U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Marine and Hydrokinetic [MHK] Technology: Background Information

Marine and Hydrokinetics Distributed and Alternate Applications Forum

November 2017

Contents

- **Glossary**
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  - Resource
  - Device Types: Wave and Currents (Tidal, River, Ocean)
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Glossary

International Energy Agency – Ocean Energy Systems (IEA – OES) General Ocean Energy Glossary
https://www.ocean-energy-systems.org/publications/oes-reports/guidelines/document/ocean-energy-glossary-2007-/

International Electrotechnical Commission (IEC) TC114 Marine Energy Terminology Technical Specification: IEC TS 62600-1. Marine Energy – Wave, Tidal, and other Water Current Converters – Part 1: Terminology
http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID,FSP_LANG_ID:1316,25/

Terms Used in Forum Documents	
Term	Description
kW	Kilowatt – Rate of energy transfer. Average use rate of U.S. household.
kWh	Kilowatt hour – Amount of energy transferred. One k.ilowatt for one hour. Equivalent to electric heater running for one hour.
WEC	Wave Energy Converter
CEC	Current Energy Converter
PV	Photovoltaic
Availability	Percentage of time energy device is operational and able to convert energy.

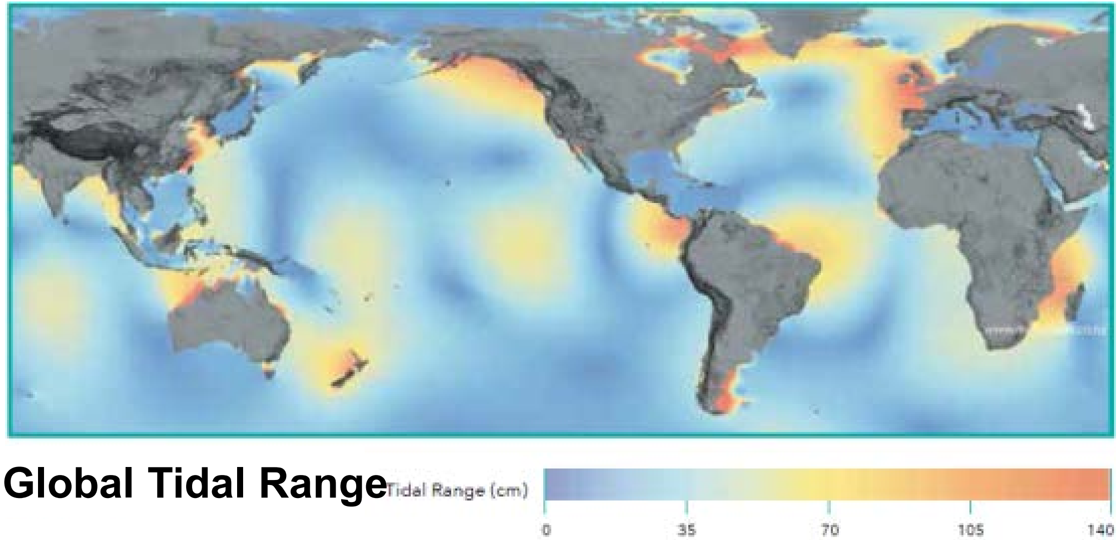
Glossary

Term	Description
ROV	Remotely Operated Vehicle
UUV	Unmanned Underwater Vehicle (DoD)
AUV	Autonomous Underwater Vehicle
Electrolysis	The process of using electricity to split water into hydrogen and oxygen. his reaction takes place in an electrolyzer.
EEZ	Exclusive Economic Zone. Extends no more than 200 nautical miles from the territorial sea baseline and is adjacent to the 12 nautical mile territorial sea of the United States, including any other territory or possession over which the United States exercises sovereignty. Within the EEZ, the United States has: Sovereign rights for the purpose of exploring, exploiting, conserving, and managing natural resources, whether living or nonliving, of the seabed and subsoil and the superjacent waters and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds.
Reverse Osmosis	The movement of freshwater through a semipermeable membrane when pressure is applied to a solution (such as seawater) on one side of it.
Array	An arrangement of similar devices. In ocean energy devices, this means a number of similar devices arranged into a single group to provide a combined energy output. Also known as a "farm."
Bathymetry	The measurement of water depth and the shape of seabed — often as shown on a map of the sea or hydrographical chart.

Glossary

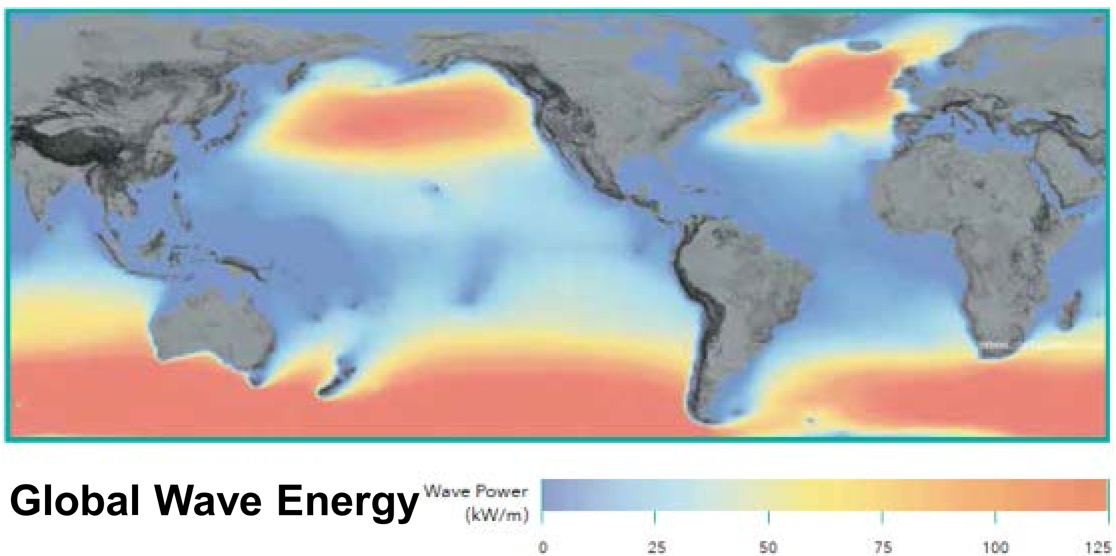
Term	Description
Availability	The degree to which a system is free from degradation or interruption in its output, resulting from component failures, maintenance, or operational scheduling. Availability is often expressed as an annual percentage derived from the following equation: Availability = Time available for operation / Total time in period.
Capacity Factor	Same as load factor or full load factor. The ratio of the mean generation to the peak generation on a renewable energy generator. Either expressed in percentage (referring to a reference time period) or in equivalent full load hours per year.
Conversion Efficiency	The conversion efficiency (η) of a device is the proportion of energy converted to a useful form (e.g., electricity) compared to the total energy available to the device.
Installed Capacity	The installed capacity of a device is the total power that the device can produce when operating correctly and at full power output. Traditionally, this is the installed capacity of the electrical generator in a device. Installed capacity is usually measured in kilowatts (kW) or megawatts (MW).
Power-Take-Off (PTO)	A system incorporated to a renewable energy device that allows energy from the physical motions of the deviceto be converted to a useful form, such as electricity.
Survivability	A measure of a device's ability to remain intact and operational in extreme environmental conditions.

