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Sandia National Laboratories

Advancing hydrokinetic energy technologies to commercialization: Opportunities & challenges

Vincent S. Neary, Water Power Technologies

Ruby Jubilee Lecture Series 2021, Lectures, Indian Institute of Technology, Roorkee, 15 September 2021

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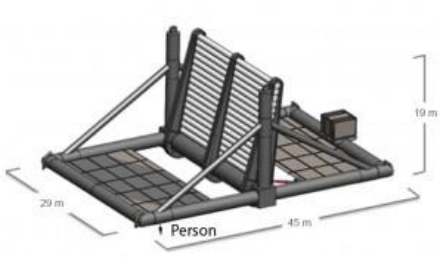
Hydrokinetic (marine) energy technologies: What are they?

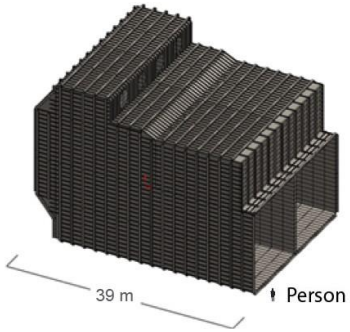
Renewable energy in waves, water currents, osmotic/thermal gradients, solar, wind and marine biomass

Energy conversion technologies:

Wave energy converters (WEC)



RM5 – oscillating body



RM6 –oscillating water column

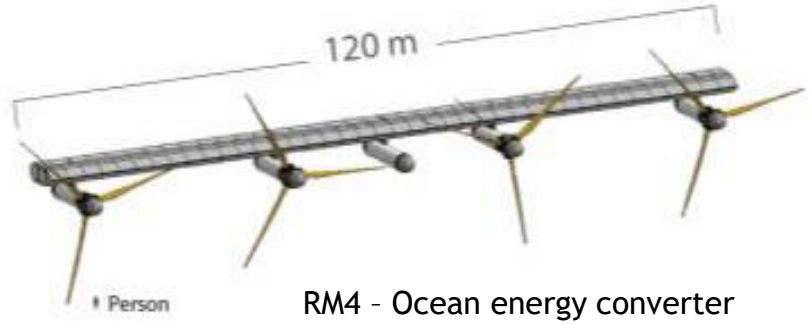
RM3 – oscillating body

USDOE's Reference Model WECs [Neary et al. 2013]

Current energy converters (CEC)

USDOE's Reference Model CECs [Neary et al. 2013]

RM1 – Tidal energy converter



RM4 – Ocean energy converter

RM2 – River energy converter

Ocean energy sailing ships: Wind and hydrokinetic energy converters

Windsail power drives hydrokinetic turbine inflow speeds between 5 to 10 m/s

Mobility provides high capacity factors, 70-80% avoids hazards, and reduces market barriers and costs

