Techno-economic Modeling of Marine Energy Systems with the System Advisor Model

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Photo by Dennis Schroeder, NREL 55200

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NREL Marine Energy R&D: Techno-economics

Techno-economic analysis evaluates the economic and technical performance through:

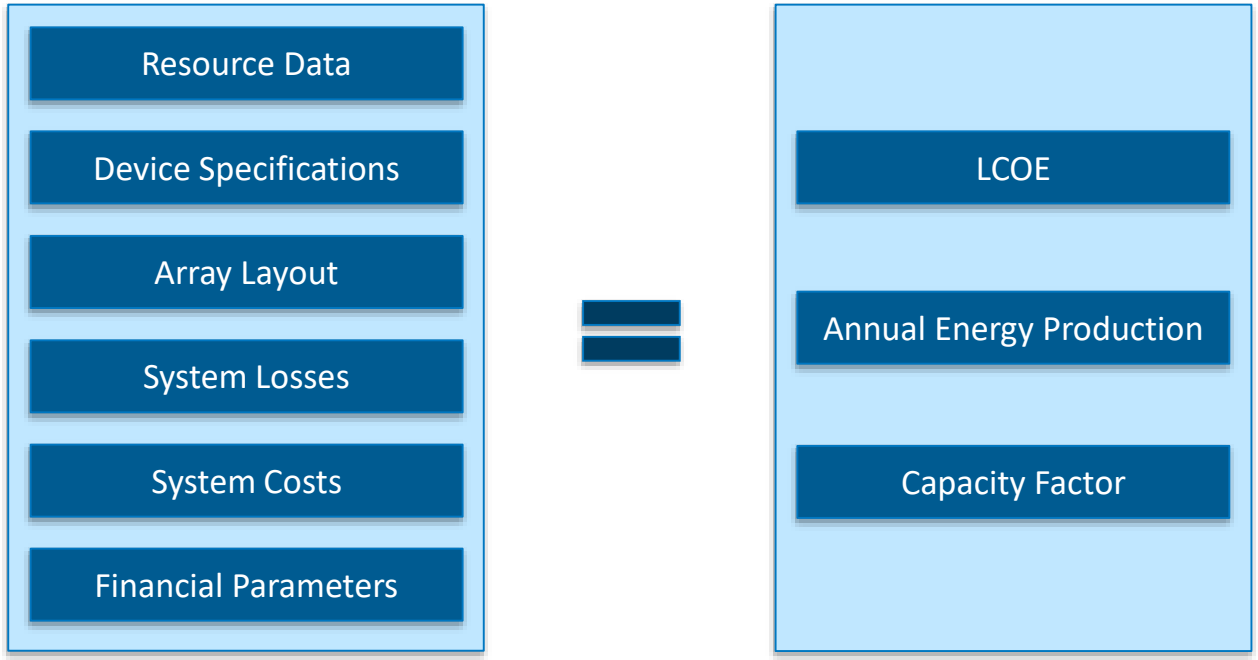
- Benchmarking/baselining
- Comparative studies of emerging technology to some existing commercial or reference benchmark
- Power performance modeling
- System cost-estimating
- Levelized cost of energy analysis
- Tool Creation
- Customized analysis for end users

https://www.nrel.gov/water/economic-analysis.html

System Advisor Model (SAM)

- The System Advisor Model (SAM) is a free, publicly available modeling software designed to evaluate system design, performance, and project economics for a suite of renewable energy technologies.
- SAM's marine energy module offers multiple simulation options for wave and tidal energy systems:
  - Power performance modeling to estimate AEP
  - Levelized cost of energy calculator
  - Financial cash flow model

Modeling Marine Energy Systems



Levelized Cost of Energy (LCOE)

$$LCOE = \frac{CAPEX * FCR + OPEX}{AEP}$$

- CAPEX: Capital expenditures
- FCR: Fixed-charge rate
- OPEX: Operational expenditures
- AEP: Annual energy production

Fixed-Charge Rate

FCR as baked in assumptions!

