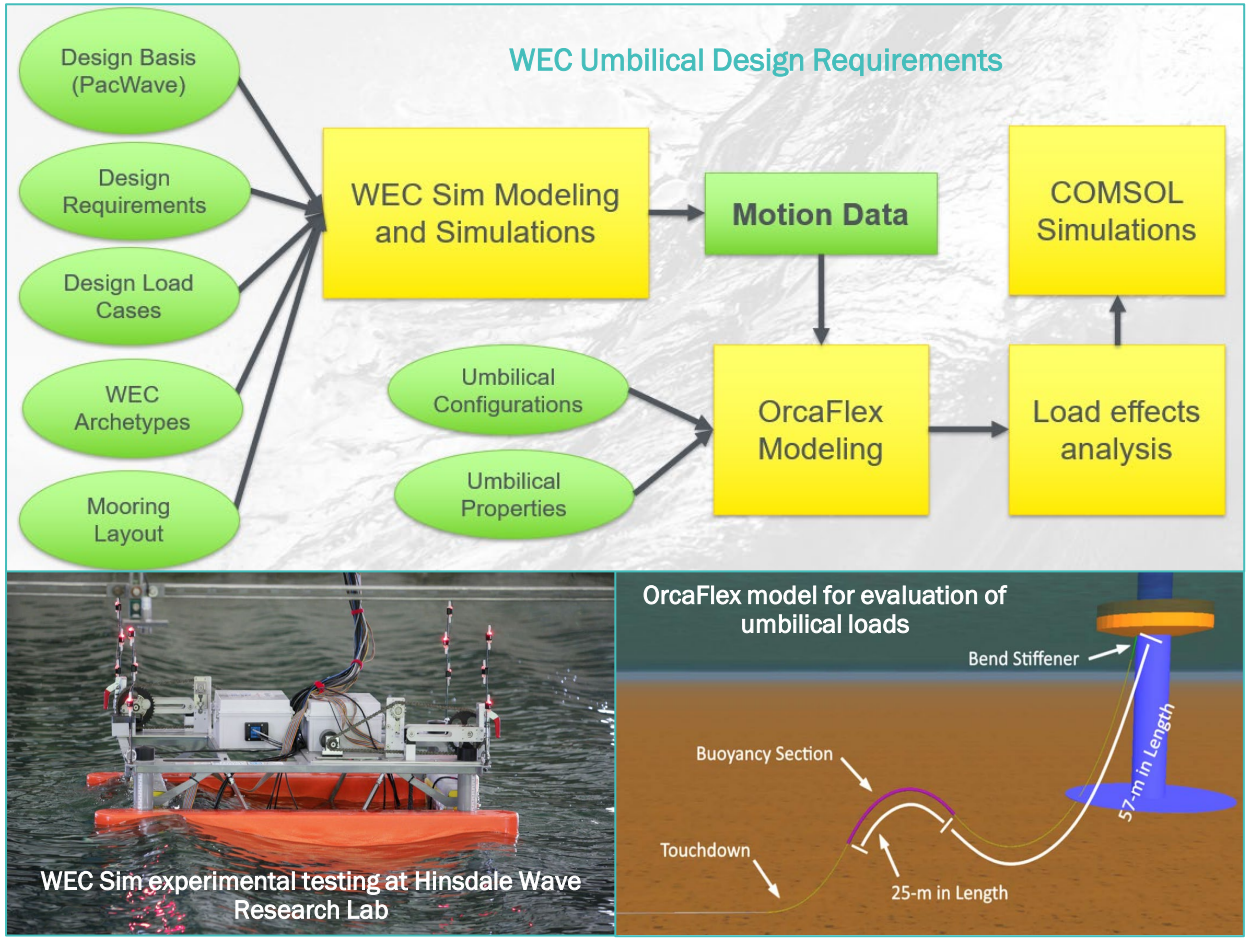
2.1.4.404 – WEC Interlink Umbilical Cables Design Requirements



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July 18th, 2022

Project Overview

Project Summary

- The project aimed to accelerate the development of robust medium voltage power and communication umbilicals that connect a floating WEC to a subsea transmission line. Design information, methods, and tools were developed to be supplied to industry and the MHK community to improve robustness, reliability, and lifetime of offshore dynamic umbilical cables. The approach was unique in that it developed a WEC model, evaluated improved umbilical design using bend stiffeners to enhance lifetime, and investigated dielectric breakdown of the insulation, which was missing in previous work.