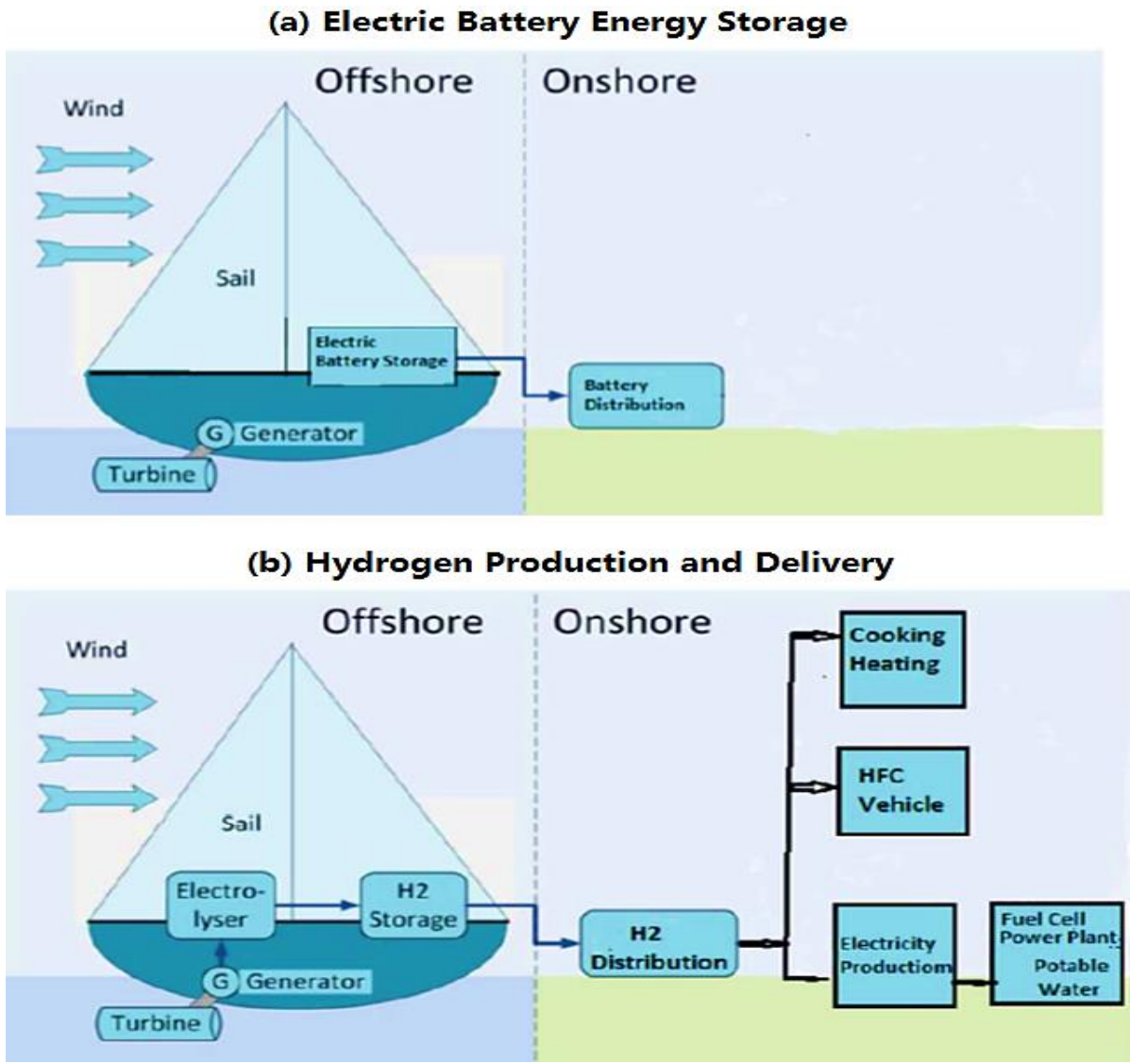
Most subsystems at TRL 9

Can be scaled to deliver 3-30 MW per ship

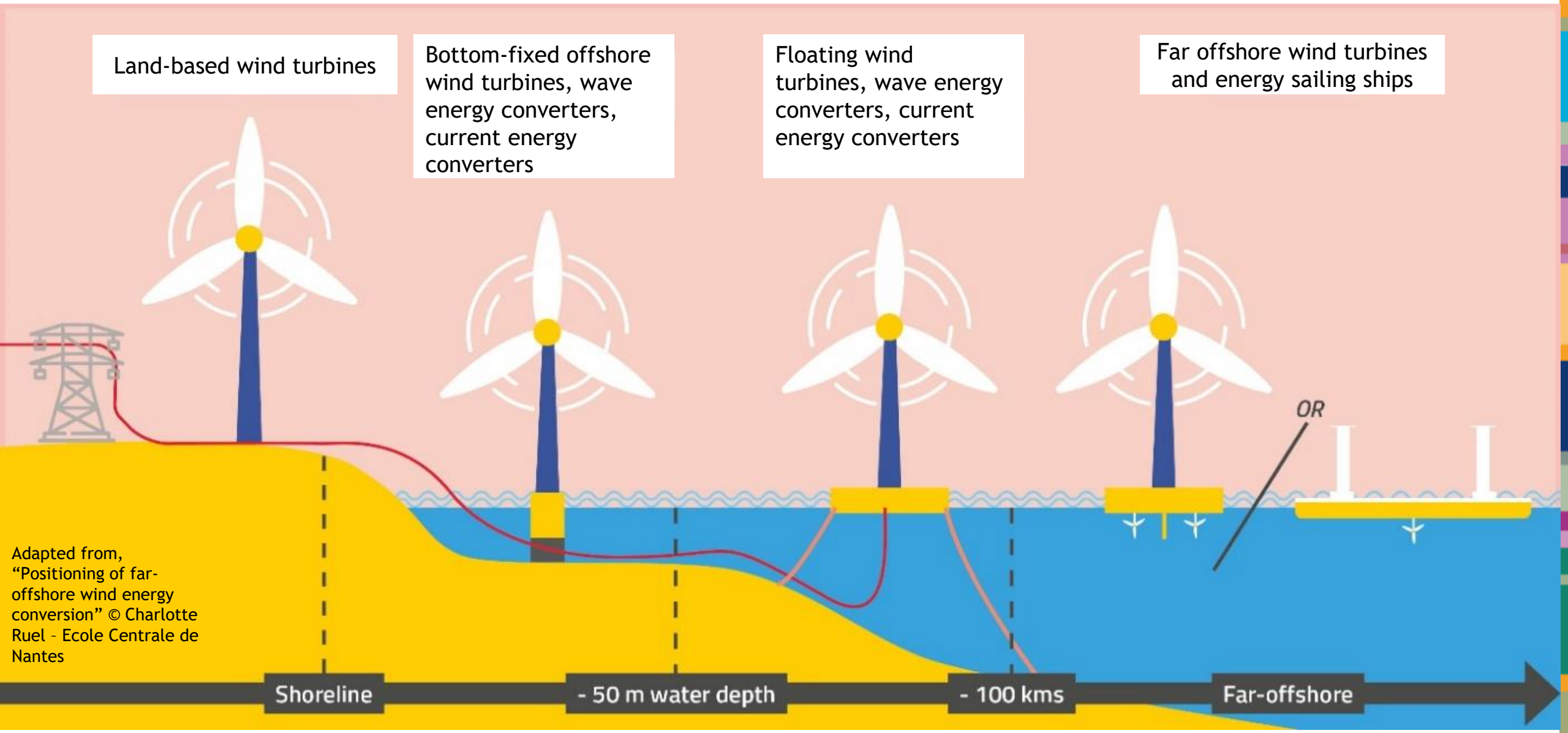
Millions of energy ships can satisfy the global energy demand

A variety of energy storage options, e.g., battery-stored electrical energy, sustainable liquid fuels, compressed or liquefied hydrogen