$$D = \tau \times \sum_{t=1}^{t=6} \frac{MACRS_t}{(1+r)^t * (1+i)^t}$$

$$\boldsymbol{FCR} = \frac{r}{1 - \frac{1}{(1+r)^N}} \times \frac{1-D}{1-\tau}$$

Symbol	Variable	Standard Value
r	Real discount rate (i.e. real WACC)	.07
i	Inflation rate	.025
τ	Composite federal-state tax rate	.396
$MACRS_t$	Depreciation schedule	MACRS 5-Year Property
D	Present value of depreciation tax shield	.309
N	Project economic life	20 Years
FCR	Fixed charge rate	.108

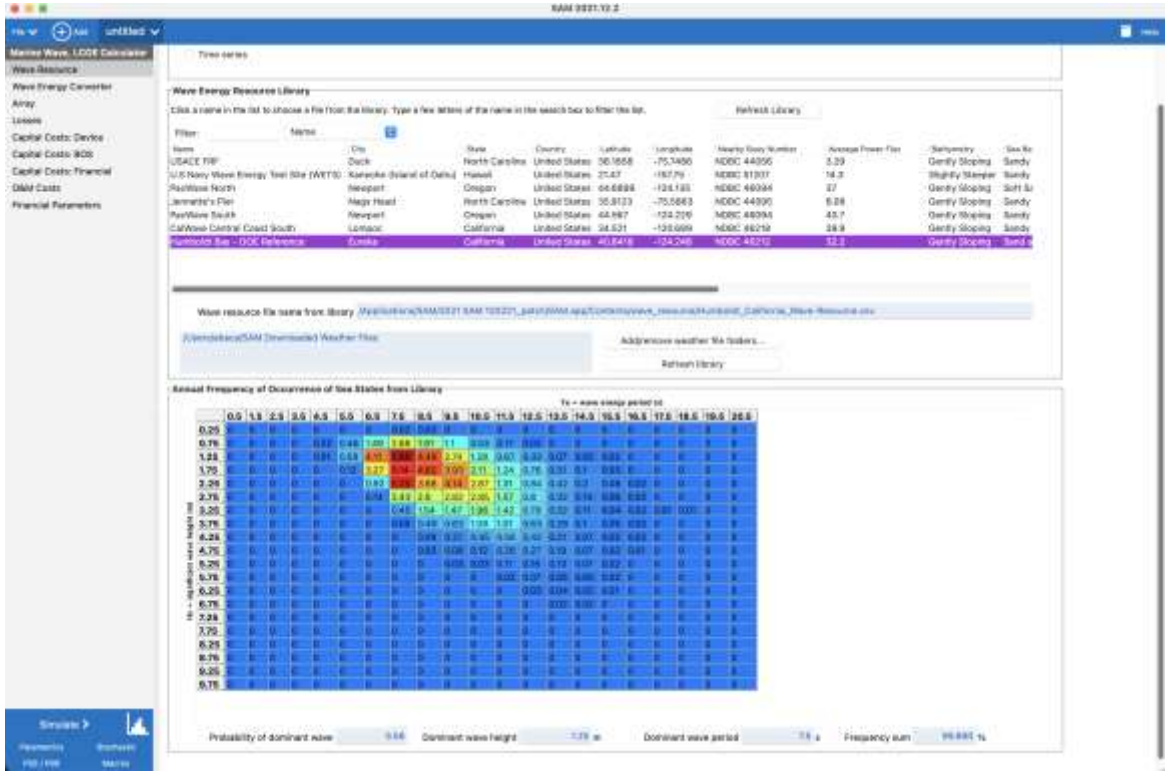
Cost Breakdown Structure

CapEx			
CBS #	Level	Category	Description
1	1	Capital Expenditures (CapEx)	All installed costs incurred prior to commercial operations date (COD). CAPEX components include marine energy converter, balance of system, and financing.
1.1	2	Marine Energy Converter (MEC)	Converts kinetic energy from water into three phase alternating current (AC) electrical energy.
1.1.1	3	Structural Assembly	Primary energy capture (e.g. float paddle, turbine, flap, etc.) and supporting structural components.
1.1.2	3	Power Take-Off System (PTO)	Power Take-Off System is comprised of a drivetrain (converts the energy captured by the device into mechanical power), a generator (converts mechanical power into electrical power), short term storage, and power electronics.
1.1.3	3	Mooring, Foundation, and Sub-Structure	All elements of the marine energy converter mooring system and/or foundation
1.2	2	Balance of System (BOS)	
1.2.1	3	Development	All activities from project inception to financial close, where financial close is the date when project and financing agreements have been signed and all the required conditions have been met.
1.2.2	3	Engineering and Management	Engineering and management activities from financial close through commercial operation date (COD).
1.2.3	3	Electrical Infrastructure	All electrical infrastructure to collect power from generators and deliver to the grid.
1.2.4	3	Plant Commissioning	Cost incurred by owner or prime contractor to test and commission the integrated power plant.
