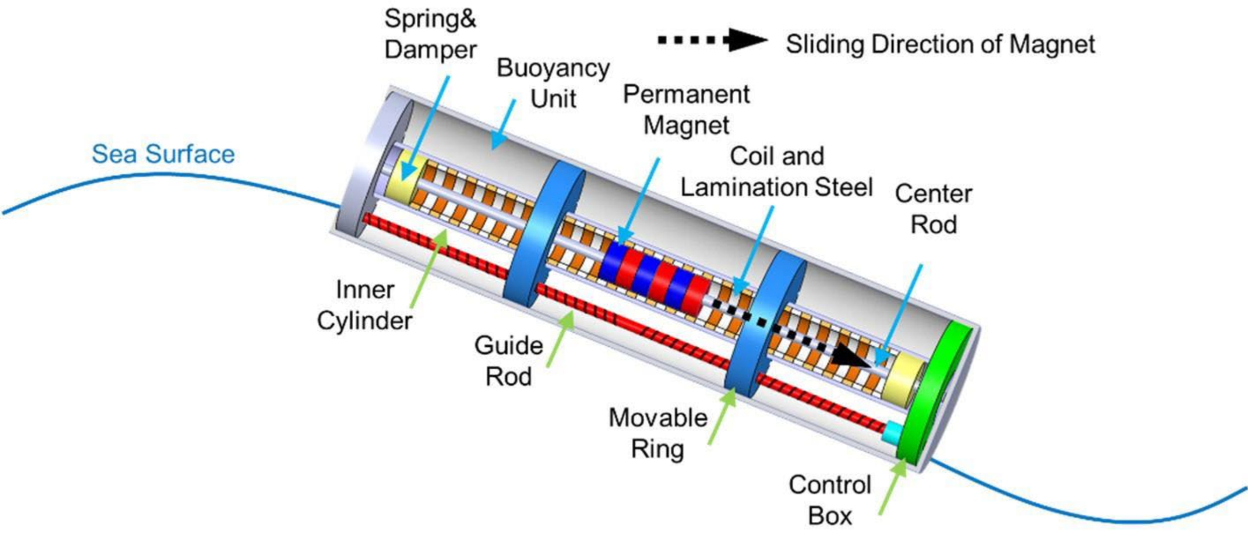
DE-EE 8630 – An innovative SR-WEC for a market-disruptive LCOE



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Project Overview

Project Summary

- The objective is to develop and test a scaled prototype of Surface Riding Wave Energy Converter (SR-WEC) that can result in a market-disruptive Levelized Cost of Energy (LCOE) below 40 cents/kWh by combination of 1) extended operating window, 2) substantially lowered costs, and 3) amplified average power output by simple optimum control.
- The original objective also involves development of design methodology and proper simulation tools.

Intended Outcomes

- The project is 1) to complete optimum design of SR-WEC for the maritime market applications, 2) to confirm full performance of the SR-WEC using scalable wave tests of the scaled prototype in the wave basin and advanced global performance simulation, 3) to confirm the market disruptive LCOE less than 40 cents/kWh for single operation in the target application using the global performance simulation correlated with the scalable tests, and 4) identify remaining uncertainties and risks to be resolved in the larger scale prototype tests.

Project Information

Principal Investigator(s)

- PI: HeonYong Kang,
- Co-PI: Hamid Toliyat, Kuang-An Chang, Moo-Hyun Kim

Project Partners/Subs

- Dr. Toan Tran, Dr. David Ogden, Ms. Elena Baca from NREL.

