DOCKETED	
Docket Number:	24-IEPR-04
Project Title:	Wave and Tidal Energy
TN #:	258404
Document Title:	Presentation - Wave and Tidal Energy - Evaluation of Feasibility, Costs, and Benefits - Senate Bill 605 Report
Description:	supersede TN # 258329
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Organization:	Aspen Environmental Group
Submitter Role:	Commission Staff
Submission Date:	8/9/2024 11:36:44 AM
Docketed Date:	8/9/2024

WAVE AND TIDAL ENERGY

EVALUATION OF FEASIBILITY, COSTS, AND BENEFITS

SB 605 Report

August 8, 2024

Report Organization

The report complies with the first requirement of SB 605(a), wave and tidal energy:

- Chapter 1. Technological and economic feasibility of deploying offshore wave and tidal energy in the state.
- Chapter 2. Evaluate factors that may contribute to the increased use of wave energy and tidal energy in the state.
- Chapter 3. Evaluate wave energy and tidal energy project potential transmission needs.
- Chapter 4. Permitting requirements.
- Chapter 5. Evaluate wave energy and tidal energy project economic and workforce development needs.
- Chapter 6. Identify near-term actions for investments, workforce and economic development.
- Chapter 7. Monitoring strategy.

Phase 2 of this study (to be presented in a separate report) will address the second requirement of SB 605(c): Agency consultation, tribal and fisheries outreach, resource protection, and transmission.

Chapter 1 - Wave Energy Technology Overview

- Harness the kinetic and potential energy in waves and convert it to useable energy
- Potential for wave energy conversion is largest at mid-latitudes, i.e., the California coast
- California's wave resource is estimated at 140 TWh/yr (Kilcher et al. 2021), providing 23% of California's energy needs (EPRI 2007)
- Wave resources vary by region and water depth
  - Numerous (hundreds) wave energy converter (WEC) devices
  - Six main WEC device archetypes

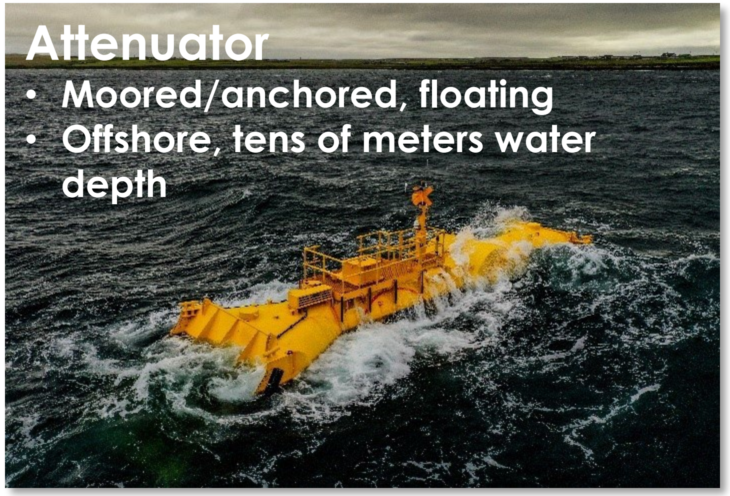
Kilcher, L., M. Fogarty, and M. Lawson (2021) Marine Energy in the United States: An overview of opportunities, National Renewable Energy Laboratory, NREL/TP-5700-78773, Golden, CO.

Electric Power Research Institute (EPRI) (2007) California Ocean Wave Energy Assessment, Report by EPRI for the California Energy Commission, 85 pp.

Wave Energy Technology Overview

Attenuator

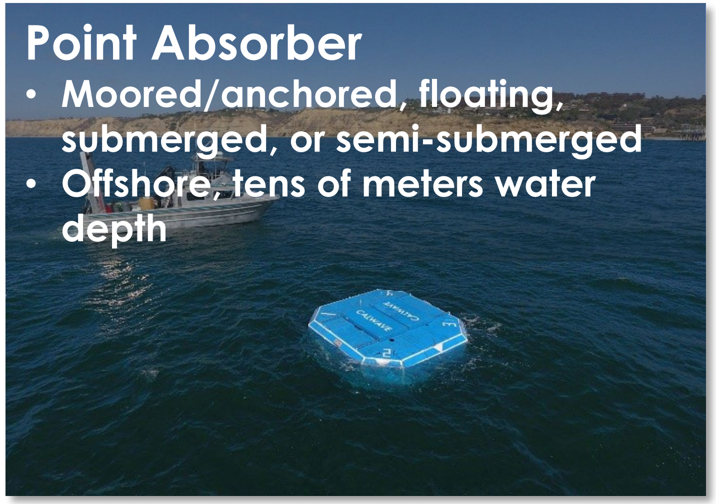
- Moored/anchored, floating
- Offshore, tens of meters water depth