Autonomous operation in international waters subject only to the Law of the Sea

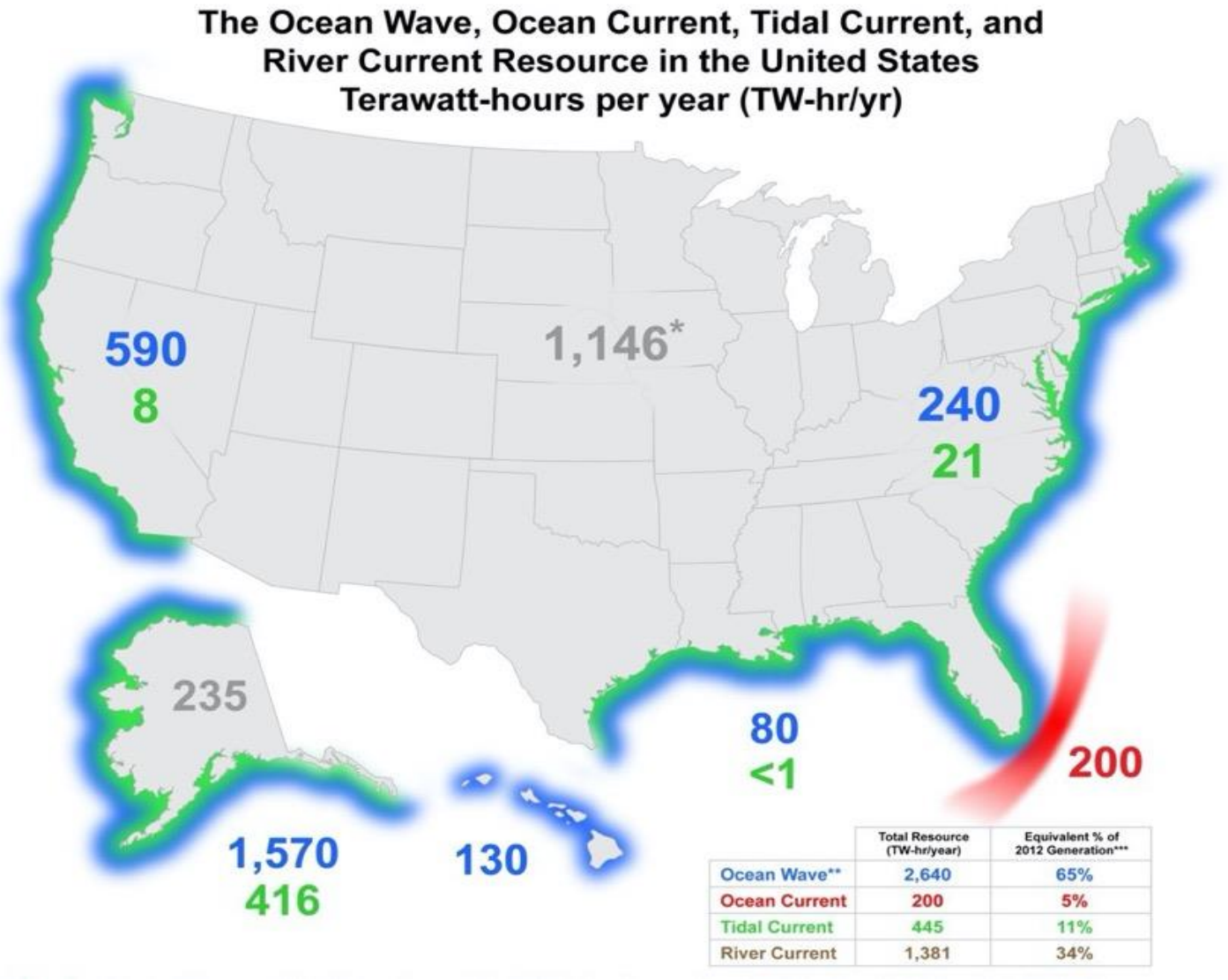


Migration of renewable kinetic energy generation technologies

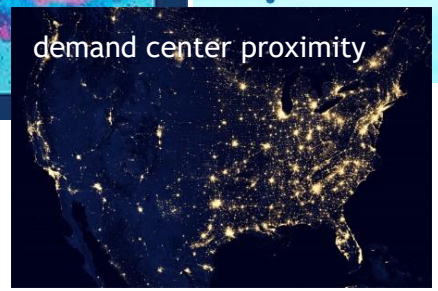


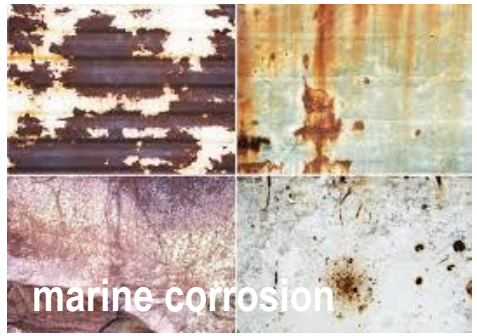
Adapted from, "Positioning of far-offshore wind energy conversion" © Charlotte Ruel – Ecole Centrale de Nantes

How & where are hydrokinetic energy resources available?



Marine renewable energy; Opportunities and challenges





MARINE CORROSION FORUM
FOR ALL WET CORROSION ISSUES
www.marinecorrosionforum.org

Opportunities

Urgency to move to renewable energy dominant portfolios [IPCC 2018]

Vast resources with large power densities close to population centers [NASA 2012]

Blue economy – local energy sources for maritime markets, e.g., desalinization, aquaculture, observation & navigation[USDOE 2019]

Challenges

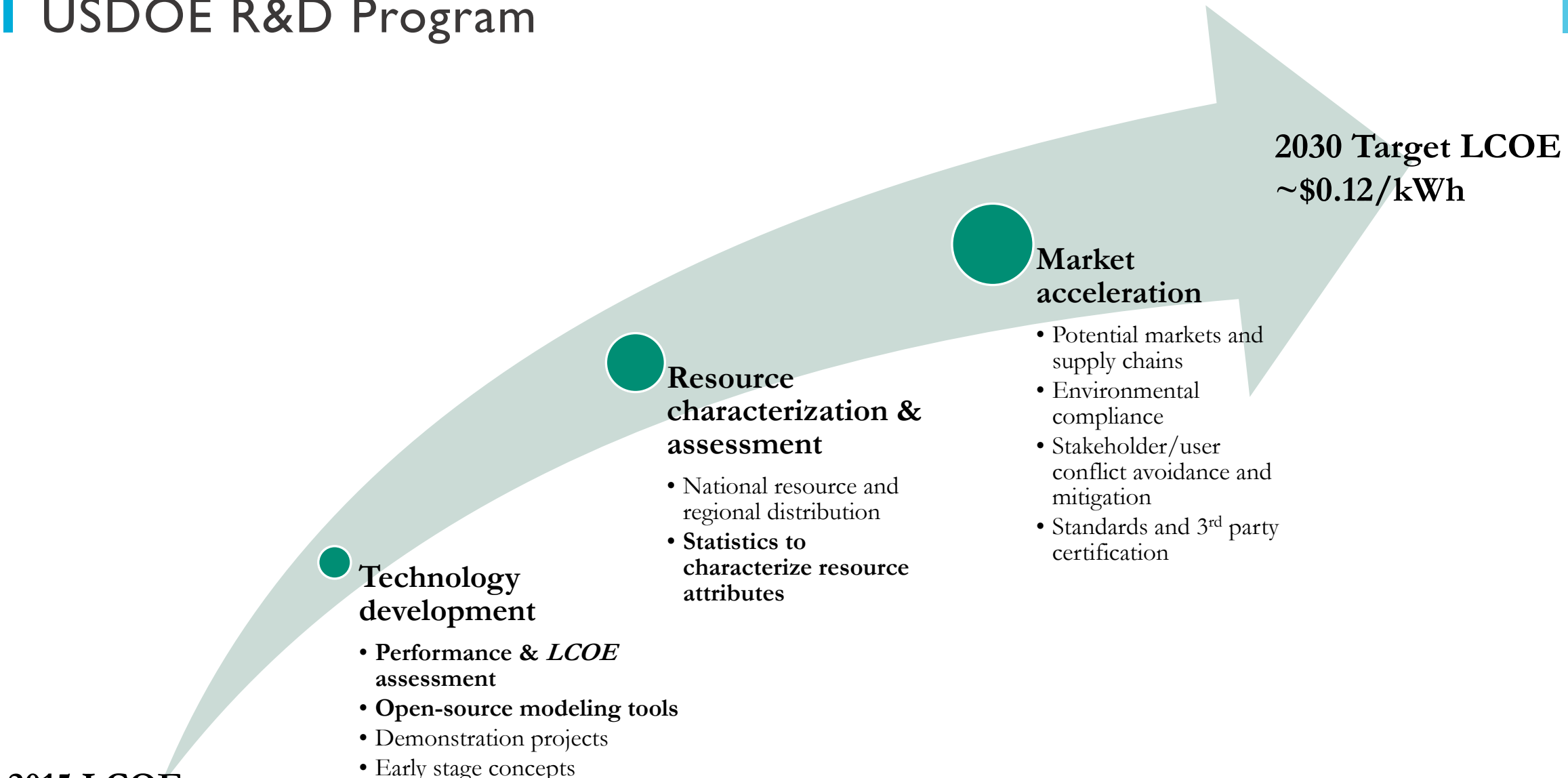
High capital, installation, operation and maintenance (IO&M) costs [Neary et al. 2013]

Difficult engineering - Harsh marine environment

Complex and costly permitting process for environmental compliance

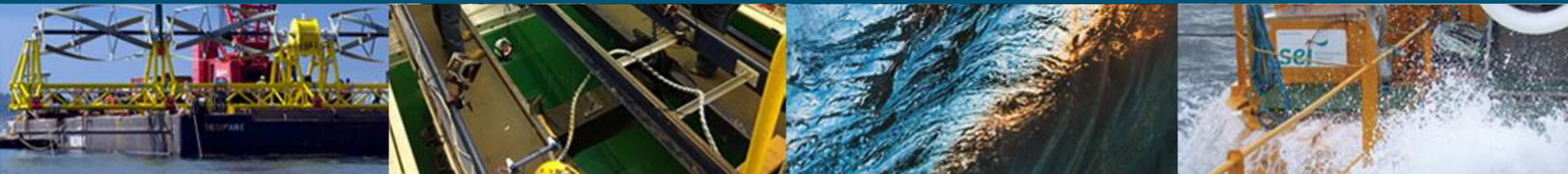
Market opportunities unclear, and no established supply chains