Intended Outcomes

- Numerical models for a variety of WECs, mooring configurations (WEC-Sim), and umbilical cables (OrcaFlex) have been made publicly available. Umbilical design basis and failure modes, such as bending fatigue and dielectric breakdown were evaluated and recommendations given to enhance the lifetime of dynamic umbilicals. Generated design guidance is expected to enable much longer WEC service life and improved lifetime prediction.

Project Information

Principal Investigator(s)

- Leo Fifield (PNNL), Yi-Hsiang Yu (NREL)

Project Partners/Subs

- Mychal Spencer, Tom McDermott (*PNNL*)
- Jennifer Van Rij, Rick Driscoll (*NREL*)
- Billy Ballard (*Delmar*)
- Thomas Andritsch, James Pilgrim (*SOTON*)
- Tim Mundon (*Oscilla*)

Project Status

Completed (December 2021)

Project Duration

- August 2, 2018
- December 30, 2021

Total Costed (FY19–FY21)

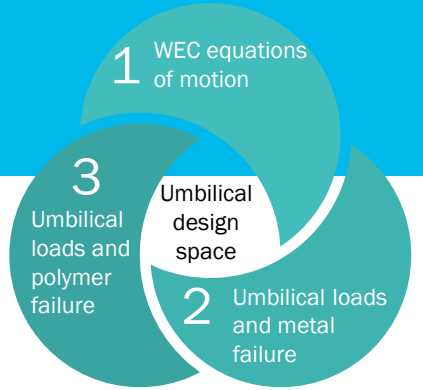
$825k

Project Objectives: Relevance

Relevance to Program Goals:

Marine Energy Challenge Addressed	Approach
Difficult Engineering to Convert ME Challenge: -measure, model, and predict WEC umbilical longevity in relevant sea states and operating conditions	**Foundational R&D:** -Develop and validate numerical modeling tools including WEC-SIM, OrcaFlex, MATLAB, COMSOL
Installing and Operating Reliable Systems: - testing, operations, and maintenance (O&M) improvement through inclusion and utilization of condition monitoring tools in WEC umbilical cables	**Technology-Specific System Design and Validation:** - Validate performance and reliability through testing of cable designs and correlation of experimental fatigue, electrical and condition monitoring testing with simulation - Improve cost-effective methods for IO&M with added condition monitoring tools

Project Objectives: Approach



Approach:

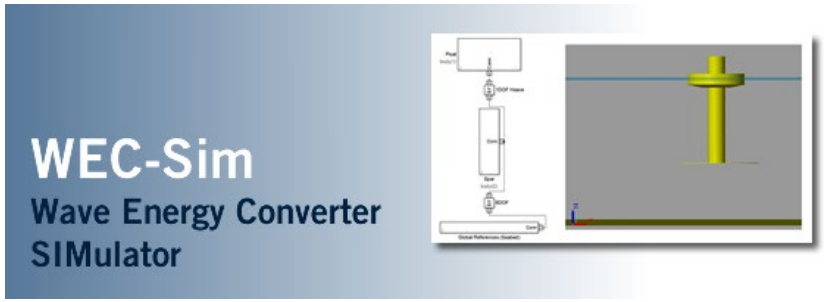
Task 1
WEC Modeling

Task 2
Load Effect Analysis

Task 3
Electrical Strength FEA

Project Objectives: Approach

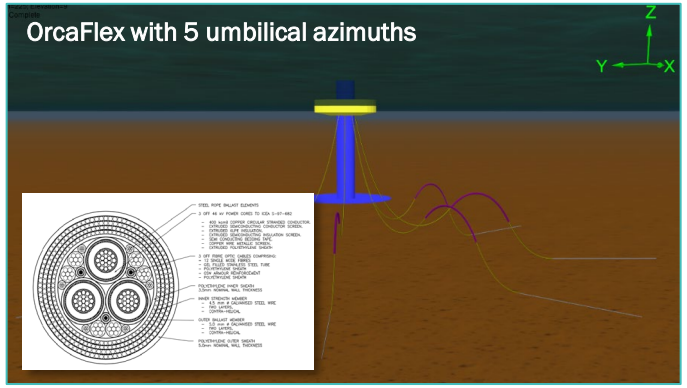
Task 1
WEC Modeling

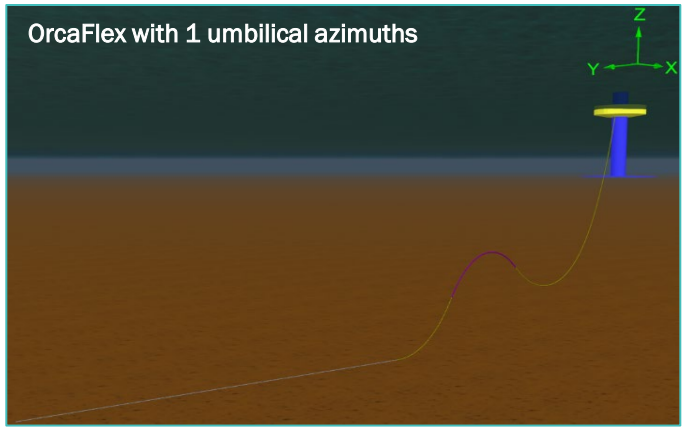


- Developed open-source code in MATLAB/SIMULINK to model the motion of WECs (NREL)
  - WEC-Sim can model the dynamics of devices that are comprised of rigid bodies, power-take-off (PTO) systems, and mooring systems.
  - WEC-Sim uses hydrodynamic coefficients derived from frequency-domain boundary element (BEM) simulations to model the relevant hydrodynamics.
  - Time-domain simulations are performed by solving the governing WEC equations of motion in 6 degrees-of-freedom
- Evaluated reference WEC at 168 sea states to determine device response (NREL)
  - Simulations directed towards load effect analysis (Task 2) using OrcaFlex