Mocean Energy

Point Absorber

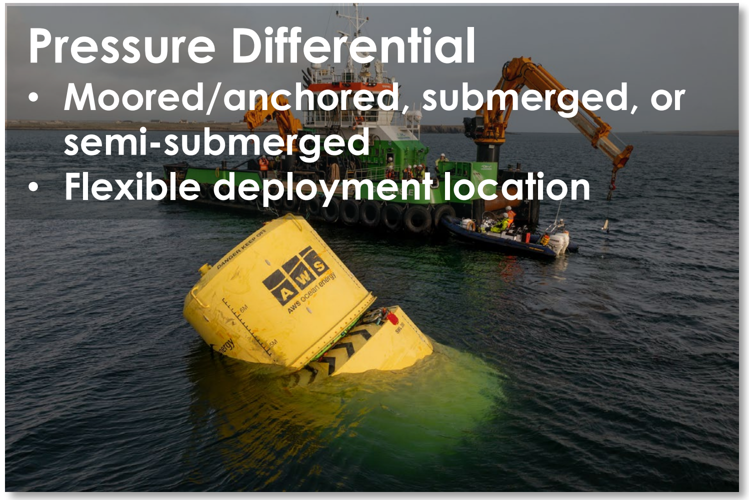
- Moored/anchored, floating, submerged, or semi-submerged
- Offshore, tens of meters water depth



CalWave

Pressure Differential

- Moored/anchored, submerged, or semi-submerged
- Flexible deployment location



AWS

Oscillating Water Column

- Fixed on land or seabed, or moored
- Shore-based, nearshore, or offshore

Ocean Energy

Overtopping

- Fixed on land or seabed or moored
- Shore-based, nearshore, or offshore

Wave Dragon

Oscillating Wave Surge

- Moored/anchored, floating, submerged, or semi-submerged, or bottom-fixed
- Nearshore, <12m water depth

Resolute Marine Energy

Tidal Energy Technology Overview

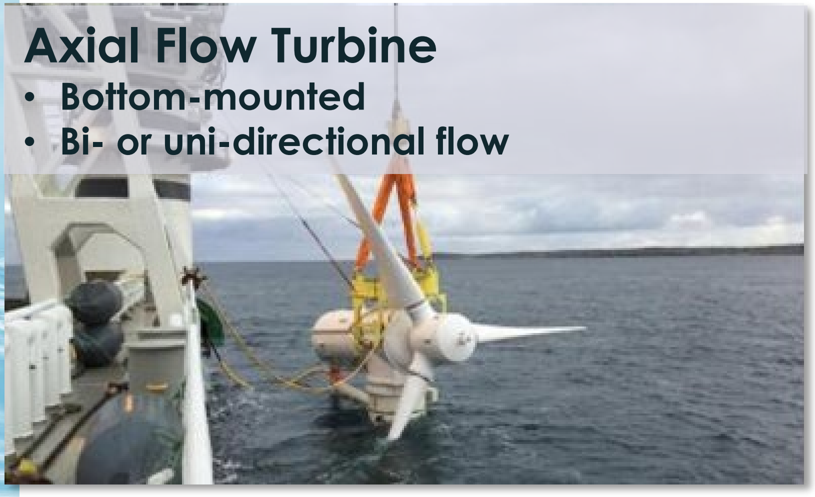
- Harness the movement of water due to tides
- Tidal energy resource along the California coast is estimated at 1.8 TWh/yr (Kilcher et al. 2021), a fraction of that estimated for wave energy
- Tidal energy converters (TECs) vary by size, shape, and energy capture methods
- TEC characteristics depend on available resource, deployment area, and mounting methods
    - Six main TEC device archetypes

Kilcher, L., M. Fogarty, and M. Lawson (2021) Marine Energy in the United States: An overview of opportunities, National Renewable Energy Laboratory, NREL/TP-5700-78773, Golden, CO.