MHK Resources Are Widely Distributed



Global Tidal Range

Tidal range is very predictable, although it can be modified by local weather conditions. The worldwide theoretical power of tidal energy, including tidal currents, has been estimated at around 1,200 TWh/year.



Global Wave Energy

The wave energy map has been shaded to enhance the wave power flux between 15 and 75 KW/m, which is the likely operational range of wave energy converters. The worldwide theoretical potential of wave power has been calculated as 29,500 TWh/year.

Ocean Energy Systems: Vision for Ocean Energy 2017
https://www.ocean-energy-systems.org/news/oes-vision-for-international-deployment-of-ocean-energy/

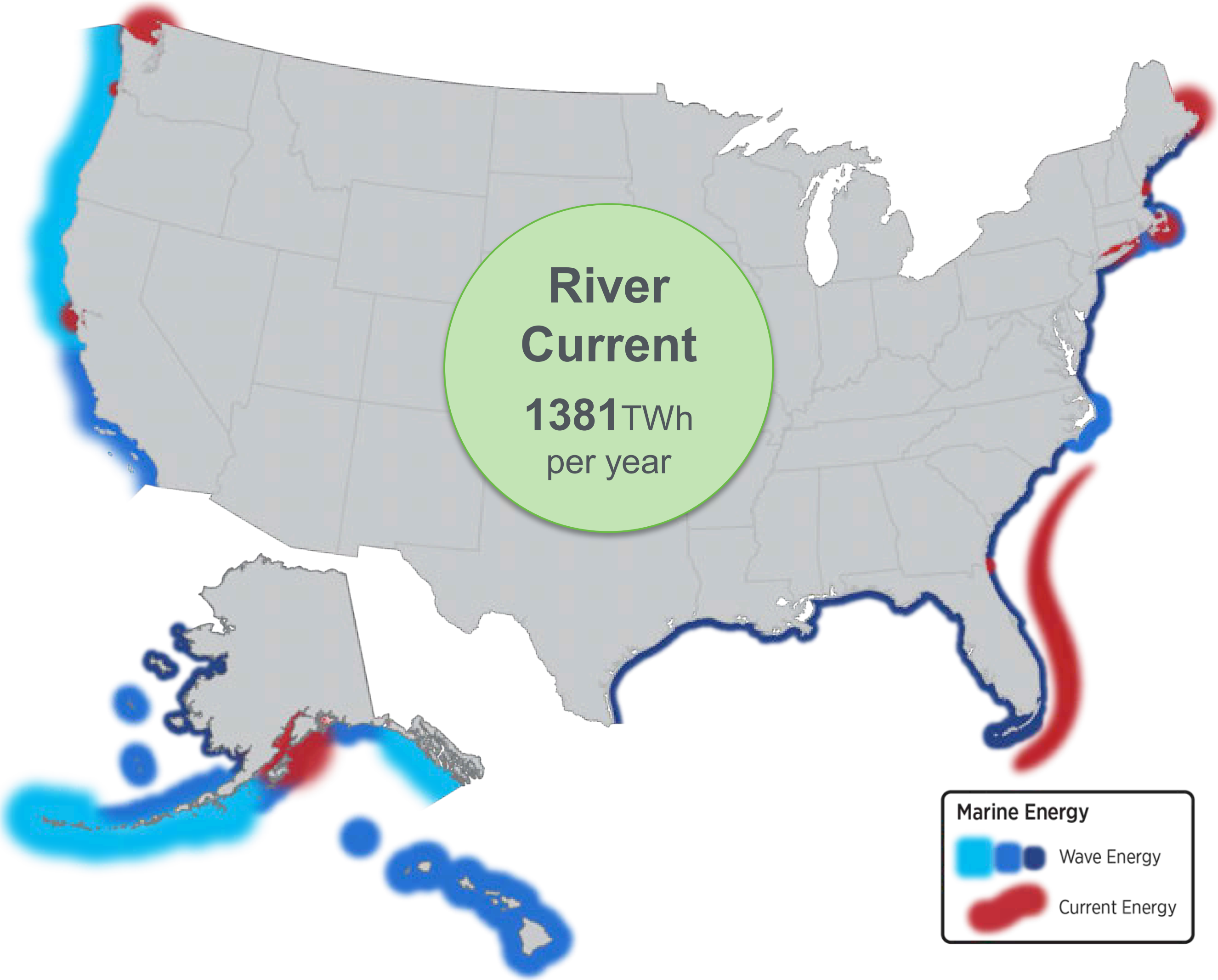
The U.S. Has Significant, Distributed MHK Resources