Project Objectives: Approach

Task 2
Load Effect Analysis



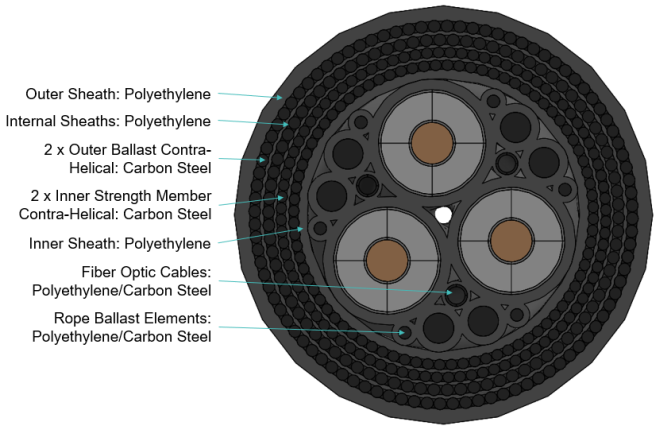


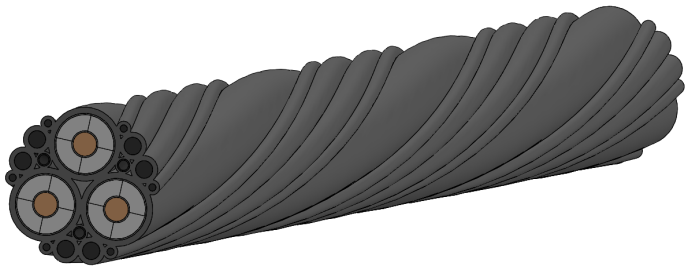
- Evaluated response of umbilical using OrcaFlex (Delmar)
  - WEC motion from WEC-Sim imported into OrcaFlex software (developed pre- and post-processing scripts for rapid multi-case simulations)
  - Evaluated umbilical cable response - tension, curvature, stress, and fatigue
  - Investigated two water depths (50-m and 100-m) and the 168 sea states evaluated using WEC-Sim (672 total conditions evaluated)
- Determination of umbilical lifetime due to fatigue and effect of bend stiffener (Delmar)
  - Focused on metallic components
  - Primarily concerned with buoyancy section due to reduced lifetime
  - Evaluated design improvement (bend stiffener) to enhance lifetime

Project Objectives: Approach

Task 3
Electrical Strength FEA

Evaluated 3D dynamic umbilical cable





Jacket removed to show internal structure

- Evaluated response of umbilical using COMSOL (PNNL)
  - Insulation commonly ignored during design of umbilicals, but dynamic/offshore umbilicals have unique design requirements
  - Investigated three scenarios: increasing tension up to maximum working load, curvature up to minimum service bend radius, and mean tension with increasing curvature up to minimum service bend radius
  - Evaluated 3D stress and electric field distribution in insulation
- Determined effect of loadings on dielectric breakdown of insulation (PNNL)
  - Focused on polymeric components
  - Coupled electromagnetics and solid mechanics (multiphysics)
  - Evaluated electric field strength locally and along length of umbilical
- Developed report on NDE electrical condition monitoring approaches to evaluate health of umbilical (PNNL)

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- Open-source model to capture the motion of WECs (WEC-Sim)
- Publicly available numerical models for variety of WECs, mooring configurations, and umbilicals
- Peer reviewed publications on methodology for electrical and mechanical strength analysis of umbilicals
- Report on literature review of umbilicals and program for future physical fatigue testing of umbilicals

Outcomes:

- Reduction in IO&M activities (redundant cables, inspection intervals, capital costs) on WECs due to reduced failure of medium voltage umbilicals
  - Incorporation of bend stiffeners to significantly increase the lifetime of dynamic umbilicals
  - Improved electrical response of insulation to avoid dielectric breakdown
- Increased investment in WECs due to reduced uncertainty regarding design of connecting transmission lines or umbilicals

Project Timeline

Condition Monitoring

FY 2019

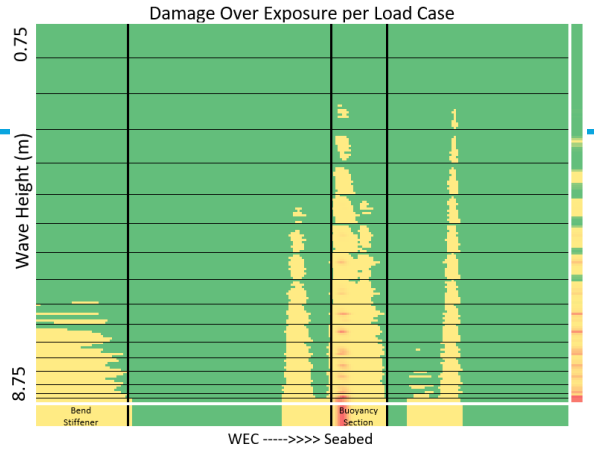
WEC Modeling

Motion determined for various sea states

FY 2020

Load Effect Analysis

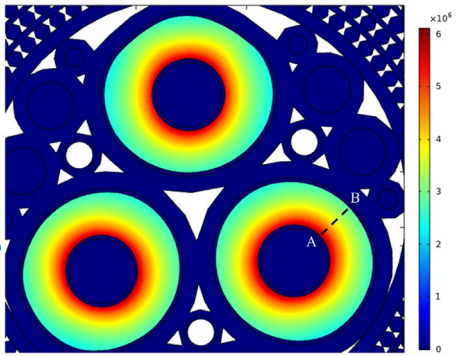
Lifetime limiting fatigue damage determined