Electric Power Research Institute (EPRI) (2007) California Ocean Wave Energy Assessment, Report by EPRI for the California Energy Commission, 85 pp.

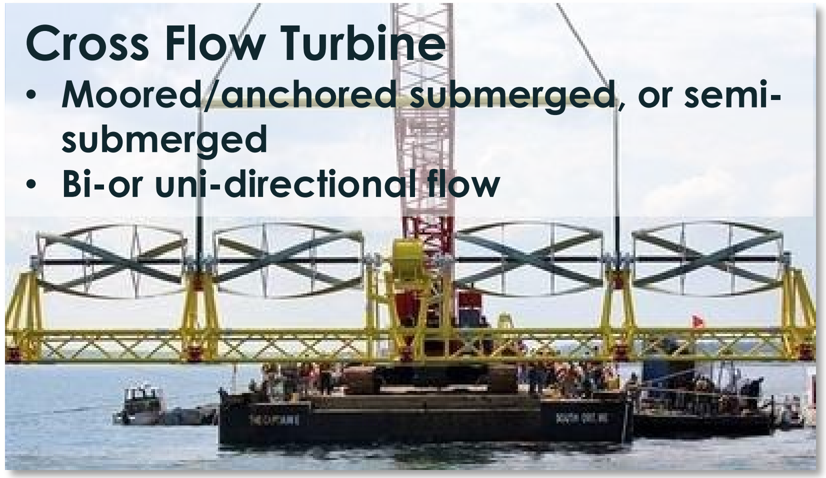
Tidal Energy Technology Overview

Axial Flow Turbine
- Bottom-mounted
- Bi- or uni-directional flow



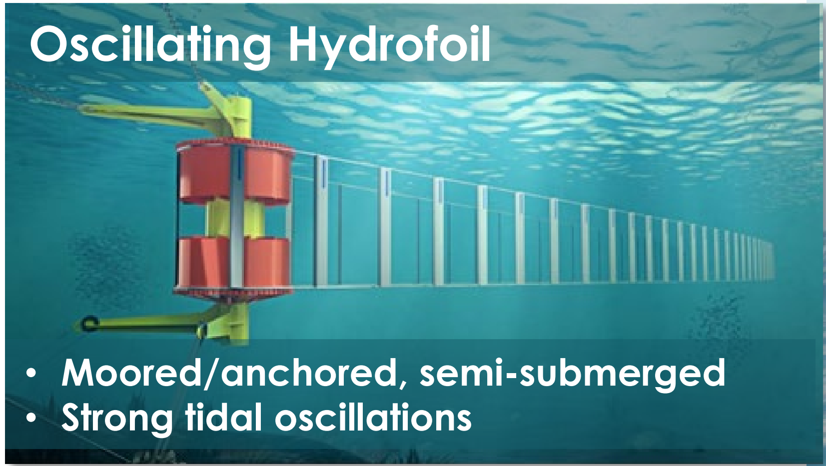
SAE Renewables

Cross Flow Turbine
- Moored/anchored submerged, or semi-submerged
- Bi-or uni-directional flow



Ocean Renewable Power Company

Oscillating Hydrofoil
- Moored/anchored, semi-submerged
- Strong tidal oscillations



Tidal Sails

Tidal Kite
- Submerged, cabled to sediment bed
- Optimized to meet tidal conditions