Project Status

Ongoing

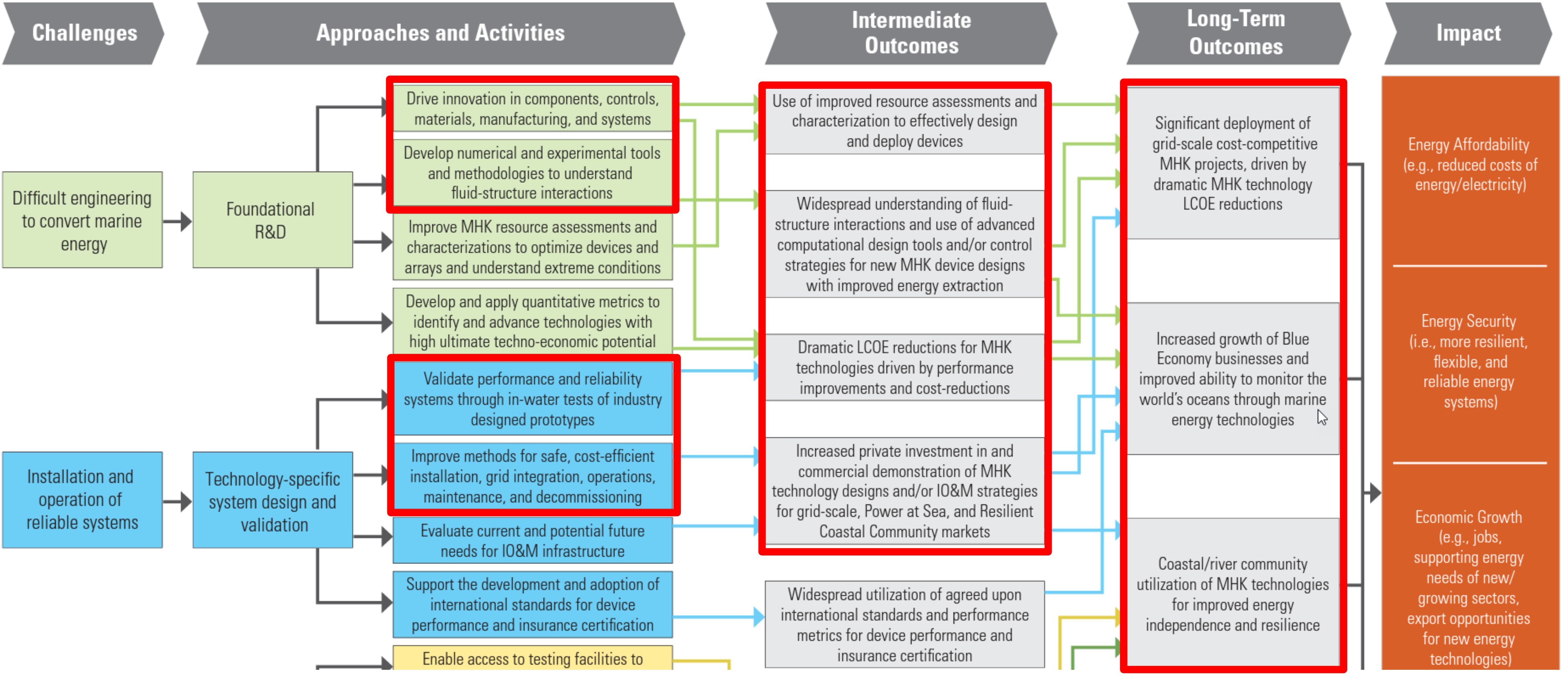
Project Duration

- Project Start Date:9/1/2019
- Project End Date:1/31/2023

Total Costed (FY19–FY22)

$504K

Project Objectives: Relevance to Program Goal (red boxes)



Project Objectives: Approach

Approach: Development of Design Methodology

[Coupled Multi-Physics & Multi-Variables Design Optimization vs. segmented or decoupled]

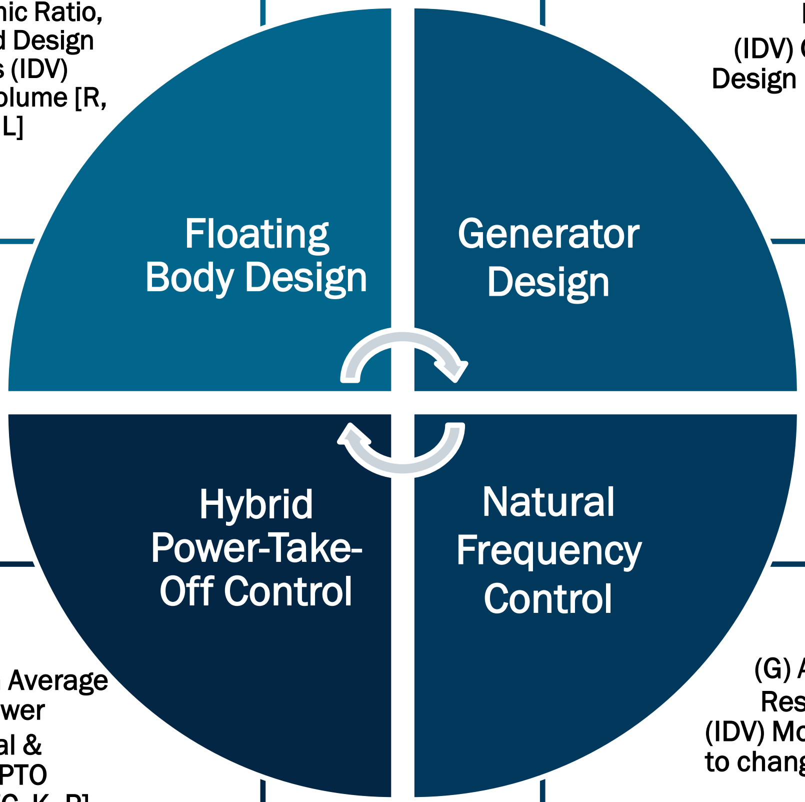
Step 1. Out of the 4-variable parametric studies (10,000s to 100,000s cases), select a submerged volume that will ensure the first maximum energy conversion to a floating body in the form of hydrodynamics.