Ocean
Wave
2640TWh
per year

Tidal
Current
445TWh
per year

Ocean
Current
200TWh
per year

River
Current
1381TWh
per year

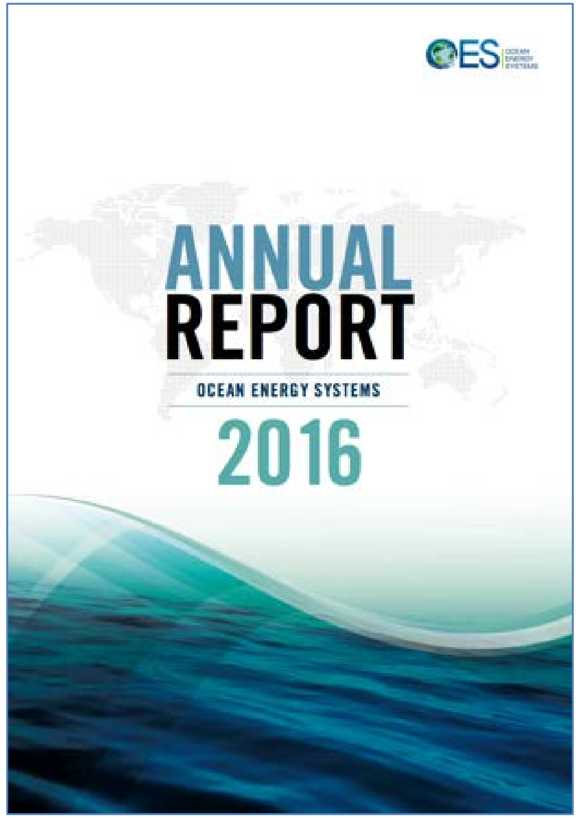


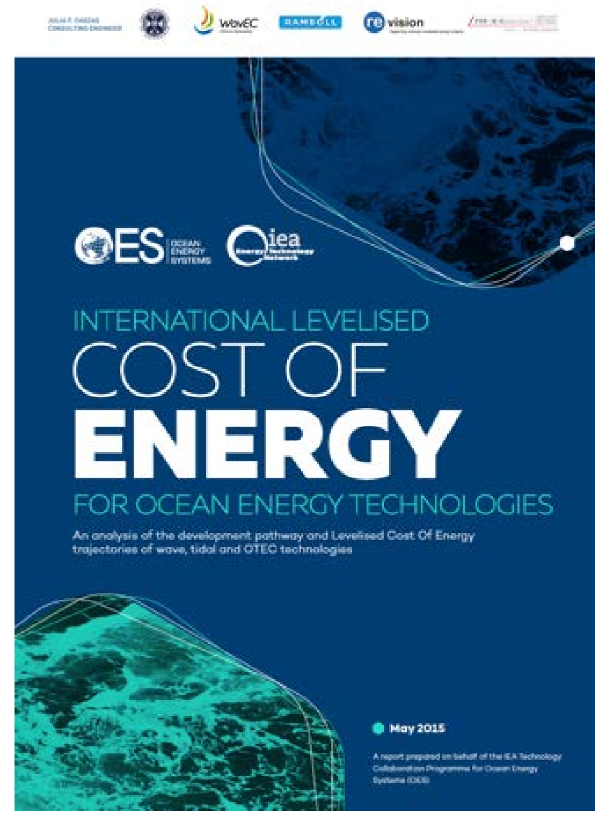
https://energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization

International Organizations Guide Sector and Technology Development and Outline Progress

International Energy Agency: Ocean Energy Systems

- Established 2001
- 25 member countries
- https://www.ocean-energy-systems.org/index.php



