SurfWEC
Getting Wave Energy up to Speed

New Jersey Sierra Club
Monday, April 22, 2019
Michael Raftery, M.E.

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NJ is a fun place to live

- It has a lot of stuff
- It tends to lead in technology: First to make an industrial mess and first to clean it up, Lightbulbs, telephone, pharma, canals, nuclear ships (NY shipbuilding in Camden), liquid fuel rocketry (look it up), RADAR, Radio, controlled flight (look it up)
- It is progressive and has more engineers and scientists per square mile than any other state in the union[1].
- Today it has a real commitment to sustainable energy

1. https://www.politifact.com/new-jersey/statements/2012/sep/06/choose-new-jersey/new-jersey-leads-world-number-scientists-engineers/
2. Clues RG and SA

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Glory Days

spectrum.ieee.org

njcleanenergy.com

oceanpowertechnologies.com

https://www.oceanpowertechnologies.com/uploads/10fac4f75ab4d841abb198d8eb96488e.pdf

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Where are we?

- Nice solar roof top penetration
- Tons of Teslas in Monmouth County (and other plug ins too)
- Solar farms (love those on the land fills)
- Not too much onshore wind (yet?)
- We are working very hard on offshore wind
- We are starting to like our nuclear powerplants
- So are we doing all we can?
- Biofuel? We farm a lot too, but does it make sense?

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The truth is the numbers count

- Musts:
- be sustainable
- provide reliable power
- make more power revenue than it costs to make
- help NJ economy
- produce gobs of energy, we are NJ we need a lot of clean energy/power
- be something we want to live with
- make economic sense
- Let's: take a look at economic sense

Sustainable Technologies

Type	Theoretical Viability	Technical Viability	Truly Sustainable?	Carbon Neutral?	Carbon Zero?	Cost Competitive?	Installed Base
Hydro	viable	viable	mostly	yes	yes, nearly	yes	at maximum
Landbased Wind	viable	viable	yes	yes	yes, nearly	yes	fights for land
Thermal Solar	viable	viable	yes, mostly	yes	yes, nearly	maybe	fights for land
PV Solar	viable	viable	yes, mostly	yes	yes, nearly	yes	fights for land
Rooftop PV	viable	viable	yes	yes	yes, really close	close	growing
Tidal	viable	sometimes	yes, mostly	yes	yes, nearly	occasionally	occasional
Offshore Wind	viable	viable	yes	yes	yes, nearly	not quite yet	growing
Biomass	viable	viable	in right application	could be	depends	sometimes	modest
Corn Ethanol	poor	viable	nope	not really	not really	nope	too high
Algae	questionable	possible	unknown	could be	could be	unknown	zero
Nuclear Fission	viable	viable	yes, mostly	yes	yes, but …	could be	probably too low

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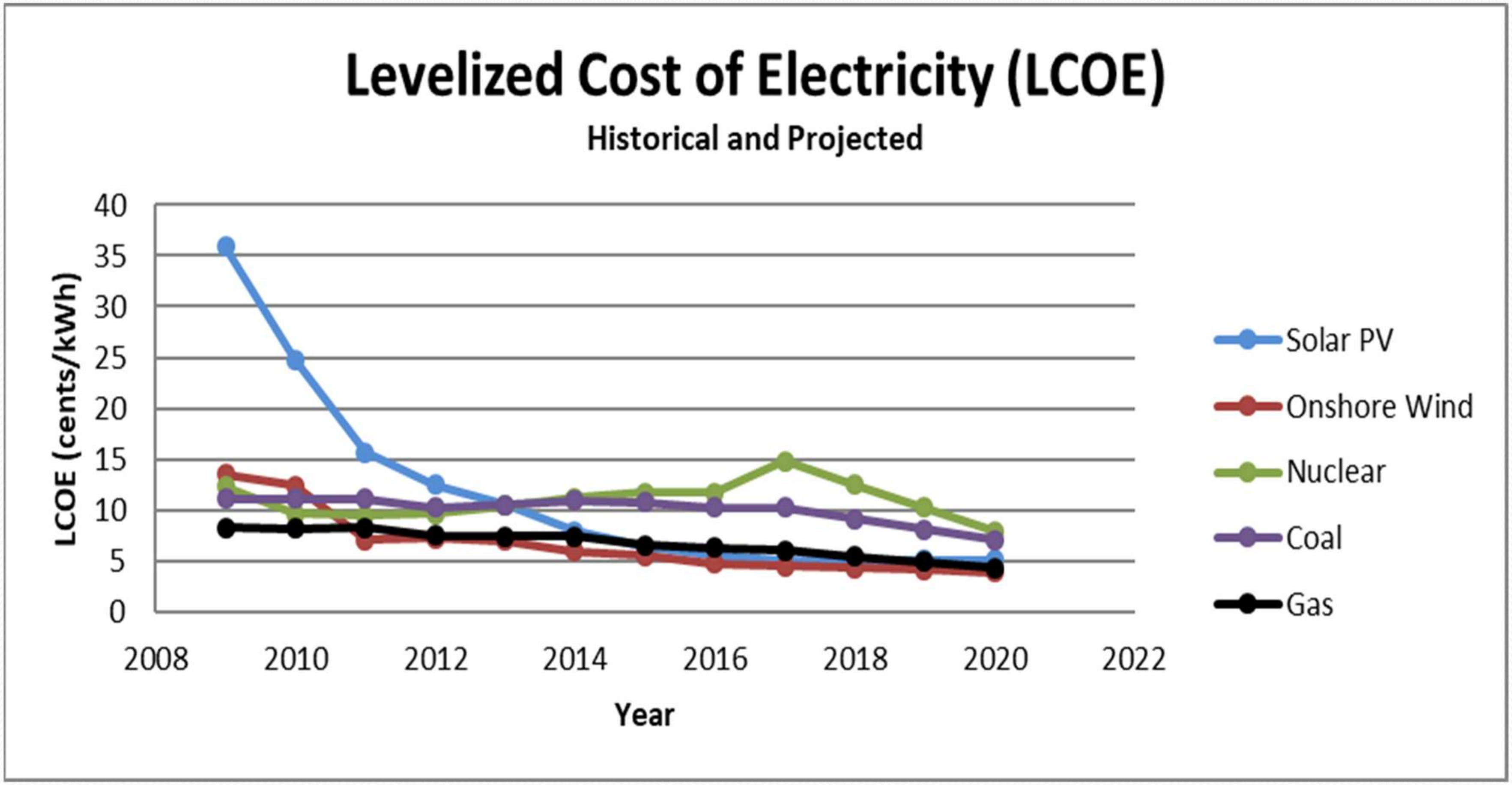
So how are we doing with sustainable energy in the US?