Goal (G) Maximum Hydrodynamic Ratio, Interrelated Design Variables (IDV) Displaced Volume [R, D, H, L]

(G) Target Generator Force
(IDV) Generator Design [AG, MT, WT, P]

Step 2. From Step 1, the total mass of the linear generators is given, and specifications of linear generators are optimally designed through the 4-variable parametric studies (10,000s to 100,000s cases)

LCOE Updated
Time Dom. Analysis



All Design Parameters Specified
Freq. Dom. Analysis

Step 4. Out of the 3-variable parametric studies (1000s cases), find the optimum PTO parameters to maximize average power output.

(G) Maximum Average Electrical Power
(IDV) Electrical & Mechanical PTO Parameters[C, K, P]

(G) Adaptive Resonance
(IDV) Moveable Mass to change MMI [CoG]

Step 3. Out of the fixed system design, determine the natural frequency for each sea state's peak period to result in the maximum conversion to the rotational motion's mechanical energy.

Project Objectives: Approach

Approach: Development of Innovative Wave Energy Conversion Mechanism

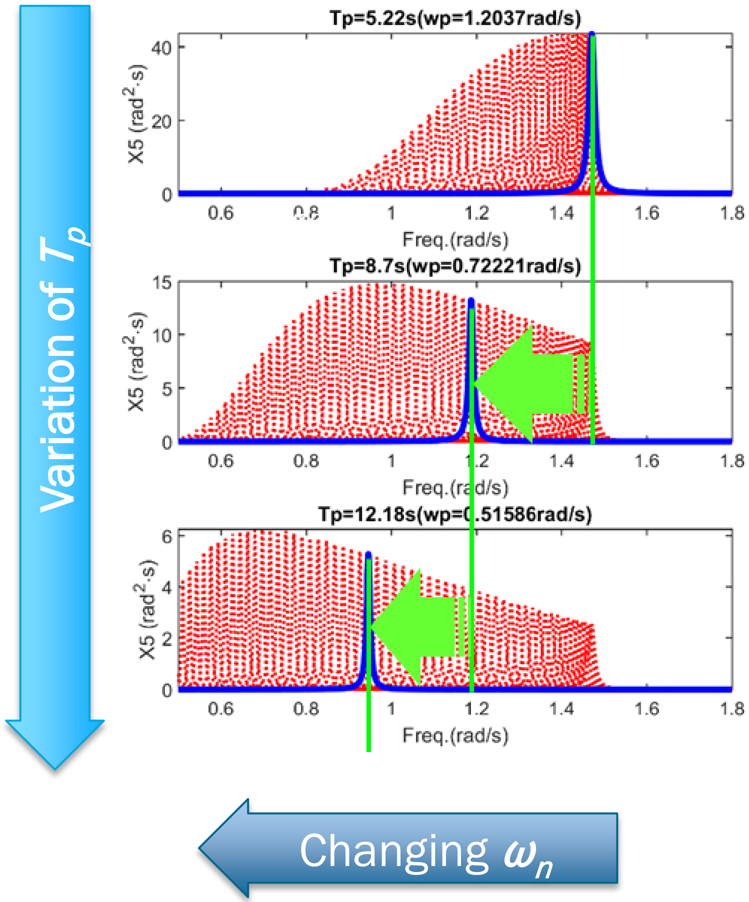
[Adaptive Resonance for Varying Random Waves vs. targeting few frequencies]

Developed a Wave Energy Conversion Mechanism that achieves "effective energy capture for much wider sea state range" by "Adaptable Resonance" featuring

In-situ Tp Measurements

Individual Resonance for In-situ Tp

resulting in the maximum conversion to the mechanical power



Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- New Design Methodology integrating multi-physics and multi-variables
- New Wave Energy Conversion Mechanism effective for varying irregular waves
- Scaled-prototype of I/S-SR-WEC
- Deep-learning Fully Nonlinear Simulation
- Validation data from physical wave tests and Correlated simulation models
- Full Prototype Design of I-SR-WEC validated for average power 5 kW with LCOE below 40 ¢/kWh
- Journal Publications(2-2/5-2/+),Patent(2+)

Outcomes:

- Guidance to design a WEC
- Design and performance improvement of other WECs
- Commercial applications in Powering the Blue Economy at the average power scale up to 5 kW.
- Promote more accurate prediction using fully nonlinear simulations accelerated through deep learning

Project Timeline

FY 2019-21

Design Methodology Development

Optimum Design Development

Performance Assessment (AEP, LCOE)