FY 2021

Electrical Strength FEA

Lifetime limiting dielectric breakdown determined



Experimental Verification

Project Budget

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	Costed	Costed	Total Costed
$425K	$400K	$K	$825K

- COVID shutdowns, cable sample availability and funding timing constraints resulted in planned cable purchase and cable physical testing at the University of Southampton not happening.

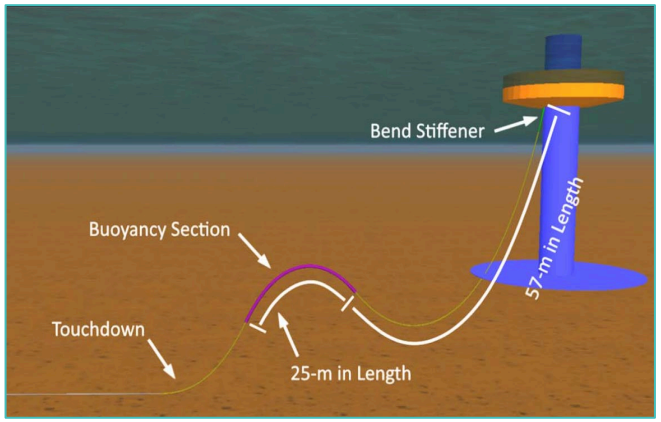
End-User Engagement and Dissemination

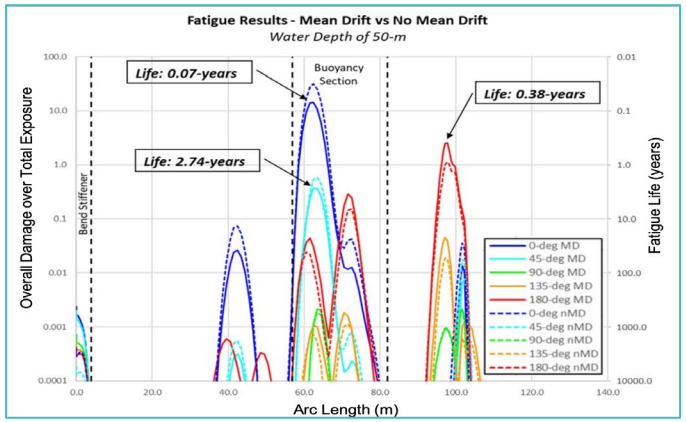
- This project provides design guidance for umbilical manufacturers and users
- Cable manufacturers need to be engaged directly in the future
- Cable installer Delmar guided needs and development of guidance
- Cable user Oscilla Power provided end-user perspective
- University of Southampton (SOTON) provided industry and test lab input

- Outputs were disseminated through conference participation and should be directly communicated with cable designers/manufacturers.

Performance: Accomplishments and Progress

- Evaluated lifetime of WEC dynamic umbilical and observed significantly reduced lifetime without incorporating bend stiffeners
  - Including mean wave drift force critical to accurately capture fatigue life of umbilical
  - Fatigue damage more significant in shallow water (50-m vs 100-m)
  - Lazy-S arrangement of umbilical increased lifetime
  - Bend stiffener at umbilical connection to WEC critical to limit bending stress
    - Further improvement in lifetime with stiffener at buoyancy and touchdown sections