1.2.5	3	Site Access, Port & Staging	Activities and physical aspects of a staging port. Elements needed to support the delivery, storage, handling, and deployment of marine energy converter (MEC) components.
1.2.6	3	Assembly & Installation	Assembly and installation activities conducted at the staging port and at the project site. Assume financial costs related to warranties, contractor insurance, Selling, General & Administrative (SG&A), profit margin, etc., are loaded in day rates for vessels, labor, and equipment.
1.2.7	3	Other Infrastructure	Other capital investments made by the project company prior to commercial operation date (COD).
1.3	2	Financial Costs	
1.3.1	3	Project Contingency Budget	Liquid financial instrument set up to respond to "known unknown" costs that arise during construction, does not include contingences set by manufactures and contractors as part of supply contract pricing.
1.3.2	3	Insurance During Construction	Insurance policies held by owner during construction period, can include construction all risk, marine cargo, commercial general liability, workers compensation, environmental site liability, pollution liability, etc. Does not include insurance held by contractors.
1.3.3	3	Carrying Costs During Construction (Construction Financing Costs)	Carrying charges of expenditures on equipment and services incurred before commercial operation date (COD).
1.3.4	3	Reserve Accounts	Payments (before commissioning) into reserve accounts. Generally required by either financiers or regulators.

- Uniform format to categorize cost for Marine Energy devices
- Organized by category with levels from 1-6
- Higher level numbers have higher level of detail
- Aids in uniform comparative analysis and can be used to collect consistent data

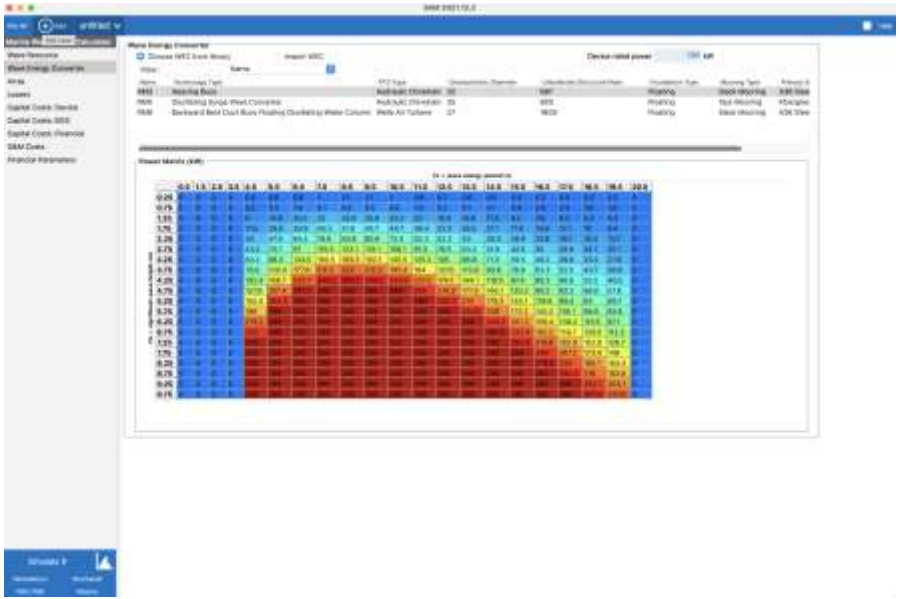
ME SAM: Wave Resource

- Resource: Humboldt Bay in Eureka, California
- SAM has multiple site locations in the library
- User may upload resource joint probability distribution
- User can search and download wave resource data