Minesto

Archimedes Screw
- Attached to floating platform
- Bi- or uni-directional flow

Jupiter Hydro

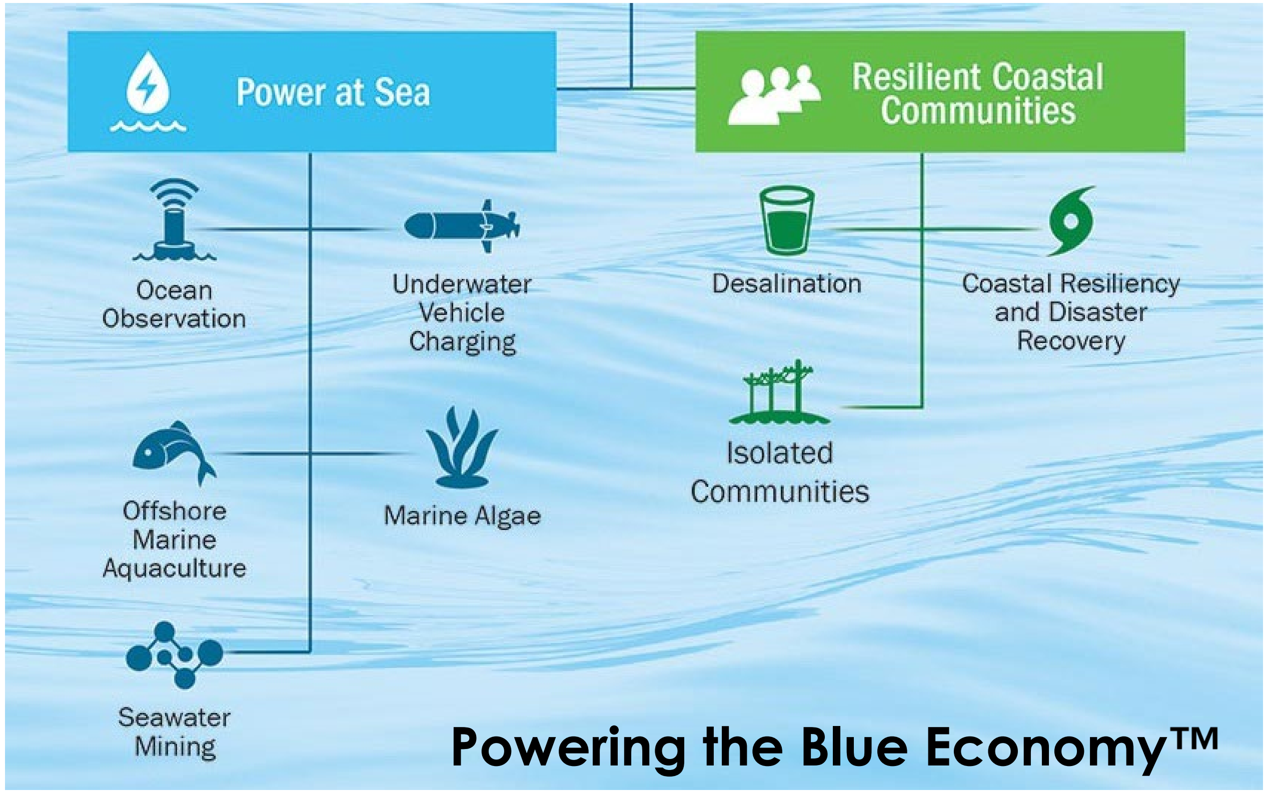
Vortex Induced Vibration
- Bottom mounted attached to generator

Vortex Hydro Energy

Marine Energy Applications in California

Commercial-scale
- Multiple devices in arrays, grid connected
- Not yet realized in California

Distributed
- Small and pilot-scale
- Reduce reliance on vulnerable energy supply chains
- Example applications: ports and harbors, remote communities, military installations, Powering the Blue Economy™



https://www.nrel.gov/water/powering-blue-economy.html

Challenges to Developing Marine Energy

- Technology Development: Immature technologies, lack of long-term (1-yr or more) demonstrations
- Resource Variability: Predicting waves and tides is necessary to optimize technologies, may be difficult with climate change
- Grid Integration: Technically and logistically challenging and costly for remote or offshore environments, not applicable to distributed energy
- Environmental Impact: Stressor-receptor interactions are largely unknown, particularly for large arrays
- Cost Competitiveness: Levelized cost of wave energy estimated at three times higher than other forms of renewable energy (solar, wind)
- Socioeconomics: Seaspace conflicts (e.g., fisheries, cultural resources, recreation)

Comparative Advantages of Wave and Tidal Energy

	Offshore Wind	Onshore Wind	Solar	Hydroelectric	Wave and Tidal
Pathway to Permitting	–	✓	✓	✗	–
Remote Delivery	✓	–	–	–	✓
Availability	–	–	✗	–	✓
Adverse Weather*	✗	✗	✗	✗	–
Ecological Impact	?	–	–	✗	?