FY 2021

Go/No-Go Decision

Presented the milestones and deliverables

Received GO

FY 2022-23

Prototype Fabrication & Validation

Performance Assessment Update

Correlated Simulation (Linear and Fully Nonlinear)

Project Budget

Total Project Budget – Award Information		
DOE	Cost-share	Total
$752K	$188K	$940K

FY19-21	GNG Meeting in August 2021	FY21-22	Total Actual Costs FY19–FY22
Costed		Costed	Total Costed
$414K		$90K	$504K

- Before GNG Meeting in August 2021, we had 6-month of No Cost Time Extension

End-User Engagement and Dissemination

- **Stakeholder and/or end-user engagement strategy**
  - Target End-User Group: diverse offshore operations that require remote energy supply up to average 5 kW from the single unit, including ocean observation, exploration, aquaculture, and integration with existing offshore platforms.
  - Commercialization initiative with individual end-users (**ABS, Navy NAVFAC EXWC**): shared technical details including benefits to end-users, communicating specific applications to develop for the end-users.
  - Plan to form or engage End-user Advisory Group when prototype tests start to specify required functionalities for the commercial applications.
  - Research outputs disseminated through invited talks, training program, and research outreach for underrepresented groups.
- **Dissemination:** along with publications in journals and proceedings, TEES Office of Commercialization and Entrepreneurship will manage technology transfer as well as commercialization.

Performance: Accomplishments and Progress

Sequential Design Optimization → Time Domain Simulation (Linear/Nonlinear) for each sea state → LCOE Calculation using NREL SAM

- ✓ Time-domain floating body dynamics by Cummins' Equation
- ✓ Time-domain generator dynamics for nonlinear power-take-off
- ✓ Decoupled floating body dynamics with the generator dynamics
- ✓ Uncertainties in OpEx

I-SR-WEC
35.84
kW/MN

vs

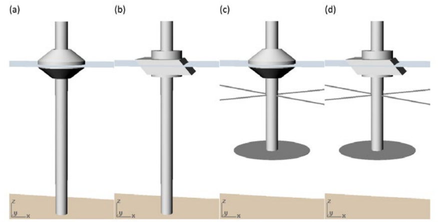


Fig. 1. OPT PowerBuoy geometries: (a) symmetric float with monopile, F1-MP, (b) rhombus float with monopile, F3-MP, (c) symmetric float with spar-plate, F1-SP, and (d) rhombus float with spar-plate, F3-SP.

	P_{avg}^{1yr}/W_{disp} (kW/MN)
F1-MP (0°)	8.23
F3-MP (0°)	7.80
F3-MP (30°)	7.51
F1-SP (0°)	**9.13**
F3-SP (0°)	7.12

Location	NOAA Buoy Location	Linear Generator	Average Power	Average Annual Power Production (kWh)	LCOE (¢/kWh)
East Coast	41002	**6 m, 14 units**	5 kW	38,092	37.68
		4 m, 20 units		38,119	47.12

Progress

Refinement of the Optimum Design using Fully Nonlinear Simulation

Fabrication and Wave Basin Test of a Scaled Prototype

Update Performance Metrics

Performance: Accomplishments and Progress (cont.)

Publications

1. Naghavi, F., Sheshaprasad, S., Gardner, M., Meduri, A., Kang, H., & Toliyat, H. (2021, October). Permanent Magnet Linear Generator Design for Surface Riding Wave Energy Converters. In 2021 IEEE Energy Conversion Congress and Exposition (ECCE) (pp. 4369-4375). IEEE. (The most reputed conference in electrical engineering.)
2. C.K. Jin, H.Y. Kang, M.H. Kim, “Performance Evaluation of Surface Riding Wave Energy Converter with Linear Electric Generator”, Ocean Engineering 218, 108141 (**SCI, Impact Factor 3.302**)
3. C.K. Jin, H.Y. Kang*, M.H. Kim, I.H. Cho, “Optimum Performance Estimation of Resonance-Enhanced Dual-Cylinder Wave Energy Converter in Random Waves using Correlated Time-Domain Simulation”, Renewable Energy 160, 1445-1457 (**SCI, Impact Factor 6.274**)

Simulation or Computation Tool

1. Development of Fully Nonlinear Simulation accelerated by GPU parallelization and Deep Learning
2. Development of Control of National Frequency to adapt the resonance for a given in-situ sea state

Future Work

- Refinement of Final Optimum Design using Accelerated Fully Nonlinear Simulation
- Fabrication of Scaled-Prototype and Test Gradually from Subsystems
  - ✓ 3D Printing + Generator Fabrication and Assembly
  - ✓ Dry Actuator Tests for regular/irregular waves
  - ✓ 2D Wave Basin Tests for regular/irregular/varying regular & irregular waves
- Performance Metrics Validation & Update
- Correlation of Simulations with Experiment Data
- Continuous Design Evolution

Q&A