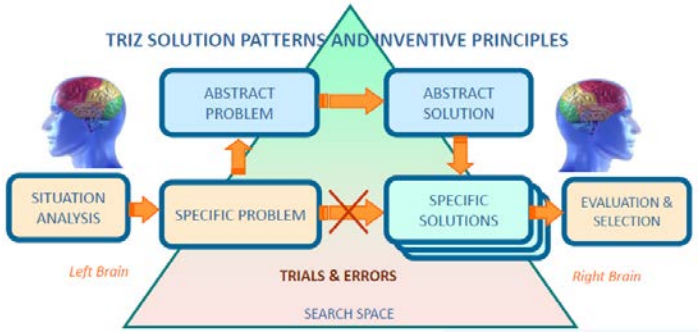
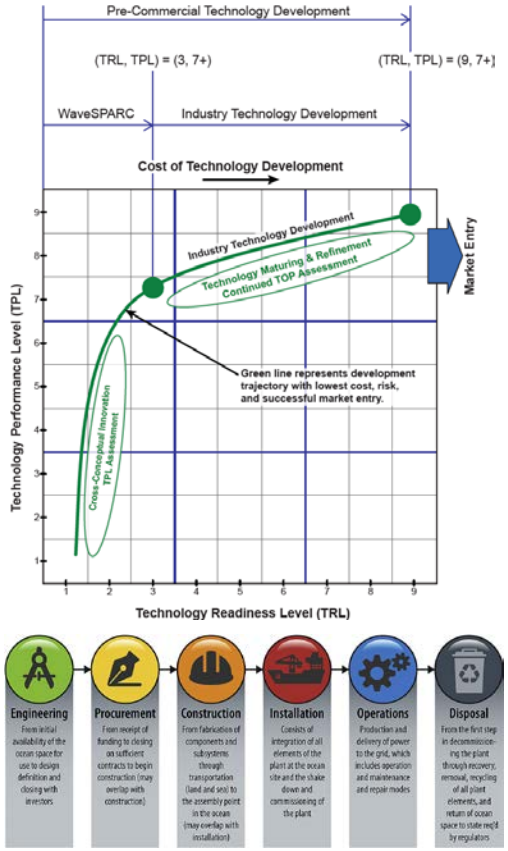
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





Wave-SPARC

Systematic Process and Analysis for Reaching Commercialization

2.2.1.402

Marine and Hydrokinetics Program

9 October 2019

Jochem Weber & Jesse Roberts

National Renewable Energy Laboratory
Sandia National Laboratories

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

The core objective of WaveSPARC is empowering the marine energy community with the tools necessary to achieve a significant improvement in techno-economic performance of wave generated grid power. A detailed systems engineering approach simultaneously balances around 100 cost and performance drivers (functional requirements and capabilities) for wave energy converters (WECs). This holistic approach is crucial for unlocking the vast wave energy opportunity.

Publicly accessible technology innovation and assessment methods and tools (new to the wave energy sector) have been delivered. These tools are used to identify potential novel, high-promise WEC concepts for further exploration, development, and commercialization. Leveraging these tools, WEC techno-economic performance increases can be realized through the implementation of the technology development trajectories with the lowest possible cost, schedule, and risk mitigation at the earliest stages of development (see right figure on cover page) [1,2,3] with role of WaveSPARC.

Future efforts will expand WaveSPARC capability to the various Powering the Blue Economy maritime markets (e.g. ocean observation, AUV recharge, desalination

Project Objective & Impact

The major goals and objectives of WaveSPARC regarding priority, investment and impact are:

1. Invention, assessment, identification, verification and validation of novel and high techno-economic-potential WEC technology concepts to **deliver high-confidence "seeds"** for subsequent industrial development to full commercial application and economic viability
2. Development and delivery of WEC technology **innovation and assessment methodologies and tools** and provision of these as services and for free use by industry and the entire sector
3. **International collaboration** for global best practice alignment of assessment and innovation methods

All of the above elements are essential to accomplishing the implementation of technology development trajectory with reduced development cost, time and risk and increasing success by first aiming for high TPL prior to maturing the technology the TRLs, while maintaining high TPL in order to achieve market entry requirements at TRL9 and TPL7 or higher. This is implemented through the provision of the final project products: innovation of high-confidence "seeds" for commercial development by industry, and the development, application and provision of technology innovation and assessment tools. The project has extensive national and global impactful and strong potential of significantly advancing the state-of-the art by applying the internally developed and internationally recognized best approach to early stage technology development through full maturity. WaveSPARC has been collaborating with an international project portfolio of over €25 million. Over 500 TPL assessment applications are estimated since its first release providing empowerment across the sector. It has the potential to bring about a step change in techno-economic performance and technology advancement through structured techniques of innovation, development of effective tools and methods.