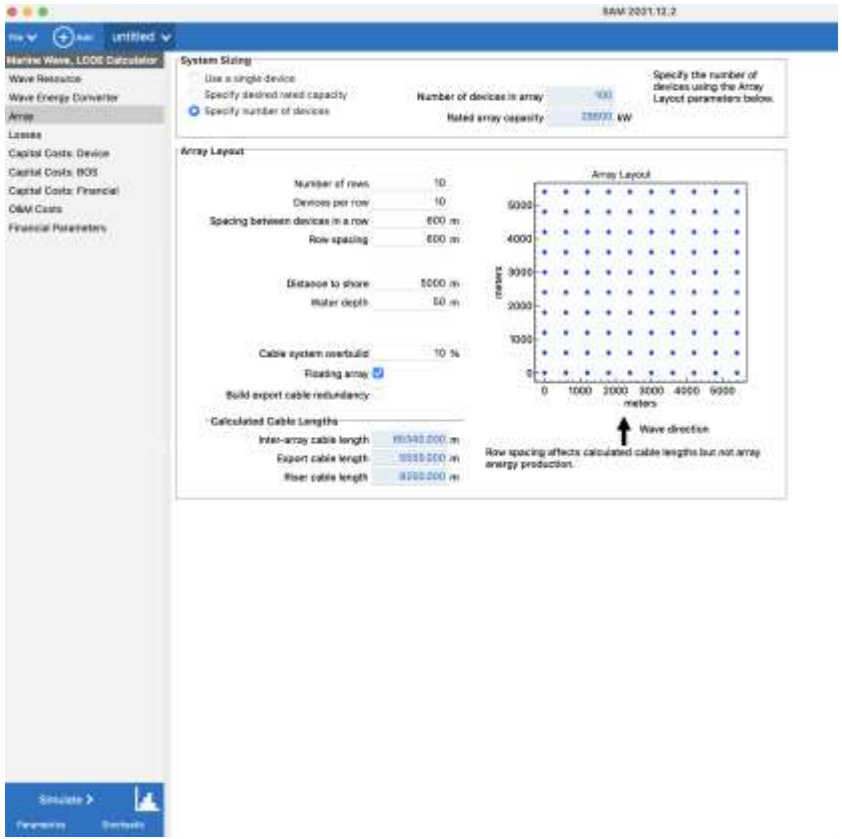
ME SAM: Wave Energy Converter

- Device: US Department of Energy's Reference Model 3 (RM3)
- SAM has Reference Model power matrices that a user may select
- User can upload their own power matrix