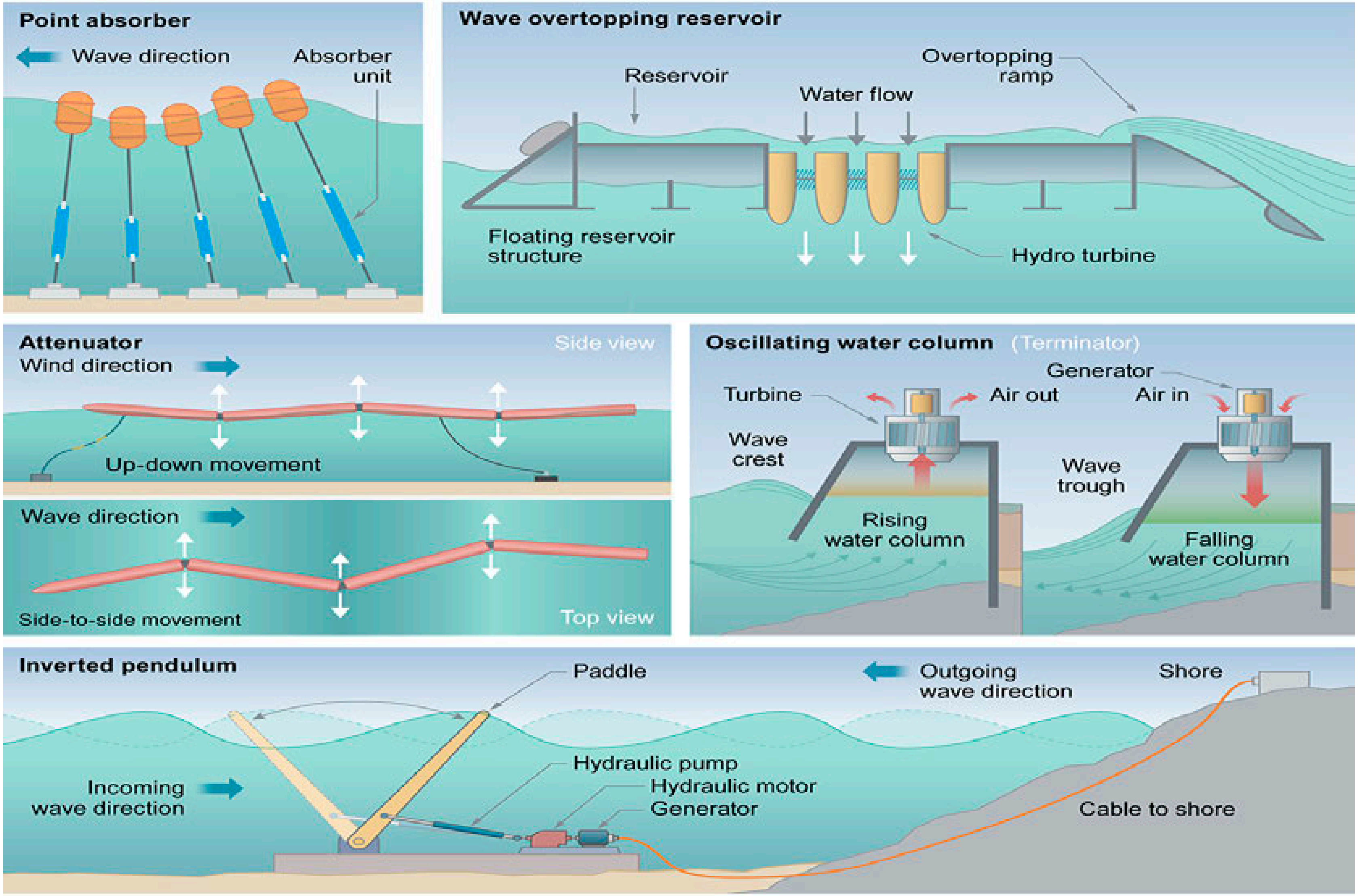


International Electrotechnical Commission

- Founded 2008
- 15 participating member countries and 11 observer
- 8 Technical Specifications published
- http://www.tc114.us/

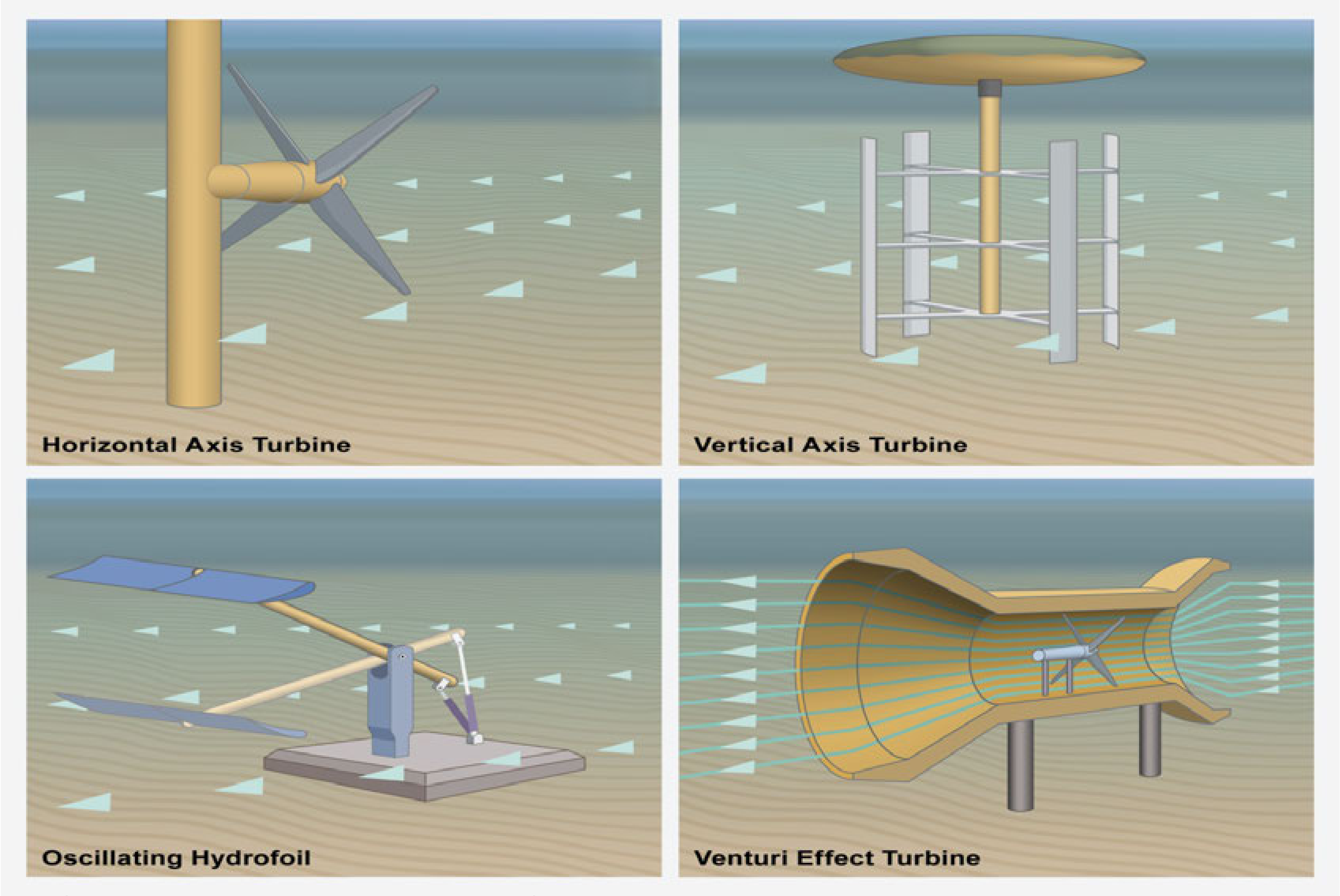
IEC TC-114
US Technical Advisory Group

A Range of Different Wave Energy Technology Types Are Presently In Development: Some Examples Below



Source: Renewable Electricity Futures Study NREL TP-6A20-52409-2 (https://www.nrel.gov/docs/fy12osti/52409-2.pdf)

Different Current (Tidal, Ocean, River) Energy Technology Types Are also in Development: Some Examples Below