*Weather and climate considered together

Conflicts, Community Perceptions, and Colocation

- Generally viewed positively
  - Could change as knowledge increases
  - Reduced scale and visual impact
- Potential for colocation
  - Aquaculture and other offshore industry
  - Coastal protection
- Ecological impacts largely unknown
  - e.g. biofouling vs fish attraction

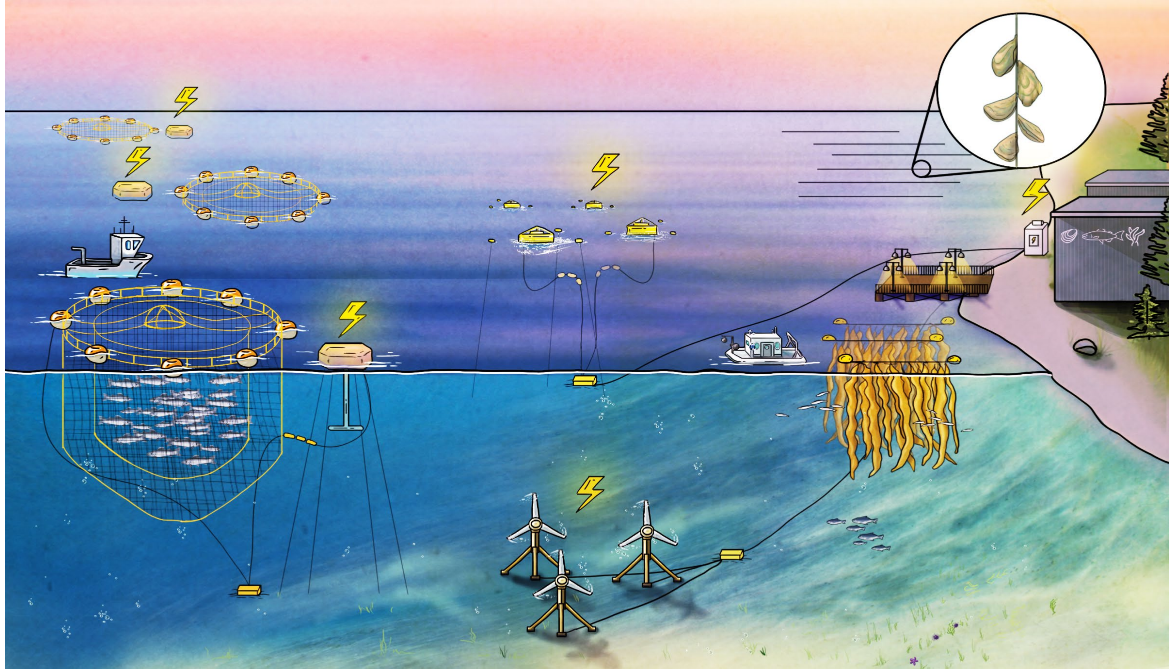


Photo Source: Stephanie King of PNNL

Transmission Overview

Alternating Current (AC) vs Direct Current (DC) Transmission

The scope of this research focuses on **AC transmission**. AC systems are used offshore when export capacities are **less than 1,000 MW** or distance from shore is **less than 80 km.** DC systems may be seen in the future for much larger applications.

Offshore Substations

Offshore substations **collect and export** power to shore, although are not always required for smaller applications, approximately less than 100 MW. Substations come in different forms including: **fixed/floating** on the surface of the water, **subsea substations**, or **smart subsea hubs.**

Subsea Cables

Array cables are lower voltage and often connect one converter to another. For smaller applications (approximately less than 100 MW), array cables can deliver power onshore. **Export cables** are used to transport larger amounts of power onshore. **Fixed** offshore infrastructure uses **static** cables, while **dynamic** cables are required for **floating** offshore platforms.