ME SAM: Array Layout

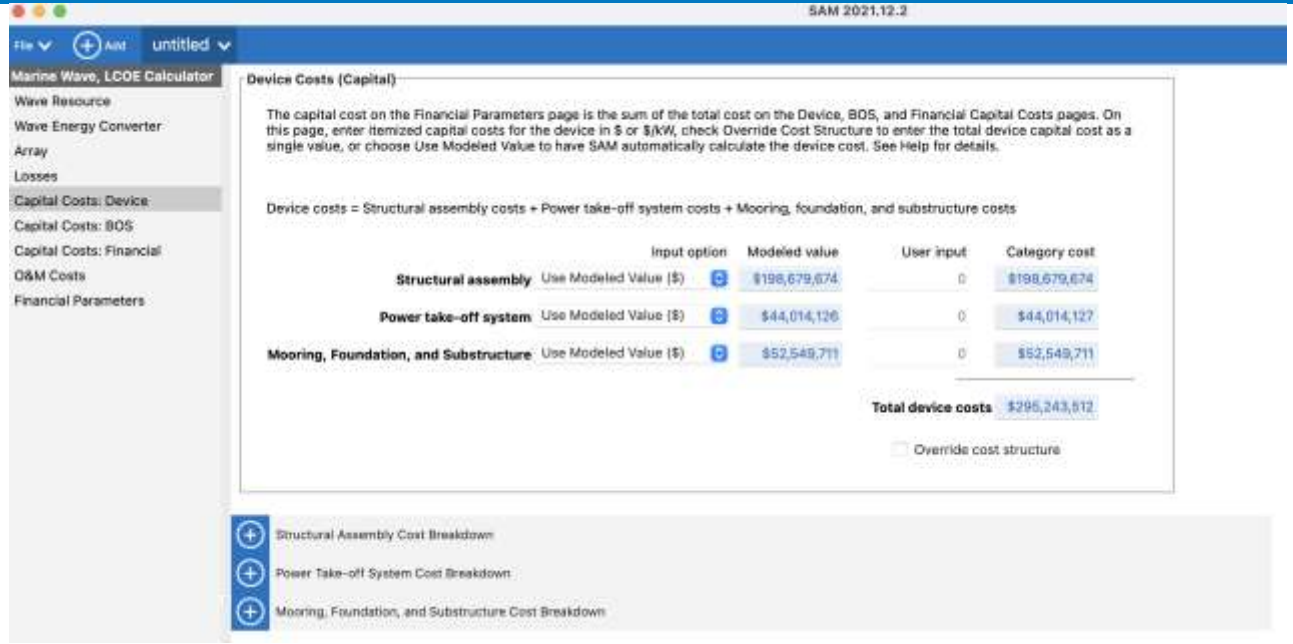
- 100-unit array (10 x 10)
- 600 meter spacing
- Distance to shore: 5000 meters
- Water depth: 50 meters
- Floating foundation



ME SAM: WEC Plant Losses

- 95% availability
- 2% transmission losses
- Note: SAM does not estimate wake losses and should be accounted for here

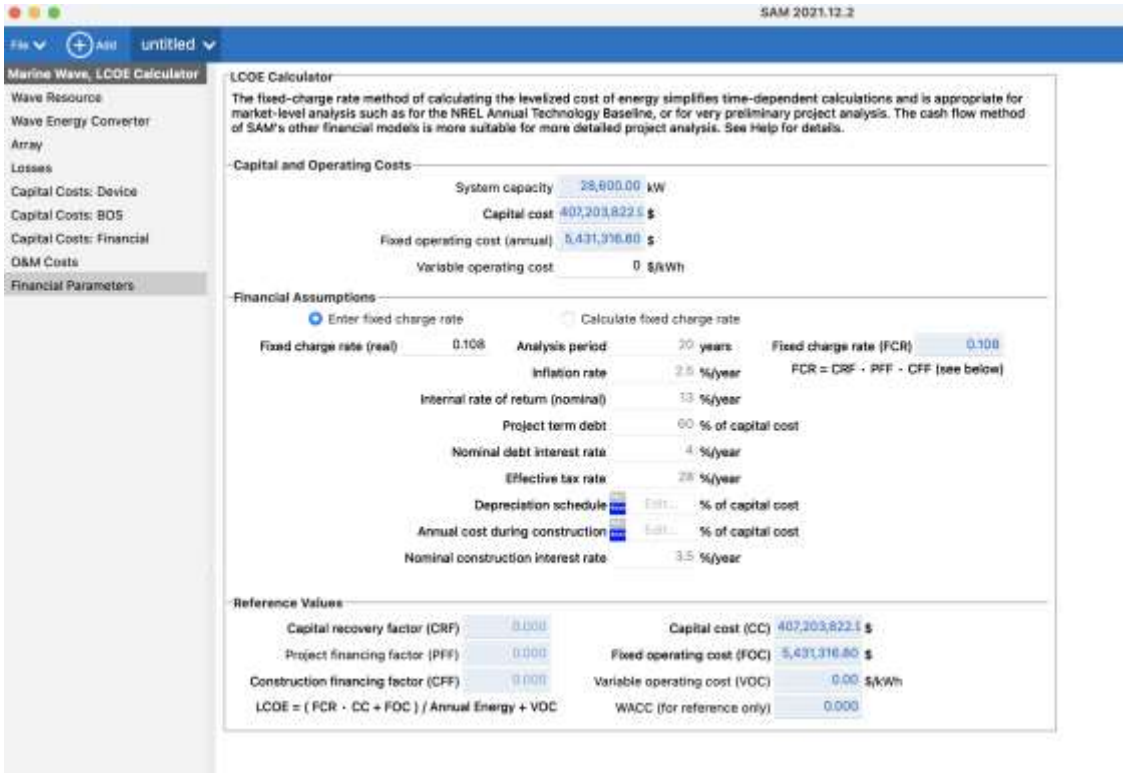
ME SAM: System Costs



- Selected SAM's modeled value for all costs
- All costs may be customized by the user