Source: Renewable Electricity Futures Study NREL TP-6A20-52409-2 (https://www.nrel.gov/docs/fy12osti/52409-2.pdf)

Cost Are Presently High for Utility Application

Deployment Stage	Variable	Wave		Tidal	
		Min	Max[1]	Min	Max
First array / First Project[2]	Project Capacity (MW)	1	3 [3]	0.3	10
	CAPEX ($/kW)	4000	18100	5100	14600
	OPEX ($/kW per year)	140	1500	160	1160
Second array/ Second Project	Project Capacity (MW)	1	10	0.5	28
	CAPEX ($/kW)	3600	15300	4300	8700
	OPEX ($/kW per year)	100	500	150	530
	Availability (%)	85%	98%	85%	98%
	Capacity Factor (%)	30%	35%	35%	42%
	LCOE ($/MWh)	210	670	210	470
First Commercial-scale Project	Project Capacity (MW)	2	75	3	90
	CAPEX ($/kW)	2700	9100	3300	5600
	OPEX ($/kW per year)	70	380	90	400
	Availability (%)	95%	98%	92%	98%
	Capacity Factor (%)	35%	40%	35%	40%
	LCOE ($/MWh)	120	470	130	280

International Energy Agency Ocean Energy Systems 2016 Report: "International Levelised Cost of Energy (LCOE) for Ocean Energy Technologies." https://www.ocean-energy-systems.org/

Note:
LCOE for deployed energy systems typically range from 40-100 $/MWh and up to 250 $/MWh for diesel systems

"Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2017"

https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

Significant Cost Reductions Are Targeted in Wave Energy

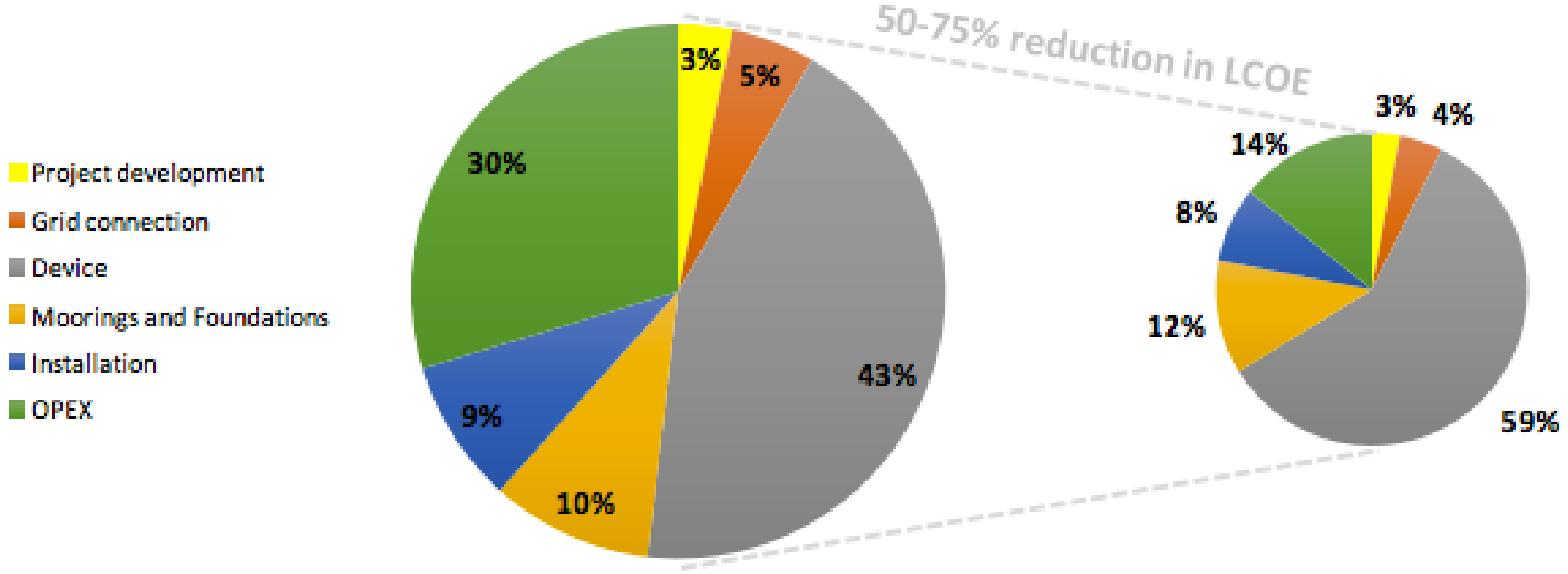


Figure 19: Wave LCOE Percentage Breakdown by Cost Centre Values at Current Stage of Deployment (Left) and the Commerical Target (Right) [Note: the area of the chart represents the LCOE].

Figure from International Energy Agency Ocean Energy Systems 2016 Report: "International Levelised Cost of Energy (LCOE) for Ocean Energy Technologies." https://www.ocean-energy-systems.org/