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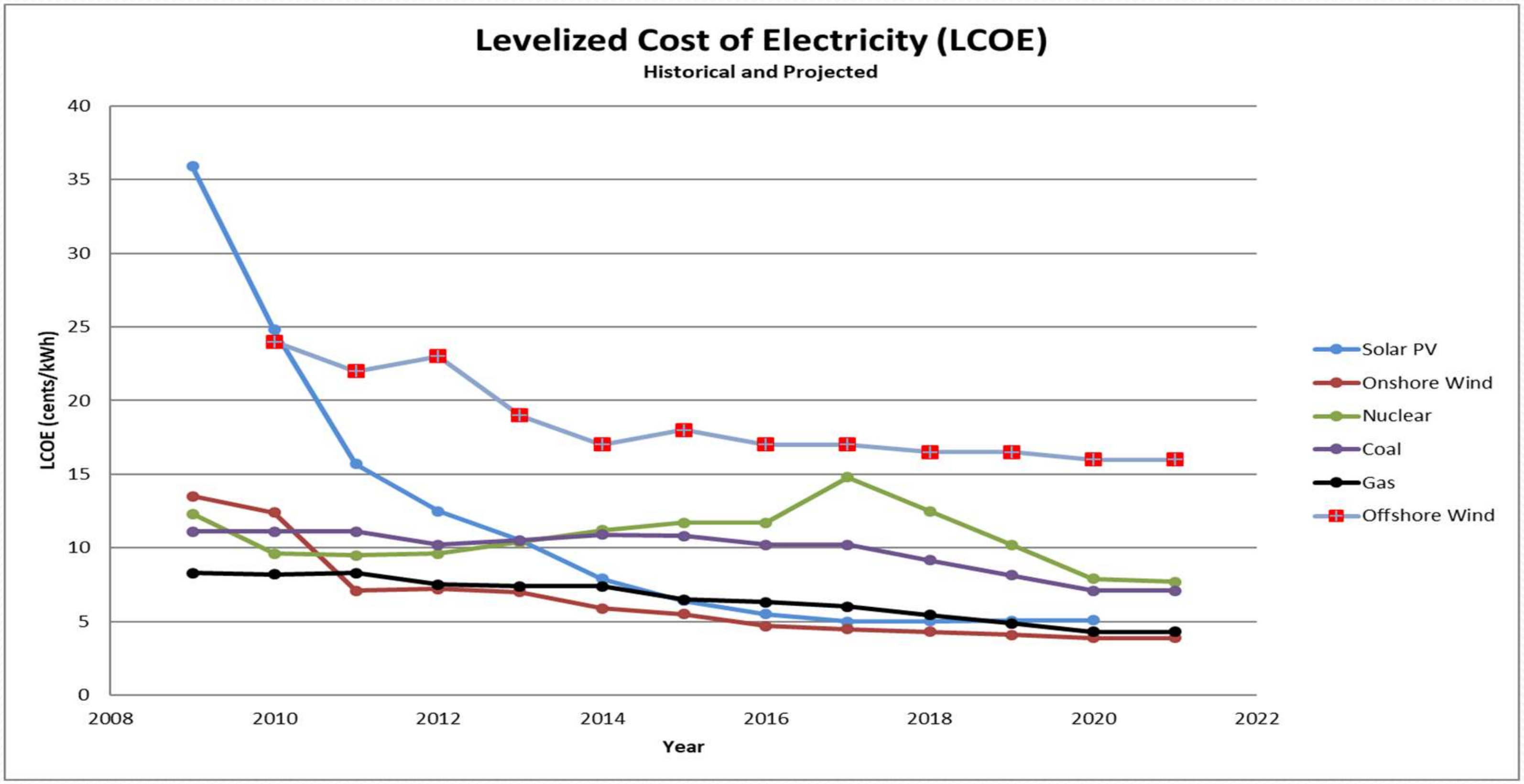
Offshore wind has become a proven technology in Europe



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Where is the Wave Power?

- There is plenty of wave energy out there
- How hard can it be?
- The principles are well established, mostly
- Actually, it is really hard because it is maritime
- If it were easy everyone would be doing it
- But lots of people have tried and are trying

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Why wave power?

- These is tons out there
- It combines with Offshore wind infrastructure
- We have a ton of coast and waves
- It helps the sustainable power triad
- The “sustainable power triad”[2] is wind, solar and waves.
- (with nuclear to even out the bumps and lots of storage like pumped reservoirs, batteries and hydrogen production)
- The triad is nice because it reduces the need for nuclear since when it is cloudy there may be waves, etc.
- So where is the wave power?

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2. Rik van Hemmen

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Active WEC Projects

	Project	Trial Result	Location	Technical Viability	Commercial Viability	Utility Viability	Largest Proven Capacity (kW)	One Size Fits All?
1	**LIMPET 250 kW, 2000 – present, OWC/terminating**	18 years	UK	good	marginal	local power supply only	250	no
2	**Mutriku 300 kW, 2009 – present, Oscillating Water Column/terminating**	9 years	Spain	good	marginal	local power only	300	no
3	**Bolt Sea Power Fred Olsen device 50 kW, 2000 - present, point absorber reel device**	Working	Multiple	good	marginal	local power only	50	no
4	**Ocean Power Technologies 15 kW, 1984 – present, point absorber**	working	Multiple	good	marginal	special need only	15	no
5	**Wavesub 5MW (not confirmed), 2009 – present, submerged point absorber using wave circulation with an apparent shoaling effect**	not known	UK	poor	poor	poor	5	no
6	**Uppsala University WEC Concept 30 kW, 2007 – present, Point Absorber with linear electric generator**	working	Sweden	good	marginal	local power only	30	no
7	**Resolute Marine Energy (RME)- AirWEC 2 kW, 2009 - present, point absorber**	working	US	good	marginal	special need only	2	no

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Active WEC Projects

	Project	Trial Result	Location	Technical Viability	Commercial Viability	Utility Viability	Largest Proven Capacity (kW)	One Size Fits All?
8	**ARCHIMEDES WAVE SWING 25 kW - 250 kW, 2004 – present, submerged point absorber**	unknown	UK	marginal	poor	poor	0	no
9	**AW-ENERGY WAVEROLLER 1MW, 1993 – present, attenuator**	unknown	Multiple	marginal	unknown	poor	0	no
10	**Carnegie Clean Energy, CETO 1MW, 2008-present, submerged point absorber**	working	Australia	good	unknown	local power only	250	close
11	**WELLO OY, PENGUIN 500 kW, 2008 – present, attenuator**	planned	Indonesia	unknown	marginal	local power only		no
12	**CorPower Ocean 250 kW, 2009 – present, point absorber**	under trial	Sweden	unknown	marginal	local power only		unknown
13	**Laminaria 200 kW, 2014 – present, point absorber**	planned	UK	good	marginal	local power only		unknown
14	**Eco Wave Power (EWP) 10 kW, 2011 – present, attenuator**	working	Black Sea	good	marginal	special need only	10	no
15	**OE Buoy (OE35) 1.25MW, 2008 - present OWC**	unknown	Hawaii	good	unknown	unknown	0	no