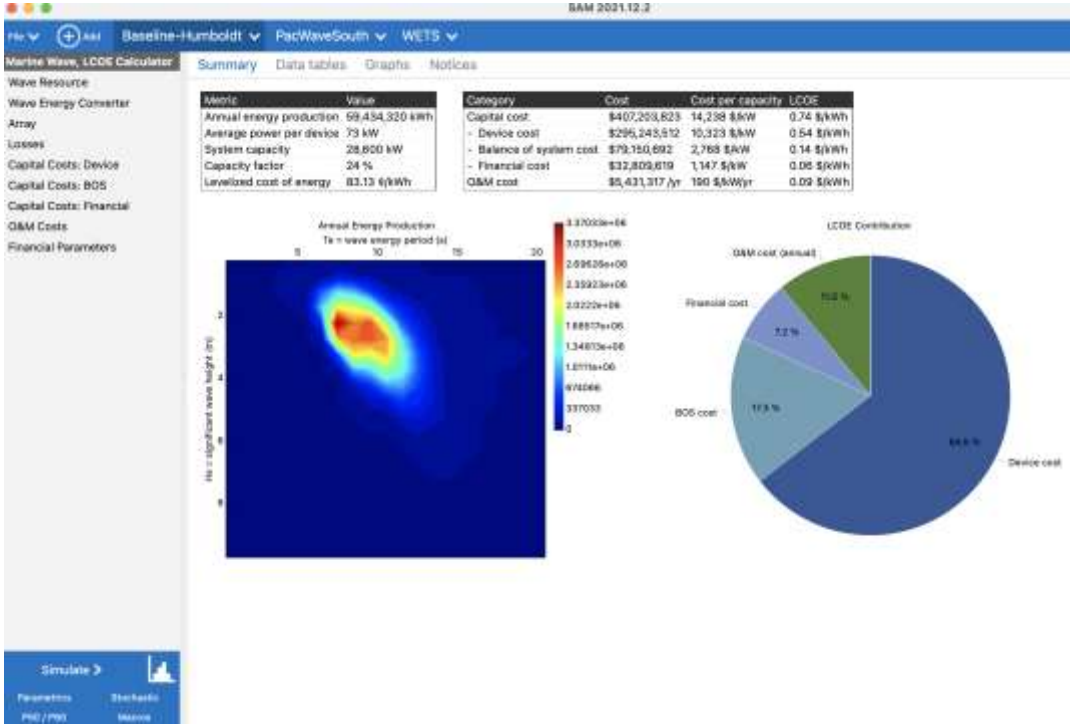
ME SAM: Financial Parameters

- Used the default fixed-charge rate of 10.8%
- Financial parameters may be customized by the user