Significant Cost Reductions Are Targeted in Tidal Energy

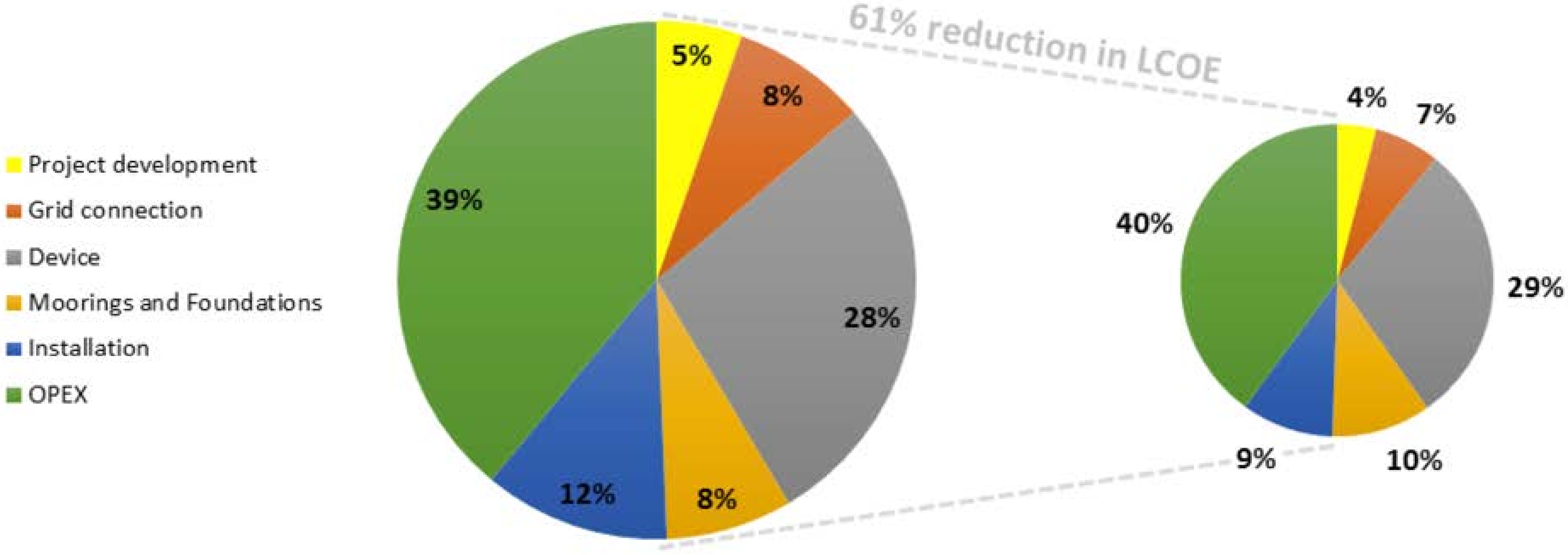


Figure 9: Tidal LCOE Percentage Breakdown by Cost Centre Values at Current Stage of Deployment (Left) and the Commerical Target (Right) [Note: the area of the chart represents the LCOE]

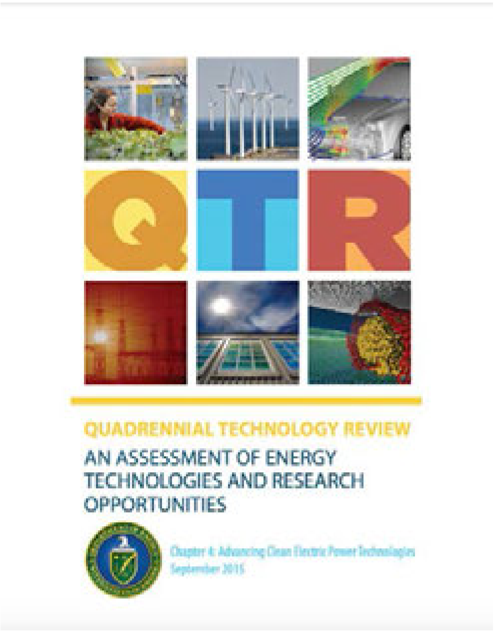
Figure from International Energy Agency Ocean Energy Systems 2016 Report: "International Levelised Cost of Energy (LCOE) for Ocean Energy Technologies." https://www.ocean-energy-systems.org/

DOE Has Outlined MHK Status, Challenges, and Opportunities in the Quadrennial Technology Review

- https://energy.gov/under-secretary-science-and-energy/quadrennial-technology-review-2015
- **Section 4.2.9 Marine and Hydrokinetic Power Technology**

The 2015 Quadrennial Technology Review (QTR 2015) examines the most promising research, development, demonstration, and deployment (RDD&D) opportunities across energy technologies to effectively address the nation's energy needs.

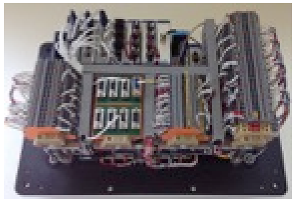
Specifically, this analysis identifies the important technology RDD&D opportunities across energy supply and end use in working toward a clean energy economy in the United States. The insight gained from this analysis provides essential information for decision makers as they develop funding decisions, approaches to public-private partnerships, and other strategic actions over the next five years.



Present MHK R&D Efforts

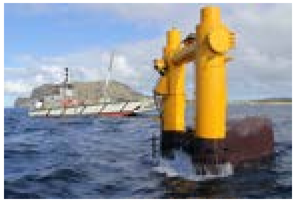
Performance

- Drive and empower innovation
- Verify and optimize power performance and quality
- Identify opportunities and approaches for improvement



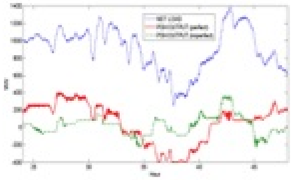
Reliability

- Assess and improve system and component reliability
- Identify areas and approaches for O&M focus and cost reduction



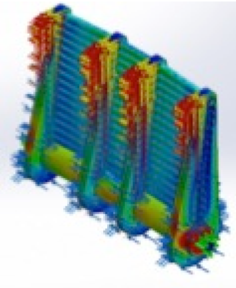
Capex

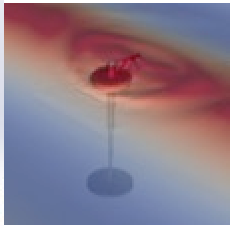
- Drive down capital costs
- Validate structural and dynamic models
- Collaborate with industry to refine designs



Risk / Risk Perception

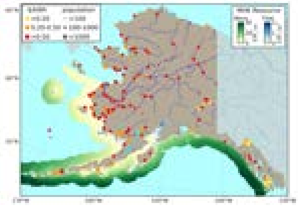
- Decrease real risks and risk perception
- Characterize grid and grid fault response
- Verify systems operate as designed — ready for deployment
- Device certification testing





Deployment

- Early application assessment
- Grid response, services, and power market value
- Market barrier and opportunity assessment
- Project feasibility assessment