Commercial Availability

The transmission technologies required for distributed applications **and larger scale, commercial** applications exist. In the future, larger (GW+) tidal/wave farms may require technologies similar to what is in development for commercial **floating offshore wind**. (i.e., dynamic high voltage DC export cables)

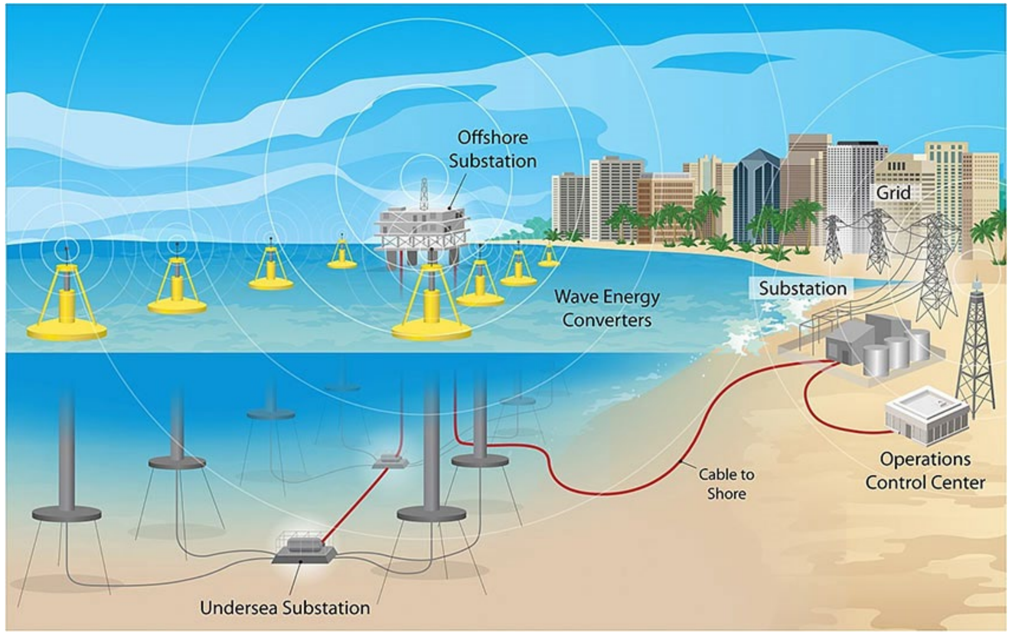
Tidal and Wave Transmission Configurations

Onshore and Very Nearshore Tidal Configurations

Located within several meters from shore, these wave/tidal configurations are similar to the integration and transmission scheme seen for onshore renewable resources. Leveraging **lower voltage, static AC cables**, this transmission is generally less complex compared to configurations further from shore.

Nearshore and Offshore Wave Configurations

Nearshore configurations are typically a few hundred meters from shore, while offshore configurations can be beyond 100 km from shore. Floating or fixed, they would leverage **dynamic or static export cables** in addition to some form of **offshore or subsea substation** or **smart hub**.



Source: Colorado State University

Deep Water Wave Configurations

Located hundreds of kilometers from shore, and in thousands of meters of water, these wave energy converters are likely for **small, distributed applications** to support other marine activities. Short distance and **lower voltage dynamic AC cables** would be required with the potential for **smart undersea hub** technology.

Grid Integration Challenges

Limited Onshore Transmission Infrastructure

- Economic, logistical, and technical factors determine where marine power connections make landfall.
- Existing grid infrastructure may be inadequate to take on massive injections of power without multi-year planning, upgrades and expansion processes. Onshore expansion may be required to reach load.

Technical Analysis and Studies Required

- Technical analysis and studies will be required for integration off offshore resources into the grid.
- These studies reveal constraint mitigation and grid infrastructure expansion needs under various system conditions over the near- and long-term due to the additional power injection

Logistics, Cost Recovery, and System Reliability

- Transmission expansion efforts must consider logistics, cost recovery and system reliability.
- Land acquisition for infrastructure expansion should also be considered when evaluating marine energy grid connections.

Workforce and Economic Development: Methodology and Model Inputs

Methodology	Guidehouse leveraged NREL's Jobs and Economic Development Impact (JEDI) model for marine and hydrokinetic power to estimate workforce and economic development from wave and tidal energy projects

Inputs	• **Descriptive data:**
	  • **Project size:** 10 MW and 100 MW scenarios
	  • **Project location:** California
	  • **Construction year:** 2027
	• **Capital costs and operating and maintenance costs** come from NREL's System Advisor Model (SAM) for Marine Energy
	• **Financial parameters** were assumed to be default JEDI values
	• **Local share** was informed by requirements to obtain additional tax credits established by the Inflation Reduction Act of 2022

Workforce and Economic Development: Model Outputs

JEDI outputs for workforce and economic impact are categorized as direct, indirect, and induced impacts.