Project Information

Project Principal Investigator(s)

Jochem Weber, Chief Engineer
Jesse Roberts, Principal Scientist, Sandia

WPTO Lead

Bill McShane

Project Partners/Subs

Wave Venture, Sub
Ramboll, SUb
Black & Veatch, Sub
Xodus, Sub
EMEC & Central Nantes, Collaborator

Project Duration

Start Date: 1 October 2014
Project End Date: 30 September 2023

Alignment with the Program

Marine and Hydrokinetics (MHK) Program Strategic Approaches

Data Sharing and Analysis

- Foundational and Crosscutting R&D
- Technology-Specific Design and Validation
- Reducing Barriers to Testing

Alignment with the MHK Program

Foundational and Crosscutting R&D

- Drive innovation in components, controls, manufacturing, materials and systems with early-stage R&D specific to MHK applications
- Develop, improve, and validate numerical and experimental tools and methodologies needed to improve understanding of important fluid-structure interactions
- Improve MHK resource assessments and characterizations needed to optimize devices and arrays, and understand extreme conditions
- Collaboratively develop and apply quantitative metrics to identify and advance technologies with high ultimate techno-economic potential for their market applications

- WaveSPARC develops, applies and refines **technology assessment and innovation methodologies** and delivers these and innovative technology concept solutions to the MHK industry for use and for full development and commercialization.
- It drives **innovation** at farm systems, device and sub-system levels in all of the above-mentioned areas and beyond.

Alignment with the MHK Program

Foundational and Crosscutting R&D

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- WaveSPARC develops and applies holistic and **quantitative techno-economic assessment metric systems** to identify technology weaknesses and strengths, ultimately to advance technology **towards their markets applications.**
- The TPL systems are current focused on continental grid markets but can and will be adapted to all other focus markets under **Powering the Blue Economy**

Alignment with the MHK Program

Technology-Specific Design and Validation

- Validate performance and reliability of systems by conducting in-water tests of industry-designed prototypes at multiple relevant scales
- Improve methods for safe and cost efficient installation, grid integration, operations, monitoring, maintenance, and decommissioning of MHK technologies
- Support the development and adoption of international standards for device performance and insurance certification
- Evaluate current and potential future needs for MHK-specific IO&M infrastructure (vessels, port facilities, etc.) and possible approaches to bridge gaps

- WaveSPARC **supports the validation of performance** and of reliability of systems that are being tested in open waters by **retiring critical risks prior to in-water testing**, through detailed technology assessment and early stage tank testing.
- This de-risking approach is applicable to all WEC systems that are currently under development and to the novel systems invented in the project.

Alignment with the MHK Program

Technology-Specific Design and Validation

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- Support the development and adoption of international standards for device performance and insurance certification
- Evaluate current and potential future needs for MHK-specific IO&M infrastructure (vessels, port facilities, etc.) and possible approaches to bridge gaps

- WaveSPARC, through the holistic TPL assessment methodology, **considers all cost and performance drivers** of the complete wave farm system over its lifecycle.

Alignment with the MHK Program

Technology-Specific Design and Validation

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- Support the development and adoption of international standards for device performance and insurance certification
- Evaluate current and potential future needs for MHK-specific IO&M infrastructure (vessels, port facilities, etc.) and possible approaches to bridge gaps

- The WaveSPARC team actively contributes to a large number of **international collaborations**, EU or global projects on technology assessment, metrics development, innovation techniques, and is a key contributor to international standards and collaboration including IEA-OES.

Project Budget

Lab	FY17 (Q1 to Q4)	FY18 (Q1 to Q4)	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Lab	Costed	Costed	Costed	Total Costed	Total Authorized
NREL	[$600K]	[$806K]	[$288K]	[$1,694K]	[$2,500K]
Sandia	[$666K]	[$668K]	[$350K]	[$1,684K]	[$2,366K]
TOTAL	[$1,266K]	[$1,474K]	[$638K]	[$3,378K]	[$4,866K]

- Significant increase in staff and team members in WaveSPARC in Q3 and Q4 of FY19 has shown noticeable increase in project expenditures as increased staff involvement and research are being conducted.
- Current expenditures are in pace with authorized budget.