Lack of Impacts Observed Globally Summarized in Recent Report

ENVIRONMENTAL EFFECTS OF MARINE ENERGY DEVELOPMENT AROUND THE WORLD

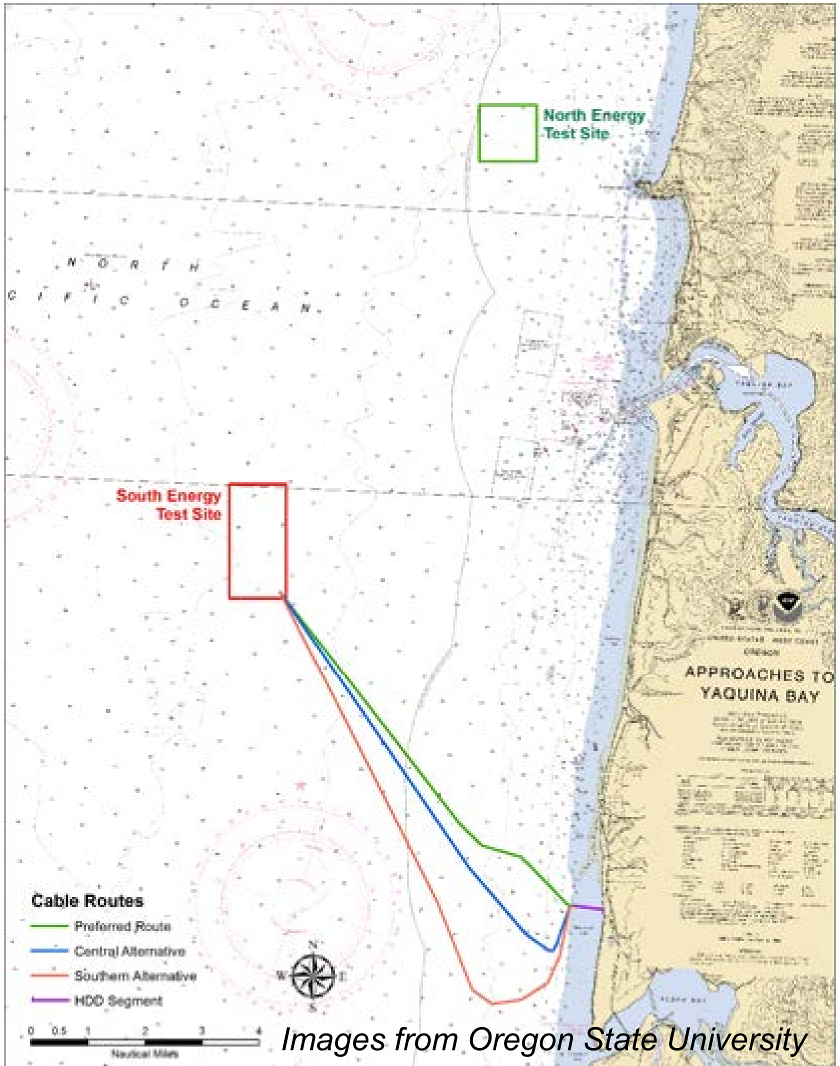
OES OCEAN ENERGY SYSTEMS
An IEA Technology Initiative

ANNEX IV

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

http://tethys.pnnl.gov/publications/state-of-the-science-2016

U.S. Wave At-Sea Validation and Optimization Site in Development: PMEC SETS



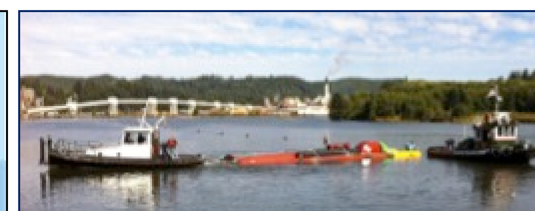
Images from Oregon State University

NNMREC
Northwest National Marine Renewable Energy Center

Umbrella organization for wave, current, in-river academic & scientific research

PMEC
Pacific Marine Energy Center

Umbrella organization for all marine renewable energy test facilities at partner institutions



http://nnmrec.oregonstate.edu/facilities/pmec-sets

NNMREC
Northwest National Marine Renewable Energy Center

U.S. Wave At-Sea Validation and Optimization: Navy Wave Energy Test Site and University of Hawai’i

- Provides three grid connected berths (30/60/80 m depth; 1 to 2 km offshore)
- For technical evaluation and environmental impact assessment studies of in-water WEC devices