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Inactive WEC Projects

	Project	Trial Result	Location	Technical Viability	Commercial Viability	Utility Viability	Largest Proven Capacity (kW)	One Size Fits All?
	Inactive Systems							
16	**Salter Duck (6MW?) (1973, attenuator)**	never trialed		good	marginal	local power only	0	possibly
17	**OSPREY 2MW (1995 , OWC)**	sank	Scotland	poor	poor	poor	0	possibly
18	**Wavebob 1MW (1999 – 2013, point absorber)**	14 years	UK	good	marginal	poor	unknown	possibly
19	**Finavera AquaBuOY 250 kW (2007, point absorber)**	sank	OR	marginal	marginal	unknown	0	no
20	**Oregon State University SeaBeav I 10kW (2008, point absorber)**	worked	OR	marginal	poor	poor	10	no
21	**Trident Energy - Direct Energy Conversion Module (DECM) 20 kW (2009, attenuator)**	capsized	UK	poor	poor	poor	20	no
22	**AQUAMARINE OYSTER 800 kW (2012, Flapper/attenuator)**	worked	UK	marginal	poor	poor	315	no
23	**Pelamis 750 kW (1998 - 2012, attenuator)**	unknown	Portugal	marginal	poor	poor	unknown	no
24	**Ecole Centrale de Nantes - SEAREV G1 70 kW? (2002 - ?, point absorber/termination)**	never trialed	France	marginal	poor	poor	0	no
25	**Seatricity – Oceanus 2, 1MW (2016, point absorber)**	unknown	UK	poor	poor	poor	unknown	no
26	**Wavedragon 1.5MW – (2003-2012, overtopping)**	scale test	Denmark	good	marginal	poor	0	no
27	**SDE Energy/WERPO**	worked	Israel	good	marginal	special need	10	no
28	**TAPCHAN - (1985- 1988 overtopping)**	worked, destroyed by storm	Norway	challenging	marginal	local power only	350	no

Here's the thing

- There have been some dismal failures (immediate sinking, breakup in first storm)
- Often the timing has been wrong
- There are actually efforts out there that make no physical sense and are spending millions
- Many are science projects
- There is some good engineering out there (OPT, Bolt Lifesaver, OE Buoy, etc.)
- There is a lot of experience out there
- There are some small scale efforts that are producing energy
- We have not found any WEC approaches that make sense at a utility level
- Because there is a Physical Goldilocks hurdle

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The WEC Goldilocks problem

- Small WECs can harvest small waves and can be made to harvest big waves too
- Solid State devices can be easily scaled (Think PV Solar Cells)
- Wind turbines are mechanical devices and can be increased in size to have fewer bigger devices
- All WECs are mechanical devices, but big WECs cannot harvest small waves, and to be cost competitive we need fewer large mechanical devices
- Damn those waves; why can't they all be big all the time?

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Wave Steepness Matters

- Shoaling makes waves higher and objects in waves move faster, and the speed of objects determines the performance of kinetic energy conversion systems
- Shoaling naturally occurs on the beach, but offshore, a depth-controlled man-made beach can safely make the ideal wave shape for WEC operations
- At the beach waves get too high and steep and will trash your WEC
- Nobody wants to operate WECs in the dangerous surf zone
- Based on wave tank tests, we can use the shoaling effect of our variable-depth base to control the steepness of waves and do it safely offshore

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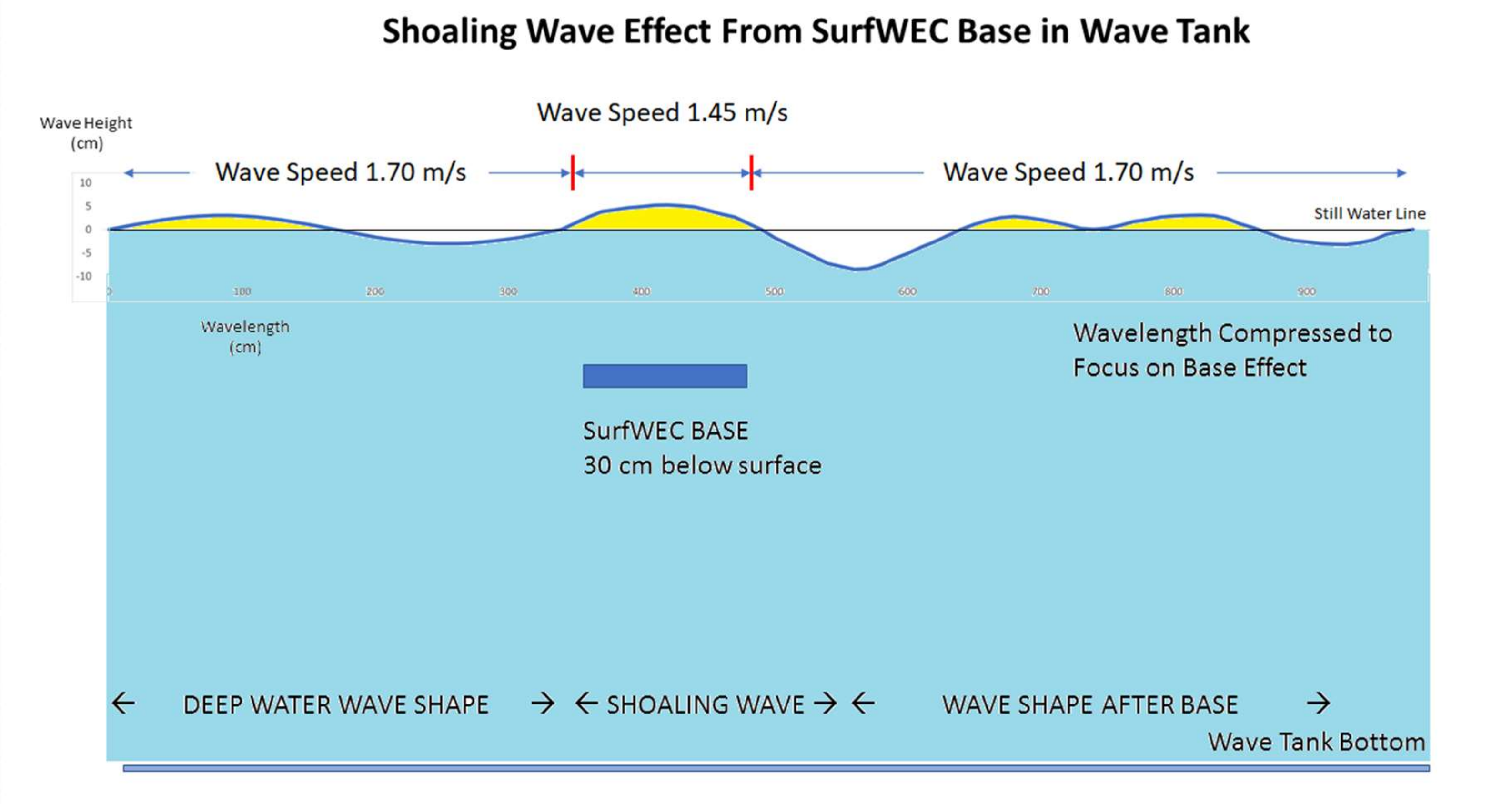
Wave Energy and Power are Concentrated in the Shoaling Process



There is a 250+% increase in wave power density over the platform.
Now we can make waves higher and make big WECs move fast.