Workforce impacts: total full-time equivalent employment for one year, otherwise known as "job-years"

Economic impacts: earnings, economic output, and value added

- **Earnings:** wage and salary benefits
- **Economic output:** economic activity or value of production in the state or local economy
- **Value added:** the difference between the total gross output and the cost of intermediate inputs

Direct impacts: on-site construction and installation labor and project development industries

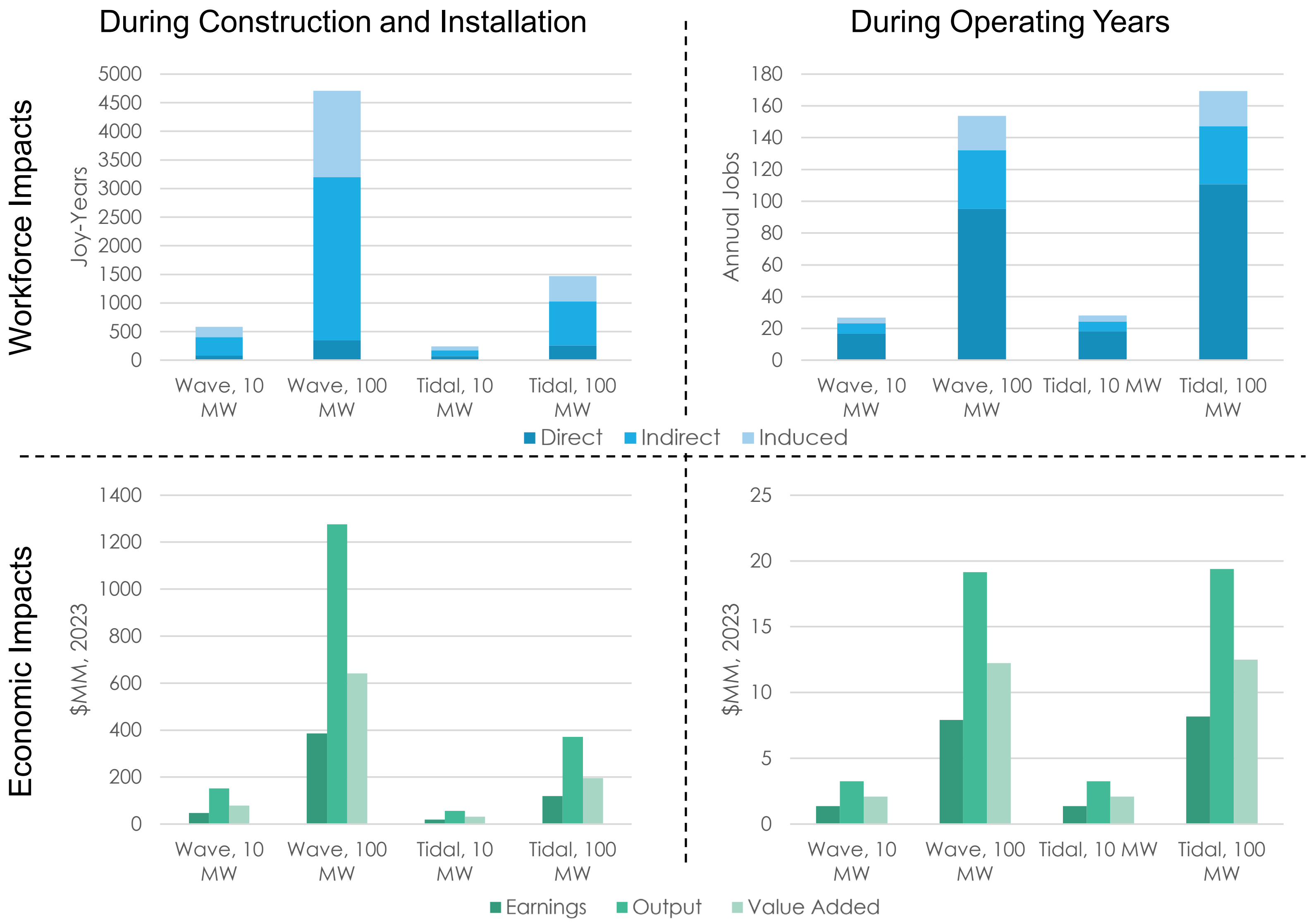
Indirect impacts: equipment and supply chain impacts, local revenue driven by increased demand for goods and services from direct on-site spending