USDOE R&D Program



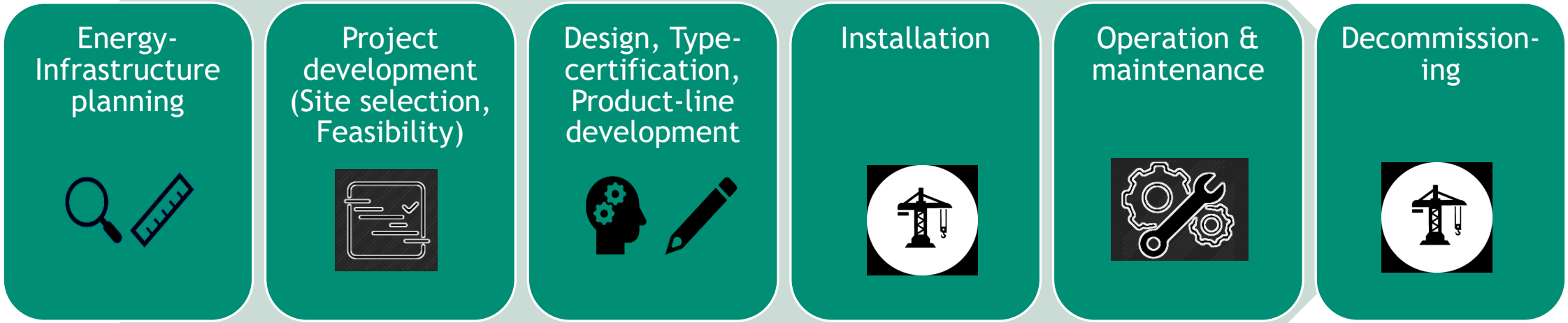
Neary et al, (2015). DOE Reference Model Project, SAND2019-6109 M, http://energy.sandia.gov/rmp

US wave energy resource characterization



Resource characterization needs in project life cycle

Resource information, data



Ocean energy project life-cycle

Motivation

- National resource assessments quantified potential contribution of wave energy to electricity production nationally and regionally [EPRI 2011, Chawla et al. 2013]
- More refined and comprehensive characterization needed to support energy planning, project development and WEC design
- Three assessment levels (area, Δx, Δt)
  - Reconnaissance (>300 km), 5 km, 3 h ☑
  - Feasibility (20-500 km), 500 m, 3 h ☐
  - Design (<25 km), 50 m, 1 h ☐

The MHK Atlas wave power density map.
Source:[NREL 2019].https://maps.nrel.gov/mhk-atlas/

Resource	Theoretical Resource
Waves	**3,500 TWh/year**
Tidal streams	445 TWh/year
Ocean currents	200 TWh/year

Source: USDOE 2015 Quadrennial Technology Review, http://energy.gov/qtr

Goals

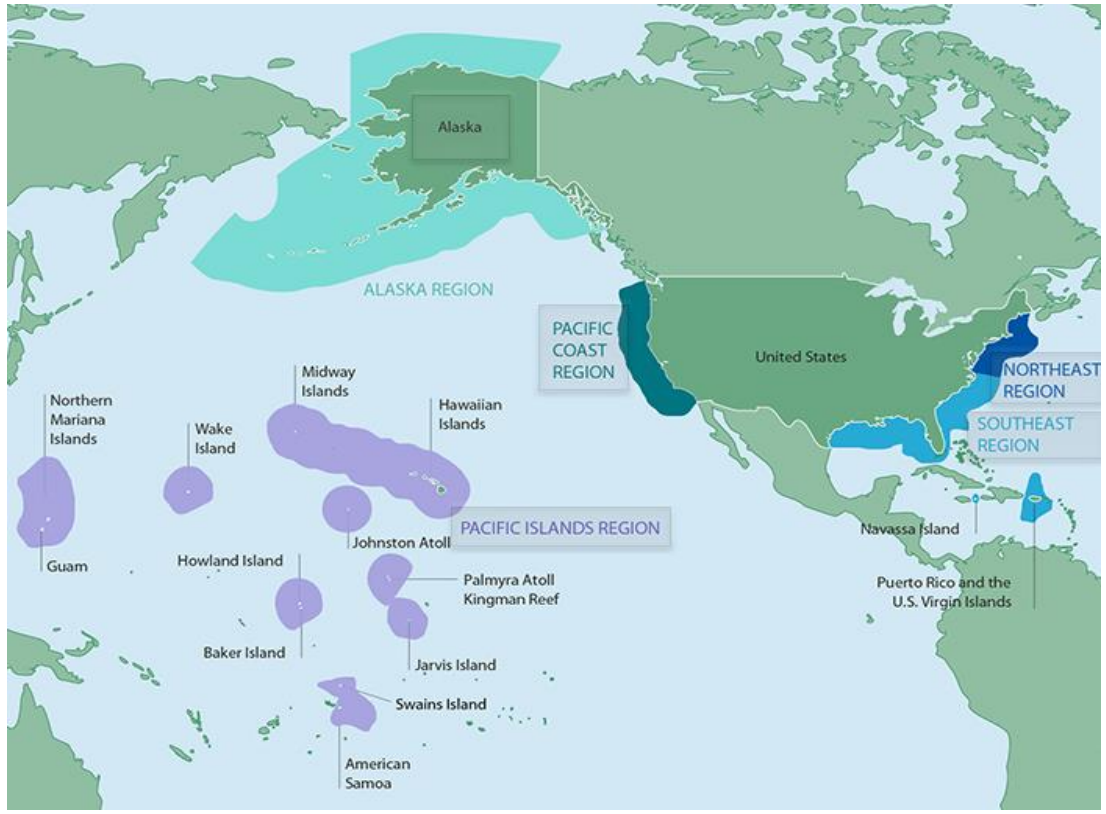
Generate high-resolution resource data source covering all US economic exclusion zones (EEZ) from 32-40 year wave model hindcast

Improve data source ☑

Improve characterization ☑

Improve data/information dissemination ☑

Region	Area, km²	Status
West Coast	825,549	Complete
East Coast	915,763	Complete
Alaska	3,770,021	Complete
Hawaii Islands	1,579,538	2019
Gulf of Mexico	707,832	2019
Pacific Islands	3,328,925	2020
Puerto Rico, US Virgin Islands	211,429	2020



US Economic Exclusion Zones (EEZ)

U.S. EEZ consists of following sub-regions: (a) Pacific West Coast; (b) East Coast (Northeast and Southeast regions); (c) Alaska; (d) Gulf of Mexico; (e) Puerto Rico and U.S. Virgin Islands; (f) Hawaii and Pacific Islands. EEZ is defined as a sea zone that extends 370 km (200 nmi) offshore from its coastal baseline. The image is obtained from NOAA National Ocean Service. https://www.worldatlas.com/articles/countries-with-the-largest-exclusive-economic-zones.html

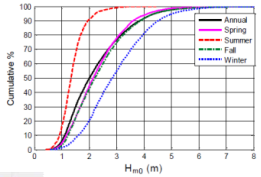
Open source tools: Resource data and information dissemination