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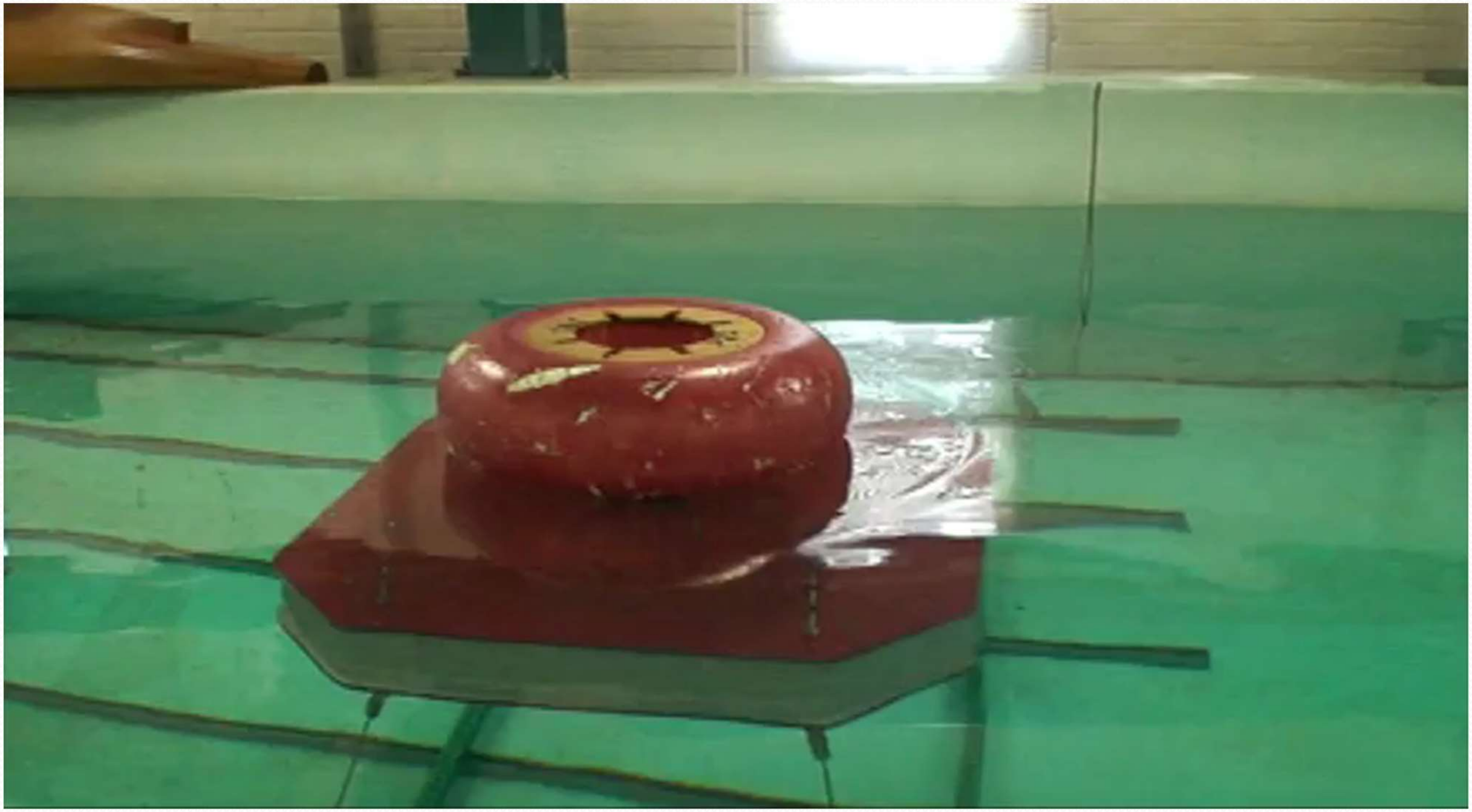
SurfWEC Motion in Ocean Waves