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

Wave Venture

RAMBOLL

BLACK & VEATCH

DNV·GL

Management and Technical Approach

Summarized Research Questions:

- What are the core learnings from two eras of wave energy technology development regarding the development methodology and what is the best possible, **most effective and efficient technology development** trajectory?
- How can such development trajectories be implemented and what **methods and tools** are required?
- How can labs develop the required methodology and tools and initiate such technology development and **provide both, tools and high potential technology concepts** to the U.S. industry for use and full development to achieve economic and commercial deployment with success for the industry and the sector as whole?

Summarized Technical Approach:

- **Analyze** strengths, weakness and learnings of technology development since the 1970s and identify best technology development trajectory regarding cost, time, risks and success. Identify methodological flaws and required improvements.
- **Develop**, test and apply the required methods and tools. These include:
  - Formulate complete and agnostic set of functional requirements and capabilities for wave energy farms.
  - Develop realistic and effective technology assessment methodology and tools, applicable at all TRLs.
  - Identify and apply the most potent and promising structured inventive techniques.
- Engage and **deliver** to industry and sector
  - All assessment and innovation methodologies and tools as service to and internal use by industry.
  - All invented high potential WEC system and subsystem solutions to industry with easy and non-exclusive access.

Summarized Management Approach:

- Deliver project with world class team of experts from labs and subcontractors.
- Maintain closed engagement with DOE, Marine Energy Council, industry and users.
- Disseminate project approach, progress and outcome continuous via publications, conferences, workshops.
- Provide free services to industry applying and deploying the developed tools with mutual benefit and learning.
- Develop, maintain domestic and international collaboration for dissemination, learning and global alignment

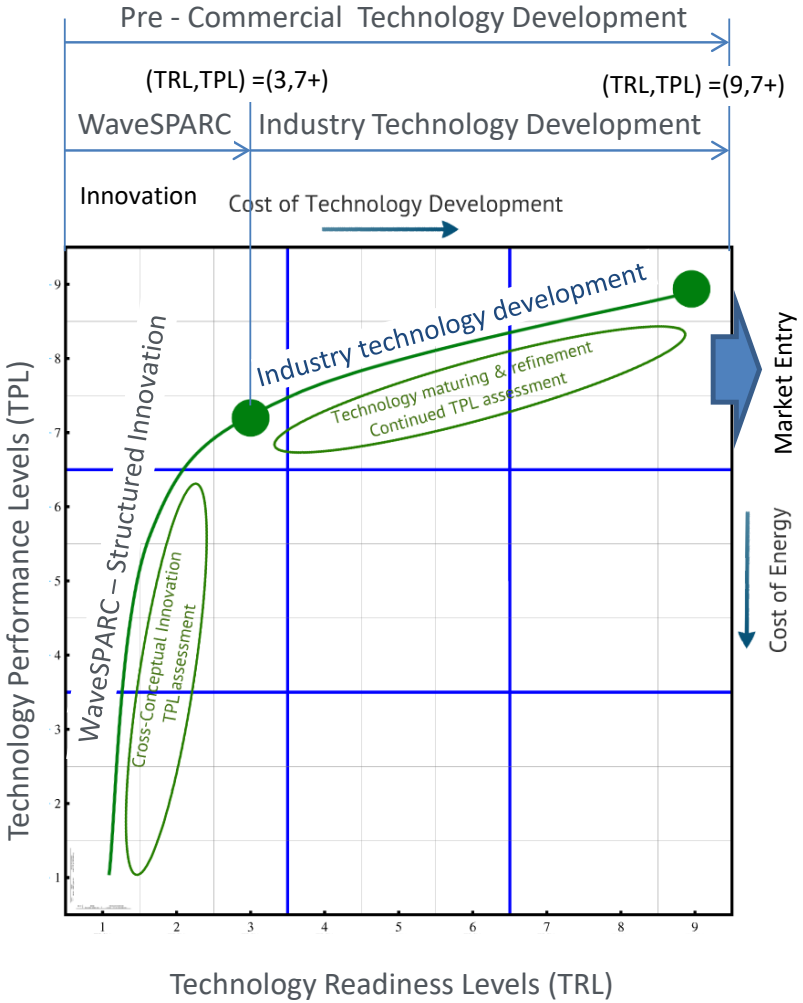
Technical Approach

TRL – TPL – Matrix:

To efficiently achieve market entry WaveSPARC drives the optimal technology development trajectory regarding technology development cost, time and risk

WaveSPARC delivers:

- Novel High performance WEC Concepts: TRL3, TPL7+
- Range of innovation and technology assessment developed Methods and Tools
- Extensive US and International Stakeholder Engagement