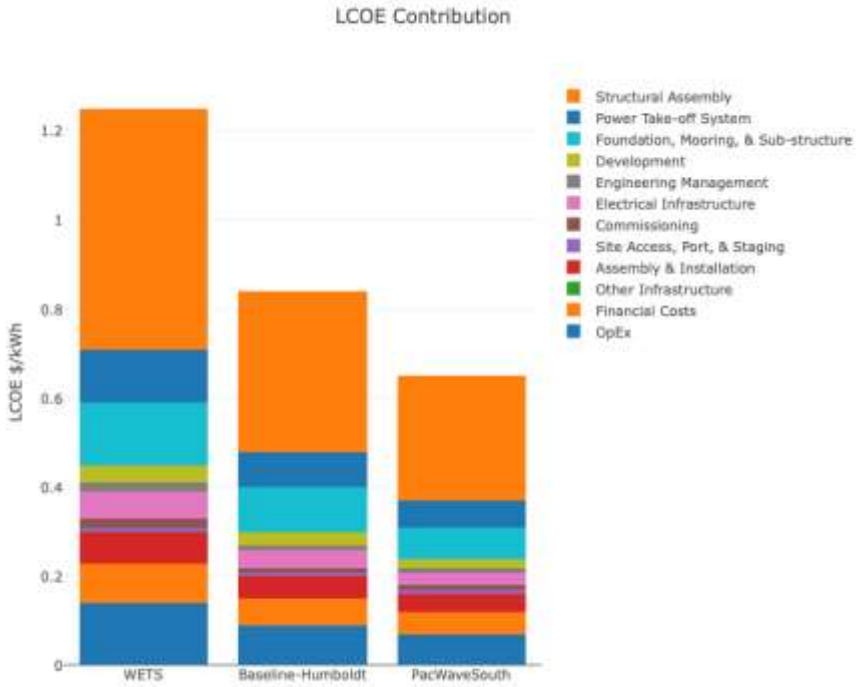


ME SAM: Baseline Results

- AEP: 59,434 MWh
- Capacity Factor: 24%
- Avg power per device: 73 kW
- System Capacity: 28.6 MW
- LCOE: $0.83/kWh
- Note: LCOE is higher than the original reference model report



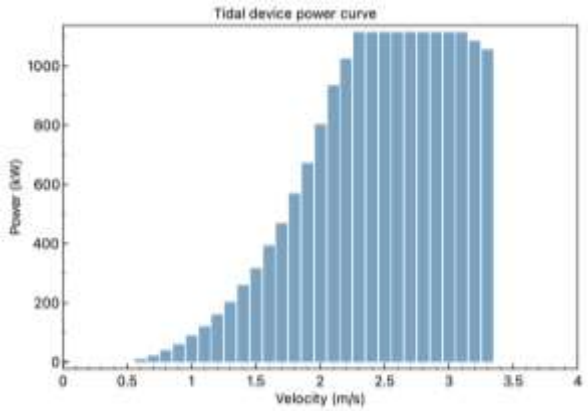
ME SAM: Site Location Case Comparison

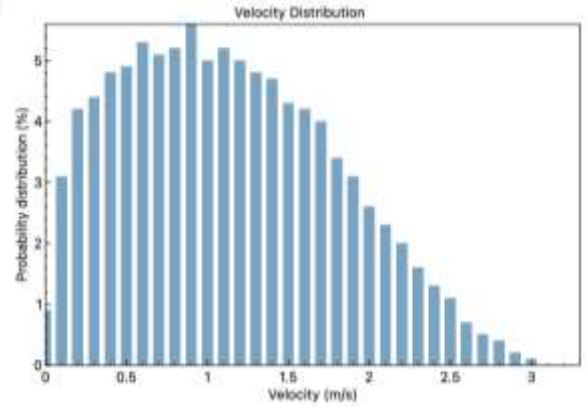


	WETS (Kaneohe, Oahu, HI)	Humboldt Bay (Eureka, CA)	PacWave South (Newport, OR)
Levelized Cost of Energy	$1.24 /kWh	$0.83 /kWh	$0.65 /kWh
Annual Energy Production	39,844,224 kWh	59,434,320 kWh	75,937,816 kWh
Capacity Factor	15.9%	23.7%	30.3%
Capital Expenditures	$14,238 /kW	$14,238 /kW	$14,238 /kW
Operational Expenditures	$190 /kW/yr	$190 /kW/yr	$190 /kW/yr
Fixed Charge Rate	10.8%	10.8%	10.8%

ME SAM: Tidal Energy Modeling

- SAM's tidal module has similar methodology and workflow to the wave energy module
- Requires a power curve for the tidal device
- Requires tidal resource histogram for the site location
- Tidal resource data library





SAM Summary

- Use SAM for a fast and standardized techno-economic assessments
- Standardized reporting
- Custom macros
- Hybrid system modeling
- Regular updates typically in November each year

Download SAM here:

https://sam.nrel.gov/download.html

Q&A

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