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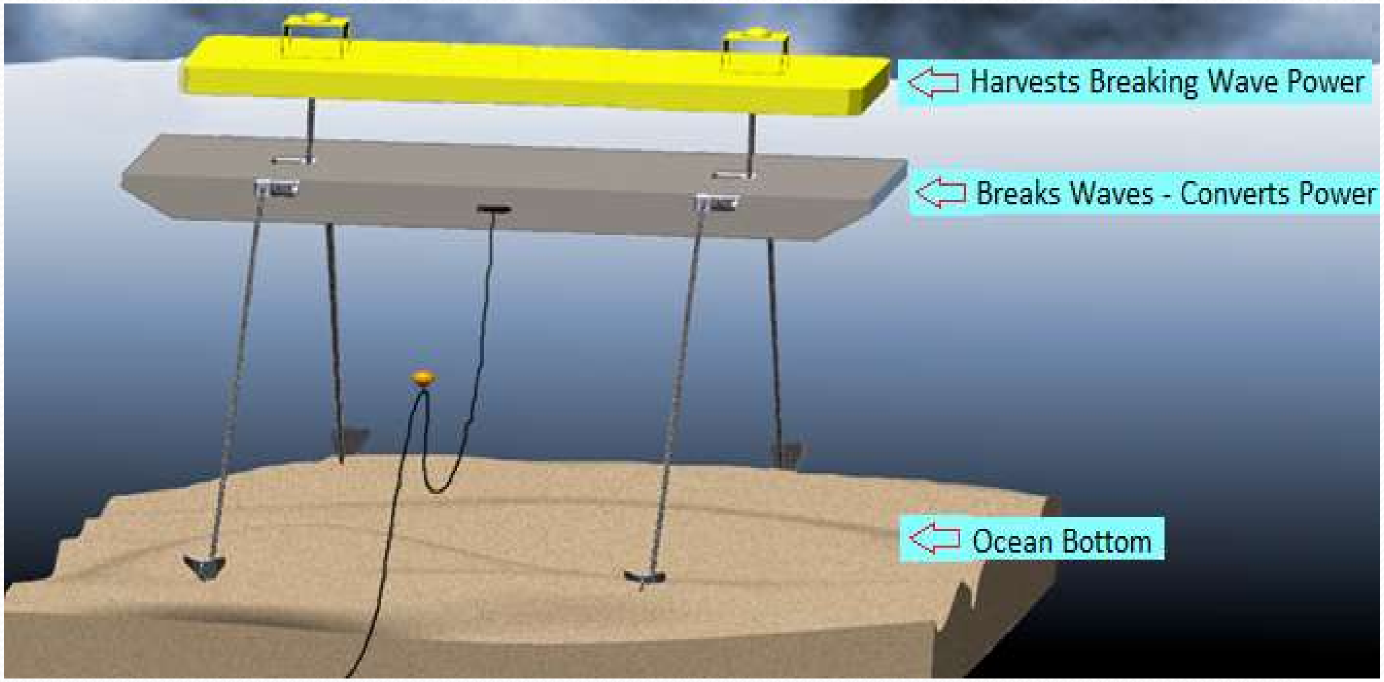
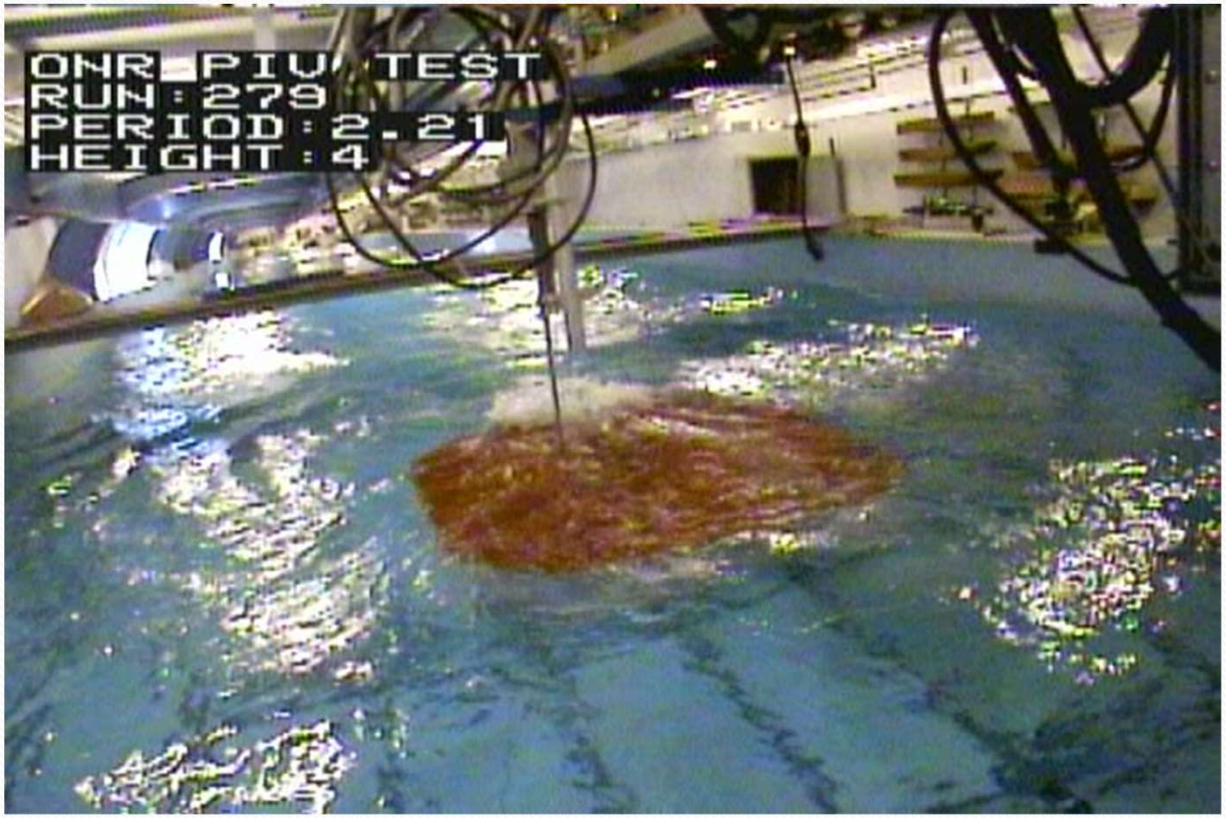
SurfWEC Concept

- Patented variable-depth, 2-part system shoals mild and moderate waves and tunes response frequency with winches using neural network control system.
- Grey Base dimensions in this rendering: 60m (196 ft) long by 20m (66 ft) beam by 3m (10ft) depth
- Yellow Buoy dimensions: 50m (164ft(by 10m (33ft) beam by 2m (6.5ft) depth
- A 40m square base with a 30m diameter cylindrical buoy is being designed to eliminate directional wave issues, and two more winches are being added to tether the buoy for 6DOF power takeoff (PTO)
- Bobber mass: 150,000 kg (148 long tons) (both designs)
- 10x more capable than legacy WEC's in average (5-30 sec) wave conditions (calculations on next slide)
- Self-protecting during hurricanes (SurfWEC lowers near ocean bottom)
- Low Cost Power: expected initial deployment cost of $1.50 per Watt ($7.5M per 5.2MW deployed unit)
- Produces energy with zero green house gas emissions and no negative environmental impacts



1000+ Wave Runs to Learn the Process



Stevens Institute model basin test: Near-Surface Platform Changes the Effective Water Depth for Waves in Offshore Locations and Creates a Shoaling Effect