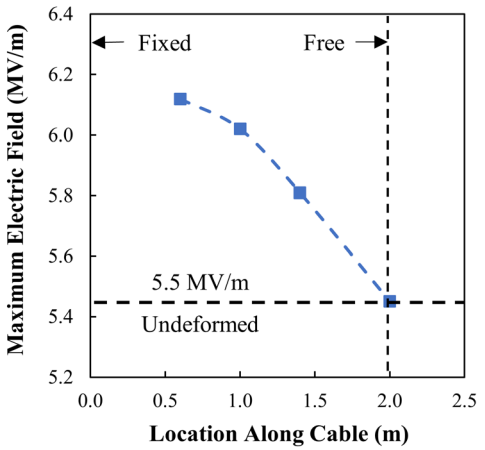


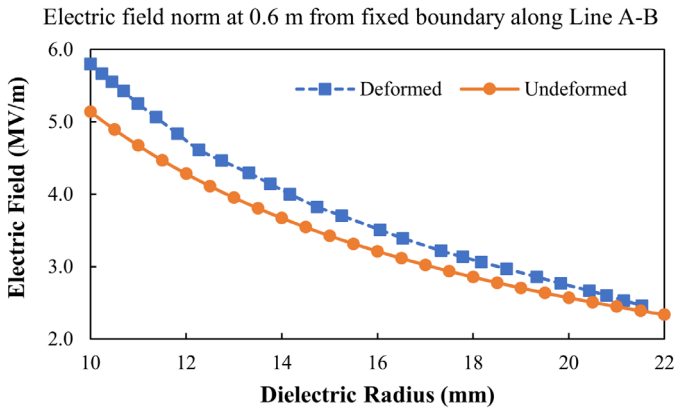
Max Cumulative Damage for three different cases with and without bend stiffener at different sections of the umbilical

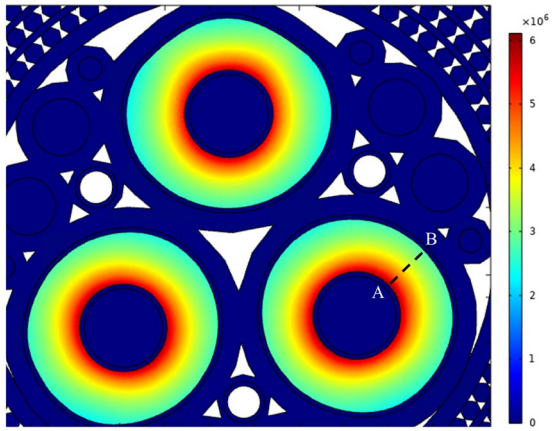
Case	WEC Connection	Buoyancy Section	Touchdown	Fatigue Life
(A)	✓			~0.39-years
(B)	✓	✓		~7-years
(C)	✓	✓	✓	~163-years

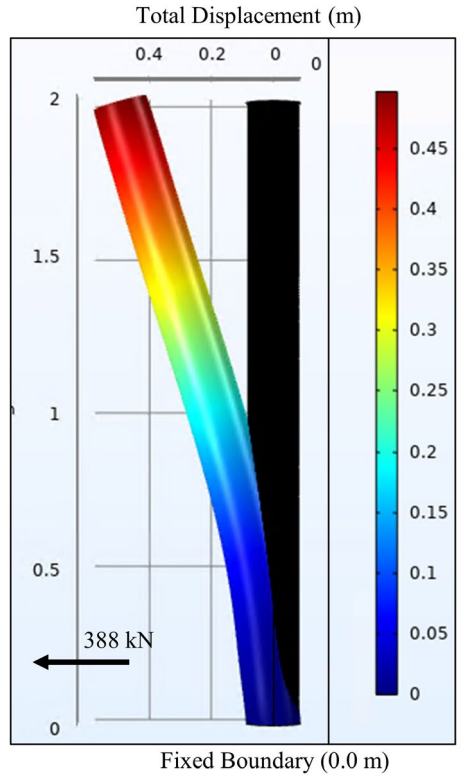
Performance: Accomplishments and Progress (cont.)