Technical Approach

Deliver complete and agnostic formulation of wave energy challenge

Thorough application of Systems Engineering and Stakeholder Analysis

Develop Methods and Tools for Innovation and Assessment

Innovate, describe, investigate, optimize, validate and deliver novel high performance and promise early stage WEC concepts at TRL3, TPL7+

Identify, enable and initiate the best technology development trajectory regarding cost, time, risk and technological and commercial success

Management Approach

Technical, strategic and managerial leadership at NREL and Sandia

Closely imbedded world-class wave energy subcontractors

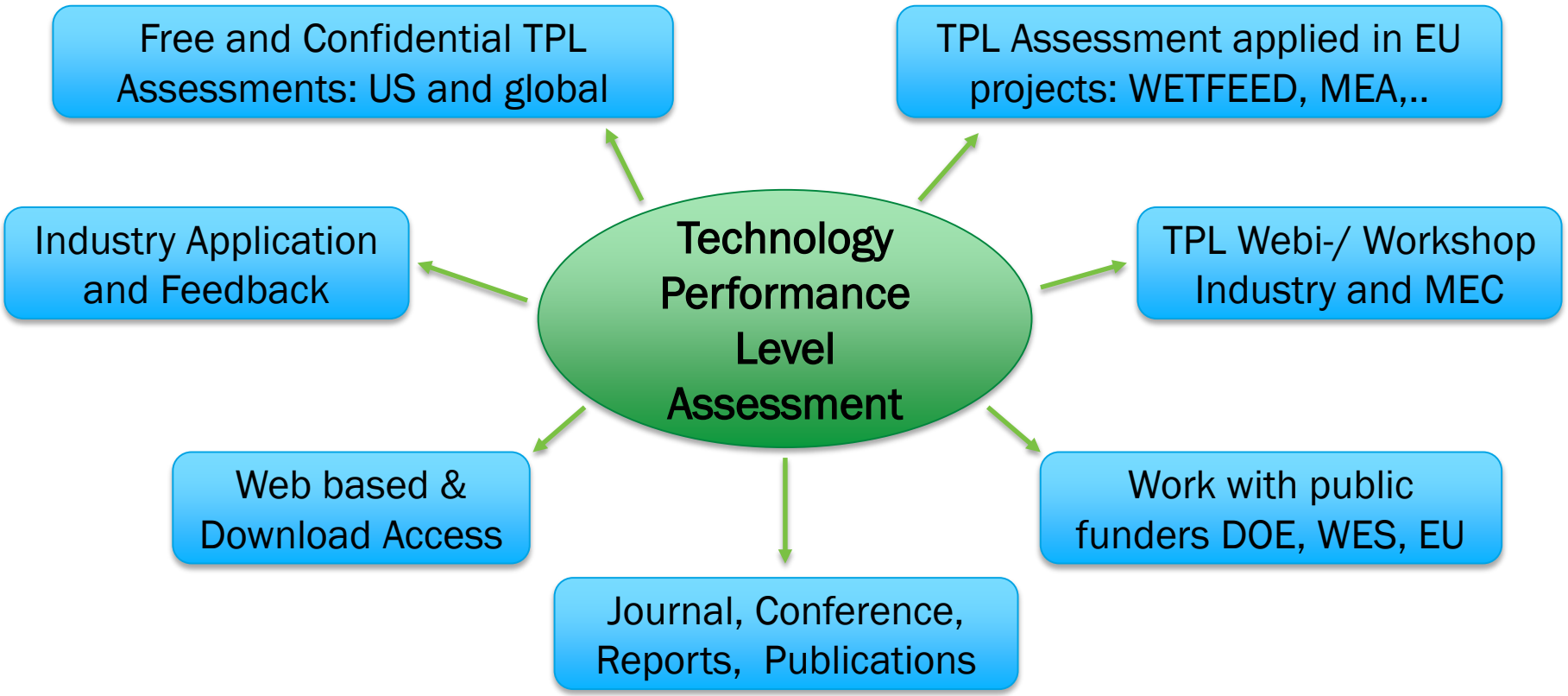
International collaboration: diverse, relevant, beneficial at all levels incl. IEA-OES