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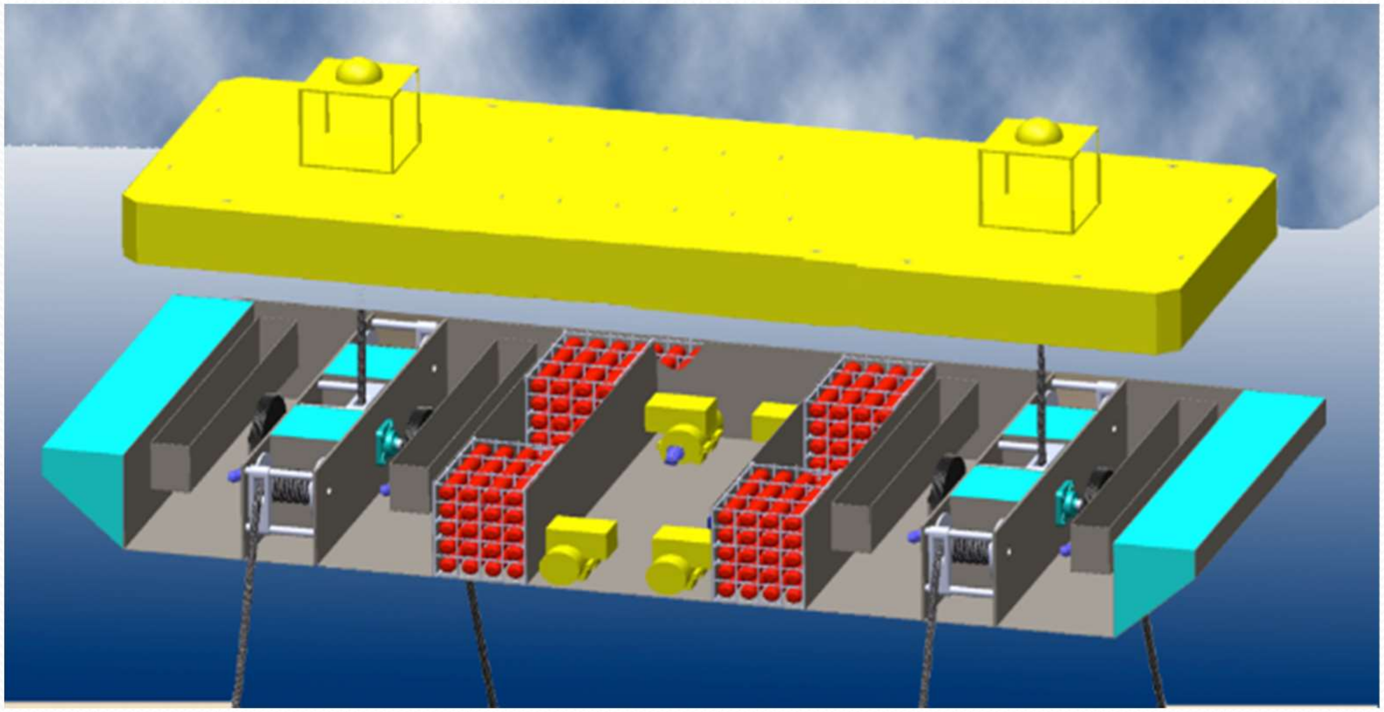
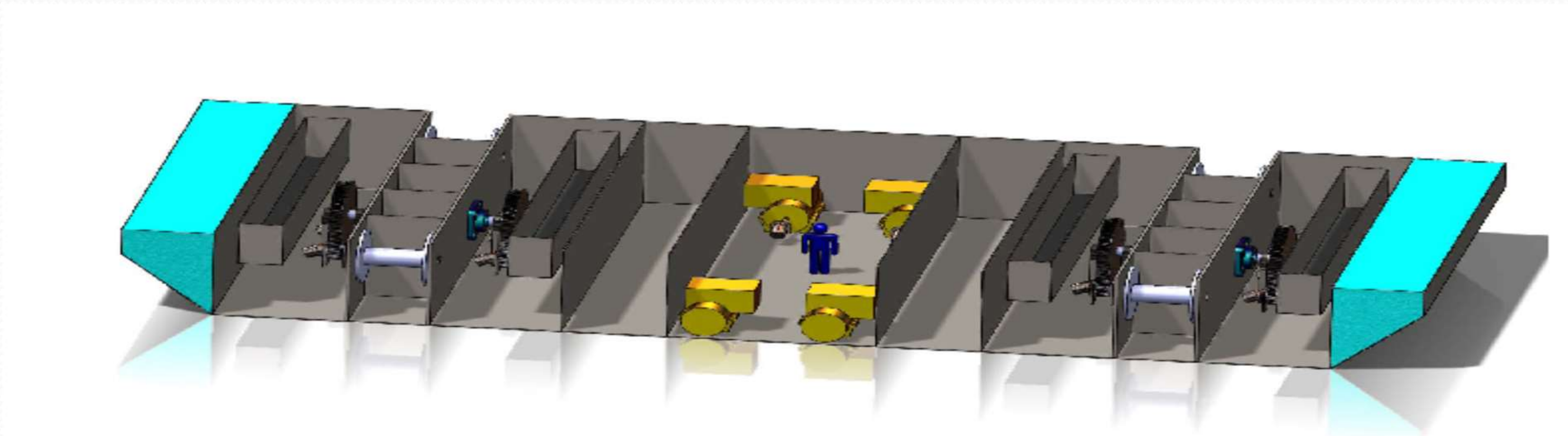
SurfWEC Internal Components

- 500 kWh Energy Storage Capacity (80 – 400 liter, 5000 psi, Red Accumulators) reduce waste/rate arbitrage/power winches
- Buoyant Integrity – Foam-Filled Compartments Ensure Survivability (Blue Compartments)
- Easy, Low Cost Maintenance from Proven Technologies Integrated into a System Solution
- Simple Routine Maintenance - Raise Base, Access Parts from Deck at Safe Heights and Stable Conditions (4 - Point Moored)
- 5 Year Major Overhaul – Release Anchors, Tow Entire Unit to Shore for Maintenance



Big, but still handy



- Same Capacity as Existing Offshore Wind Turbines
- Salvageable
- Transportable with small tugs
- All components except base and bobber are road transportable
- Well paying job creator
- Easy to find maintenance and deployment waterfront footprint

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We can do all this in NJ

- Stevens, Hoboken
- SurfWEC, Tinton Falls
- OHMSETT, Leonardo
- Port of NJ/NY
- Oyster Creek Nuclear Plant Grid Infrastructure
- A lot of money to get it to work for you and me, say $40M
- For NJ that is just about the right amount to buy something we all will own for the betterment of the world to show that NJ Makes and the World Takes.

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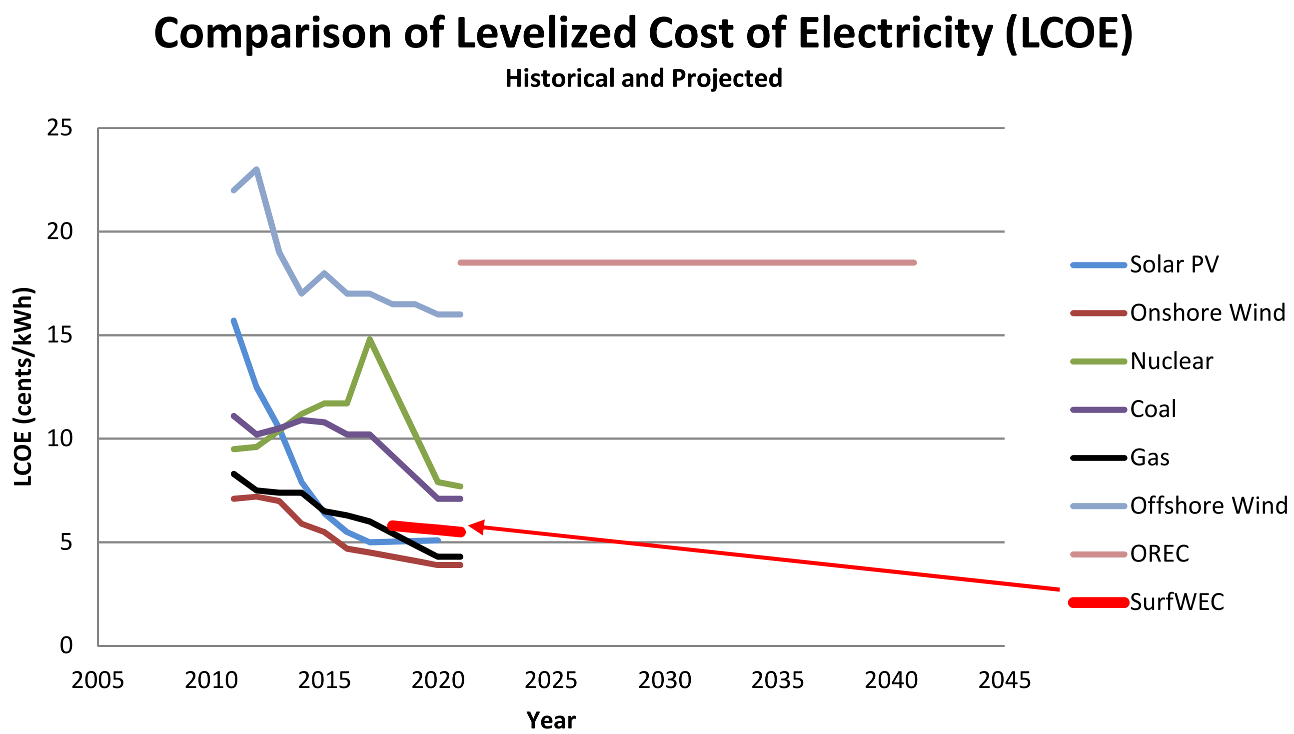
SurfWEC Solution Comparison