Induced impacts: effects driven by reinvestment and spending of earnings of direct and indirect beneficiaries

Workforce and Economic Development Impacts

Key Takeaways

- During construction and installation, the majority of jobs required are in indirect industries (equipment and supply chain)
- During operating years, the majority of jobs required are in direct industries (onsite operators and technicians)
- When scaling projects from 10 to 100 MW, workforce and economic impacts are approx. 8 times larger for wave energy and 6 times greater for tidal energy



Permitting Requirements

Permitting requirements vary depending on location of deployment, purpose, size, and whether the power generated is grid-connected or used offshore. Permits may be required from the following agencies:

State Requirements	Federal Requirements
State Lands Commission Issues state tidelands leases. Lead Agency for California Environmental Quality Act compliance	**Federal Energy Regulatory Commission** For marine projects interconnected to the electric power grid; Lead Agency for National Env. Policy Act compliance
Water Resources Control Boards Water Quality Certification under Clean Water Act, California Ocean Plan, etc.	**U.S. Army Corps of Engineers** Permits under Section 404 of Clean Water Act and Rivers and Harbors Act
California Department of Fish and Wildlife Permits for take of state listed species. Manages Marine Protected Areas.	**U.S. Coast Guard** Marine safety, obstruction of waterways
California Coastal Commission Consistency with Coastal Zone Management Act	**Bureau of Ocean Energy Management** Leasing of lands under federal waters offshore
	NOAA Fisheries, U.S. Fish & Wildlife Service Consultation on endangered species

Adaptive Management

Adaptive Management to address permitting uncertainties:

- Provide a seamless implementation process for future decision-making
  - Potential interactions with high environmental risk and high uncertainty
  - Threshold triggers informed by studies
  - Protection, mitigation and enhancement (PM&E) measures
- Phase 2 will address these issues in more detail

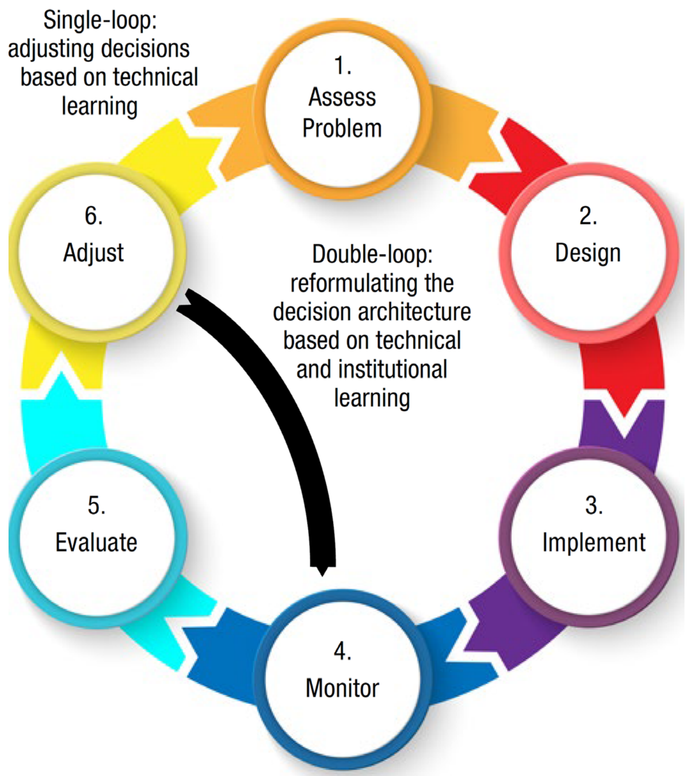


Figure 12.1. The adaptive management (AM) cycle. The original concept of AM concerned single loop learning, while later additions recognize the value of double loop learning, particularly to inform planning and siting for future MRE installations in a region. (Graphic by Robyn Ricks. Adapted from Williams 2011a; Williams and Brown 2018)

Source: Copping, A.E. and Hemery, L.G., editors. 2020. OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). doi:10.2172/1632878