Closed engagement with DOE, MEC, industry, developers, academia

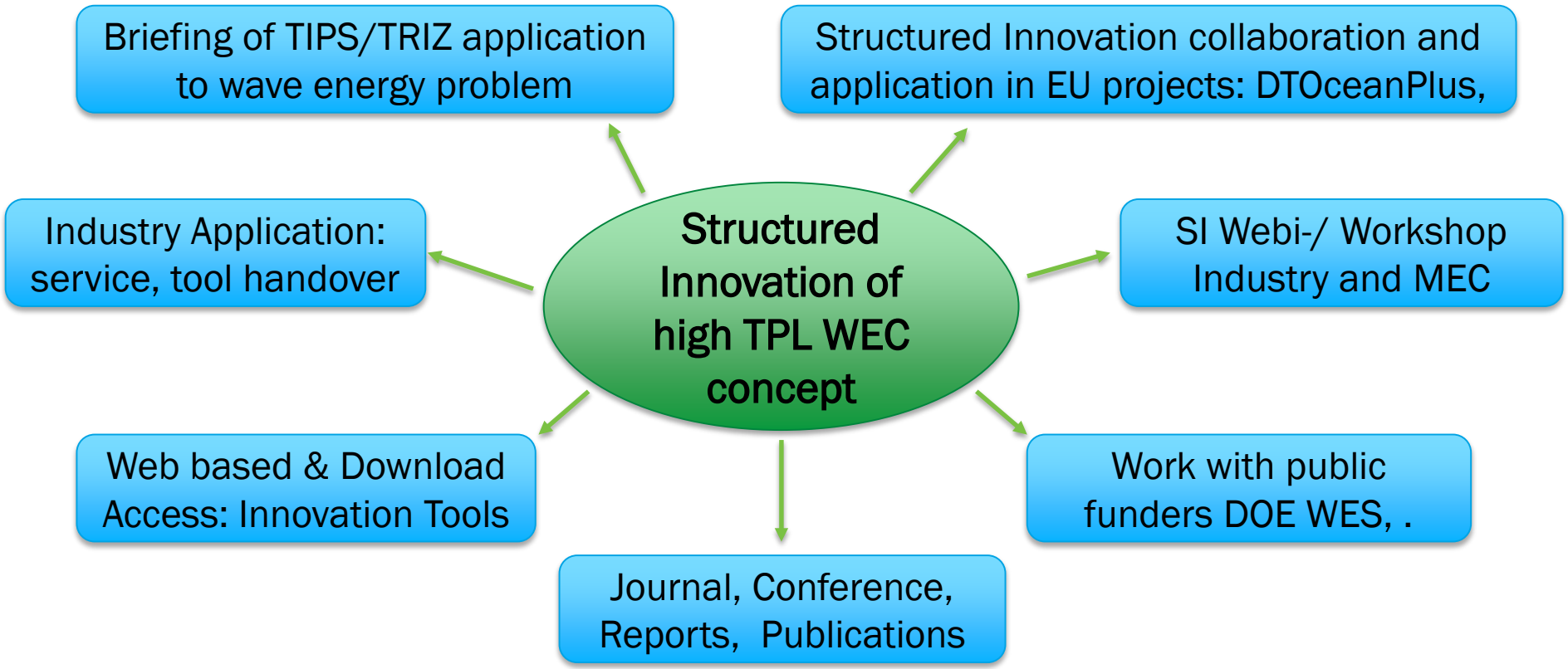
Continuous application, testing, improvement of methods and tools: internal & external

Expansion of project scope and benefits to wider MHK space and exploratory beyond

