to remove lead by 20% or higher. This zeolite will have a total capacity greater than or equal to current market-available products.

5. Create and submit the proposal for WEP

EXPECTATION:

The expectation is that TRL be completed as part of the proposal. If the TRL of 2 is not met, then it is unlikely that a proposal will be accepted. It is expected that to achieve a TRL of 2 should take between 2-3 months.

4.3 TRL-3

Technology Readiness Level 3 is about executing critical functions of the technology in the laboratory. This TRL should address proof of concept principles. "Can we make what we set out to make?". From the current knowledge set, is it feasible to validate this product?

Example:

For media development, there are three main considerations to be made:

1) Scale of the media development
2) Contaminant of Concern (or family of concern) (COC)
3) Introduction into a system

If the proposal is centered around a new media to remove a contaminant, then TRL-3 should truly be concerned with the development of the new media as a critical component of the technology. Optimization is not considered here, nor is the testing of the material for a COC.

To achieve a TRL of 3 the following must be accomplished:

1. Complete synthetic reactions
   a. Confirm no IP infringement
   b. Determine yield
2. Fully characterize the Physical Properties of the media
   a. Composition by ICP-MS, XRD or EDS
   b. Crystallinity by PXRF and XRD
   c. Particle Size by PSD Analysis
   d. Thermal Stability by TGA, DTA and DSC, followed by PXRD
   e. Surface Area Analysis – BET
   f. Pore Volume - Porosimeter
   g. Density – lbs/ft^3

h. Band-gap analysis by Solid-state UV-Vis
i. Surface functionalization by IR/Raman

3. IP Search / Disclosure based on the formulation of a new state of matter
4. Literature update

EXPECTATION:

This is a significant portion of the work that must be completed. This may constitute between 3 months to 1 year of testing, depending on the type of synthesis / development / project.

4.4 TRL-4

Technology Readiness Level 4 is about critical validation of the technological components. This TRL should further address proof of concept principles but extend into validation of the hypothesis. "Does our technology do what it is supposed to do in a simplified environment?"

From a media perspective, TRL 4 should concentrate on the critical information that is needed for validation. Mainly – does this media remove the contaminants, and if so – quantify the values.

To achieve a TRL of 4 the following must be accomplished:

1. Theoretical vs Actual Capacity should be evaluated
   a. Complete isotherms (one component) for each of the contaminants of concern (COC)
2. Complete a selectivity list and determine selectivity / separation factors

Example: Sr>> Cs> K>NH_4>Mg>Ca>Na

3. Complete Kinetic studies; determine the reaction order, 1^{st}, 2^{nd}, pseudo-first…
4. Determine the number and types of sites

Example: 2 sites – one specific for Sr, the other specific for Cs. Site A constitutes 80% of the number of sites, Site B, 20%.

5. Determine post-sorption characteristics
   a. Composition, crystallinity, thermal, IR/Ramen
6. Determine stability in varying pHs, water, solvents.
7. Begin developing / formulating simulants and justify
8. Update IP with findings
9. Update literature

EXPECTATION:

This is a significant portion of the work that must be completed. This may constitute between 3 months to 2 years of testing, depending on several factors.

4.5 TRL-5

Technology Readiness Level 5 is about critical validation of the technological components in real systems. Optimization and scale up of the media /technology. This TRL should expand the basic principles to include engineering information. How the technology will work on a larger scale and in real-world conditions. “Does the system, product or process meet expectations in simulated to real environments?”.

From a media perspective, TRL 5 will be split into two sections. 1) Scale up of the media to larger quantities. From 0 lbs to 1 ft^3. 2) Further validation testing, but in challenging conditions to being to optimize the media / system.

To achieve a TRL of 5 the following must be accomplished:

1. Scale the media from laboratory scale to engineering /pilot scale. The goal is to make enough media that an engineering scale project can be initiated in TRL-6
2. Conduct Testing in relevant environments
    a. Actual waste water or high-fidelity simulants
    b. Isotherm w/ above – compare to original
    c. Kinetics w/ above – compare to original
    d. Initiate column testing w/ above solutions
        i. Optimize space velocity, linear velocity, aspect ratio and other key parameters
        ii. Compare the capacity of the column test with the isotherm test
    e. Attempt reversibility using different methods
        i. Check characterization after regeneration
3. Determine preliminary cost information
4. Determine if media performance can be enhanced by formulation changes
5. Design a strategy for Optimization / Plan
6. Complete IP Update
7. Complete Literature update
8. Transfer knowledge to Industry Teams (Individual Companies)

EXPECTATION:

This is a significant portion of the work that must be completed. This may constitute between 8 months to 2 years of testing, depending on several factors. Product, process or system should begin transitioning to industry.

4.6 TRL-6

Technology Readiness Level 6 is about conducting testing of the technology in relative / actual environments at the $1/10^{th}$ (Engineering) scale or pilot scale. “Can the system be scaled appropriately and achieve goals”?

It is expected that most of the technology transfer to companies / other entities should have occurred by this point. A one-on-one relationship between the PI and separate industrial

members should begin. TRL 6 represents the take-over of industrial professionals in relationship with actual client interactions.

Example: to achieve a TRL of 6 in a media-development project the following must be accomplished:

1. Scale up to commercial quantities (1 ft^3 to 1000 + ft^3).
2. Media installed into a system
   a. Breakthrough evaluated vs previous tests
3. Finalized cost information
4. Known-unknowns completely addressed.
5. Achievement of technical goals
6. Tech transfer to sales / industry completed
7. Final IP filed and completed
8. Evaluation of system performance at scale completed.

EXPECTATION:

The PI will have a significantly reduced role in this aspect. While consultation may occur for scale-up and other issues that arise, the technology transfer should be well at hand.

4.7 TRL-7

- Full scale in relative /actual environments. “Can system be scaled, and goals achieved?”. This must be completed with real waste

4.8 TRL-8

- Full scale system in actual environments
  - Commissioning completed
  - Cold Testing Completed
  - Hot Testing moves from ongoing to completed

4.9 TRL-9

- Full system operation