- Evaluated electric field distribution in fully three-dimensional dynamic umbilical cable towards understanding effect of deformation on dielectric breakdown
  - Novel and accurate deformation of umbilical using three-dimensional model
  - Umbilical bending limiting case for failure (vs axial or torsion)
  - Armor layers primary load bearing components
  - Significant increase in electric field strength due to umbilical bending, which may lead to electrical failure prior to mechanical failure









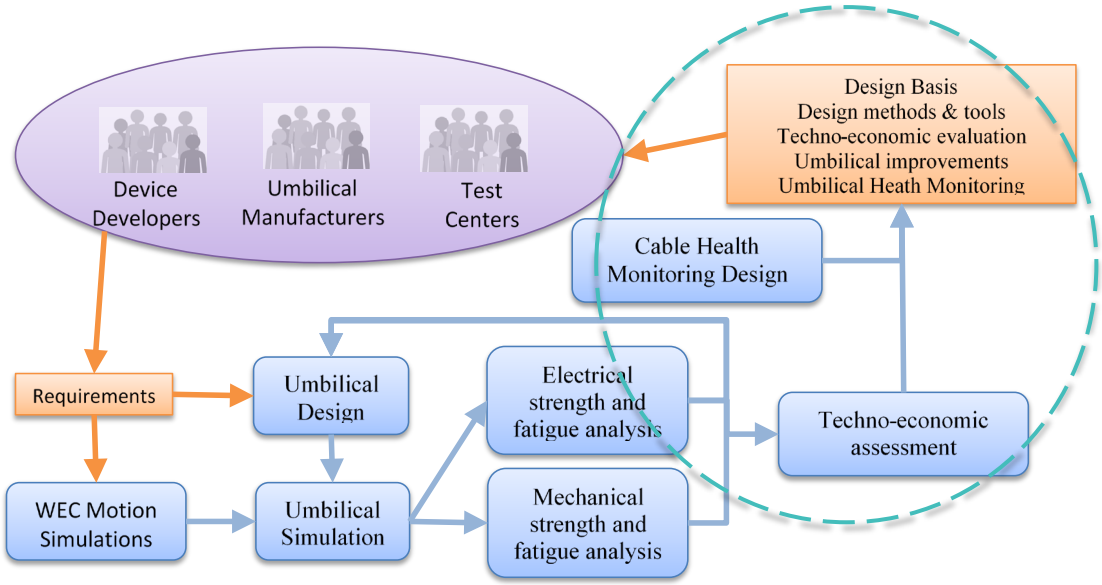
Performance: Accomplishments and Progress (cont.)

- Publications and Reports
  - Glass, S.W., et., al., PNNL Report on Non-Destructive Condition Monitoring of WEC Umbilical Cables, Report.
  - Andritsch, T., et. al., *Literature Review on the Topic of Fatigue and End of Life Failure for Mechanically Dynamic Umbilical Cables*, 2018, Report.
  - Andritsch, T., et. al., *Outline for a Programme of Laboratory Fatigue Testing of WEC Electrical Cable System*, 2019, Report.
  - Spencer, M., et. al., *Effect of Mechanical Deformation on the Dielectric Electric Field in Dynamic Umbilical Cables*, CEIDP, 2021, Conference.
  - Yu, Y., et. al., *WEC Umbilical Electro-Mechanical Analysis and Design*, WCOE, 2021, Poster.

Future Work

- Techno-economic assessment of umbilical cables
- Failure model and recommended umbilical design improvement based on physical testing that considers both mechanical and electrical failure (not currently done)
  - Direct comparison between experimental and simulation results to supply umbilical designers information regarding critical parameters to include in analysis
  - Experimentally informed digital twin of umbilical to guide design decisions

- Publish peer reviewed methodologies for performance electrical and mechanical strength and fatigue analysis and testing of interlink umbilical cables for WECs
- Advancement of non-destructive umbilical health monitoring methods



Q&A