MHK ATLAS upgrade (In-progress)
- All 6 IEC parameters, monthly averages and average annual values
- Hs(50, 5, 1-year)
- 200-300 m resolution within US EEZ
- Includes shallow nearshore waters

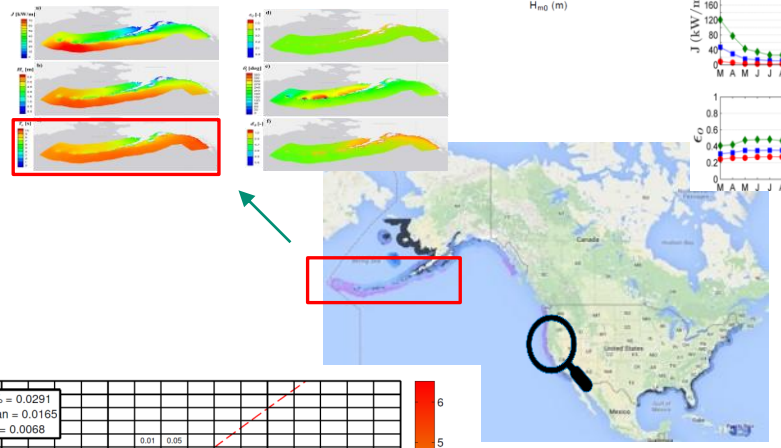
MHK Data Repository (In-progress)
- 2D spectra, ***O***(100) points each region
- Partitioned bulk parameters, ***O***(1,000) points each region
- IEC parameter time series, ***O***(1M) points

Functional GIS dissemination platforms (TBD)
- Bureau of Ocean Energy Management (BOEM), US Dept. of Interior (USDOI)
- NOAA, Ocean Project Planning Tool,
- US Dept. of Commerce (USDOC)
- Private vendor, e.g., Open Ocean (Marine data intelligence) http://www.openocean.fr/en/

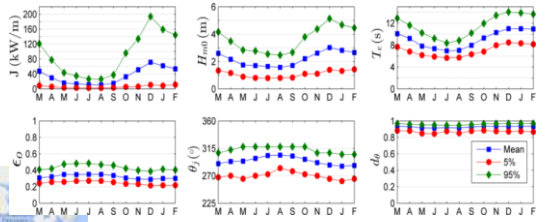
Cumulative frequency

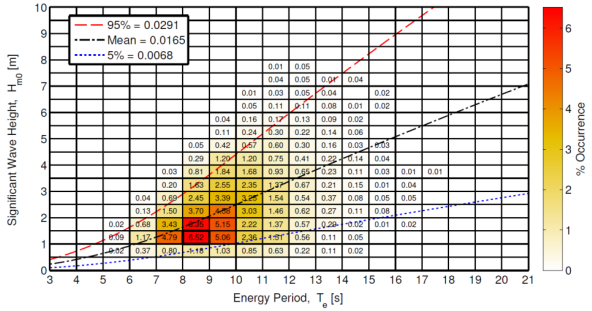


Spatial distribution

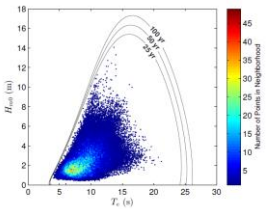


Seasonal variations (monthly averages)

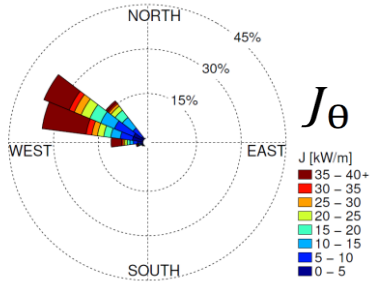




Sea state scatter plots



Environmental contours



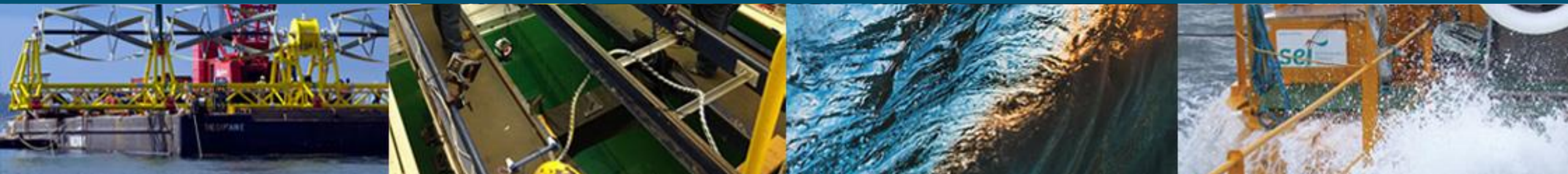
Wave rose

BOEM Bureau of Ocean Energy Management

U.S. DEPARTMENT OF ENERGY

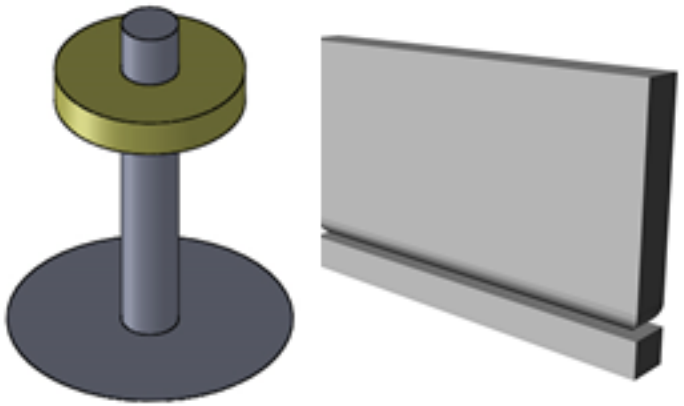
NOAA National Oceanic and Atmospheric Administration, U.S. Department of Commerce

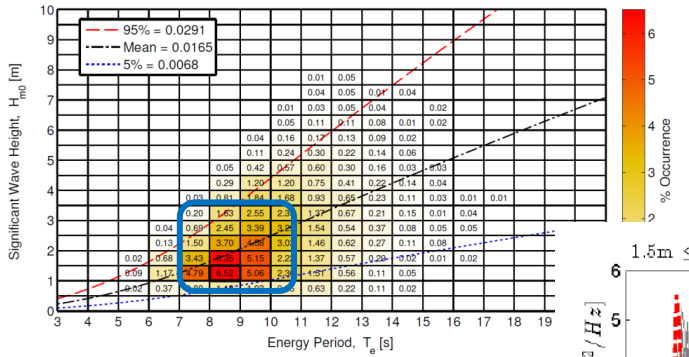
Open-source modeling tools for WEC design & analysis



Open-source tools: WEC-Sim [Coe et al. 2018, Neary et al. 2018]