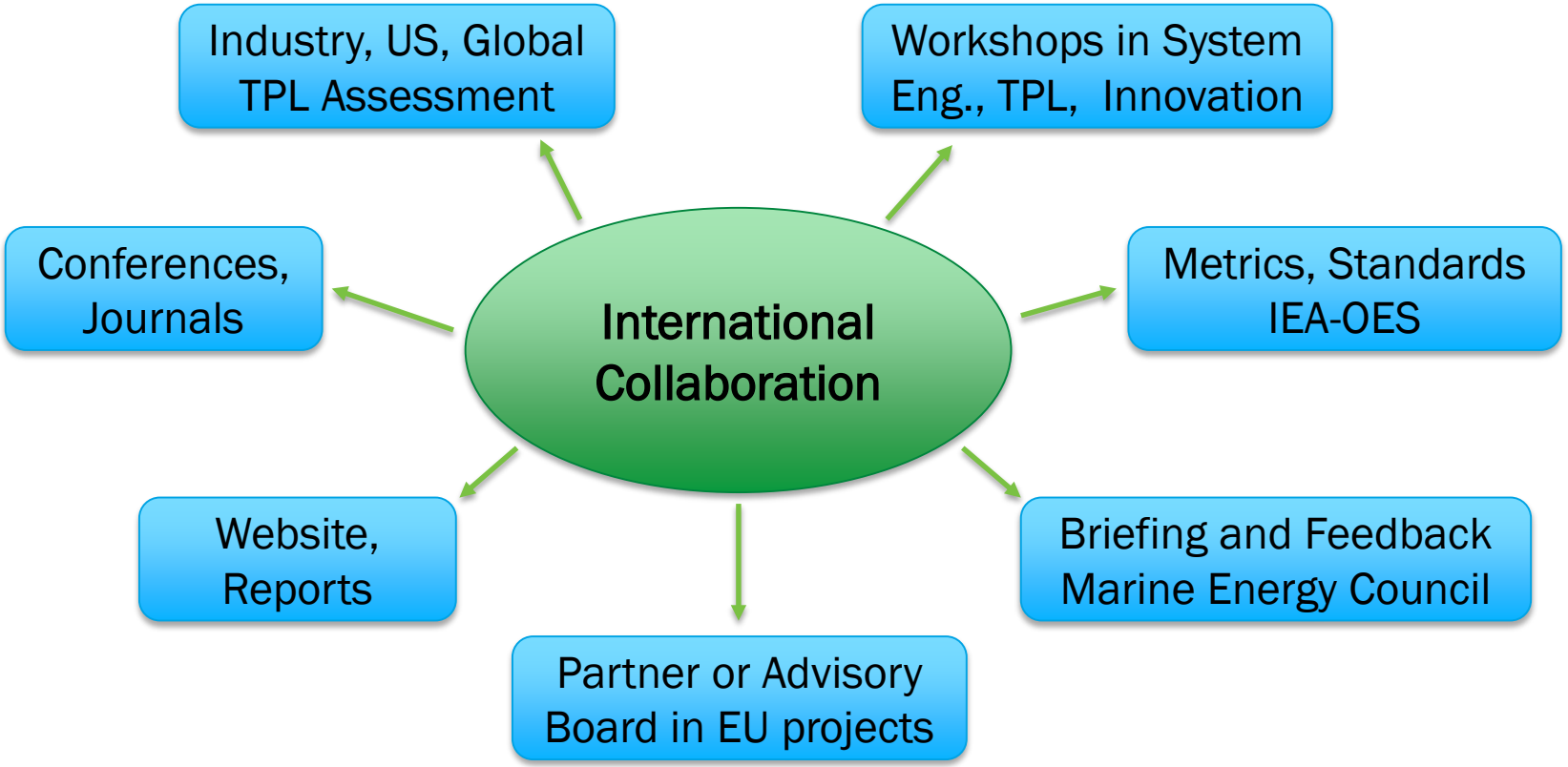
End-User Engagement and Dissemination Strategy



End-User Engagement and Dissemination Strategy



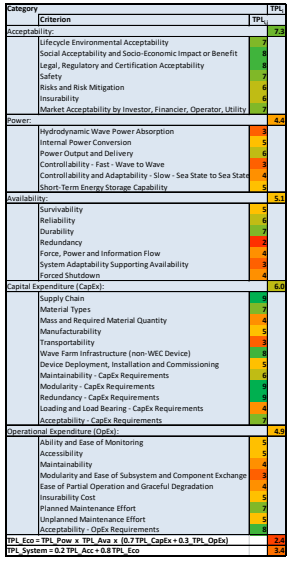
End-User Engagement and Dissemination Strategy



Technology Performance Level Assessment

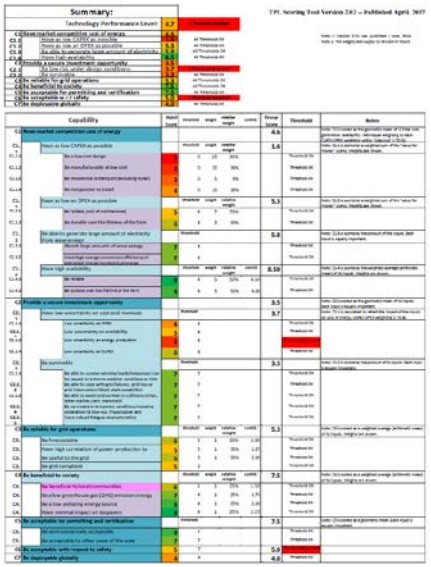
- Continuous improvement development and release for TPL assessment tool
- TPL Assessment: Versions 1.0 to 4.0 over 500 use cases of over 100 technologies
- Free TPL Assessments for US and global industry & Internal use in FlexWEC, FOAs
- Significant advancements in functionality and user friendliness in Version 5.0