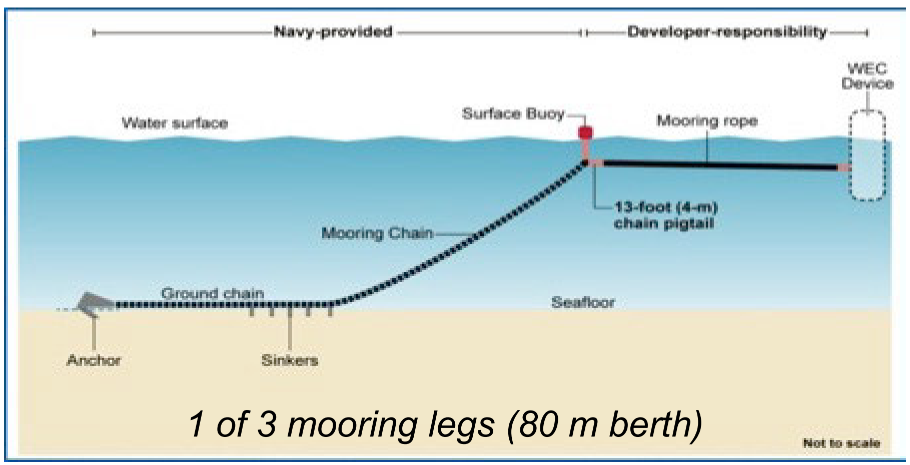


Figure from University of Hawai’I Manoa

http://hinmrec.hnei.hawaii.edu/nmrec-test-sites/wave-energy-test-site/

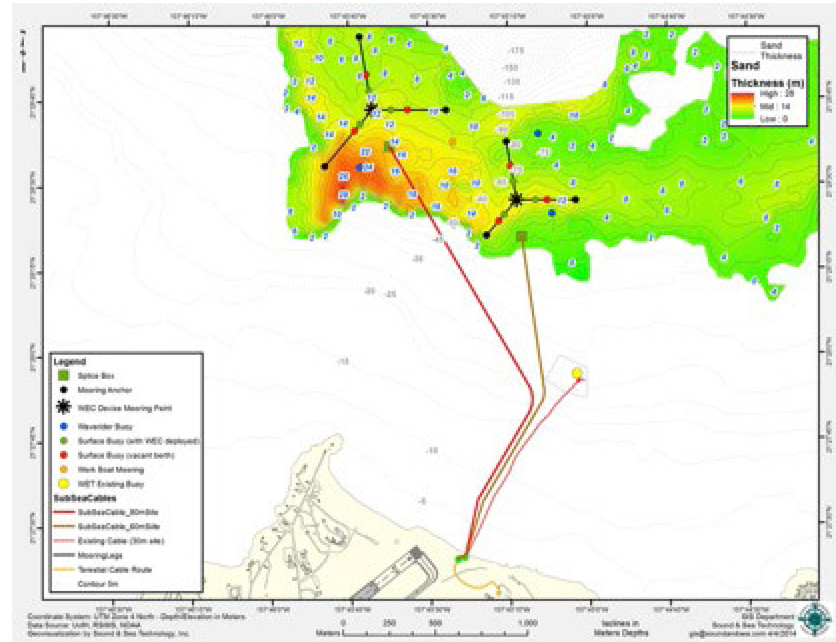
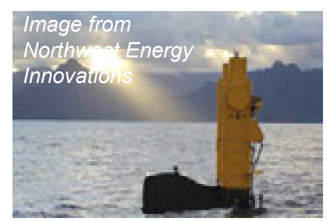


Figure from University of Hawai’I Manoa



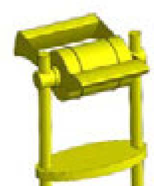


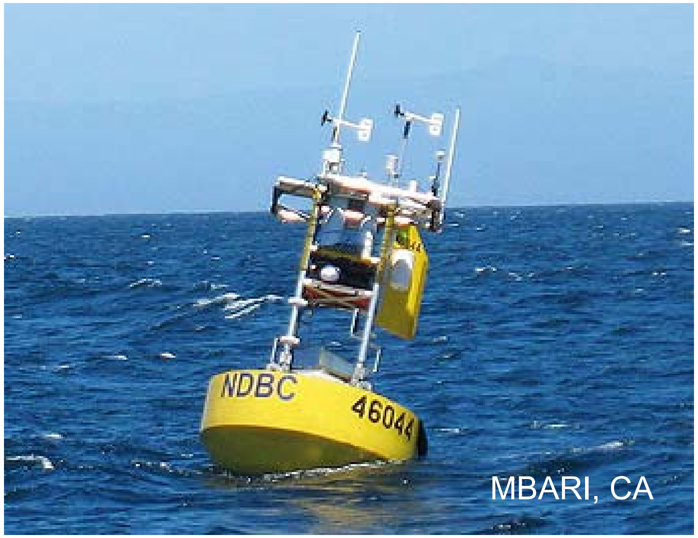
Image from Columbia Power Technologies

Examples of Tidal Current Validation Sites in Operation

Remote Installation and Operation and Maintenance Considerations

1. Vessels and Harbors
2. System Access
3. Mechanical and Electrical Service Expertise

Verdant Power, NY



MBARI, CA

Houston Ship Repair

Vessels and Harbors

Vessels

- Needed for site selection, installation, and maintenance – minor and major
- Smaller deployments will likely utilize existing vessel fleet regionally – project/design constraint
- Larger deployments could utilize larger vessels from more distant ports at significantly greater expense
- Rates and availability fluctuate significantly for larger vessels (competing with other industries, e.g., oil and gas)

Northwest Energy Innovations

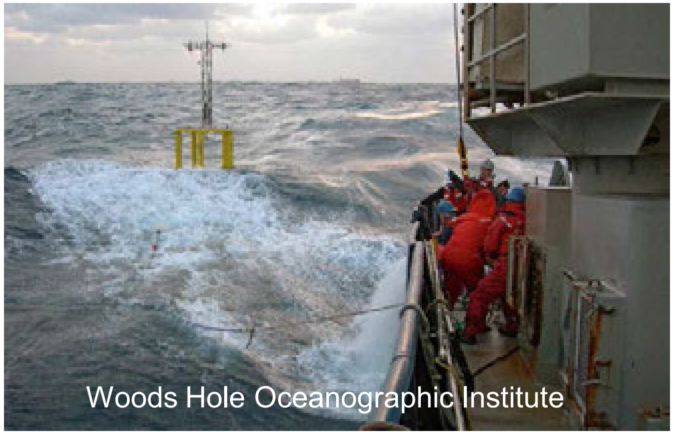
Harbors

- Air and water draft limitations
- Cranes and lift capacity constraints
- Docks and berths
- Existing nearby fabrication and manufacture
- Sufficient assembly and service areas
- Relevant ocean operations services

Port of Newport, OR
[Image: Oregon State University]

System Access Considerations

- Distance from relevant port
- Seabed conditions and depths
- Weather windows
- Environmental constraints (e.g., migratory mammals)
- Service paradigm and plan
- Acceptability of down time/ availability


Woods Hole Oceanographic Institute


Verdant Power

Mechanical and Electrical Service Expertise

- Early deployments will have customized engineering, equipment, controls, and construction with little uniformity or commonality among systems
- Limited local technical skills for installation and maintenance
- Constrained by adequate infrastructure and available equipment and tools
- The more remote, the more limited and expensive access
- Therefore, highly reliable systems are desired!


Hydrex


Zamakona Yards