WEC device specification

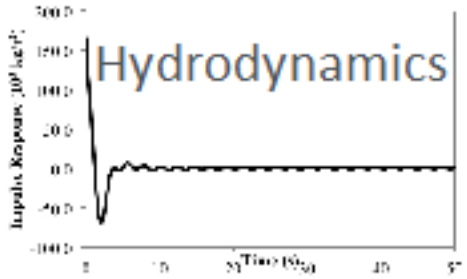




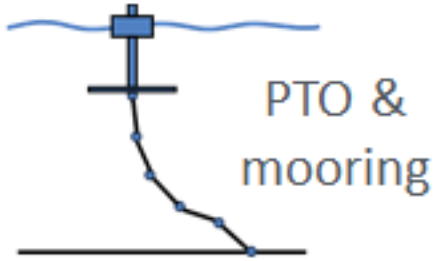
Sea states scatter plot

Relevant numerical methods

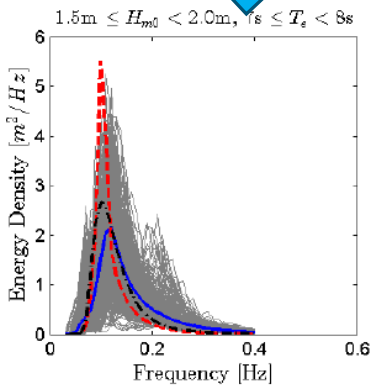
Multi-body dynamics



Hydrodynamics

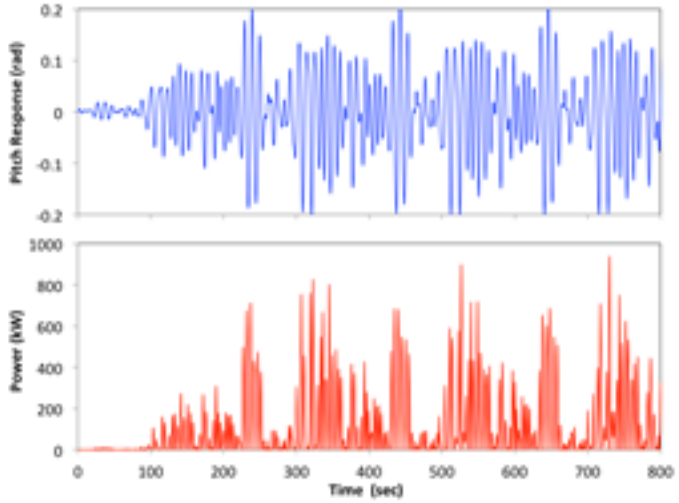


PTO & mooring



Hourly wave spectra

WEC performance, motions, and loads

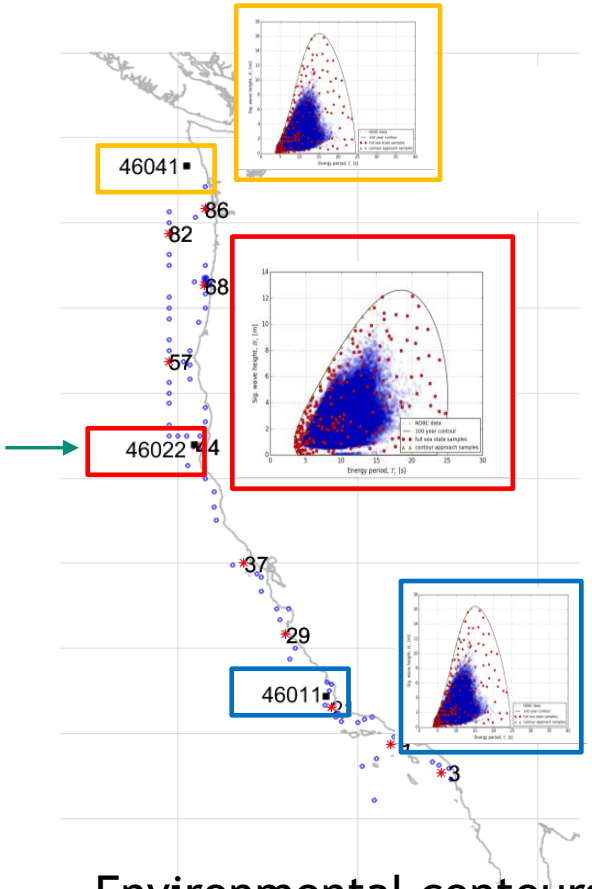


Power Matrix (kW) Cd_float=1.4; Cd_plate=4.25 (Based on CFD)

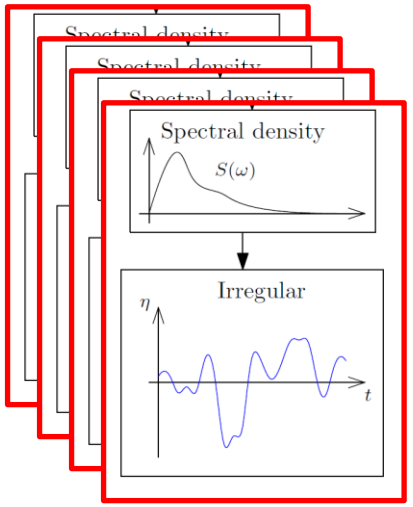
Hs (m) \ Energy Period (s)	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7
0.25	0.42	0.71	0.97	1.19	1.36	1.46	1.49	1.45	1.36	1.24	1.11	0.99	0.87
0.75	3.77	6.36	8.75	10.73	12.22	13.14	13.38	13.02	12.21	11.17	10.03	8.91	7.85
1.25	10.51	17.66	24.32	29.80	33.96	36.49	37.17	36.15	33.92	31.02	27.86	24.74	21.80
1.75	21.66	34.79	47.66	58.41	66.55	71.52	72.85	70.86	66.49	60.80	54.62	48.49	42.73
2.25	37.64	61.75	79.03	96.55	110.02	118.23	120.43	117.14	109.92	100.50	90.28	80.16	70.64
2.75	57.95	100.66	121.83	144.23	164.34	176.62	179.90	174.98	164.19	150.13	134.87	119.74	105.52
3.25	81.24	150.37	178.99	204.14	229.54	246.68	251.27	244.40	229.33	209.69	188.37	167.24	147.38
3.75	108.16	209.85	249.53	279.77	306.79	328.42	334.52	325.38	305.32	279.18	250.78	222.66	196.22
4.25	138.93	272.93	332.45	371.07	399.54	421.84	429.68	417.93	392.17	358.59	322.12	285.99	252.04
4.75	173.54	340.92	426.99	477.32	509.06	530.38	536.73	522.05	489.87	447.92	402.37	357.24	314.83
5.25	212.00	416.47	531.26	597.80	634.90	655.75	657.31	637.74	598.43	547.19	491.54	436.41	384.60

https://wec-sim.github.io/WEC-Sim/

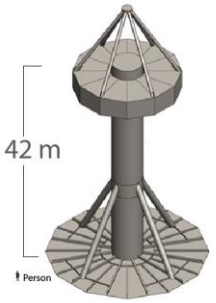
Open-source tools: WEC design response toolbox (WDRT) [Coe et al. 2018, Neary et al. 2018, Coe & Neary 2014]