Version 2.0

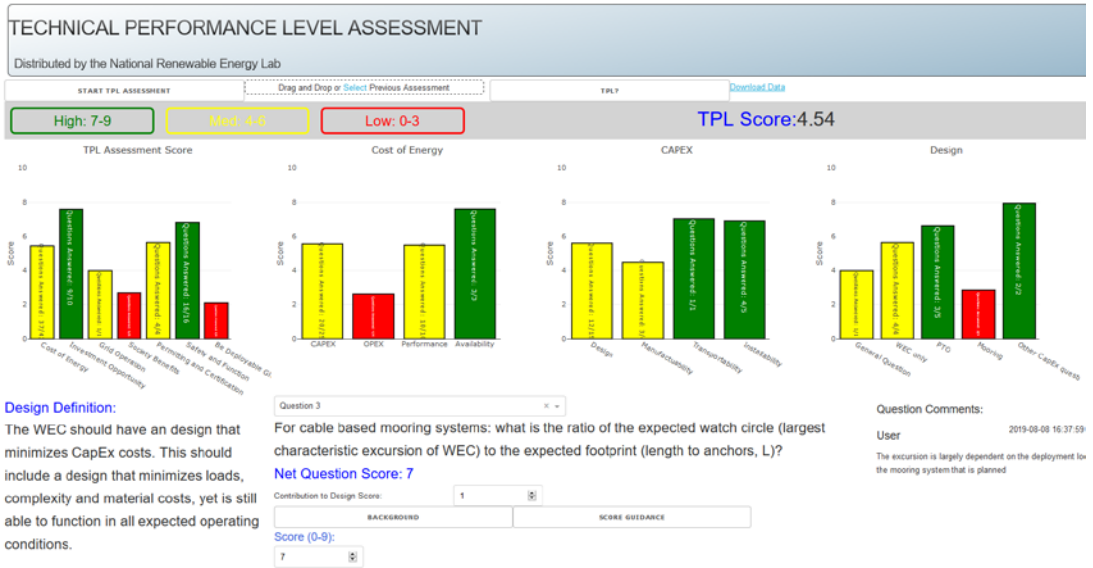


Category	Criterion	TPL
Acceptability:		7.3
	Lifecycle Environmental Acceptability	7
	Social Acceptability and Socio-Economic Impact or Benefit	8
	Legal, Regulatory and Certification Acceptability	8
	Safety	7
	Risks and Risk Mitigation	6
	Insurability	6
	Market Acceptability by Investor, Financier, Operator, Utility	7
Power:		4.4
	Hydrodynamic Wave Power Absorption	3
	Internal Power Conversion	5
	Power Output and Delivery	6
	Controllability - Fast - Wave to Wave	3
	Controllability and Adaptability - Slow - Sea State to Sea State	4
	Short-Term Energy Storage Capability	3
Availability:		5.1
	Survivability	5
	Reliability	6
	Durability	7
	Redundancy	3
	Force, Power and Information Flow	4
	System Adaptability Supporting Availability	3
	Forced Shutdown	5
Capital Expenditure (CapEx):		6.0
	Supply Chain	8
	Material Types	7
	Mass and Required Material Quantity	4
	Manufacturability	5
	Transportability	3
	Wave Farm Infrastructure (non-WEC Device)	8
	Device Deployment, Installation and Commissioning	5
	Maintainability - CapEx Requirements	6
	Modularity - CapEx Requirements	5
	Redundancy - CapEx Requirements	6
	Loading and Load Bearing - CapEx Requirements	4
	Acceptability - CapEx Requirements	7
Operational Expenditure (OpEx):		4.9
	Ability and Ease of Monitoring	5
	Accessibility	5
	Maintainability	4
	Modularity and Ease of Subsystem and Component Exchange	3
	Ease of Partial Operation and Graceful Degradation	4
	Insurability Cost	5
	Planned Maintenance Effort	7
	Unplanned Maintenance Effort	5
	Acceptability - OpEx Requirements	5
TPL_Eco = TPL_Pow x TPL_Ava x (0.7 TPL_CapEx + 0.3_TPL_OpEx)		2.0
TPL_System = 0.2 TPL_Acc + 0.8 TPL_Eco		5.0