SurfWEC annual availability comparison:

<u>SurfWEC - 80%</u> Wind – 45% Solar - 30%

SurfWEC power production wave height range: 2’ to +30’

Cost competitive with renewable, nuclear, and fossil fuels
“OREC” is the projected Offshore Renewable Energy Certificate rate for New Jersey

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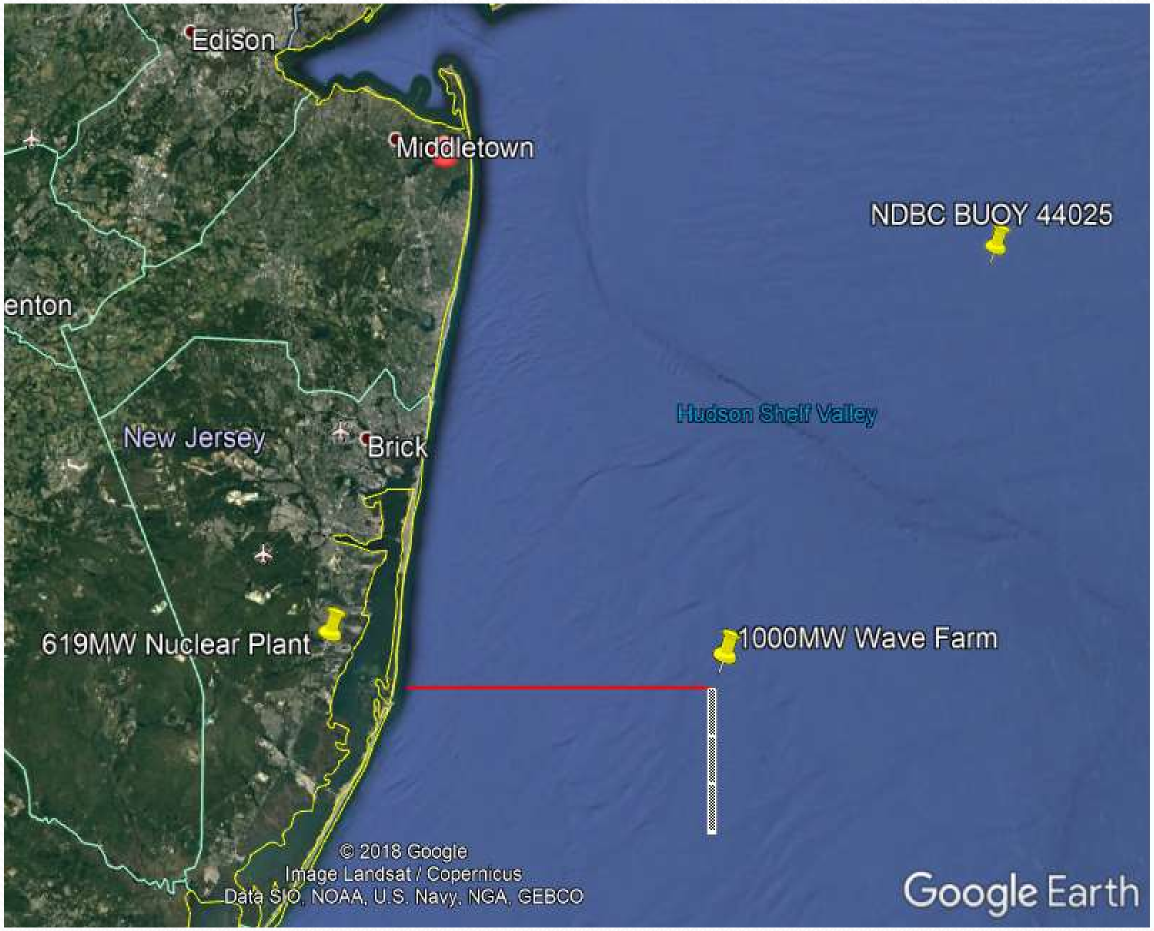
New Jersey SurfWEC Power Plant



Surf-making Wave Energy Converter (SurfWEC) Power Plant
200 units, 24 miles offshore, Average Annual Electricity Production: 2 million+ MWh
Using 12 to 16 BOEM Aliquots Depending on Easement Requirements

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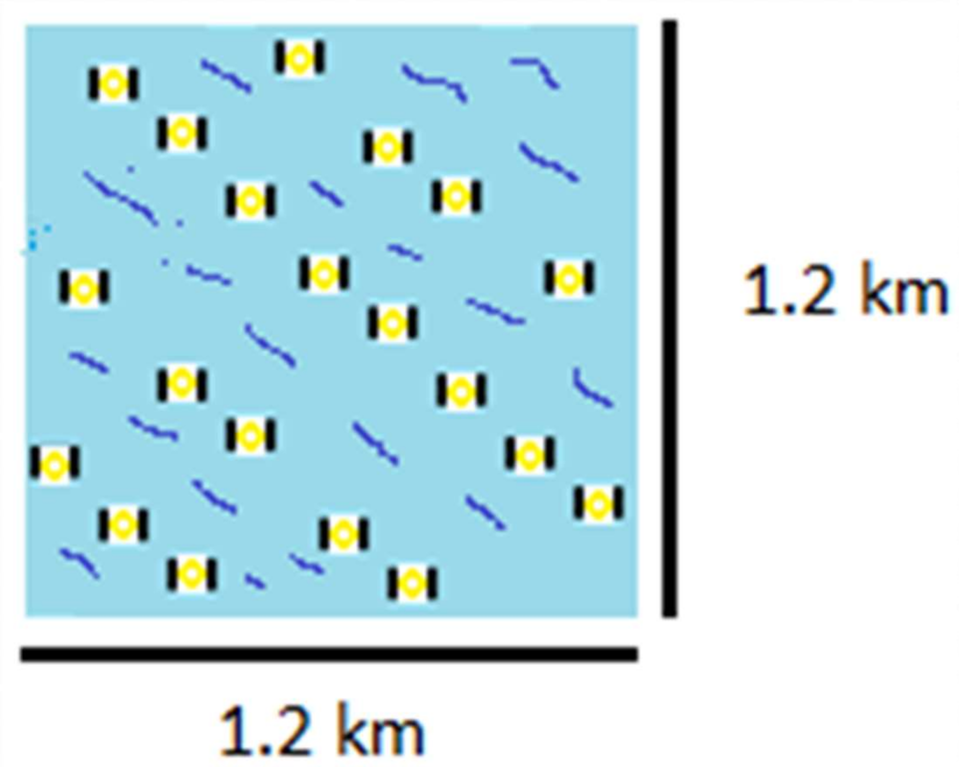
Typical Spacing of SurfWEC Units



The Bureau of Ocean Energy Management (BOEM) uses 1.2 km square Aliquots within their 4.8 square km Outer Continental Shelf (OCS) Permit Blocks as their minimum Permit Lease Areas