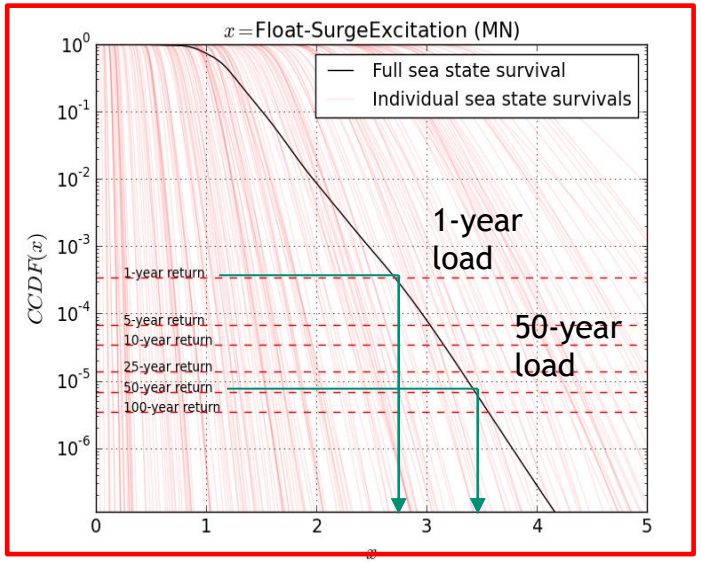
Environmental contours from (Hs, Te) time-series
Select 200 random sea states [Eckert-Gallup et al. 2016]



200, 3h design waves for wave site



WEC-Sim



200 short term response distributions averaged to generate one long term distribution extreme loads (Heave, Surge, etc.)

https://wec-sim.github.io/WDRT/index.html

Concluding remarks

USDOE R&D roadmap provides comprehensive framework for advancing marine energy systems to commercialization with primary goal of reducing LCOE

Knowledge of resource attributes and extreme conditions, critical inputs to planning WEC projects, and design and analysis of WECs

Accurate resource data & information, and validated models and tools critical for reducing LCOE of 1st generation technologies

ACKNOWLEDGEMENTS:

Contributors to this work include Sandia colleagues Bibiana Seng, Sara Bredin, Dr. Seongho Ahn; Pacific Northwest National Laboratory researchers Dr. Zhaoqing Yang, and Dr. Taiping Wang; Georgia Tech researcher Dr. Kevin Haas; and North Carolina State University researchers Dr. Nabi Allahdadi and Dr. Ruoying He. The model test bed study benefited from review and input from steering committee members including Dr. Bryson Robertson, University of Victoria, Dr. Arun Chawla of NOAA.

Thank you

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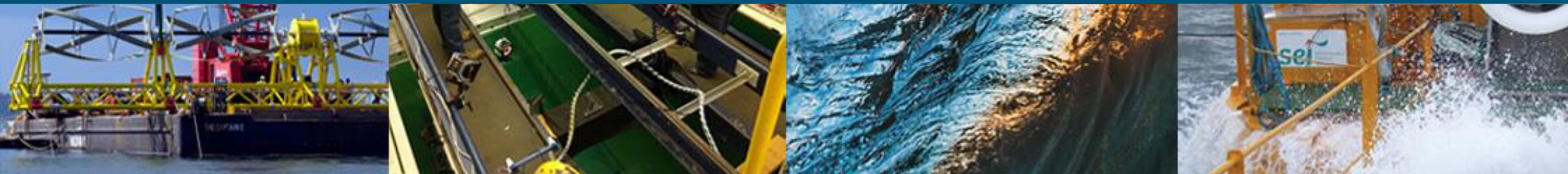
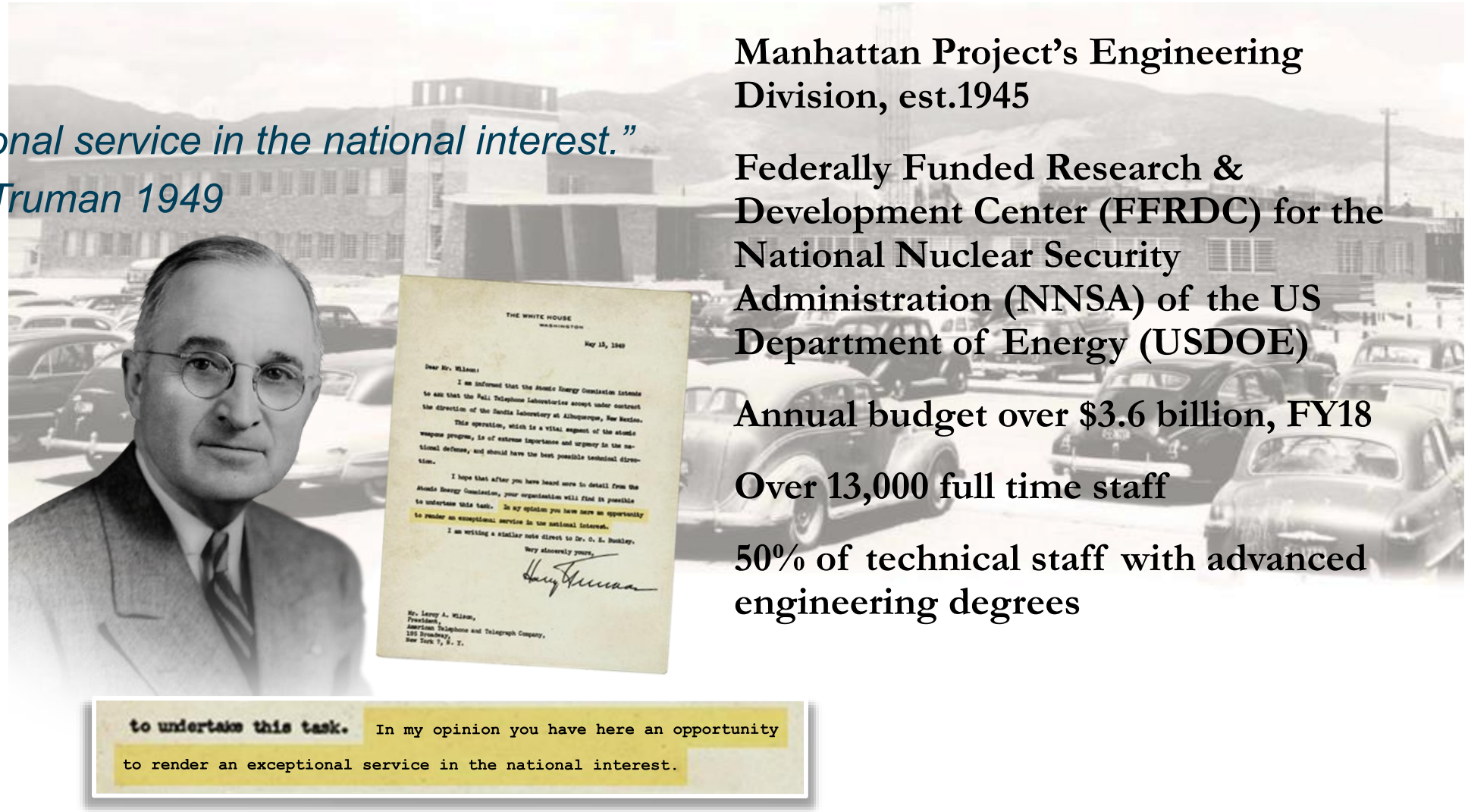
Extra slides