Version 4.0

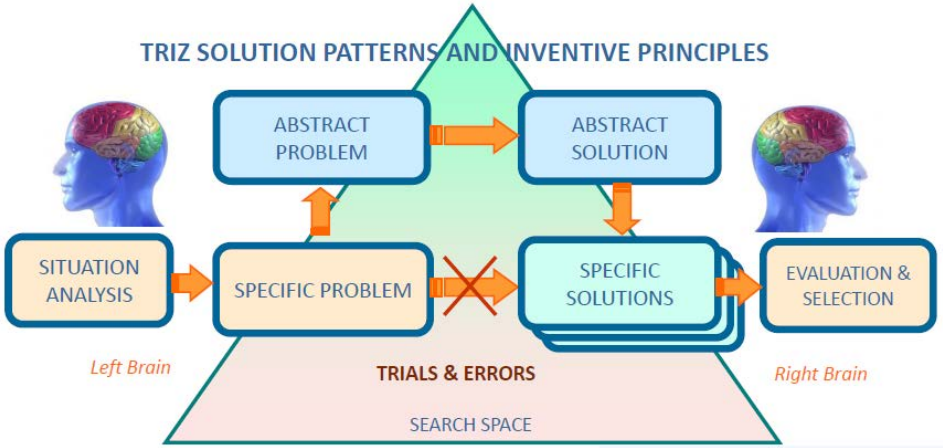


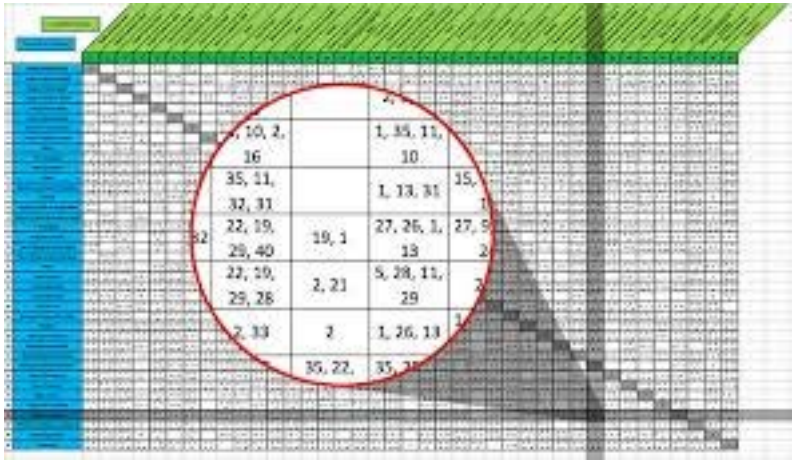
Version 5.0



Structured Innovation

- Assessment, selection of best techniques for inventive problem solving (TIPS/TRIZ)
- Translation and Adaptation of Wave Energy Technology Challenge for effective Application in TRIZ
- Invention, Description and Assessment of 2+ novel WEC System Concepts and 2+ novel WEC Subfunctions Solutions
- Dissemination of Learnings through domestic and international Collaboration, Publications and Innovations Workshops





Technical Accomplishments

International Collaboration

- Significant international collaboration across all Stakeholder types of the sector
- Remarkable adaptation and use of the developed techniques and tool globally
- NREL and Sandia are increasingly engaged in large, impactful projects globally
- Exchange and mutual learning in all project relevant methods and tools
- Key players are deploying TPL as service, progress assessment and award selection

Progress Since Project Summary Submittal

- Significant enhancement to TPL assessment software Version 5.0– fresh, complete and sophisticated implementation on Python (moving on from Excel).
- Active contributions and feedback at EWTEC 2019.
  - Innovation workshop: presentations and round table discussion
  - Two oral presentations and conference publications on assessment criteria requirements and evaluation innovation methodologies
  - Multiple references and strong recognition for Wave-SPARC work during presentations, discussion and personal exchange
- Further WEC innovations.
- Assessment of inventive principles completed.
- Close collaboration with EU Marine Energy Alliance underway – TPL tool development towards deployment in U.S. and EU.
- TRL – TPL alignment started. Important addition to the projects scope.
- Initiating implementation of Public Relations Strategy.

Future Work

- Simulation of novel high potential WEC concepts
  - Hydrodynamics
  - Power conversion
- Validation
  - Tank Testing in close collaboration with the U.S. wave energy industry
- TPL assessment tool – ongoing improvement, testing and release
- Extend Services Package to Industry
  - TPL assessment
  - Innovation techniques: Technology specific improvements and resolution of limiting trade-offs through the focused application of TRIZ
- Branching out to Powering the Blue Economy (PBE)
  - Requirement Specification: Stakeholder and functional requirements
  - TPL assessment adaptation to reflect application relevant capabilities
  - Apply Innovation Techniques, TRIZ to specific applications and problem statements
- Extend domestic and International stakeholder engagement and collaboration to relevant PBE domain

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