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Sustainable Technologies (a bigger picture)

Type	Theoretical Viability	Technical Viability	Truly Sustainable?	Carbon Neutral?	Carbon Zero?	Cost Competitive?	Installed Base
Hydro	viable	viable	mostly	yes	yes, nearly	yes	at maximum
Landbased Wind	viable	viable	yes	yes	yes, nearly	yes	fights for land
Thermal Solar	viable	viable	yes, mostly	yes	yes, nearly	maybe	fights for land
PV Solar	viable	viable	yes, mostly	yes	yes, nearly	yes	fights for land
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Tidal	viable	sometimes	yes, mostly	yes	yes, nearly	occasionally	occasional
Offshore Wind	viable	viable	yes	yes	yes, nearly	not quite yet	growing
Biomass	viable	viable	in right application	could be	depends	sometimes	modest
Corn Ethanol	poor	viable	nope	not really	not really	nope	too high
Algae	questionable	possible	unknown	could be	could be	unknown	zero
Nuclear Fission	viable	viable	yes, mostly	yes	yes, but …	could be	probably too low
Nuclear Fusion	viable	maybe in 30 years	yes	yes	yes	who knows?	zero
Wave Energy Conversion	viable	in some cases	yes, mostly	yes	yes	never at large scale	minuscule
SurfWEC	viable	early development	yes	yes	yes	yes	zero

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Remember how expensive that offshore wind was?

- All new technologies are expensive
- The trick is to have a whole systems approach
- We need to spend money on all emerging technologies
- We need to make sure that emerging technologies can complement each other
- We need to make sure we do not spend too much money on competitive technologies. That is not technology development; that is corporate welfare.
- Sometimes spending a few extra dollars increases flexibility

Co-location with Offshore Wind

- Reduced lease costs due to multi use for a single lease
- Reduced permitting cost
- Robust infrastructure, larger cable to shore, more capacity
- Potentially, offshore stored energy capacity for both wind and wave energy
- Enhanced power availability for the system since wind and wave energy are related, but do not necessarily coincide at one point in time
- Reduced logistics costs with regard to maintenance

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Conclusions

- Spend $ on WEC that perform at utility level in simulations and model tests
- Develop co-location regulations
- NJ "Big Tent" for 1st 1000MW+ WEC project
- "Big Tent" means everyone must get involved including utilities, offshore wind developers, WEC developers, fishermen, environmentalists, scientists, engineers, and the public

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Questions?

Technical, Regulatory, Environmental?

SurfWEC Value Proposition

Efficiency and Availability

Higher availability and efficiency than all other renewables

Cost Competitiveness

LCOE less than current Offshore Wind (OSW) in Europe

Patented Self-Tuning

Patented automatic wave tuning keeps base and float moving in opposite directions to maximize power conversion

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Improvement on Current Technologies

10x+ more kinetic energy capture than other wave energy products in same waves

OSW Farm Protection

Capable of breaking waves before waves enter an offshore wind farm or reach a shoreline means reduction of OSW maintenance costs

Highly Scalable

Independently or jointly with OSW with proven technologies innovatively integrated

SurfWEC LLC

- A New Jersey company formed by Martin & Ottaway with other partners
- Skyrock Advisors and Stevens Institute of Technology
- SurfWEC LLC controls the patent
- Refining the technical design and economic model with technology partners
- Using a big tent approach with a focus on New Jersey
- Spreading the message in the present sustainable industry field
- Identifying investing, government, technology and utility partners

Design Team Partners:

Bosch-Rexroth - Hydraulics/PTO
ISCO Industries – Hull Materials
HYDAC Technologies – Accumulators
InterOcean Systems– Winch Systems
Sampson and Lankhorst Rope - Cordage
Delmar Systems - Anchoring System

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Project Timeline

Completed	Year 1 & 2	Year 2.5	Year 3 & 4
Product Development and Patent	**1/20 Scale Prototype**	**Hydraulic System Bench Testing**	**Full Scale Prototype**
8 years R&D at Stevens Institute of Technology and 1k test tank runs for patent US8093736B2	2 years for Design, simulations, construction, and tank testing $2m budget: $500k CAD and FEA $200k SCADA systems $250k physical model $500k wave tank tests $350k project team $200k overhead	6 months for 500k cycles $1.5m for system setup and testing	2 years for construction and sea trials $10m Prototype construction $2m Sea trials / testing

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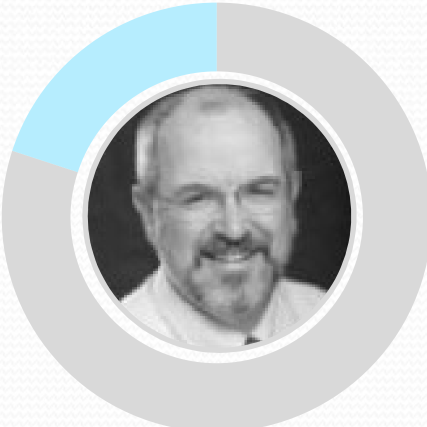
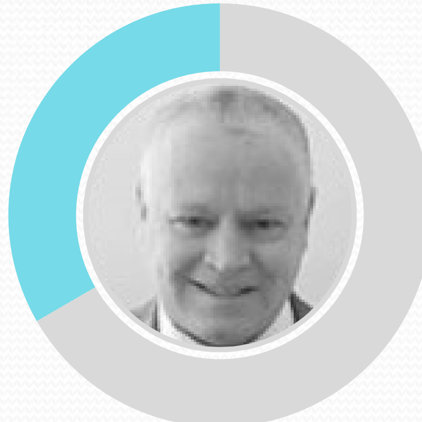
SurfWEC Team





Rik van Hemmen, P.E.

President, Martin & Ottaway (M&O)

Martin & Ottaway is a New Jersey based Marine Engineering firm that has been in continuous operation since 1875. 30+ Years in the marine industry as a professional engineer and marine consultant. Naval Architecture and Aerospace Engineer.

Michael Raftery, M.E.

Ocean Engineer & Oceanographer, M&O

Inventor: SurfWEC - Wave Energy Harnessing Device US Utility Patent 8,093,736B2 while at Stevens. 15 Years in the emerging Ocean Wave Energy Industry.

Peter Ford

Strategic Advisor

Executive with over 24 yrs in the logistics and port sectors. C-Suite experienced in business leadership, operations, M&A, and strategy development over 3 continents. Advisor to other innovative organizations like Cornell's CPIP curriculum and StoryLines residential cruise ship.

Other Design Team Partners

Bosch-Rexroth US - Nathan Godiska - Energy Technology and Special Machinery
ISCO Industries - Mike Whitehouse – Fabrication Specialist
HYDAC Technologies – Randy Symes - Accumulators
InterOcean Systems– Stephen Pearlman - Marine Winch Designer
Lankhorst Ropes – Mark Frölich – Senior Business Manager
Sampson Rope - Gabrielle Maassen – Application Engineer
Delmar Systems - John Shelton, P.E. – V.P. Technical Services, (Anchoring system)

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