Sandia National Laboratories: Background

"…exceptional service in the national interest."
President Truman 1949



to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

Manhattan Project's Engineering Division, est.1945

Federally Funded Research & Development Center (FFRDC) for the National Nuclear Security Administration (NNSA) of the US Department of Energy (USDOE)

Annual budget over $3.6 billion, FY18

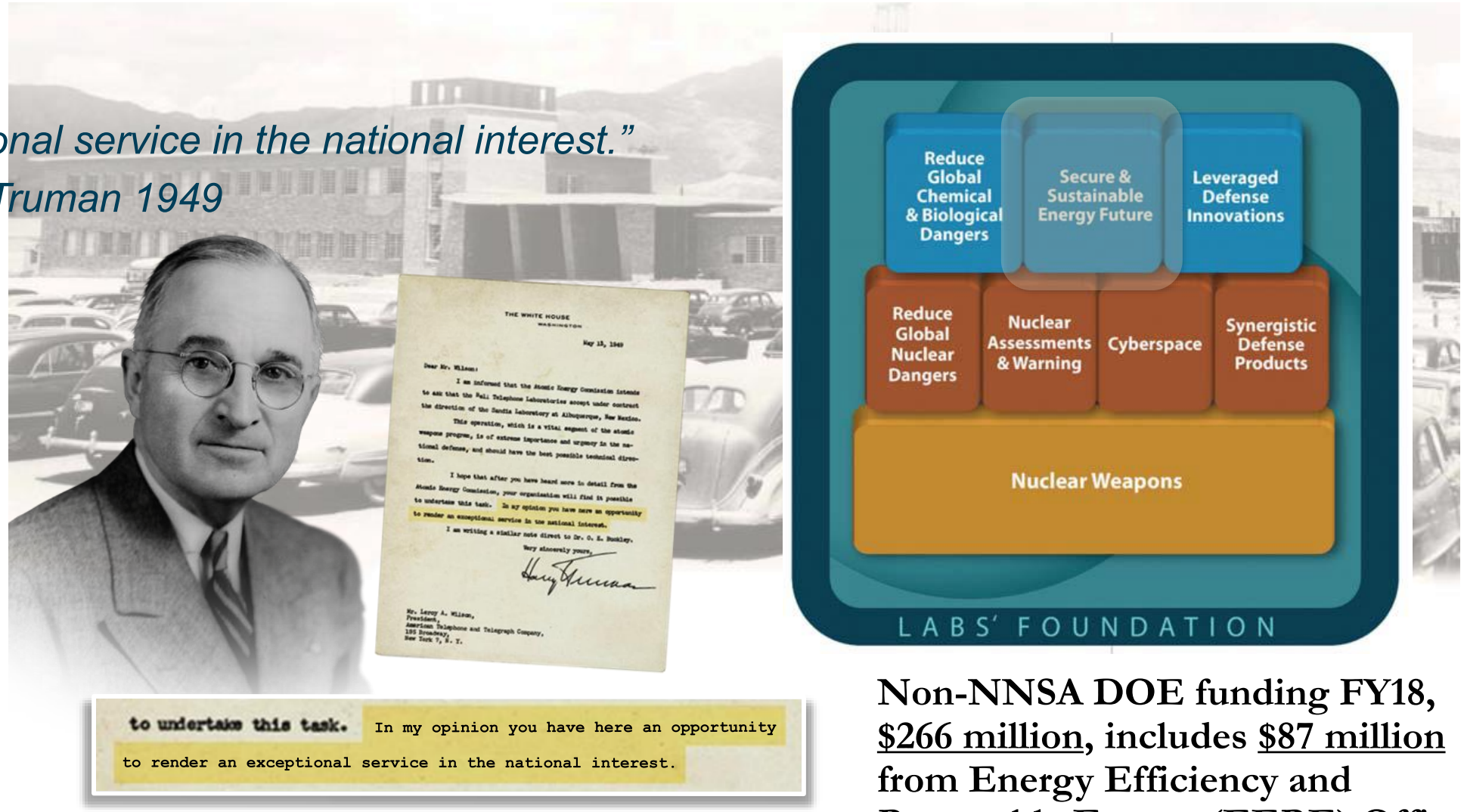
Over 13,000 full time staff

50% of technical staff with advanced engineering degrees

Sandia National Laboratories

Sandia National Laboratories: Securing Our Nation's Future

"…exceptional service in the national interest."
President Truman 1949



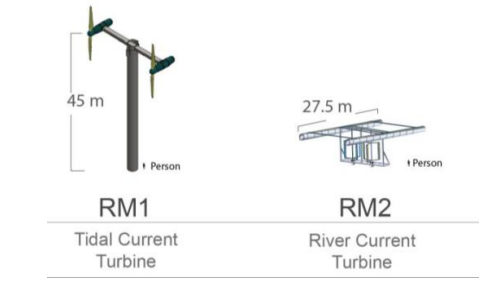
Non-NNSA DOE funding FY18, $266 million, includes $87 million from Energy Efficiency and Renewable Energy (EERE) Office

Sandia National Laboratories

Benchmarking *LCOE* for 1st generation marine energy converters

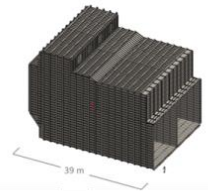
CECs – 10 MW Projects
- ≈ $0.31-0.45/kWh
- Cost drivers PTO, structure, O&M

WECs – 10 MW Projects
- $0.98/kWh for RM3, RM5
- $1.53/kWh for RM6
- Cost drivers power absorption, structure, mooring, O&M

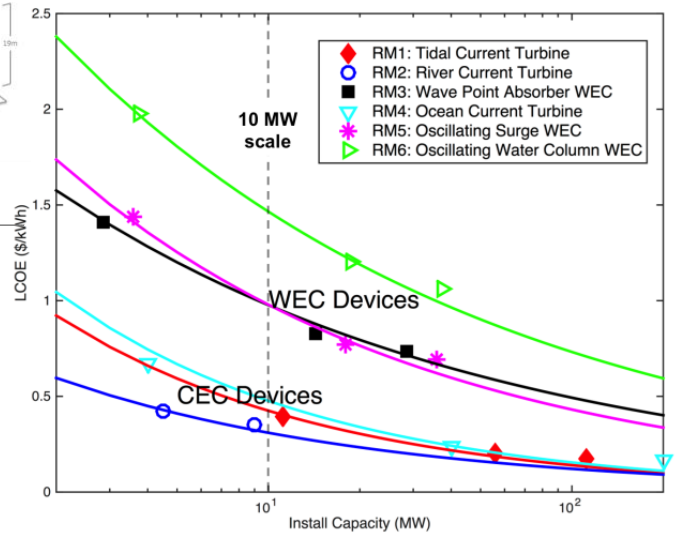


RM3 Wave Point Absorber

RM5 Oscillating Surge Flap



RM6 Oscillating Water Column



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